Efficiency Analysis of New Zealand Universities in the Australasian Context

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Abstract

This thesis investigates the productivity and efficiency of New Zealand universities from 2008 to 2018 compared to Australian universities. It applies both Malmquist productivity indexes (MPI) and stochastic frontier analysis (SFA) to a consistent dataset across both countries.

Enhancing university efficiency and productivity is vital for ensuring the competitiveness and sustainability of New Zealand universities. The university sector faces constrained public funding and rising expectations for educational outcomes. However, existing studies on New Zealand university productivity and efficiency are scarce, with few employing comprehensive methodologies or quality-adjusted output measures.

This study addresses these gaps. First, it applies both MPI and SFA to provide robust assessments of productivity and efficiency. Second, it introduces quality-adjusted output measures to improve the validity of evaluations. Third, it systematically explores inefficiency determinants using the Battese and Coelli (1995, known as the BC95) model. Finally, it examines the sensitivity of the results to alternative variable measures and presents efficiency scores in a clear and consistent way.

The first empirical analysis examines partial labour productivity in teaching and research. Findings indicate that, despite steady improvements, New Zealand universities had lower productivity than Australian universities, with a notable persistent productivity gap between universities in the two nations. However, when productivity is assessed using all inputs, including capital, the results are less positive, suggesting that improvements in labour productivity have not translated into broader efficiency gains.

The MPI captures changes in total factor productivity (TFP) by accounting for multiple inputs and outputs. Results show that New Zealand universities experienced an average annual decline in TFP of 0.7% due to efficiency declines (-1.4%) despite modest technological improvements (0.6%). In contrast, Australian universities achieved annual TFP growth of 1.6%, driven by both technological progress (1.3%) and efficiency gains (0.3%).

The second empirical analysis applies the BC95 model to estimate technical efficiency using SFA. Results suggest that New Zealand universities were more technically efficient than Australian universities, reflecting their smaller and more research-focused system. This outcome is partly due to differences in defining undergraduate completions: New Zealand includes sub-degree completions while Australia does not. This may bias results in favour of New Zealand institutions. The

inefficiency analysis also reveals that larger percentages of international and female enrolments are related to lower efficiency, and regional effects also matter.

The third empirical analysis applies a stochastic cost frontier analysis (SCFA) using the BC95 model to examine cost efficiency across universities. Results indicate that Australian universities, particularly the Australian Technology Network (ATN) universities, are more cost-efficient than New Zealand universities. Differences in income sources, financial capacity to invest in staff and infrastructure, and institutional size potentially explain this gap.

Across universities, several characteristics are associated with cost efficiency. Universities with medical schools and higher proportions of female students tend to have lower cost efficiency. In contrast, universities with larger shares of international students and higher general-to-academic staff ratios are more cost-efficient. Regional variations in cost efficiency outcomes are also observed, suggesting that geographic location may influence university operating environments.

The comparative results show that methodological differences (MPI, SFA, SCFA) capture distinct aspects of productivity and efficiency, they are not contradictory. Instead, they reflect different purposes and address research questions. New Zealand universities may appear more technically efficient but less cost-efficient, while Australian universities benefit from economies of scale, revenue diversification, and stronger resource capacity.

Efficiency outcomes are also shaped by contextual factors such as programme definitions, institutional scale, funding structures, and regional conditions. Recognising these differences is essential to avoid misinterpretation, and incorporating quality-adjusted measures provides a more comprehensive and meaningful assessment of university performance.

Overall, this thesis highlights the need for funding models that are flexible, equitable, and responsive, alongside strategic investment in staff, infrastructure, and digital technologies. It stresses the importance of diversifying income sources to reduce reliance on international tuition, while ensuring targeted support for regional and specialised universities. Addressing discipline-based imbalances, embedding quality-adjusted measures in performance frameworks, and strengthening data quality are also critical for thorough assessment and evidence-based policy. These findings provide notable insights for policymakers and university leaders aiming to enhance performance and sustainability in New Zealand universities.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Abbreviations

New Zealand Universities	
Auckland	The University of Auckland
Waikato	The University of Waikato
Massey	Massey University
VUW	Victoria University of Wellington
Canterbury	The University of Canterbury
Otago	The University of Otago
Lincoln	Lincoln University
AUT	Auckland University of Technology
Australian University Groupings	
Go8	Group of Eight universities
IRU	Innovative Research Universities Australia
RUN	Regional Universities Network
ATN	Australian Technology Network
Non-aligned	Non-aligned Universities

AAGR	Average Annual Growth Rate
AEA	Australia's Economic Accelerator
AGR	Annual Growth Rate
ANZSRC	Australian and New Zealand Standard Research Classification
ARC	Australian Research Council
AQF	Australian Qualification Framework
Australian DoE	Australian Government Department of Education
BC88 model	Battese and Coelli (1988) Time-Invariant Model Specification
BC92 model	Battese and Coelli (1992) Time-Variant Model Specification
BC95 model	Battese and Coelli (1995) Model Specification
CE	Cost Efficiency
CD	Cobb-Douglas model
CGS	Commonwealth Grant Scheme
CNCI	Category Normalised Citation Impact
C(NE) staff	PBRF ranking C (New and Emerging) staff
COLS	Corrected ordinary least squared
CoREs	New Zealand Centres of Research Excellence
CPI	Consumer Price Index
CRC	Cooperative Research Centre grants
CRC-P	Cooperative Research Centre Projects grants
CRS	Constant Returns to Scale
CSPs	Commonwealth Supported Places
DEA	Data Envelopment Analysis
DESE	Australian Department of Education, Skills and Employment

DFA	Deterministic Frontier Analysis
DISER	Australian Department of Industry, Science, Energy and Resources
DMU	Decision Making Unit
DoE	Australian Government Department of Education
DRS	Decreasing Returns to Scale
EFTS	Equivalent Full-Time Student
EI	Engagement and Impact Assessment
EP	Evidence Portfolio
ERA	Excellence in Research for Australia
ERI	External Research Income
FoR	Field of Research
FTE	Full-Time Equivalent staff
GDP	Gross Domestic Product
HDRs	Higher Degree by Research
HECS	Higher Education Contribution Scheme
HEIs	Higher Education Institutions
HELP	Australian Higher Education Loan Program
HEPs	Higher Education Providers
HRC	New Zealand Health Research Council
ISI	Institute for Scientific Information's publication data sources
IRS	Increasing Returns to Scale
LR	log-likelihood ratio
MBIE	New Zealand Ministry of Business Innovation and Employment
MFP	Multi-Factor Productivity
ML	Maximum likelihood
MoE	New Zealand Ministry of Education
MOLS	Modified ordinary least squares
MPI	Malmquist Productivity Index
MREA	Australian NHMRC's Medical Research Endowment Account
MRFF	Medical Research Future Fund
NCGP	National Competitive Grants Program
NE	New and Emerging staff
NHMRC	National Health and Medical Research Council
NZQA	New Zealand Qualification Authority
NZQF	New Zealand Qualification Framework
ODF	Output Distance Function
OECD	Organisation for Economic Co-operation and Development
OIA	New Zealand Official Information Act
OLS	Ordinary Least Square
PBRF	Performance-Based Research Funding income
PPE	Property, plant and equipment
PPP	Purchasing Power Parity

QE	Quality Evaluation
QS	Quacquarelli Symonds) Word University Rankings
RAE	UK's Research Assessment Exercise
RBGs	Research Block Grants
RDC	Research Degree Completion
REF	UK's Research Excellence Framework
RGS	Research Grant Services
RLP	Research Labour Productivity
RSP	Research Support Program
RTP	Research Training Program
SCFA	Stochastic Cost Frontier Analysis
SE	Scale Elasticity
SFA	Stochastic Frontier Analysis
SME	Small and Medium Enterprise
STEM	Science, Technology, Engineering, and Mathematics
TE	Technical Efficiency
TEC	New Zealand Tertiary Education Commission
TEOs	Tertiary Education Organisation s
TFP	Total Factor Productivity
THE	Times Higher Education World University Rankings
TLP	Teaching Labour Productivity
UAG	University Advisory Group
UK	United Kingdom
UOF	University Operation Fund in Taiwan
WoS	Web of Science

Chapter 1 Introduction

Tertiary education plays an important role in economic growth. Since universities often receive public funding, understanding their productivity growth is essential for efficient resource use and greater social impact (Johnes et al., 2017). In times of fiscal austerity, there is increased attention to how public funds are allocated (Witte & López-Torres, 2017). The OECD's *Education at a Glance* report (2013, p. 15) states that what matters more are the choices countries make in allocating their education spending and the policies aimed at improving the efficiency and relevance of education. Efficient education provision makes optimal use of inputs to achieve maximum outputs. In an inefficient system, it is impossible to either increase educational attainment for a given spending level or reduce resource use without compromising outcomes (Bessent & Bessent, 1980).

A significant portion of New Zealand's economy is supported by universities through their staff, graduates, and teaching and research activities. Universities develop skilled graduates and conduct research that drives economic growth and innovation (Universities New Zealand, n.d.). Each year, around 182,900 students are enrolled in New Zealand universities. These universities produce approximately 45,300 graduates annually, 95% achieving a bachelor's degree or higher (Ministry of Education, 2022). In 2019, public spending on tertiary education rose to $4.2 billion, with government funding for this sector representing 1.5% of gross domestic product (GDP) (Universities New Zealand, n.d.).

Additionally, New Zealand universities significantly impact regional economies, contributing up to 6.3% of regional GDP in 2018 (New Zealand Institute of Economic Research, 2020; Universities New Zealand, n.d.6). Research from the London School of Economics indicates that the advantages of universities "spill over" into surrounding regions, with the greatest benefits experienced by those located closest to universities (London School of Economics Business Review, 2016). Universities play a vital role in the development of regional economies and the health of local communities (Universities New Zealand, 2023). Therefore, tertiary education is a critical driver of long-term productivity growth.

Despite considerable government funding for tertiary education in New Zealand, total expenditure per student (including both government and private funding) remains relatively low by international standards. In 2019, total spending per student at public tertiary institutions, measured in equivalent US dollars, was $19,663 in New Zealand, compared to $24,297 in Australia and $31,094 in the United States (OECD, 2022). At the same time, real government funding per student has declined over the long term. As a result, students and other non-government sources now contribute a larger share of tertiary education costs (Universities New Zealand, 2023). Notably, the New Zealand government chose not to increase funding for student places in the 2018 budget for the first time in 20 years. Instead, it allocated more than $500 million to implement a "first-year free fees" policy, aiming to reduce the direct costs borne by students (University of Auckland, 2018, p. 7). From 2025, this policy shifts to cover the final year of study, aiming to motivate and reward students for completing their qualifications and to reduce the overall cost of their studies (New Zealand Tertiary Education Commission, 2025).

Moreover, productivity data from Statistics New Zealand (StatsNZ) at a national level indicate that the productivity growth of the education and training sector (entire sector)—which includes early childhood, primary, secondary, technical and vocational education, universities and wānanga—has significantly lagged behind that of the private sector and the overall economy (New Zealand Productivity Commission, 2018a). For instance, between 1996 and 2017, the education and training sector experienced negative productivity growth, including declines in labour productivity (-1.4%), capital productivity (-2.7%), and multifactor productivity (-1.7%), falling behind the private sector on every measure of productivity (New Zealand Productivity Commission, 2018a).

Public services such as health and education can improve outcomes even under fiscal pressure by increasing productivity (New Zealand Productivity Commission, 2018a, p. 8). Spending in these areas is increasingly viewed as investment rather than consumption (Cullen & Ergas, 2014). Education particularly delivers both public and private returns. Public benefits include stronger productivity, innovation, and improved social outcomes. Private benefits include high individual earnings. For example, Scott (2020)[1] finds that degree holders earn more annually and experience faster income growth than those without degrees.

In New Zealand, the university sector is critical to driving economic performance and social well-being. The New Zealand Productivity Commission (2016) highlights the growing demand for adaptable skills and the need to expand access to tertiary education. As skills needed evolve across a person's working life, universities need to respond with flexible and accessible learning options. However, rising participation in higher education has increased pressure on governments to sustain public funding. This has created a need for universities to operate more efficiently.

[1] The New Zealand Ministry of Education publishes this report. One finding indicates that obtaining a degree or higher-level education leads to increased annual earnings and earnings growth, data based on people who left school in 2009 and their education and earnings experiences through to 2018. For instance, nine years after leaving school, individuals with a degree can expect to earn 15% to 20% more than those of the same age who completed their education with university entry.

1.1 Objectives of the Thesis

This thesis aims to empirically examine productivity and efficiency at New Zealand universities using (a) Malmquist Productivity Indexes (MPI) and (b) estimates from Stochastic Frontier Analysis (SFA). Due to the small size of the New Zealand sector, which includes only eight universities, and the similarities between the higher education systems in New Zealand and Australia, this study also includes data from 37 Australian universities to support comparative estimates of productivity and efficiency. Specifically, this study seeks to address the following research questions:

1. What is the mean efficiency score of public universities in New Zealand and Australia?

This research question aims to analyse the technical and cost efficiency of public universities in New Zealand and Australia by calculating their efficiency scores. More specifically, this analysis will determine whether public universities in these two countries are operating efficiently, and how New Zealand universities are performing relative to Australian universities.

2. What is the Malmquist productivity change in New Zealand and Australia's public universities?

This thesis investigates productivity changes in New Zealand and Australian public universities from 2008 to 2018 using the MPI. The MPI measures changes in total factor productivity (TFP) over time. Unlike partial labour productivity measures, MPI accounts for multiple inputs, making it suitable for universities that combine labour, capital and other resources. It offers insights into how university productivity has changed over time, highlighting whether institutions are improving their performance and how this varies across universities. The analysis identifies which universities have improved productivity, whether technological progress has contributed to productivity gains, and how overall trends differ between the two countries.

3. Does adjusting the quality of teaching and research output variables, as used in Malmquist productivity and stochastic frontier analysis, impact productivity growth and efficiency estimates of New Zealand and Australian public universities?

This study examines teaching and research output variables, specifically those used in Malmquist productivity indexes and stochastic frontier analysis. The focus is on how quality adjustments to these variables, such as using credit and income weights on teaching output (e.g., qualification completions), impact productivity growth and efficiency. This involves including these quality-adjusted teaching and research output variables in the analysis to assess their effect on university performance.

4. What are the major determinants of efficiency or inefficiency in New Zealand public universities?

One of the main objectives of this study is to identify the key factors contributing to efficiency or inefficiency in New Zealand public universities. Using SFA output distance and cost functions, this study aims to identify the main source of efficiency changes and evaluate the efficiency levels of individual universities. This study also compares the results using both unadjusted and quality-adjusted outputs within these stochastic frontier frameworks.

1.2 **Motivation**

Efficiency in education has become increasingly important since the foundational work of Bessent and Bessent (1980), Charnes et al. (1978, 1981), and Bessent et al. (1982). It is achieved when resources are used optimally to maximise educational outcomes (Witte & López-Torres, 2017). In inefficeint system, resources are not used optimally, meaning there are opportunities either to improve outcomes without increasing inputs or to reduce resource use while maintaining performance (Bessent & Bessent, 1980). In addition to the increased awareness of public sector efficiency, increasing education costs might be a reason for the interest in efficiency in education (Witte & López-Torres, 2017).

When evaluating productivity and efficiency in higher education, it is crucial to consider the sector's unique features. Johnes (2006, 2008) noted that measuring efficiency in this context is challenging due to several inherent characteristics. Notably, public universities are non-profit, lack clear output and input prices, and produce multiple outputs from multiple inputs.

To manage these complexities, studies have used different methods. Early work applied ordinary least-squares (OLS) regressions (Johnes, 1996; Liu, Patton & Kenney, 2018), while later studies increasingly adopted data envelopment analysis (DEA) (Johnes, 2006) or SFA (Johnes, 2008; Abbott & Doucouliagos, 2009; Kempkes & Pohl, 2010; Letti et al., 2022).

The frontier methods are particularly appropriate in this thesis. They neither require output and input price data nor impose specific behavioural assumptions on universities (Coelli et al., 2005). Moreover, there are only a small number of observations in New Zealand, given that there are only eight universities. SFA is especially well-suited to this context because it pools data across multiple years to address small data size issues and incorporates technological change.

Productivity measures how well an organisation uses its inputs to produce outputs. Improving productivity entails using resources more efficiently to produce more or high-quality outputs from the same inputs. It is not simply about working longer hours or saving costs. Rigorous productivity measures should account for changes in the quantity and quality of outputs and inputs. For example, budget cuts that might result in declining output quality are unlikely to lead to genuine productivity improvements. Therefore, this study investigates university productivity and efficiency using quality-adjusted outputs for teaching and research.

It is also valuable to examine productivity and efficiency at Australian universities to assess whether the patterns observed in New Zealand are reflected in an international context with similar goals and funding models. Therefore, this study also examines the productivity and efficiency of both Australian and New Zealand universities to benchmark the performance of New Zealand universities against that of Australian universities.

To provide some contextual information about the size and growth of New Zealand and Australian universities, Table 1.1 shows the average number of qualification completions and equivalent full-time student (EFTS) enrolments at New Zealand and Australian universities from 2008 to 2018. During this period, Australian public universities experienced substantial growth. EFTS enrolments in Australian universities increased 41%, from 19,304 in 2008 to 27,262 in 2018, while qualification completions rose from 6,532 to 8,658. In contrast, enrolments in New Zealand universities remained relatively stable, increasing only 7% from 15,796 in 2008 to 16,964 in 2018. Completions increased modestly, from 5,204 to 5,621.

Despite its smaller population, New Zealand had relatively high enrolment and completion levels compared to Australia. This is partly due to structural differences in qualification offerings. New Zealand universities include a broader range of sub-degree qualifications, while Australian universities generally offer qualifications at the diploma level and above. Therefore, New Zealand's completion figures may appear inflated in direct comparisons.

Table 1.1
Mean Completions and EFTS enrolments at New Zealand and Australian Universities (2008-2018)

Year	NZ Completions	AUS Completions	NZ EFTS	AUS EFTS
2008	5,204	6,532	15,796	19,304
2009	5,216	6,804	16,744	20,547
2010	5,195	7,189	17,092	21,716
2011	5,552	7,548	16,669	22,207
2012	5,671	7,468	16,782	22,817

2013	5,652	7,759	16,571	23,576
2014	5,481	7,875	16,474	24,404
2015	5,453	7,927	16,471	24,903
2016	5,519	8,036	16,614	25,581
2017	5,455	8,255	16,629	26,423
2018	5,621	8,658	16,964	27,262
Growth	8%	33%	7%	41%

Note: New Zealand completions include Levels 1 to 4 certificates, Level 5 and 6 certificates and diplomas sub-degree qualifications and above offered by universities, while Australian universities primarily award qualifications at Level 5 and 6 diplomas and above.

New Zealand and Australian universities share a similar tertiary education system, strongly focusing on educational quality. As stated in an OECD report (Santiago et al., 2008), Australasian (Australia and New Zealand) universities are increasingly expected to demonstrate accountability for public funding, deliver value for money, and be responsible for the composition of their teaching staff. Therefore, evaluating higher education institutions' productivity and efficiency has become increasingly important (Agasisti et al., 2016).

Although New Zealand universities have improved in global rankings (see below Table 1.2), they face growing financial pressures and international competition and limited government fundings. Enhancing university efficiency and productivity is crucial for maintaining the competitiveness and sustainability of New Zealand universities.

This study focuses on how New Zealand universities deliver quality teaching and research with constrained resources. It also compares their performance with Australian universities. This thesis applies both MPI and SFA methods to a consistently constructed dataset covering New Zealand and Australian universities. It estimates efficiency scores, tracks productivity over time, and explores the effects of quality-adjusted outputs. It also tests the robustness of variable definitions and model specifications and examines efficiency determinants using the Battese and Coelli (1995) model.

This study contributes to the literature in several ways. It is the first to apply both MPI and SFA to a consistent dataset for New Zealand and Australia. It includes quality-adjusted outputs, which are rarely used in Australasian studies. Combining New Zealand and Australian data enables cross-country comparison and addresses small-sample issues. The study also includes inefficiency determinants such as institutional features, regional variations, student demographics and staff composition. Finally, it explores alternative variable measures and presents efficiency scores in a clear and consistent way. Together, these contributions provide new empirical evidence and methodological insights into university productivity and efficiency in Australasia.

1.3 New Zealand Universities

This section provides background on the university sector in New Zealand, discussing its history, funding arrangements, and, specifically, research funding arrangements. Section 1.4 provides a similar overview for Australian universities.

1.3.1 *New Zealand University History*

Established by statute in 1870, the Federal University of New Zealand served as the examination and degree-granting body for all New Zealand university institutions with affiliated member colleges. The predecessors of Otago, Canterbury, Auckland, Lincoln, and Victoria University of Wellington (VUW) were among its early member colleges. The University of New Zealand was dissolved in 1961, and most constituent colleges became autonomous universities. Most New Zealand universities, therefore, trace back to the 19th century.

New Zealand has eight public universities. In order of the founding year, they are University of Auckland, University of Otago, Massey University, Victoria University of Wellington, University of Waikato, University of Canterbury, Lincoln University, Auckland University of Technology (AUT).

The University of Otago, established in 1869, was the first university in New Zealand. It is home to one of New Zealand's two medical schools and remains the only one offering dentistry and surveying programmes (Universities New Zealand, n.d.3). Canterbury College, the second university, was founded in 1873. It was renamed Canterbury University College in 1933 and became the University of Canterbury in 1957 (Universities New Zealand, n.d.7).

Lincoln University, the third-oldest institution, began as the School of Agriculture in 1878. It became Canterbury Agricultural College in 1896 and Lincoln College in 1961. Although technically a constituent college of the University of Canterbury following the dissolution of the University of New Zealand, Lincoln maintained an independent identity. It gained university status in 1990 and remains New Zealand’s smallest and only land-based specialist university (Universities New Zealand, n.d.8).

The University of Auckland was formally opened in 1883 as Auckland University College, part of the University of New Zealand. Auckland University College officially became the University of Auckland in 1961 when the University of New Zealand was dissolved. It offers the most comprehensive range of programmes in New Zealand and is the only university that grants degrees in both engineering and medicine. It is also the country’s largest research organisation, with over 12,000 staff and postgraduate students engaged in fundamental and applied research (Universities New Zealand, n.d.1).

Victoria University College was established in 1897. Following the dissolution of the University of New Zealand, it became Victoria University of Wellington in 1962. It was New Zealand's top-ranked university for research intensity in the 2018 Performance-based Research Fund (PBRF) and is home to more than 40 research centres (University New Zealand, n.d. 4).

Massey University in Palmerston North began as New Zealand Agricultural College in 1926 and became Massey Agricultural College in 1927. It became a constituent college of the University of New Zealand in 1928 and received university status in 1964. Massey University is a global pioneer in distance education, with over 60 years of experience and a five-star QS[2] (World University Rankings) rating for distance learning and online study (Massey University, n.d.).

The University of Waikato was established in 1964 to serve the Waikato region, including Hamilton, now New Zealand's fourth-largest city. It was the first New Zealand university approved by the Chinese Ministry of Education to deliver full degrees in China[3] (University of Waikato, n.d.1).

Auckland Technical opened in 1895. Its technical division became the Auckland Technical Institute (ATI) in 1963, providing advanced vocational education. After gaining degree-awarding authority in 1989, AIT was renamed the Auckland Institute of Technology (AIT). In 2000, the Auckland University of Technology (AUT) became the last institution to gain university status and the first polytechnic in New Zealand to become a university.

New Zealand public universities are geographically dispersed and are included in the Quacquarelli Symonds (QS) World University Rankings and Times Higher Education (THE) World University Rankings (see Table 1.2). Auckland has two universities (the University of Auckland and AUT). The main campuses of the others are located in Waikato, Wellington, Canterbury (University of Canterbury and Lincoln University), Otago and Manawatū-Whanganui.

Table 1.2
New Zealand Universities in Regions and World University Rankings 2024

[2] The QS (Quacquarelli Symonds) World University Rankings are global university rankings produced by Quacquarelli Symonds, a United Kingdom-based higher education analytics company.

[3] The University of Waikato and Chinese Zhejiang University City College (ZUCC) opened a new joint institute in 2017 in Hangzhou, China. It provides three of Waikato's degrees delivered in Hangzhou. This enables ZUCC students to finish their degree programmes in China and receive degrees from both universities. See more at https://www.waikato.ac.nz/international/partnerships/zhejiang-university-city-college.

New Zealand Universities	Region	2024 QS	2024 THE
University of Auckland	Auckland	68	150
University of Otago	Otago	206	301-350
Massey University	Manawatū-Whanganui	239	501-600
Victoria University of Wellington	Wellington	241	401-500
University of Waikato	Waikato	250	401-500
University of Canterbury	Canterbury	256	501-600
Lincoln University	Canterbury	362	401-500
Auckland University of Technology	Auckland	407	401-500

Source: Universities New Zealand (2024), Times Higher Education (2024a), QS TOP UNIVERSITIES (2024).
Note 1: Sixteen regions in New Zealand are divided between the North and South Islands. There are five universities on the North Island: The University of Auckland and AUT; the University of Waikato; Massy University; and Victoria University of Wellington. The other three universities are all located on the South Island, including the University of Otago, the University of Canterbury, and Lincoln University.

Table 1.2 shows that the University of Auckland is the highest-ranked New Zealand university, ranked 68th in the QS rankings and 150th in the Times rankings. It is the top New Zealand university in 37 of the 40 QS subject areas and ranks in the global top 50 for 16 subjects (Universities New Zealand, n.d.1). The University of Otago, New Zealand's second-highest ranked university, holds 206th place in QS, and ranks within 301-350th in the Times ranking. Its School of Dentistry is ranked 12th globally—the highest individual subject ranking in the country (Universities New Zealand, n.d.3).

Victoria University of Wellington is ranked 241st in QS and 401-500th in Times. It ranks in the top 2% of the world's universities and the top 100 globally for 12 subjects, such as earth and marine sciences. It also ranked at the top for research intensity in the 2018 PBRF exercise (Universities New Zealand, n.d.4). Massey University ranks 239th in QS and 501-600th in Times. It has 15 subjects ranked in the global top 300 (Universities New Zealand, n.d.9).

Lincoln University, New Zealand's only specialist land-based university, ranks in the global top 150 for agriculture and forestry, reflecting its strength in this field (Universities New Zealand, n.d.8). The University of Canterbury is ranked equal 256th in QS and 501-600th in Times. It performs well in Linguistics, geography, and geology, ranking in the top 250 globally. It ranked first in PBRF 2018 for Ecology, public health, and political sciences (Universities New Zealand, n.d.7).

AUT is ranked equal to 407th in QS and 401-500th in Times. It has a five-star QS rating for teaching, employability, internationalisation, facilities and inclusiveness, and has five subjects ranked in the global top 250 (Universities New Zealand, n.d.5). The University of Waikato is ranked 250th in QS and 401-500th in Times, with 11 of its subjects ranked in the global top 350 (University of Waikato, n.d.3).

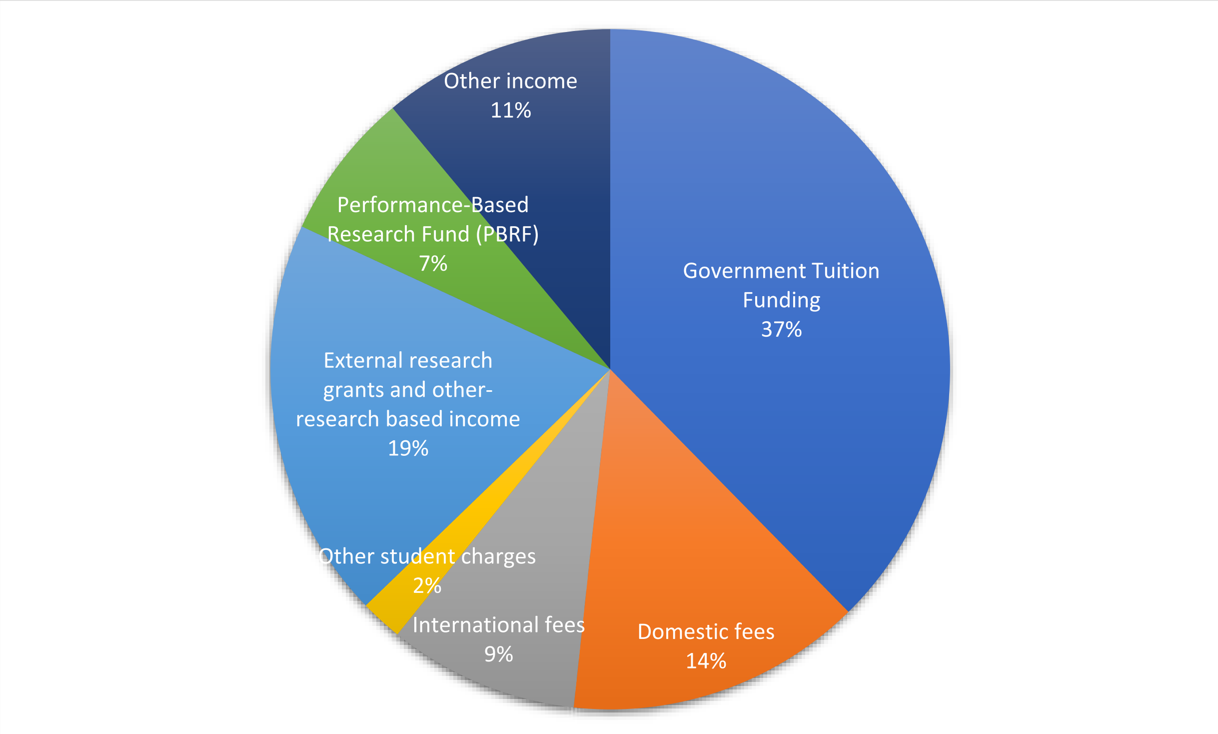
1.3.2 ***New Zealand University Funding***

Figure 1.1 illustrates the distribution of income sources for New Zealand universities in 2022. A significant portion of university funding (46%) is derived from government sources, including tuition grants, Student Achievement Component (SAC) funding[4], other student charges, and PBRF. Additionally, 30% of university income comes from research and other sources, such as interest and dividends. This reflects the universities' efforts to secure research grants and diversify income streams.

Students contribute 24% of total university income through tuition fees and compulsory charges. Between 2008 and 2018 (see Table 1.1), EFTS enrolments and international students in New Zealand remained relatively stable. This reflects the increasing demand for university education both domestically and internationally.

[4] Student Achievement Component (SAC) funding represents the New Zealand Government's contribution towards the direct costs associated with teaching, learning and other costs that are driven by student numbers (Studylink for Provider, n.d.). The amount of SAC funding allocated to a Tertiary Education Organisation (TEO) is determined by the Tertiary Education Commission (TEC) based on Investment Plans.

Figure 1.1
Distribution of Income Sources for New Zealand Universities, 2022



Source: New Zealand Tertiary Education Commission (2022).

Note: 1. Data are based on 2022 figures. Each category is calculated as a proportion of total university income across all universities. For instance, the proportion of PBRF income is calculated by dividing total PBRF income by the aggregate total income of all universities.

2. Government tuition funding includes EFTS-related TEC funding, such as SAC funding.
3. Domestic fees include student tuition fees, compulsory tuition-related charges and levies.
4. Other student charges cover other compulsory student charges and levies.
5. External research grants and other research-based income exclude PBRF and include external research grants and other research-based revenue.
6. Other income consists of interest and dividends.

Figure 1.1 highlights the universities' reliance on government tuition funding, student fees, and research-related income to support their operations. Table 1.3 summarises the 2022 income sources for each university, reflecting the differences in the financial structure of these universities. Most rely on government tuition funding and research income. For instance, AUT (47%) and the University of Canterbury (45%) receive a large share of their total income from the government to provide tuition. In contrast, Lincoln University depends highly (65%) on research and other sources, reflecting its specialist focus.

Domestic fee income[5] also varies. AUT receives 19% of its total income from domestic fees, while Lincoln University has the lowest domestic fee income share (4%). International fees contribute a

[5] The New Zealand Minister of Tertiary Education, Skills and Employment caps any increase to domestic student fees through the Annual Maximum Fee Movement (AFM). For 2021, the Government imposed a

smaller portion of total income aggregated across universities (9%) but are important for AUT and the University of Auckland (13% of total income each).

Table 1.3
Distribution of Income Sources for each New Zealand University, 2022

University	AUT	Lincoln	Massey	Auckland	Canterbury	Otago	Waikato	VUW	Total
Government Tuition Funding	0.47	0.24	0.36	0.32	0.45	0.4	0.37	0.39	0.37
Domestic fees	0.19	0.04	0.16	0.12	0.17	0.14	0.16	0.15	0.14
International fees	0.13	0.06	0.11	0.13	0.07	0.04	0.09	0.06	0.09
Other student charges	0.04	0.01	0.02	0.02	0.03	0.01	0.03	0.03	0.02
External research grants and other-research based income	0.06	0.24	0.17	0.24	0.14	0.21	0.16	0.17	0.19
PBRF	0.05	0.08	0.07	0.07	0.06	0.08	0.05	0.07	0.07
Other income	0.07	0.33	0.11	0.1	0.07	0.13	0.14	0.13	0.11

Source: New Zealand Tertiary Education Commission (2022).

The PBRF is an important part of university funding. In 2022, it accounted for around 7% of total income in most universities. While proportions were similar, actual values varied. PBRF income in 2022 was, in New Zealand dollars, $93.59 million at the University of Auckland, $37.83 million at Massey University, $35.96 million at Victoria University of Wellington, $61.49 million at University of Otago, $26.70 million at University of Canterbury; $10.09 million at Lincoln University, $13.60 million at University of Waikato, and $20.66 at AUT.

All eight universities are research-based institutions (Universities New Zealand, n.d.2). These PBRF figures highlight research's role in supporting teaching and maintaining international reputation. PBRF distributions encourage universities to focus on high-quality research and integrate research activities with teaching. This fosters a competitive research environment and drives continuous improvement in universities' research standards. More detailed information on the PBRF is provided in the following sub-section.

Therefore, the diversity in income sources reflects each university's strategy in balancing public funding, student fees, research, and other income, depending on their size, focus, and locations.

maximum fee increase of 1.1%, compared with a significantly higher cap of 6% set for 2024 (Universities New Zealand, 2024).

1.3.3 *New Zealand University Research Funding*

1.3.3.1 The Performance-Based Research Fund (PBRF)

Background and Purpose of PBRF

In the past, New Zealand's tertiary education organisations (TEOs) received funding for research-led teaching via research top-ups based on domestic enrolments at degree level or above (Smart, 2019a). This system depended on student subject choices, making it vulnerable to fluctuations in demand. Between 2004 and 2006, this scheme was gradually phased out and replaced by the PBRF.

Established in 2002, the PBRF aims to improve research quality by encouraging and rewarding research excellence in New Zealand's degree-granting organisations. It assesses the research performance of TEOs and allocates funding based on performance (New Zealand Tertiary Education Commission, 2024b). The PBRF does not directly fund specific research projects as an on-Plan fund. Instead, it provides bulk funding to support institutional research capability, research-led teaching at degree and postgraduate levels and research excellence.

The Three Funding Components of the PBRF

The PBRF is a performance-based assessment regime that combines peer review and performance measures (New Zealand Tertiary Education Commission, 2022, p. 8). Managed by the Tertiary Education Commission (TEC), the PBRF has three components:

1. Quality Evaluation (QE). This component accounts for 55% of the PBRF funding pool. It is conducted every six years to assess the quality of research by eligible TEO staff. TEOs submit Evidence Portfolios (EPs) for their staff, which expert peer review panels assess. Funding is based on peer-reviewed evaluation of individual EPs. Four rounds were held in 2003, 2006, 2012 and 2018. The QE share decreased from 60% to 55% in 2015-2016.

2. Research Degree Completions (RDC). This component accounts for 25% of the fund. It measures the number of completed PBRF-eligible postgraduate research-based degrees each year at participating TEOs.

3. External Research Income (ERI). This component makes up 20% of the fund. It measures the total annual research income received from external sources. The ERI share increased from 15% to 20% in 2015-2016.

PBRF funding allocations are calculated annually based on the performance of participating TEOs in these three components. RDC and ERI performance are measured annually, while the QE ratios were set after the 2018 round and will remain fixed until the next QE.

The Quality Categories of QE

The PBRF QE uses quality categories to assess and allocate funding based on the research performance of eligible TEO staff. TEC assigns the full-time equivalent (FTE) staff to funded quality categories (A, B, C, and C (NE)) in the 2012 and 2018 evaluations. In 2006, two additional categories, C (New and Emerging, C(NE)) and R (New and Emerging, R(NE)), were introduced to recognise early-career researchers. These researchers are assessed using specific criteria with a lower threshold.

PBRF QE funding is based on (1) the FTE status of eligible staff, (2) subject-area weightings[6], and (3) quality-category[7] weightings (e.g., A, B, C or C(NE)). Each eligible staff member submits an EP, peer-assessed and is assigned a quality category. These categories carry numerical scores that determine funding levels: A = 5, B = 3, C=1, and C(NE) = 2[8]. Staff assigned “R” or “R(NE)” categories are not funded. Notably, the C(NE) weighting was increased in the 2018 QE round—from a weighting of 1 (used between 2008 and 2011) to 2. This recognises the contributions of new and emerging researchers and strengthens support for early-career staff.

Current Development—UAG established and PBRF QE 2026 Cancelled

In 2024, the government cancelled the scheduled PBRF QE 2026 and established the University Advisory Group (UAG) to review the current university system supporting excellence in teaching and research (New Zealand Tertiary Education Commission, 2024a). The UAG reviews policy settings, including funding mechanisms, incentives, and allocation strategies for research and teaching

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[6] Subject-area weightings reflect research cost differences based on an EP’s primary discipline (New Zealand Tertiary Education Commission, 2022, p. 16; Smart. 2005, p. 4). High-cost subjects (e.g., engineering and technology, clinical medicine, dentistry) are weighted at 2.5; fields like chemistry and physics at 2; and arts and economics at 1. For more, see https://www.tec.govt.nz/assets/Publications-and-others/PBRF-Publications/PBRF-User-Manual-updated-February-2022.pdf.

[7] Quality categories, assigned by peer-review panels, determine funding: A = 5 (world-class research, including new and emerging researchers), B = 3 (high-quality, nationally recognised), C = 1 (institution/community recognised, excluding new and emerging researchers), C(NE) = 2 (new and emerging researchers with quality-assured outputs), R and R(NE) categories are unfunded (New Zealand Tertiary Education Commission, 2019, p. 12).

[8] Each Quality Category is assigned a numerical “quality weighting”. From 2008 and 2011, C(NE) was weighted as 1 (Smart & Engler, 2013, p. 5; New Zealand Tertiary Education Commission, 2006, p. 70; 2013, p. 85; 2019, p. 40).

(particularly the PBRF). Its main focus is the university sector, though recognising its relevance to the wider higher education sector. At the time of writing, the UAG's review was ongoing. Notably, the PBRF was in place over the entire analysis period of this thesis (2008 – 2018).

International Comparisons

New Zealand's PBRF was influenced by systems in countries such as Australia (see Subsection 1.4), the United Kingdom and Hong Kong. These systems use peer-review evaluations to assess and reward research excellence.

The United Kingdom (UK) introduced a PBRF system in 1986 to improve the selective allocation of public resources (OECD, 2010; Geuna & Piolatto, 2016). The Research Assessment Exercise (RAE) was held in 1986, 1989, 1992, 1996, 2001 and 2008. It was later replaced by the Research Excellence Framework (REF) in 2014 and 2021. The next REF is scheduled for 2028. Both the RAE and REF assess research at the department level using expert reviews. The RAE assessed research outputs, research environment, and indicators of esteem (Research Assessment Exercise 2008, 2017). The REF evaluates research performance using three components: research output (65%), social impact (20%), and research environment (15%) (Research Excellence Framework 2021, 2022).

Hong Kong's Research Assessment Exercise (RAE) was modelled in the UK's RAE and conducted in 1993, 1996, 1999, 2006, 2014, and 2020. The next assessment is scheduled for 2026. Until 2005, funding was split between teaching (about 75%) and research (about 25%) (University Grants Committee, 2013, p. 6). Hong Kong's RAE evaluates performance across disciplines using units of assessment. Since 2020, its evaluation has included 70% research outputs, 15% research impact case studies, and 15% research environment submissions (University Grants Committee, 2017).

*1.3.3.2 **New Zealand Government Contestable Research Funding***

The main sources of contestable research funding from the New Zealand Government to universities are the Marsden Fund administered by the Royal Society, the Health Research Council (HRC), and the Ministry of Business Innovation and Employment (MBIE) (Universities New Zealand, n.d.2). Universities also receive contestable funding from other sources, such as charitable foundations, commissioned research and internationally funded grants.

Marsden Fund[9]

Established in 1995, the Marsden Fund is administered by the Royal Society of New Zealand[10] on behalf of the Marsden Fund Council. It is New Zealand's primary mechanism for funding pure research to increase knowledge. It supports *investigator-driven* research rather than those driven by funders or industry (University of Waikato, n.d.4). Competition for this funding is intense. The 2016 Budget added $66 million over four years, increasing the fund from $57.8 million in 2016/17 to $79.8 million annually by 2019/20 (Royal Society of New Zealand, 2024).

Health Research Council[11] **(HRC)**

The HRC is the Government's principal health research agency (Health Research Council of New Zealand, 2017). It supports research that improves health outcomes, strengthens healthcare delivery, and produces economic benefits for New Zealand (Universities New Zealand, n.d.2). Most of its funding is awarded annually to independent, researcher-driven projects. It also provides career development awards for emerging researchers, including Māori and Pacific researchers. The 2016 budget added $97 million over four years, increasing it from $87.2 million in 2016/17 to $120.2 million annually by 2019/20 (Health Research Council, 2024).

Ministry of Business, Innovation and Employment[12] **(MBIE)**

MBIE is the Government's lead business-facing agency and plays a central role in shaping and delivering a strong New Zealand economy. Its funding aims to build a high-performing science and innovation system supporting a more diverse, technologically advanced, smart nation (Ministry of Business, Innovation & Employment, 2024). MBIE works closely with several agencies, such as the HRC and the Royal Society of New Zealand (see footnote 10), to promote science and innovation. MBIE invests in science through contestable funding rounds and supports programmes that build

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[9] Further information is available at https://www.royalsociety.org.nz/what-we-do/funds-and-opportunities/marsden/.

[10] The Royal Society of New Zealand is an independent, national academy of sciences, a federation of scientific and technological societies (Royal Society of New Zealand, 2024), and a non-for-profit membership organisation. Its functions include fostering a culture that supports science and technology and providing expert advice on important public issues to the government and community. See more at https://www.royalsociety.org.nz/.

[11] Further information is available at https://www.hrc.govt.nz/.

[12] More information is available at https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities.

high-performing science and innovation systems. The Ministry administers several research funds, including the Endeavour Fund[13] and the Catalyst Fund[14].

1.4 Australian Universities

1.4.1 *Australian University Description and International Ranking*

There are five main university groups in Australia. The Group of Eight (Go8) includes Australia's eight leading research-intensive universities. The Innovative Research Universities Australia (IRU) is a network of seven universities collaborating to improve higher education outcomes, such as teaching or research. The Regional Universities Network (RUN) consists of seven regional institutions. The Australian Technology Network (ATN) includes four universities with a strong focus on technology, which were initially institutes of technology. Universities that do not belong to these groups are categorised as Non-aligned. Table 1.4 summarises the five university groups and their rankings. The university group classifications are based on the 2001-2019 Australian University Research Block Grants (RBG) allocation series that reflect state-level data rather than institutional groupings.

The Go8 universities consistently achieve the highest rankings among Australian universities in both the QS and THE rankings. The University of Melbourne ranks highest in the QS (14th) and THE (37th) rankings. The University of Sydney and New South Wales are both ranked 19th in QS. These universities, alongside Australian National University (34th QS), Monash University (42nd QS, 54th THE) and University of Queensland (43rd QS, 70th THE), maintain strong global rankings, reflecting their research-intensive reputations.

ATN universities generally rank in the mid-range. The University of Technology Sydney is the highest-ranked ATN member (90th QS, 148th THE). Universities in the IRU group typically rank between 200 and 500 in both QS and THE rankings. La Trobe University (242nd QS, 251-300 THE) and Griffith University (243rd QS, 251-300 THE) outperform most other IRU members.

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[13] Endeavour Fund, previously known as the Contestable Fund, is New Zealand's biggest open contestable fund. It focuses on supporting longer-term research in science or technology or related activities that have a high potential to positively transform New Zealand's economic, environmental and societal outcomes and give effect to the Vision Mātauranga policy (Endeavour Fund, 2024). The fund increased from $183m in 2015/16 to $200m in 2019/20 (University New Zealand, n.d.2). See more at https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities/investment-funds/endeavour-fund.

[14] Catalyst Fund, managed by the Royal Society of New Zealand, supports activities that develop and foster international collaborations that take advantage of international science and innovation for New Zealand's benefit (Catalyst Fund, 2023). See more at https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities/investment-funds/catalyst-fund.

RUN universities are mostly ranked outside the top 500 in both rankings. The University of Southern Queensland is the highest-ranked RUN institution (410th QS, 351-400 THE). Non-aligned universities show mixed rankings. Macquarie University (130th QS, 180th THE), University of Wollongong (162nd QS, 201-250 THE), the University of Newcastle (173rd QS, 201-250 THE), and QUT (189th QS, 199th THE) perform strongly, with rankings similar to those for ATN universities. Australian Catholic University[15] (801-850 QS, 401-500 THE) ranks among the lowest in this group.

Table 1.4
Australian Universities Groups in State/Territory and World University Rankings 2024

Australian Universities	Abbreviation	Group	State/Territory	2024 QS	2024 THE
The University of Melbourne	Melbourne	Go8	Victoria	14	37
The University of Sydney	Sydney	Go8	New South Wales	19	60
The University of New South Wales	NSW	Go8	New South Wales	19	84
Australian National University	Australian National	Go8	Australian Capital Territory	34	67
Monash University	Monash	Go8	Victoria	42	54
The University of Queensland	Queensland	Go8	Queensland	43	70
The University of Western Australia	Western Australia	Go8	Western Australia	72	143
University of Adelaide	Adelaide	Go8	South Australia	89	111
University of Technology, Sydney	Technology Sydney	ATN	New South Wales	90	148
RMIT University	RMIT	ATN	Victoria	140	251-300
Curtin University of Technology	Curtin	ATN	Western Australia	183	201-250
University of South Australia	South Australia	ATN	South Australia	326	301-350
La Trobe University	La Trobe	IRU	Victoria	242	251-300
Griffith University	Griffith	IRU	Queensland	243	251-300
Western Sydney University	Western Sydney	IRU	New South Wales	375	301-350
Flinders University	Flinders	IRU	South Australia	380	251-300
James Cook University	James Cook	IRU	Queensland	415	351-400
Murdoch University	Murdoch	IRU	Western Australia	431	351-400
Charles Darwin University	Charles Darwin	IRU	Northern Territory	601-610	401-500
University of Southern Queensland	Southern Queensland	RUN	Queensland	410	351-400
Central Queensland University	Central Queensland (CQU)	RUN	Queensland	590	501-600
Southern Cross University	Southern Cross	RUN	New South Wales	651-660	501-600
Charles Sturt University	Charles Sturt	RUN	New South Wales	801-850	801-1000
The University of New England	New England	RUN	New South Wales	951-1000	-

[15] Australian Catholic University is located in the multi-state since ACU has seven campuses across Australia: Ballarat (Victoria), Brisbane (Queensland), Canberra (Auckland Capital Territory), Melbourne and Sydney (Blacktown—Western Sydney, North Sydney, Strathfield). Most campuses are in the South-Eastern locations. Due to most campuses being in Sydney, this university is classified under New South Wales State and belongs to the Non-align (N-A) university group. Although ACU operates across multiple states, it is classified under New South Wales due to most campuses being in Sydney.

Federation University Australia	Federation University	RUN	Victoria	-	601-800
University of the Sunshine Coast	Sunshine Coast	RUN	Queensland	1001-1200	501-600
Macquarie University	Macquarie	Non-aligned	New South Wales	130	180
University of Wollongong	Wollongong	Non-aligned	New South Wales	162	201-250
The University of Newcastle	Newcastle	Non-aligned	New South Wales	173	201-250
Queensland University of Technology	Queensland Technology (QUT)	Non-aligned	Queensland	189	199
Deakin University	Deakin	Non-aligned	Victoria	233	251-300
Swinburne University of Technology	Swinburne	Non-aligned	Victoria	285	201-250
University of Tasmania	Tasmania	Non-aligned	Tasmania	307	251-300
University of Canberra	Canberra	Non-aligned	Australian Capital Territory	421	351-400
Edith Cowan University	Edith Cowan	Non-aligned	Western Australia	529	351-400
Victoria University	Victoria	Non-aligned	Victoria	711-720	401-500
Australian Catholic University	Catholic	Non-aligned	New South Wales	801-850	401-500

Source: Australian Government Department of Education, Times Higher Education (2024b), QS TOP UNIVERSITIES (2024).

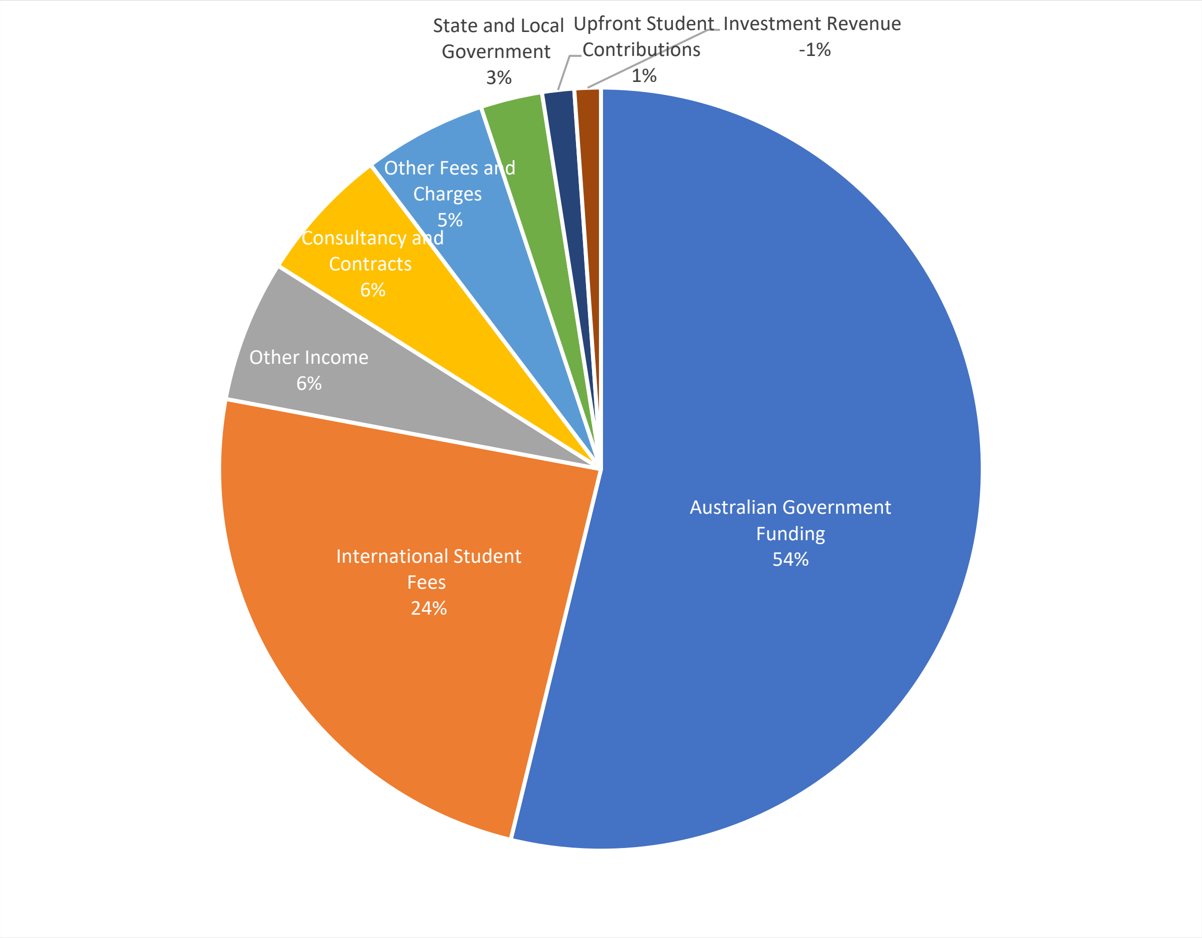
Note: 1. The university group classifications are based on the 2001-2019 Research Block Grants (RBG) allocation series and reflect state-level data rather than institutional groupings.
2. Australian Catholic University operates across multiple states, with seven campuses in Ballarat (Victoria), Brisbane (Queensland), Canberra (Auckland Capital Territory), Melbourne and Sydney (Blacktown-Western Sydney, North Sydney, Strathfield). Most campuses are in Sydney and thus the university is classified under the New South Wales State and the Non-aligned (N-A) group.
3. Charles Darwin University exited the IRU in 2022, but it remains classified in the IRU group in this study due to the thesis's data timeframe (2008-2018). The University of Canberra joined the IRU in 2021 but is classified as the Non-aligned group.
4. Deakin University and the University of Newcastle joined the ATN in 2020-2021 but are categorised as a Non-Aligned group.
5. Queensland University of Technology (QUT) left the ATN in September 2018 (Australian Technology Network of Universities, 2019) and is classified as Non-aligned in this study due to data collected in RBG 2019.

1.4.2 A*ustralian University Funding*

The Australian university system is largely funded through government research and teaching grants and a government-backed student loan scheme known as the Higher Education Loan Program (HELP) to support tuition fees. Other funding sources include state government funding, international student fees, investment income, and revenue from contract research and consultancy (Universities Australia, n.d.).

Figure 1.2 shows the revenue sources of Australian universities in 2022, providing an overview of their financial structure. Australian Government funding accounts for the largest share (54%), highlighting the significant role of public investment in higher education. International student fees account for 24% of revenue, reflecting significant reliance on overseas enrolments and the associated risks during global uncertainty. The remaining 22% comes from consultancy and contracts (6%), other income (6%, e.g., royalties, trademarks and licences), and other fees and charges (5%, beyond domestic student tuition fees, e.g., student services and amenities fees).

Figure 1.2
Australian Universities Revenue by Source in 2022



Source: Australian Government Department of Education (2022), retrieved from: https://www.education.gov.au/higher-education-publications/resources/2022-higher-education-providers-finance-tables
Note: "Other income" includes royalties, trademarks, licences, and the share of the net result of associates and joint ventures accounted for using the equity method.

Table 1.5 shows the income distribution across Australian university groupings in 2022, indicating their different financial reliance on specific revenue streams. Australian Government funding is the largest revenue source across all groups, accounting for 55% of total university sector income. Reliance on government funding varies. RUN universities are the most dependent (70%), while Go8 universities receive the lowest proportion (46%), indicating more diversified income streams.

International student fees constitute a major revenue source for Go8 universities (33%), due to their high international enrolments. In contrast, RUN universities rely less on international fees (12%) due to their regional focus and domestic student enrolments. ATN (24%) and Non-aligned universities (18%) also receive a moderate share of total income from international student fees.

Other revenue streams account for smaller proportions across all groups. Consultancy and contract income range from 3% (RUN) to 7% (Go8), reflecting Go8 universities' stronger industry engagement and research intensity. Most universities recorded negative investment income, with the Go8 experiencing the largest losses (-2%).

Overall, the data show significant variation in income structures. Go8 and ATN universities have more diversified sources, with relatively higher shares of income from international student fees, consultancy and contracts, while RUN universities remain more reliant on government funding.

Table 1.5
The Distribution of Income Sources for Australian University Groupings in 2022

University grouping	Go8	IRU	RUN	ATN	Non-Aligned	Total
Australian Government Funding	0.46	0.63	0.70	0.58	0.63	0.55
International Student Fees	0.33	0.15	0.12	0.24	0.18	0.25
Other Income	0.08	0.06	0.03	0.05	0.05	0.06
Consultancy and Contracts	0.07	0.06	0.03	0.06	0.05	0.06
Other Fees and Charges	0.05	0.06	0.06	0.04	0.05	0.05
State and Local Government	0.02	0.02	0.03	0.03	0.03	0.03
Upfront Student Contributions	0.01	0.01	0.02	0.02	0.02	0.01
Investment Revenue	-0.02	-0.002	-0.003	-0.01	-0.01	-0.01

Source: Australian Government Department of Education (2022a).
Note: 1. Australian Government Funding includes Australian Government Grants (e.g., the Commonwealth Grant Scheme and other grants; Education Research Grants; Other Capital Funding; Australian Research Council and Other Australian Government Financial Assistance) and HELP Australian Government Payments (e.g., HECS-HELP, FEE-HELP, SA-HELP, and OS-HELP).
2. Other income includes royalties, trademarks and licenses.

Government Grants for Teaching—Commonwealth Grant Scheme (CGS)

The Commonwealth Grant Scheme (CGS) is the single largest source of government funding for Australian universities. Funding is allocated based on the number of full-time equivalent domestic students in Commonwealth Supported Places[16] (CSPs). For each CSP, a university receives a Commonwealth contribution from the CGS. The amount of the Commonwealth contribution depends on the field of study, reflecting differences in teaching costs across disciplines.

[16] CSP is a place subsidised by the Commonwealth.

Demand Driven System

Before 2012, the Government capped the number of student places, limiting access for traditionally under-represented groups. In 2012, the Australian Government introduced the demand driven system, removing caps on bachelor-degree funding at public universities. This allowed institutions to respond to student demand and expand access to higher education (Australian Government Department of Education, 2014). Between 2008 and 2017, undergraduate enrolments more than doubled among indigenous students (105% increase). Enrolments from regional and remote areas increased by 50% (Universities Australia, n.d.).

However, in December 2017, the Government suspended the system and froze total funding at 2017 levels. Total funding for 2018 and 2019 was capped at 2017 levels. From 2020, the cap will rise by a small amount each year—subject to a new performance-based funding system that is yet to be announced (Universities Australia, n.d.a).

Student Contributions and Loans Schemes

CSPs are funded by a mix of Commonwealth contributions through the CGS and student contributions. Student contributions vary by field of education, reflecting differences in teaching costs.

The HELP provides loans to students to defer certain study costs, mainly student contributions (for those in CSPs) and tuition fees. Students pay HELP loans once they reach a minimum income threshold, enabling access to the university regardless of financial background. There are four HELP sub-schemes for different fee types: HECS-HELP[17], FEE-HELP[18], OS-HELP[19] and SA-HELP[20].

Students also have an option to pay their student contribution amount upfront directly to the university before the payment deadline. This loan is repaid through the student's income tax once they begin

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[17] HECS-HELP is available to CSP students to defer the cost of their student contribution amount—a system that replaced the original Higher Education Contribution Scheme (HECS). It partially subsidises study costs but does not cover the full cost. The remaining cost is called the student contribution amount. The government pays the university directly.

[18] FEE-HELP supports domestic, full-fee-paying students not enrolled in a CSP. It helps cover tuition fees.

[19] OS-HELP assists domestic undergraduate students with overseas study costs, such as accommodation and travel.

[20] SA-HELP covers the student services and amenities fee.

full-time work (Open Universities Australia, 2025). From 1 January 2023, the Government removed the 10% discount for upfront payments (Australian Government Department of Education, 2022), eliminating the financial incentive to pay early.

1.4.3 ***Australian University Research Funding***

Australian university research is funded through a combination of funding sources, including the Australian Government, state and territory governments, industry partners, and philanthropic sources (Universities Australia, n.d.a).

1.4.3.1 ***A Dual Research Funding System***

The Australian Government uses a dual funding system to support university research. It includes (i) research block grants (RBGs), which fund the systemic costs of research, and (ii) Australian nationally competitive grants, which are allocated through merit-based, peer-review processes to fund specific research projects, programmes, or fellowships (Australian Government Department of Education, 2024b; Ferguson, 2022).

(i) Research Block Grants (RBGs)

The performance-based RBGs provide funding to support research and research training at eligible higher education providers (HEPs). Administered by the Department of Education, Skills and Employment (DESE), RBGs consist of two components: the Research Training Program (RTP) and the Research Support Program (RSP).

The RTP funds the training of domestic and international students undertaking higher degrees by research (HDRs), including research doctorate and research master's degrees. It supports research student stipends and tuition fee offsets. The RSP provides funding to support systemic research costs, including libraries, laboratories, consumables, computing centres, the salaries of support and technical staff, and the indirect costs of Australian competitive grants and other sources.

HEPs have autonomy over RBG allocation, allowing them to prioritise their research and research training, including investments in research equipment and infrastructure and supporting research students, staff and projects. In 2025, the Australian Government will provide \$2.33 billion in RBGs: \$1.09 billion for the RSP and \$1.25 billion for the RTP (Australian Government Department of Education, 2024b).

(ii) Australian Nationally Competitive Grants

The main sources of Australian nationally competitive grants are (1) the Australian Research Council (ARC) and (2) the National Health and Medical Research Council (NHMRC), which fund specific research programmes, projects and fellowships through peer-reviewed processes. Other national funding bodies, such as (3) the Medical Research Future Fund (MRFF), also provide Australian nationally competitive grants.

(1) Australian Research Council (ARC)

Established in 2001, ARC is a Commonwealth entity under the Australian Government that reports independently to the Minister for Education. It awards grants competitively to individuals, research teams and large-scale centres. The ARC funds the highest-quality basic and applied research and research training. It encourages national competition in all disciplines except clinical and other medical research. It also advises the Government on research matters and administers the National Competitive Grants Program (NCGP).

National Competitive Grants Program (NCGP)

The NCGP funds basic and applied research and research training, excluding clinical and medical research (Australian Government Australian Research Council, 2023). In 2023-2024, it allocated around $895 million to leading Australian researchers (Australian Government Australian Research Council, 2023).

The NCGP includes two funding programmes. The Discovery Program supports individual researchers and teams. It promotes fundamental research by funding competitive research projects, fellowships, and awards. The Linkage Program promotes collaboration between universities, industry and other partners. It strengthens Australia's research innovation capacity and supports research projects, infrastructure and centres (Australian Government Australian Research Council, 2025).

Research Assessment and Evaluation

The ARC is responsible for the national research assessment framework, which evaluates the quality and impact of research produced in Australian universities. This framework includes two national research evaluation programmes: Excellence in Research for Australia (ERA) and Engagement and Impact (EI) assessment, with EI commenced in 2018.

Research Assessment and Evaluation—Excellence in Research for Australia (ERA)

The ERA is Australia's national research quality assessment for universities, administered by the ARC. It is conducted at the institutional level, using discipline-specific indicators and expert reviews that highlight the research strengths of individual universities (Australian Government Australian Research Council, 2025a). It is not a continuous assessment and was conducted in four rounds: 2010, 2012, 2015, and 2018. The 2023 round was paused.

ERA identifies research excellence by comparing Australia's university research against international benchmarks, incentivising improvement in research quality. It classifies disciplines using two-digit and four-digit Field of Research[21] (FoR) codes based on the Australian and New Zealand Standard Research Classification (ANZSRC).

Research Assessment and Evaluation—Engagement and Impact (EI) Assessment

The EI Assessment evaluates how well researchers engage with end-users of research and how well universities translate research into impacts beyond academia (Australian Government Australian Research Council, 2025b). The first EI assessment took place in 2018, assessing university performance in research engagement and impact. It was conducted at the discipline level within each university.

Research Grant Services (RGS)

Established in 2020, the RGS provides grants administration services to other Australian Government entities that manage research-focused grant programmes. RGS streamlines grant processes, making it easier and more efficient for applicants, assessors and users to undertake research granting activities. It also improves public access to data and helps Commonwealth research grant funders get better results from their research funding (Australian Government Australian Research Council., 2023b).

(2) National Health and Medical Research Council (NHMRC)

[21] Under the ERA, disciplines are classified using two- and four-digit Field of Research (FoRs) codes from the 2008 Australia and New Zealand Standard Research Classification (ANZSRC), released by the Australian Bureau of Statistics and Statistics New Zealand (Australian Government Australian Research Council, 2015). The classification covers major fields and related research sub-fields and emerging study areas. It follows a three-tier hierarchy: Division (2-digit), e.g., 32 (Biomedical and Clinical Sciences); Group (4-digit), e.g., 3201 (Cardiovascular medicine and haematology); and Field (6-digit), e.g., 030102 (Haematology) (University of the Sunshine Coast Australia, 2024).

The NHMRC is the Australian Government's primary funding agency for health and medical research. It supports the basic sciences of clinical, public health, and health services research. Funding to the NHMRC's Medical Research Endowment Account (MREA) increased from $185 million in 2000-01 to $750 million in 2010-11. Since then, annual allocations have remained around $800 million (Australian Government National Health and Medical Research Council, n.d.). The increased investment in medical research and researchers has strengthened the capacity and productivity of Australia's health and medical research sector.

(3) Medical Research Future Fund (MRFF)

Established in 2015, the MRFF is a dedicated Australian Government fund for investing in the translation and commercialisation of health and medical research. It provides long-term sustainable funding to improve lives, build the economy and contribute to health system sustainability (Australian Government Medical Research Future Fund, 2024). The MRFF is a $22 billion long-term investment supporting Australian health and medical research.

1.4.3.2 Other Key Sources of Australian Government Funding for University Research

The Australian Government also funds university-industry engagement, such as the Department of Education, Skills and Employment (DESE)-administered programmes for university-led collaborations (e.g., Australia's Economic Accelerator, AEA) and Department of Industry, Science, Energy and Resources (DISER)-administered programmes for industry-led collaborations (e.g., the Cooperative Research Centre (CRC) Program).

Australia's Economic Accelerator (AEA)

The AEA is a $1.6 billion programme that supports university-led collaborations in research translation and commercialisation (Australian Government Department of Education, 2025). It targets projects aligned with the Government's national priority areas, including value-add in resources; agriculture, forestry and fisheries; medical science; renewables and low emission tech; defense capability; transport; and enabling capabilities (Australian Government Australia's Economic Accelerator, 2025). AEA will initially run for ten years (2023-2032), supported with funding from the $1.6 billion investment by the Australian Government in the research commercialisation ecosystem (Australian Government Australian Research Council, 2023a).

Cooperative Research Centre (CRC) Program

Established in 1990, the CRC Program supports industry-led research collaborations between industry, researchers and the community. The programme focuses on research and development with commercial applications, aiming to improve Australian industries' competitiveness, productivity and sustainability and solve industry problems (Australian Government Business, 2025). It operates through two funding streams. The CRC grants support medium to long-term industry-led collaborations, providing funding for up to 10 years without a specified limit. The CRC Projects (CRC-P) grants support short-term, industry-led research collaborations, offering matched funding between $100,000 and $3 million for up to 3 years.

Other Public Sector Research Funding

Other public sector research funding in Australia is allocated outside of a nationally competitive basis. For example, the National Institute Program funding, administered by the DESE, supports the Australian National University. In addition, state and local governments provide grants and direct research project funding.

1.5 Outline of the Thesis

This thesis includes eight chapters, briefly outlined as follows.

Chapter 2 introduces the methodological framework for measuring productivity and efficiency. This chapter first introduces the concept of technical efficiency. It then reviews the MPI and their decomposition. The chapter also introduces stochastic frontier analysis (SFA) to estimate efficiency, including the parametric, production, distance function and cost frontiers.

Chapter 3 presents a comprehensive literature review on productivity and efficiency in higher education, focusing on applying the MPI and SFA. It begins with a review of key studies that summarise empirical methods and commonly used variables. It discusses the classification of input, output, quality-adjusted, price and inefficiency determinants used in previous studies. The chapter outlines empirical methodologies with a focus on MPI and SFA applications. It synthesises MPI and SFA applications from both New Zealand and international contexts. Lastly, it identifies gaps in the literature and outlines the key contributions.

Chapter 4 describes the datasets used in Chapters 5 to 7, introducing the key variables applied in the MPI and SFA (e.g., output distance function (ODF) and stochastic cost frontier (SCFA)) techniques. It discusses the input and quality-adjusted output variables used in the MPI analysis. The chapter also describes the variables used in SFA, including inefficiency determinants in the Battese and Coelli (1995) model (BC95 model). The inefficiency effect model incorporates specific exogenous variables that influence university performance but are not classified as inputs or outputs.

Chapter 5 presents the findings from the MPI analysis, providing critical insights into productivity and efficiency across New Zealand and Australian universities from 2008 to 2018. The analysis includes four components. First, it presents partial labour productivity estimates, indicating input and (quality-adjusted) output changes. Second, it examines MPI and its decomposition to assess efficiency and technical change variations. Third, it tracks the cumulative changes in MPI components. Fourth, a sensitivity analysis tests the robustness of MPI results under alternative variable measurements. This includes evaluating how variations in input (e.g., labour and capital), research output (e.g., research publications), and data sources affect results. Partial labour productivity provides preliminary insights but does not fully capture the functional relationship between inputs and outputs. To address this limitation, the MPI provides a more comprehensive view of productivity trends and their underlying drivers.

Chapter 6 estimates technical efficiency (TE) performance using a stochastic ODF for eight New Zealand and 37 Australian universities from 2008 to 2018. It also compares TE scores using Cobb-Douglas and translog specifications with quality-adjusted outputs. It is the first study to examine the effects of labour and capital expenses on New Zealand university efficiency. Previously, Abbott and Doucouliagos (2009) applied SFA to Australasian universities for 1997-2003. This chapter also uses the BC95 inefficiency effect model to explore how factors such as the presence of medical schools, the proportions of international and female students, regional location, and staff composition contribute to inefficiency. A sensitivity analysis also explores the robustness of results in measuring alternative variables. This includes testing the effects of changes in labour inputs, research outputs (e.g., citation-weighted publications), and data sources.

Chapter 7 uses SCFA to estimate cost efficiency using Cobb-Douglas and translog functional forms with quality-adjusted output. The analysis shows that outputs (e.g., undergraduate and postgraduate completions and research income) per equivalent full-time students (EFTS) and input prices (e.g., average costs per FTE staff and capital price) affect costs per EFTS. It also uses the BC95 inefficiency effect model to examine the effects of medical schools, regions, student demographics, and staff mix on cost inefficiency. A sensitivity analysis tests the effects of alternative capital price measures, data sources and research output measures. This is the first application of SCFA to assess cost efficiency in New Zealand universities, offering new insights into their performance.

Chapter 8 concludes the thesis. It summarises key findings, outlines the study’s contributions, and discusses policy implications. This chapter also reflects on limitations and recommendations for future research.

Chapter 2 Methodology

2.1 Productivity and Efficiency Concepts

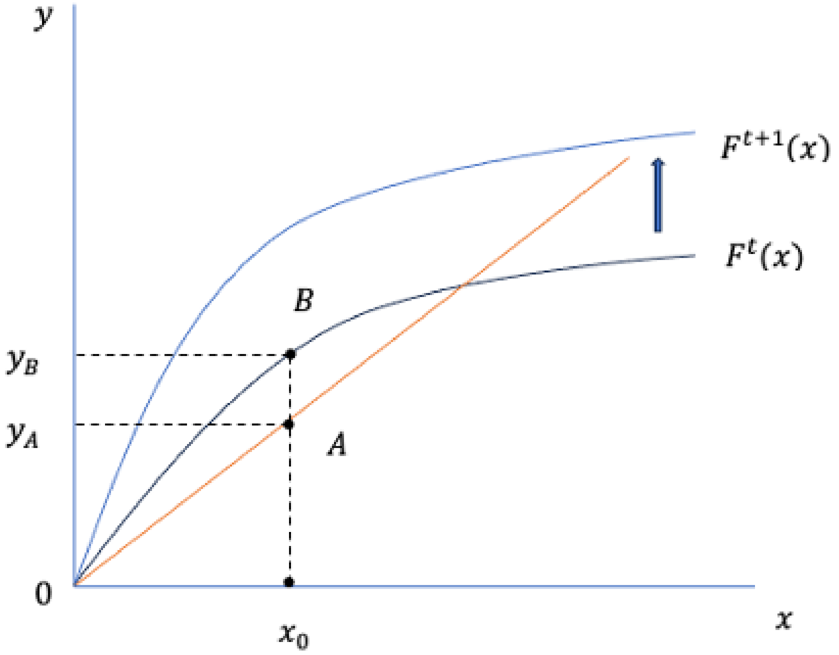
The terms "productivity" and "efficiency" are often used interchangeably, but they represent distinct concepts. Productivity is the ratio of outputs to inputs. When multiple inputs and/or outputs are involved, methods are employed to aggregate them into a single index. This measure is commonly referred to as total factor productivity (TFP), which accounts for all factors of production used by the entity and all outputs produced by that entity.

Efficiency is a method of comparing the observed performance with the perfect or best performance using a particular production technology. Farrell (1957, p.255) first proposed economic efficiency, which is defined as the product of technical efficiency (TE) and allocative efficiency (AE). TE reflects the ability of an entity to obtain maximal output from a given set of inputs. AE reflects the ability of an entity to select the mix of inputs that minimises the cost of producing a given quantity of output, given the respective prices and the production function.

As this thesis focuses on the efficiency and productivity analysis of New Zealand universities, henceforth, the term "universities" will be used rather than terms such as "entity" "observation", "firm", or "decision-making unit".

TE can be measured using either an output-oriented or input-oriented framework. In an output-oriented framework, TE is measured by comparing the observed output of a university with the maximum output that can be produced under the current production technology using the same quantities of inputs. For example, consider a case where one input, denoted by $\boldsymbol{x}$, is on the horizontal axis, and one output, denoted by $\boldsymbol{y}$, is on the vertical axis. In Figure 2.1, the production frontier $\boldsymbol{F^t}(\boldsymbol{x})$ reflects the current production technology, representing the maximum output attainable for each level of input in period $\boldsymbol{t}$.

Figure 2.1
Productivity, Technical Efficiency and Productivity Change



When one considers productivity comparisons through time, there is an additional source of productivity change, called technical change (Coelli, et al., 2005, p. 4). This involves advances in technology that can be represented by an upward shift in the production frontier, that is the movement of the production frontier $\boldsymbol{F^t(x)}$ in period $\boldsymbol{t}$ to the production frontier $\boldsymbol{F^{t+1}(x)}$ in period $\boldsymbol{t+1}$. In period $\boldsymbol{t+1}$, all universities can technically produce more output for each level of input, relative to in period $\boldsymbol{t}$.

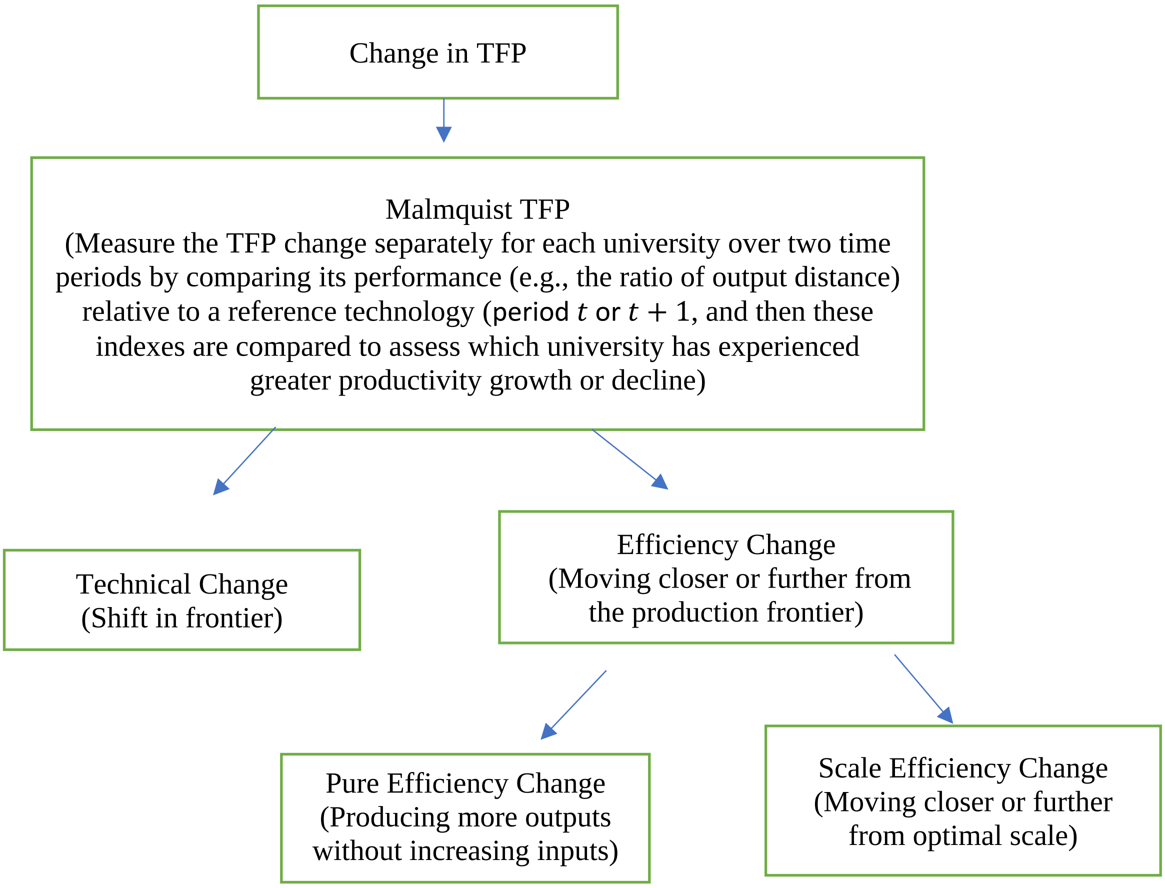
Suppose a university uses $\boldsymbol{x_0}$ units of input to produce $\boldsymbol{y_B}$ units of output, then it operates on the production frontier $\boldsymbol{F^t(x)}$ at period $\boldsymbol{t}$, at point $\boldsymbol{B}$, which means that it is technically efficient. Conversely, if the university operated at point $\boldsymbol{A}$, producing only $\boldsymbol{y_A}$ units of output with the same $\boldsymbol{x_0}$ units of input, it lies beneath the frontier and is technical inefficient. In an output-oriented framework, TE is measured by the ratio of $\boldsymbol{y_A/y_B \leq 1}$. The university operating at point $\boldsymbol{A}$ is inefficient because technically it could increase its output to the level associated with point $\boldsymbol{B}$ without requiring more of the input.

The productivity of the university operating at point $\boldsymbol{A}$ is measured by the slope of the ray passing through the origin, represented by the ratio of $\boldsymbol{y/x}$ (the orange line in Figure 2.1). If the university were to move from point $\boldsymbol{A}$ to the technical efficient point $\boldsymbol{B}$, the slope of the ray would be greater, implying higher productivity at point $\boldsymbol{B}$. Productivity is a level concept used to compare the performance of a university at a given point of time. In contrast, productivity change refers to movements in the productivity performance of a university over time.

2.2 **Malmquist Productivity Indexes (MPI)**

TFP changes can be measured using the Malmquist TFP index. As illustrated in Figure 2.2, this index captures TFP changes due to technical changes and efficiency changes, which can be decomposed into pure efficiency and scale efficiency changes. The Malmquist index is described in detail in the remainder of this subsection.

Figure 2.2
Diagram of Malmquist TFP Index



2.2.1 ***Productivity change and distance functions***

As noted above, when a university uses a single input to produce a single output, productivity is defined by the output-input ratio.

$$\boldsymbol{Productivity} = \frac{\boldsymbol{output}}{\boldsymbol{input}} = \frac{\boldsymbol{y}}{\boldsymbol{x}} \qquad (2.1)$$

Suppose the university produces a single output using a single input over two periods, $\boldsymbol{t}$ and $\boldsymbol{t+1}$, observing $(\boldsymbol{x^t},\ \boldsymbol{y^t})$ in the base period and $\left(\boldsymbol{x^{t+1}},\ \boldsymbol{y^{t+1}}\right)$ in the following period. Then,

$$\boldsymbol{Productivity\ change\ index} = \frac{\boldsymbol{y^{t+1}/x^{t+1}}}{\boldsymbol{y^t/x^t}} \tag{2.2}$$

Productivity has increased between periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$ if this ratio exceeds unity. Since universities produce multiple outputs using multiple inputs, productivity changes are represented by a TFP index. Thus, TFP denotes the index measuring productivity change from periods $\boldsymbol{t}$ to $\boldsymbol{t+1}$. This relationship can be expressed as:

$$\boldsymbol{TFPI} = \frac{\boldsymbol{TFP^{t+1}}}{\boldsymbol{TFP^t}} = \frac{\boldsymbol{y^{t+1}/x^{t+1}}}{\boldsymbol{y^t/x^t}} = \frac{\boldsymbol{y^{t+1}/y^t}}{\boldsymbol{x^{t+1}/x^t}} \tag{2.3}$$

To calculate the $\boldsymbol{TFPI}$ and the Malmquist TFP index, it is necessary to review the distance functions, which are very useful for describing technology in a way that makes it possible to measure efficiency and productivity. The concept of a distance function is closely related to production frontiers, involving radial contractions and expansion in defining these functions. In the university sector, the production process typically involves multiple outputs and inputs. Distance functions allow one to describe a multi-input, multi-output production technology without requiring information on input prices, output prices or specific behavioural assumptions (e.g., cost-minimisation or profit-maximisation) (Coelli et al., 2005, p. 47).

Following Färe and Primont (1995), let $\boldsymbol{x^t} \in \mathbb{R}_+^{\boldsymbol{K}}$ and $\boldsymbol{y^t} \in \mathbb{R}_+^{\boldsymbol{M}}$ denote an input vector and an output vector of a university, respectively, in period $\boldsymbol{t}$, $\boldsymbol{t = 1, \dots, T}$. The technology set is defined as:

$$\boldsymbol{S^t} = \{(\boldsymbol{x^t}, \boldsymbol{y^t}): \boldsymbol{x^t}\textbf{can produce } \boldsymbol{y^t}\}, \quad \boldsymbol{t = 1, \dots, T} \tag{2.4}$$

This technology set is the set of all feasible input-output vectors, such that $\boldsymbol{x^t}$ can produce $\boldsymbol{y^t}$. The production technology defined by the set, $\boldsymbol{S^t}$, can equivalently be defined using the output set, $\boldsymbol{P^t(x^t)}$, which represents the set of all output vectors, $\boldsymbol{y^t}$, that can be produced using the input vector, $\boldsymbol{x^t}$. The output set is defined by

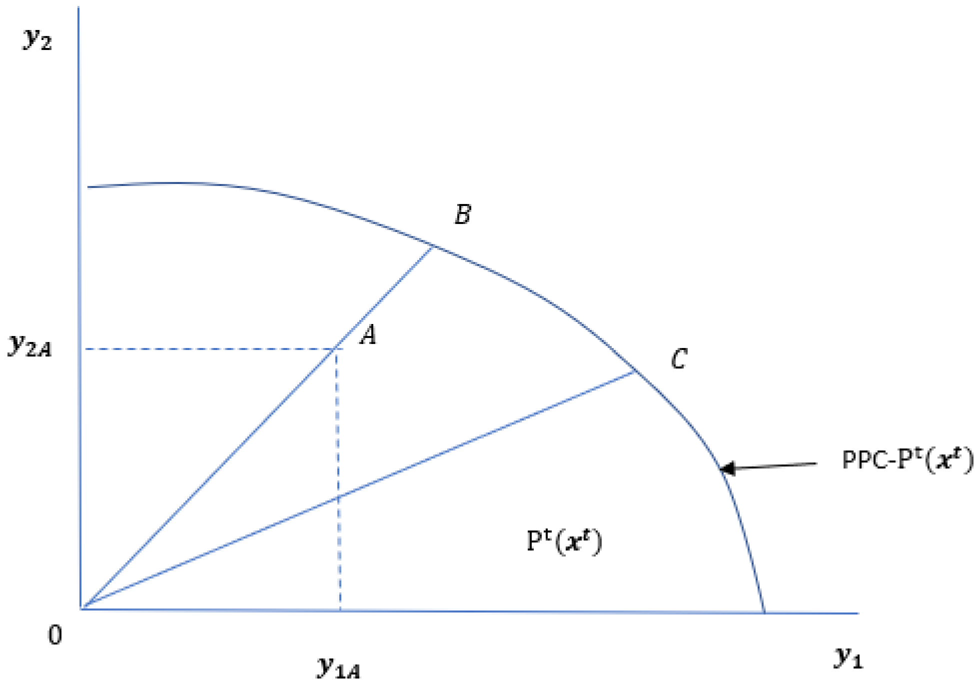
$$\mathbf{P^t}(\boldsymbol{x^t}) = \{\boldsymbol{y^t}: \boldsymbol{x^t}\ \textbf{can produce } \boldsymbol{y^t}\} = \{\boldsymbol{y^t}: (\boldsymbol{x^t}, \boldsymbol{y^t}) \in \boldsymbol{S^t}\} \tag{2.5}$$

The output distance function at time $\boldsymbol{t}$, $\boldsymbol{D_o^t(x_t, y_t)}$, can then be defined as:

$$\boldsymbol{D_o^t(x^t, y^t) = \min\{\theta: (y^t/\theta) \in \mathrm{P}^t(x^t)\} = (\max\{\theta: \theta y^t \in \mathrm{P}^t(x^t)\})^{-1}} \qquad (2.6)$$

Figure 2.3 illustrates the concept of an output distance function using an example where two outputs, $\boldsymbol{y_1}$ and $\boldsymbol{y_2}$, are produced with a single input vector, $\boldsymbol{x}$. The curve, $\mathbf{P^t}(\boldsymbol{x^t})$, represents the unit production possibility curve, which shows the various output combinations of outputs that can be produced using a given input $\boldsymbol{x}$. Point $\boldsymbol{A}$ corresponds to an inefficient university operating at a level inside the maximum possible output, represented by the production possibility frontier PPC-$\mathbf{P^t}(\boldsymbol{x^t})$. The value of the distance function for the point $\boldsymbol{A}$, with the university using input $\boldsymbol{x}$ to produce the outputs, is equal to the ratio $\boldsymbol{\theta = 0A/0B}$.

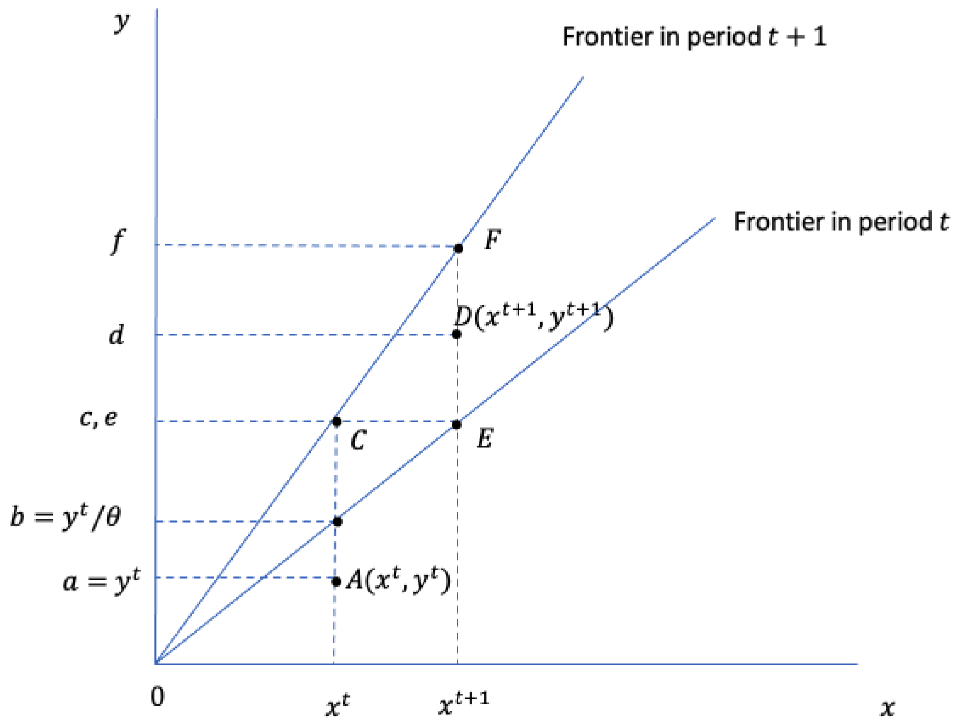
Figure 2.3
Output Distance Function and Production Possibility Set



Following Shephard (1970), Färe (1988), Färe et al. (1994) and Coelli et al. (2005), an output distance function provides the reciprocal of the "maximum" proportional expansion of the output vector $\boldsymbol{y^t}$, given the inputs vector $\boldsymbol{x^t}$. If $(\boldsymbol{x^t}, \boldsymbol{y^t}) \in \boldsymbol{P}(\boldsymbol{x^t})$, then $\boldsymbol{D_O^t}(\boldsymbol{x^t}, \boldsymbol{y^t}) \leq \mathbf{1}$. In particular, $\boldsymbol{D_O^t}(\boldsymbol{x^t}, \boldsymbol{y^t}) = \mathbf{1}$ if only if $(\boldsymbol{x^t}, \boldsymbol{y^t})$ is on the frontier which represents technical efficiency (e.g., $\boldsymbol{\theta = \frac{0A}{0B} = 1}$). When $\boldsymbol{D_O^t}(\boldsymbol{x^t}, \boldsymbol{y^t}) < \mathbf{1}$, $(\boldsymbol{x^t}, \boldsymbol{y^t})$ lies inside the frontier, indicating technical inefficiency, such as the distance $\boldsymbol{AB}$, which is the amount by which outputs could be radially increased without an increase in the input.

Figure 2.4 depicts a constant returns-to-scale production frontier in periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$. It shows that $\boldsymbol{university_A^t}$ at point $\boldsymbol{A}$ achieves the efficient output level $(\boldsymbol{y^t})$ from a given level of input $(\boldsymbol{x^t})$ in period $\boldsymbol{t}$, and that $\boldsymbol{university_D^{t+1}}$ at point $\boldsymbol{D}$ attains the efficient output level ($\boldsymbol{y^{t+1}}$) from a given level of input ($\boldsymbol{x^{t+1}}$) in period $\boldsymbol{t+1}$[22]. The Farrell output-orientated technical efficiency measures are equivalent to the output distance function, as discussed in Shephard (1970), Färe and Primont (1995), and Coelli et al. (2005, p. 57).

Figure 2.4
The Output-oriented Malmquist Productivity Index



Thus, the measure of output-orientated TE in the period $\boldsymbol{t}$ for the $\boldsymbol{university_A^t}$ (Coelli et al., 2005, p. 56; Färe et al., 1994, p. 70) is the ratio:

$$\boldsymbol{TE_A^t} = \boldsymbol{0a/0b} = \boldsymbol{D_o^t}\,(\boldsymbol{x^t},\boldsymbol{y^t}) \qquad (2.7)$$

where $\boldsymbol{D_o^t}\,(\boldsymbol{x^t},\boldsymbol{y^t})$ denotes the output distance function relative to the technology frontier in period $\boldsymbol{t}$ for a university operating at $(\boldsymbol{x^t},\boldsymbol{y^t})$.

The measure of TE in period $\boldsymbol{t+1}$ for the $\boldsymbol{university_A^{t+1}}$is the ratio:

[22] In interpreting the notation used here, it is helpful to note that subscripts denote time periods for input use and/or production, and superscripts denote time periods for production technologies.

$$\boldsymbol{TE_A^{t+1}} = \boldsymbol{0a/0c} = \boldsymbol{D_o^{t+1}}\,(\boldsymbol{x^t}, \boldsymbol{y^t}) \tag{2.8}$$

where $\boldsymbol{D_o^{t+1}}\,(\boldsymbol{x^t}, \boldsymbol{y^t})$ represents the output distance function relative to the technology frontier in period $\boldsymbol{t+1}$ for a university operating at $(\boldsymbol{x^t}, \boldsymbol{y^t})$.

Similarly, TE in periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$ for the $\boldsymbol{university_D^t}\,(\boldsymbol{x^{t+1}}, \boldsymbol{y^{t+1}})$ and the $\boldsymbol{university_D^{t+1}}\,(\boldsymbol{x^{t+1}}, \boldsymbol{y^{t+1}})$ are given by the ratios:

$$\boldsymbol{TE_D^t} = \boldsymbol{0d/0e} = \boldsymbol{D_o^t}\,(\boldsymbol{x^{t+1}}, \boldsymbol{y^{t+1}}) \tag{2.9}$$

$$\boldsymbol{TE_D^{t+1}} = \boldsymbol{0d/0f} = \boldsymbol{D_o^{t+1}}\,(\boldsymbol{x^{t+1}}, \boldsymbol{y^{t+1}}) \tag{2.10}$$

where $\boldsymbol{D_o^t}\,(\boldsymbol{x^{t+1}}, \boldsymbol{y^{t+1}})$ denotes the output distance function evaluating the $\boldsymbol{university_D^t}\,(\boldsymbol{x^{t+1}}, \boldsymbol{y^{t+1}})$ relative to the technology frontier at period $\boldsymbol{t}$. $\boldsymbol{D_o^{t+1}}\,(\boldsymbol{x^{t+1}}, \boldsymbol{y^{t+1}})$ indicates the output distance function evaluating $\boldsymbol{university_D^{t+1}}\,(\boldsymbol{x^{t+1}}, \boldsymbol{y^{t+1}})$ relative to the technology frontier at period $\boldsymbol{t+1}$.

The output distance function takes values between zero and one, with higher values indicating higher levels of technical efficiency of the university. A value of one implies that the university is fully technically efficient.

The distance function has the following properties (Färe et al., 1997; Färe & Grosskopf, 2000; Fried et al., 2008):

- By definition, the output distance function is homogeneous of degree plus one in outputs:

$$\boldsymbol{D_O}(\boldsymbol{x}, \boldsymbol{\theta y}) = \boldsymbol{\theta D_O}(\boldsymbol{x}, \boldsymbol{y}), \boldsymbol{\theta} > \boldsymbol{0}. \tag{2.11}$$

- When there is a constant return to scale, the output distance function is homogeneous of degree minus one in inputs:

$$\boldsymbol{D_O}(\boldsymbol{\theta x}, \boldsymbol{y}) = \frac{\boldsymbol{1}}{\boldsymbol{\theta}}\boldsymbol{D_O}(\boldsymbol{x}, \boldsymbol{y}), \boldsymbol{\theta} > \boldsymbol{0}. \tag{2.12}$$

Using the properties in (2.11) and (2.22), in the single input and output case, the output distance function can be written as:

$$\boldsymbol{D_O}(\boldsymbol{x}, \boldsymbol{y}) = \frac{\boldsymbol{y}}{\boldsymbol{x}}\boldsymbol{D_O}(\boldsymbol{1}, \boldsymbol{1}) \tag{2.13}$$

Applying (2.13) to $\boldsymbol{t}$ and $\boldsymbol{t+1}$ in equation (2.3) yields:

$$\boldsymbol{TFP} = \frac{y^{t+1}}{x^{t+1}} \Big/ \frac{y^t}{x^t} = \left(\frac{y^{t+1}}{x^{t+1}} \Big/ \frac{y^t}{x^t} \right) * \frac{D_O(1,1)}{D_O(1,1)} = \frac{D_O^t(x^{t+1}, y^{t+1})}{D_O^t(x^t, y^t)} \quad (2.14)$$

2.2.2 *The Malmquist TFP index*

The TFP index in (2.14) can be extended to multiple input and multiple output cases. The Malmquist TFP index, introduced by Caves, Christensen and Diewert (1982a, 1982b), measures productivity by comparing the observed outputs in periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$ with the maximum level of outputs (keeping the output mix constant) that can be produced using $\boldsymbol{x_t}$ and $\boldsymbol{x_{t+1}}$, operating under the reference technology in periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$.

The Period $\boldsymbol{t}$ output-oriented Malmquist TFP Index (Färe & Grosskopf, 2000) is defined as:

$$\boldsymbol{M_O^t}(\boldsymbol{x^t}, \boldsymbol{x^{t+1}}, \boldsymbol{y^t}, \boldsymbol{y^{t+1}}) = \frac{D_O^t(x^{t+1}, y^{t+1})}{D_O^t(x^t, y^t)} \quad (2.15)$$

This index compares universities from two different periods, $\boldsymbol{t}$ and $\boldsymbol{t}$+1, relative to the same reference technology from period $\boldsymbol{t}$. Note that the reference technology is only constructed from the universities from period $\boldsymbol{t}$ (e.g., period-$\boldsymbol{t}$ technology is the reference technology). The university from period $\boldsymbol{t+1}$ lies above the best practice frontier from period $\boldsymbol{t}$. A value of $\boldsymbol{M_O^t}$ greater than one indicates an improvement in productivity between periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$.

This approach defines productivity relative to the period $\boldsymbol{t}$ best practice. Alternatively, one could define an analogous productivity measure using the best practice frontier from period $\boldsymbol{t+1}$ as the benchmark. The Period $\boldsymbol{t+1}$ Malmquist TFP index is defined as:

$$\boldsymbol{M_O^{t+1}}(\boldsymbol{x^t}, \boldsymbol{x^{t+1}}, \boldsymbol{y^t}, \boldsymbol{y^{t+1}}) = \frac{D_O^{t+1}(x^{t+1}, y^{t+1})}{D_O^{t+1}(x^t, y^t)} \quad (2.16)$$

One can make use of the periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$ versions of the Malmquist index to form an "ideal" index, as proposed by Fisher (1922). The Fisher ideal index is defined as the geometric mean of a Paasche index[23] and a Laspeyres index[24], which represent the upper and lower "bounds (extremes)" of the "true" index. Taking the geometric mean of these bounds provides a closer approximation to the true index (Färe & Grosskopf, 2000). To avoid selecting an arbitrary benchmark, Färe et al. (1994), Coelli et al. (2005, p.70), and Johnson and Ruggiero (2014) specify the output-based Malmquist TFP

[23] A Paasche index is the ratio of the two value aggregates resulting from the valuation of the current-period quantities at current-period and base-period prices.

[24] A Laspeyres index is the ratio of two value aggregates resulting from the valuation of the base-period quantities at current-period and base-period prices.

index as the geometric mean of the $\boldsymbol{t}$ and $\boldsymbol{t+1}$ Malmquist indexes to define the output-orientated Malmquist TFP index ($\boldsymbol{M_O}$) as:

$$\boldsymbol{M_O}\left(\boldsymbol{x^t},\boldsymbol{x^{t+1}},\boldsymbol{y^t},\boldsymbol{y^{t+1}}\right)=\left[\boldsymbol{M_O^t}\left(\boldsymbol{x^t},\boldsymbol{x^{t+1}},\boldsymbol{y^t},\boldsymbol{y^{t+1}}\right)*\boldsymbol{M_O^{t+1}}\left(\boldsymbol{x^t},\boldsymbol{x^{t+1}},\boldsymbol{y^t},\boldsymbol{y^{t+1}}\right)\right]^{\frac{1}{2}}$$

$$=\left(\frac{\boldsymbol{D_O^t}(\boldsymbol{x^{t+1}},\boldsymbol{y^{t+1}})}{\boldsymbol{D_O^t}(\boldsymbol{x^t},\boldsymbol{y^t})}*\frac{\boldsymbol{D_O^{t+1}}(\boldsymbol{x^{t+1}},\boldsymbol{y^{t+1}})}{\boldsymbol{D_O^{t+1}}(\boldsymbol{x^t},\boldsymbol{y^t})}\right)^{\frac{1}{2}} \quad (2.17)$$

2.2.3 ***Decomposing the Malmquist TFP index***

It is common to observe some degree of inefficiency in the operations of most universities. Thus, assuming that, $\boldsymbol{D_O^t}(\boldsymbol{x^t},\boldsymbol{y^t})\le\boldsymbol{1}$ and $\boldsymbol{D_O^{t+1}}(\boldsymbol{x^t},\boldsymbol{y^t})\le\boldsymbol{1}$ are realistic. When technical inefficiency exists, the output-oriented Malmquist TFP index from equation (2.17) can be rewritten as:

$$\boldsymbol{M_O}\left(\boldsymbol{x^t},\boldsymbol{x^{t+1}},\boldsymbol{y^t},\boldsymbol{y^{t+1}}\right)=\frac{\boldsymbol{D_O^{t+1}}(\boldsymbol{x^{t+1}},\boldsymbol{y^{t+1}})}{\boldsymbol{D_O^t}(\boldsymbol{x^t},\boldsymbol{y^t})}\left\{\left[\frac{\boldsymbol{D_O^t}(\boldsymbol{x^{t+1}},\boldsymbol{y^{t+1}})}{\boldsymbol{D_O^{t+1}}(\boldsymbol{x^{t+1}},\boldsymbol{y^{t+1}})}\right]*\left[\frac{\boldsymbol{D_O^t}(\boldsymbol{x^t},\boldsymbol{y^t})}{\boldsymbol{D_O^{t+1}}(\boldsymbol{x^t},\boldsymbol{y^t})}\right]\right\}^{\frac{1}{2}} \quad (2.18)$$

In this equation, the ratio outside the curly brackets measures the change in relative technical efficiency over time (e.g., the change in how far observed production is from maximum potential production). The remaining components of equation (2.18) capture the shift in technology between the two periods, evaluated at $\boldsymbol{x^t}$, and $\boldsymbol{x^{t+1}}$. These changes can be expressed as:

$$\text{Efficiency change}=\frac{\boldsymbol{D_O^{t+1}}(\boldsymbol{x^{t+1}},\boldsymbol{y^{t+1}})}{\boldsymbol{D_O^t}(\boldsymbol{x^t},\boldsymbol{y^t})}=\frac{\boldsymbol{0d/of}}{\boldsymbol{0a/0b}}=\left(\frac{\boldsymbol{0d}}{\boldsymbol{0f}}\right)\left(\frac{\boldsymbol{0b}}{\boldsymbol{0a}}\right) \quad (2.19)$$

and

$$\text{Technical change}=\left\{\left[\frac{\boldsymbol{D_O^t}(\boldsymbol{x^{t+1}},\boldsymbol{y^{t+1}})}{\boldsymbol{D_O^{t+1}}(\boldsymbol{x^{t+1}},\boldsymbol{y^{t+1}})}\right]*\left[\frac{\boldsymbol{D_O^t}(\boldsymbol{x^t},\boldsymbol{y^t})}{\boldsymbol{D_O^{t+1}}(\boldsymbol{x^t},\boldsymbol{y^t})}\right]\right\}^{\frac{1}{2}}=\left\{\frac{\boldsymbol{0d/0e}}{\boldsymbol{0d/0f}}*\frac{\boldsymbol{0a/0b}}{\boldsymbol{0a/0c}}\right\}^{\frac{1}{2}}=\left\{\frac{\boldsymbol{0f}}{\boldsymbol{0e}}*\frac{\boldsymbol{0c}}{\boldsymbol{0b}}\right\}^{\frac{1}{2}} \quad (2.20)$$

The Malmquist index is illustrated in Figure 2.4. The efficiency change is equivalent to the ratio of the Farrell technical efficiency in period $\boldsymbol{t+1}$ to that in period $\boldsymbol{t}$. That is, ($\boldsymbol{0d/0f}$) is the technical efficiency of ($\boldsymbol{x^{t+1}},\boldsymbol{y^{t+1}}$) relative to the period $\boldsymbol{t+1}$ best practice frontier, and ($\boldsymbol{0a/0b}$) is the technical efficiency of ($\boldsymbol{x^t},\boldsymbol{y^t}$) relative to the period $\boldsymbol{t}$ best practice frontier.

The remaining part measures technical change, which is the geometric mean of the shift in technology between the two periods, evaluated at $\boldsymbol{x^t}$ and $\boldsymbol{x^{t+1}}$. This also captures the shift in the best practice frontier between periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$: ($\boldsymbol{0f/0e}$) measures the vertical shift at $\boldsymbol{x^{t+1}}$, and ($\boldsymbol{0c/0b}$) captures the vertical shift evaluated at $\boldsymbol{x^t}$. The geometric mean of these two shifts is a measure of technical change.

When the value of $\boldsymbol{M_O}$ is greater than one, it indicates an improvement in productivity over time. When its value is less than one, it signals a deterioration in performance over time. Note that if $\boldsymbol{x^t}=$

$\boldsymbol{x^{t+1}}$ and $\boldsymbol{y^{t}} = \boldsymbol{y^{t+1}}$ (e.g., there has been no change in inputs or output between the periods), the Malmquist productivity index indicates no change: $\boldsymbol{M_O}(\cdot) = \mathbf{1}$. Note that an improvement in productivity could be accompanied by a decline in one of the component measures, and vice versa.

Improvements in the efficiency change component are evidence of catching up to the frontier, while improvements in the technical change component indicate innovation, such as a shift in the frontier (Färe et al., 1994).

Casu et al. (2004) demonstrate that, when calculated using CRS distance function, the Malmquist productivity index can still measure productivity changes even if the underlying exhibit VRS. However, Grifell-Tatjé and Lovell[25] (1995) point out that the Malmquist TFP index may not accurately capture productivity changes under VRS, as the bias in the index is systematic and depends on the magnitude of scale economies.

Färe et al.'s (1994) decomposition reports a technical change measure reflecting the movement of the CRS frontier rather than VRS frontier. In contrast, the critiques by Ray and Desai (1997) emphasise the importance of considering VRS technologies in measuring technical change and productivity. This study adopts the decomposition of Malmquist TFP change using the Färe et al. (1994) method, the most prevalent approach for measuring productivity changes among the various methods developed (Coelli et al., 2005; Lee et al., 2011).

As the efficiency distances can be either output-orientated or input-orientated, in the tertiary education context, the universities seek to maximise outputs given a relatively fixed level of inputs, particularly in the short run, where inputs are less flexible (Bonaccorsi et al., 2006; Worthington & Lee, 2008; Barra & Zotti, 2016). This is probably due to the funding structures, regulatory settings, and the non-market nature of the university sector, in which universities typically face constraints in quickly adjusting inputs such as faculty, infrastructure, and financial resources. Hence, this study employs the output-orientated Malmquist TFP index, as it better reflects the goal of maximising outputs under these constraints.

Caves et al. (1982a) show that the Malmquist TFP index is not based on specific assumptions about the return-to-scale properties of production technologies. Consequently, all the distances involved in

[25] Grifell-Tatjé and Lovell (1995) demonstrated that the bias in the Malmquist productivity index is systematic and depends on the magnitude of scale economies. For example, when input growth exhibits an increasing return to scale, Malmquist productivity indexes tend to understate productivity growth, and overstate productivity growth when input growth occurs under the decreasing return to scale.

input-orientated and output-orientated Malmquist productivity indexes can be calculated for both variable return to scale (VRS) and constant return to scale (CRS).

When the production technology exhibits CRS, then there are only two sources of productivity growth, efficiency change and technical change, and these are captured by the Malmquist productivity index. However, if VRS technology is more appropriate, then the Malmquist TFP index fails to capture productivity change from all the different sources, such as the scale of operations or scale efficiency (Coelli et al., 2005, p.73).

When there is VRS, a university might be technically efficient, but the scale of its operation might not be optimal. Relaxing the CRS assumption and assuming the university operates under a VRS technology is straightforward. In such cases, the efficiency of the university might be improved by changing the scale of its operations, e.g., keeping the same input mix but changing the size of its operations.

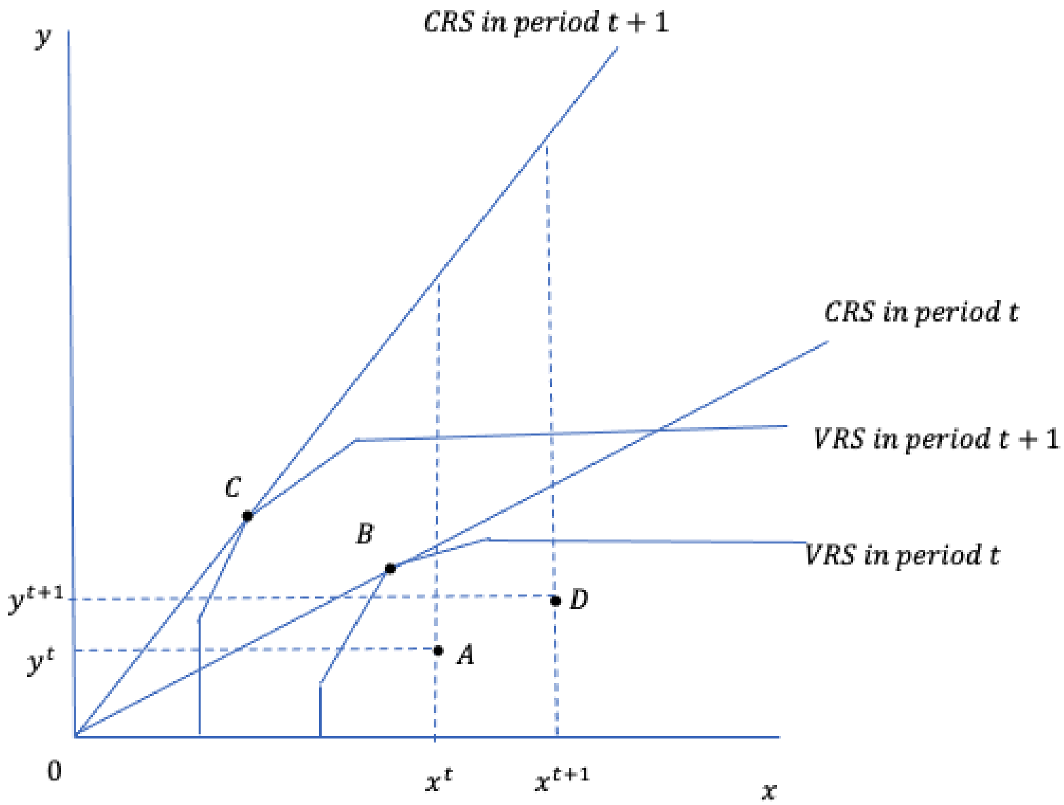
In Figure 2.5, the scale efficiency for the university is represented by the vertical distance between the VRS frontier and the CRS frontier in period $\boldsymbol{t}$, evaluated at $\boldsymbol{x^t}$. Scale efficiency measures the amount by which productivity can increase by operating at the technically optimal productive scale (TOPS) of production (e.g., points $\boldsymbol{B}$ or $\boldsymbol{C}$). That is, scale efficiency is calculated as the ratio of the CRS distance function to the VRS distance function or, equivalently, as the ratio of TE under CRS and TE under VRS. The output-orientated scale efficiency measure in period $\boldsymbol{t}$, $\boldsymbol{SE_O^t}(\boldsymbol{x^t}, \boldsymbol{y^t})$, is given by (Coelli et al., 2005, p.61):

$$\boldsymbol{SE_O^t}(\boldsymbol{x^t}, \boldsymbol{y^t}) = \frac{\boldsymbol{TE_{oc}^t}(\boldsymbol{x^t},\boldsymbol{y^t})}{\boldsymbol{TE_{ov}^t}(\boldsymbol{x^t},\boldsymbol{y^t})} = \frac{\boldsymbol{D_{oc}^t}(\boldsymbol{x^t},\boldsymbol{y^t})}{\boldsymbol{D_{ov}^t}(\boldsymbol{x^t},\boldsymbol{y^t})} \qquad (2.21)$$

The value of scale efficiency ranges from zero to one, with a value of one indicating that a university is operating at optimal scale.

Note that the extra subscripts, $\boldsymbol{c}$ and $\boldsymbol{v}$, relate to the CRS and VRS technology. When this decomposition is used, the distance functions in equations (2.15) and (2.20) would all need to be relative to a CRS technology, and thus an extra $\boldsymbol{c}$-subscript should be appended to these distance functions.

Figure 2.5
Scale Efficiency Under CRS and VRS



This study calculates the Malmquist index relative to the CRS technology[26], and uses an enhanced decomposition of the Malmquist index developed by Färe et al. (1994). This enhanced decomposition involves taking the efficiency change component, calculated in equation (2.19) relative to the CRS technology, and decomposing it into a pure efficiency change component (measured relative to the VRS frontier) and a residual scale efficiency change component, which captures the changes in the deviation between the CRS and VRS technology (Färe et al., 1997, p. 1042; Ray & Desli, 1997, p. 1036).

$$\textit{Pure efficiency change} = \frac{D_{OV}^{t+1}(x^{t+1}, y^{t+1})}{D_{OV}^{t}(x^{t}, y^{t})} \qquad (2.22)$$

And a scale efficiency change component

$$\textit{Scale efficiency change} = \left[\frac{SE_O^{t+1}(x^{t+1}, y^{t+1})}{SE_O^{t+1}(x^{t}, y^{t})} * \frac{SE_O^{t}(x^{t+1}, y^{t+1})}{SE_O^{t}(x^{t}, y^{t})}\right]^{\frac{1}{2}} \qquad (2.23)$$

[26] This Färe et al. (1994, p 74) decomposition can only be applied when the distance functions used in the efficiency change component in equation (2.19) are estimated relative to a CRS technology. This decomposition, which includes scale efficiency, has been widely adopted in the literature.

Hence, the scale efficiency change is the geometric mean of two scale efficiency change measures. The first is relative to the period $\boldsymbol{t+1}$ technology, and the second is relative to the period $\boldsymbol{t}$ technology. Consequently, efficiency change can be expressed as:

$$\boldsymbol{Efficiency\ change\ =\ Pure\ efficiency\ change\ *\ Scale\ efficiency\ change} \quad (2.24)$$

Therefore, the decomposition of the Malmquist TFP index when there is VRS can be summarised as:

$$\boldsymbol{M_O(x_t, x_{t+1}, y_t, y_{t+1}) = Techincal\ change * Pure\ efficiency\ change * Scale\ efficiency\ change} \quad (2.25)$$

2.2.4 *Summary of Decomposing the Malmquist TFP index*

This decomposition is summarised in Table 2.1, which also presents the productivity and efficiency indexes.

Table 2.1
Productivity and efficiency Change Indexes

Productivity/Efficiency change index	Description	Equation
Change in TFP	TFP index measuring productivity change between periods *t* and *t* + 1.	$\boldsymbol{TFPI = \frac{TFP^{t+1}}{TFP^t} = \frac{y^{t+1}/x^{t+1}}{y^t/x^t} = \frac{y^{t+1}/y^t}{x^{t+1}/x^t}}$ (2.3)
Malmquist TFP Index for period *t*	Output-oriented Malmquist TFP Index with the reference technology calculated for period *t*.	$\boldsymbol{M_O^t(x^t, x^{t+1}, y^t, y^{t+1}) = \frac{D_O^t(x^{t+1}, y^{t+1})}{D_O^t(x^t, y^t)}}$ (2.15)
Malmquist TFP Index for period *t* + 1	Output-oriented Malmquist TFP Index with the reference technology calculated for period *t* + 1.	$\boldsymbol{M_O^{t+1}(x^t, x^{t+1}, y^t, y^{t+1}) = \frac{D_O^{t+1}(x^{t+1}, y^{t+1})}{D_O^{t+1}(x^t, y^t)}}$ (2.16)
Malmquist TFP index	Output-oriented Malmquist TFP index ($\boldsymbol{M_O}$) to measure productivity change between periods *t* and *t* + 1.	$\boldsymbol{M_O(x^t, x^{t+1}, y^t, y^{t+1}) = \left(\frac{D_O^t(x^{t+1}, y^{t+1})}{D_O^t(x^t, y^t)} * \frac{D_O^{t+1}(x^{t+1}, y^{t+1})}{D_O^{t+1}(x^t, y^t)}\right)^{\frac{1}{2}}}$ (2.17)
Technical Change	Measures the shift in the best practice frontier between $\boldsymbol{t}$ and $\boldsymbol{t+1}$ (calculated relative to CRS technology), reflecting technological progress or regress	$\boldsymbol{Technical\ change = \left\{\left[\frac{D_O^t(x^{t+1}, y^{t+1})}{D_O^{t+1}(x^{t+1}, y^{t+1})}\right] * \left[\frac{D_O^t(x^t, y^t)}{D_O^{t+1}(x^t, y^t)}\right]\right\}^{\frac{1}{2}}}$ (2.20)

Efficiency Change	Measures the change in efficiency over time (e.g., the change in how far observed production is from maximum potential production or the best-practice frontier)	$Efficiency\ change = \frac{D_O^{t+1}(x^{t+1}, y^{t+1})}{D_O^t(x^t, y^t)}$ (2.19)
Pure efficiency change	Efficiency change due to pure efficiency change – e.g., producing more outputs without increasing inputs, which reflects an improvement in the utilisation of resources	$\boldsymbol{Pure\ efficiency\ change} = \frac{D_{OV}^{t+1}(x^{t+1}, y^{t+1})}{D_{OV}^t(x^t, y^t)}$ (2.22)
Scale efficiency change	Efficiency scale due to change in scale – e.g., operating closer to technically optimal productive scale.	$\boldsymbol{Scale\ efficiency\ change} = \left[\frac{SE_O^{t+1}(x^{t+1}, y^{t+1})}{SE_O^{t+1}(x^t, y^t)} * \frac{SE_O^t(x^{t+1}, y^{t+1})}{SE_O^t(x^t, y^t)}\right]^{\frac{1}{2}}$ (2.23)

2.3 Stochastic Frontier Analysis

2.3.1 *Parametric Frontier Analysis*

To measure productive efficiency using parametric approaches, a specific frontier function (e.g., linear, quadratic, Cobb-Douglas, or translog) needs to be specified. This technique may be further separated into the deterministic frontier analysis (DFA) and stochastic frontier analysis (SFA). In a deterministic frontier, the distance between observed production and maximum possible production (determined by the frontier and the available technology) is used to measure technical efficiency. SFA, on the other hand, allows the identification of technical efficiency and statistical noise.

The basic model for DFA is:

$$\boldsymbol{y} = \boldsymbol{f}(\boldsymbol{x}; \boldsymbol{\beta}) \cdot \mathbf{exp}\{-\boldsymbol{u}\} \qquad (2.26)$$

where $\boldsymbol{y}$ denotes a scalar output; $\boldsymbol{x}$ is a vector of inputs; $\boldsymbol{f}(.)$ is a specific production functional form; $\boldsymbol{\beta}$ is a vector of unknown parameters to be estimated, and $\boldsymbol{u}$ is a non-negative random variable associated with technical inefficiency (Coelli et al., 2005, p. 241).

Several studies have estimated a deterministic production frontier. Aigner and Chu (1968) estimated a Cobb-Douglas deterministic production frontier using mathematical programming methods[27] based on

[27] The mathematical programming is to estimate the unknown parameters to minimize the sum of the u (linear programming) or u^2 (quadratic programming) subject to the constraint of $u \geq 0$. The problem with these approaches is a lack of available statistical inference procedures and it is extremely sensitive to outliers (Aigner, Lovell & Schmidt, 1977).

cross-sectional data. Winston (1957) proposed the Corrected Ordinary Least Squared[28] (COLS) estimator regarding a deterministic frontier model. A further COLS was proposed by Afriat (1972) and Richmond (1974), known as modified ordinary least squares[29] (MOLS). Greene (1980a, b) proposed the maximum likelihood[30] (ML) estimator using a gamma distribution.

DFA has several drawbacks. First, it assumes that all deviations from the frontier are due to technical inefficiency and ignores measurement errors and other sources of statistical noise. Second, it imposes an explicit distributional assumption on the inefficiency error term (e.g., half-normal, truncated normal, exponential) (Schmidt & Sickles, 1984). Third, it imposes an explicit functional form on the production frontier representing the underlying technology (e.g., it relies on a hypothesized production function). Fourth, it is susceptible to outliers and extreme points (Harris, 1993).

Unlike DFA, SFA addresses some of these issues by adding a symmetric random error to represent statistical noise beyond the producer's control, such as measurement error, omission of relevant variables, or the choice of functional form. However, it is important to note that SFA also shares certain drawbacks with DFA, such as specifying a functional form for the production frontier.

The methodology faces various constraints due to the annually limited data availability from only eight New Zealand universities. SFA is appropriate in this case since it addresses the issue of small data size by combining observations over multiple years and integrating technology development. Moreover, since the New Zealand data combines with data from Australian universities, this approach further strengthens the analysis by expanding the dataset and allowing for a broader comparison across the two countries.

[28] The COLS requires two steps. In the first step, using ordinary least squared (OLS), is to obtain consistent and unbiased estimators of the slope coefficients but also obtain the biased estimator of the intercept coefficient. The result cannot use the OLS to calculate the technical efficiency. In the second step, the biased intercept in the OLS estimator is shifted upward so that the estimated frontier bounds the data from above (Kumbhakar & Lovell, 2003, p. 70). The COLS frontier is parallel to the OLS frontier by definition; therefore, it does not necessarily bound the data from above as closely as possible.

[29] While Richmond (1974) employed a least squares method, Afriat (1972) utilised the maximum likelihood method and assumed that u was a gamma-distributed random variable. The one-sided distribution of u, such as the half-normal or exponential distribution, is expressly assumed by MOLS to be different from COLS. The biased OLS intercept is shifted down by the estimated mean of u (Kalb, 2010, p. 22). As the MOLS frontier is still parallel to the original OLS frontier, the MOLS estimation still cannot guarantee that the estimated intercept is shifted far enough to cover all the data from the above.

[30] The ML estimator of the unknown parameters $\boldsymbol{\beta}$ is obtained by maximising the log-likelihood function with respect to $\boldsymbol{\beta}$. Compared with the COLS and MOLS techniques, the frontier produced by the ML estimate is structured differently from the OLS curve. u follows the gamma distribution via ML estimation and produces the best practice frontier that envelops all observations (Kalb, 2010, p. 23).

This study collects a dataset for this approach from eight New Zealand and 37 Australian universities, both of which have similar tertiary education systems. It is reasonable to presume that Australia and New Zealand share a technological frontier when using SFA in the context of tertiary education, given that both countries' regulatory and funding systems are similar. Several existing studies have adopted this approach, such as Abbott and Doucouliagos (2009), who analysed the efficiency of Australian and New Zealand universities. The section below provides a brief overview of SFA.

2.3.2 *Stochastic Production Frontier Analysis*

Aigner, Lovell and Schmidt (1977), and Meeusen and van den Broeck (1977) independently proposed the SFA. It is a common method for frontier estimation that assumes a given functional form (e.g., production or cost function) for the relationship between various inputs and an output to represent the benchmark. SFA is an econometric parametric method that fits a best-practice frontier to the observed data points.

The original SFA specification includes a production function designed for cross-sectional data. The basic model can be represented as follows (Coelli et al., 2005, p. 242):

$$\boldsymbol{ln y_i = \beta ln x_i + v_i - u_i} \qquad (2.27)$$

where $\boldsymbol{y}$ denotes the output scalar of the $\boldsymbol{i}$-th university; $\boldsymbol{x_i}$ is a vector of inputs; $\boldsymbol{f}(.)$ is a designated production functional form and $\boldsymbol{\beta}$ is a vector of unknown parameters to be estimated. The first error term $\boldsymbol{v_i}$ is a symmetric random error (good or bad but uncontrollable by universities), which can be positive or negative. It captures the impacts of statistical noise (e.g., measurement errors, omitted variables, random shocks). This component is normally assumed to be an independently and identically distributed ($\boldsymbol{iid}$) normal random variable with zero mean and constant variance $\boldsymbol{\sigma_v^2}$; that is, $\boldsymbol{v \sim iidN(0, \sigma_v^2)}$. The non-negative error term, $\boldsymbol{u_i} \geq \boldsymbol{0}$, is designed to represent the effects of technical inefficiency. It is a truncated version of a normal random variable with mean, $\boldsymbol{\mu}$, and variance, $\boldsymbol{\sigma_u^2}$; that is, $\boldsymbol{u_i \sim N^+(\mu, \sigma_u^2)}$.

And Equation (2.27) can also take the form:

$$\boldsymbol{y_i = \exp\,(\beta ln x_i + v_i - u_i)} \qquad (2.28)$$

Or $$\boldsymbol{y_i} = \underbrace{\exp(\boldsymbol{\beta} \boldsymbol{ln x_i})}_{\text{Deterministic component}} \times \underbrace{\exp(\boldsymbol{v_i})}_{\text{Statistic noise}} \times \underbrace{\exp(-\boldsymbol{u_i})}_{\text{Inefficiency}} \quad (2.29)$$

In equation (2.29), $\boldsymbol{y_i} = \exp(\boldsymbol{\beta ln x_i})$ represents the deterministic frontier. If a producer is technically efficient (e.g., $\boldsymbol{u_i} = \mathbf{0}$), then it operates on its stochastic frontier, that is the stochastic frontier output, $\boldsymbol{y_i} = \exp(\boldsymbol{\beta ln x_i} + \boldsymbol{v_i})$, and there is no inefficiency effect. If a university is technically inefficient (e.g., $\boldsymbol{u_i} > \mathbf{0}$, and $\mathbf{0} < \exp(-\boldsymbol{u_i}) < \mathbf{1}$) then it operates below its stochastic frontier. This implies that a given input bundle does not produce the maximum output that it could produce.

The $\boldsymbol{u_i}$ and $\boldsymbol{v_i}$ are commonly assumed to be uncorrelated with each other and both are independent of the input vector, $\boldsymbol{x_i}$. Measurement errors or other noise and outliers in SFA may affect the shape and position of the estimated frontier (Bezat, 2009, p. 26).

The stochastic frontier, $\exp(\boldsymbol{\beta ln x_i} + \boldsymbol{v_i})$, describes a producer's maximum output given inputs $\boldsymbol{x_i}$ and available technology within statistical noise. The ratio of observed output to the corresponding stochastic frontier outputs is the most common output-oriented measure for TE. The TE of the producer can be expressed as:

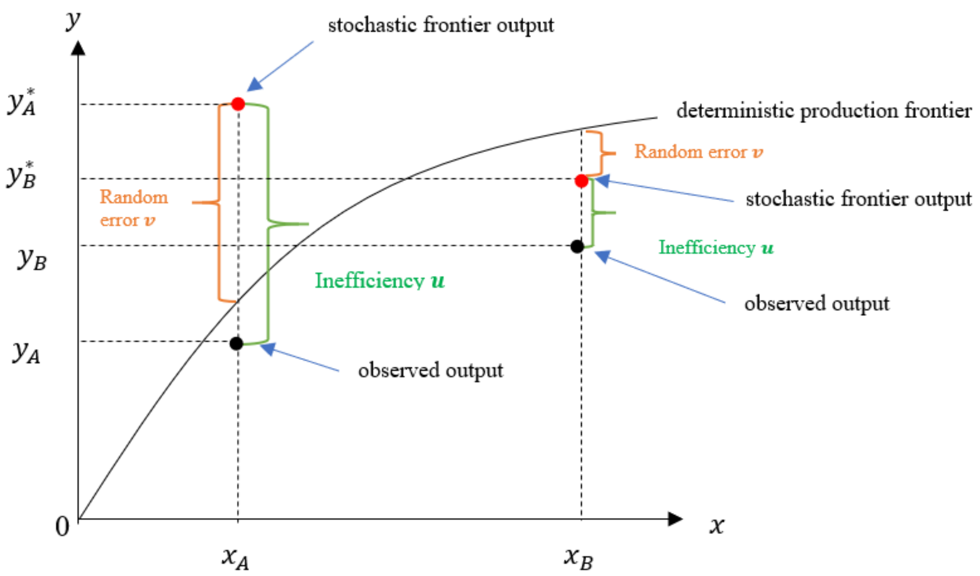
$$\boldsymbol{TE_i} = \frac{\boldsymbol{y_i}}{\exp(\boldsymbol{\beta ln x_i} + \boldsymbol{v_i})} = \frac{\exp(\boldsymbol{\beta ln x_i} + \boldsymbol{v_i} - \boldsymbol{u_i})}{\exp(\boldsymbol{\beta ln x_i} + \boldsymbol{v_i})} = \exp(-\boldsymbol{u_i}) \quad (2.30)$$

$\boldsymbol{TE_i}$ can be zero, one, or any value between these numbers ($\mathbf{0} \leq \boldsymbol{TE_i} \leq \mathbf{1}$). A value of one means that a university operates on the stochastic frontier and is fully technically efficient.

Following Coelli et al. (2005, p. 244), the stochastic production frontier is illustrated in Figure 2.6 using the inputs and outputs of two universities, $\boldsymbol{A}$ and $\boldsymbol{B}$, where the deterministic production frontier illustrates the existence of diminishing returns to scale. The horizontal axis is used to measure input levels, while the vertical axis is used to measure output levels. Producers $\boldsymbol{A}$ and $\boldsymbol{B}$ produce the outputs $\boldsymbol{y_A}$ and $\boldsymbol{y_B}$ using the input levels $\boldsymbol{x_A}$ and $\boldsymbol{x_B}$, respectively. Thus, $\boldsymbol{y_A}$ and $\boldsymbol{y_B}$ are the observed outputs. The stochastic frontier outputs are $\boldsymbol{y_A^*}$ and $\boldsymbol{y_B^*}$ if there are no inefficiency effects, which means $\boldsymbol{u_A} = \mathbf{0}$ and $\boldsymbol{u_B} = \mathbf{0}$.

In Figure 2.6, the noise impact is positive (e.g., $\boldsymbol{v_A} > \mathbf{0}$) and the stochastic frontier output for university $\boldsymbol{A}$ lies above the deterministic production frontier. The combined effects of noise and inefficiency are negative ($\boldsymbol{v_A} - \boldsymbol{u_A} < \mathbf{0}$), the observed output for university $\boldsymbol{A}$ lying below the deterministic production frontier. In contrast, due to the noise effect being negative (e.g., $\boldsymbol{v_B} < \mathbf{0}$), the stochastic frontier output for university $\boldsymbol{B}$ lies below the deterministic production frontier.

Figure 2.6
Graphical Representation of Stochastic Production Frontier



The distribution of the inefficiency error term $\boldsymbol{u}$ needs to be explicitly assumed to estimate the parameters of the stochastic production frontier (SPF) using cross-sectional data. Aigner, Lovell, and Schmidt (1977) adopted a half-normal distribution of $\boldsymbol{u}$, while Meeusen and van den Broeck (1977) used an exponential distribution. Other commonly utilised distributional assumptions include the truncated normal (Stevenson, 1980) and the gamma distributions (Greene, 1980a, b, 2003).

The parameters of the SPF can be estimated using the maximum likelihood (ML) method. The ML estimators are popular in empirical work. When the sample size increases indefinitely, the ML estimator is consistent and asymptotically efficient (Coelli et al., 2005, p.218). The computer software packages FRONTIER (Coelli, 1992; 1996) and Stata (Belotti et al., 2013) automate the ML estimations of the parameters of stochastic frontier models.

ML estimation of the stochastic frontier cross-sectional model allows composite error $(\boldsymbol{v} - \boldsymbol{u})$ to be computed, but not the inefficiency component $(\boldsymbol{u})$. Jondrow et al. (1982) and Battese and Coelli (1988) estimate inefficiency using the mean or the mode of this conditional distribution $\mathbf{E}(\boldsymbol{u}|\boldsymbol{v} - \boldsymbol{u})$, allowing them to disentangle the unobserved inefficiency component from the composite error.

Panel-data stochastic frontier models are well-established. For instance, Battese and Coelli (1988) suggest the estimate of a time-invariant normal-truncated normal model with inefficiency. In contrast, Battese and Coelli (1992) proposed a time-varying version known as the "time decay" model. The generalised form in the panel-data stochastic production frontier model is:

$$\boldsymbol{lny_{it} = \beta lnx_{it} + v_{it} - u_{it}} \qquad (2.31)$$

where $\boldsymbol{y_{it}}$ denotes the log of output for observation $\boldsymbol{i}$ at time $\boldsymbol{t}$; $\boldsymbol{x_{it}}$ is the vector of inputs in logs and includes a time trend to account for technological change; $\boldsymbol{\beta}$ is the associated vector of unknown parameters to be estimated; $\boldsymbol{f}(\cdot)$ represents the production function; $\boldsymbol{v_{it}}$ is the two-sided random noise error term (e.g., omission of relevant variables) that can increase or decrease output and $\boldsymbol{u_{it} \geq 0}$ denotes the non-negative one-sided inefficiency term that decreases output.

It is possible to fit a greater variety of time-varying inefficiency models using the panel-data stochastic frontier models compared to cross-sectional data. Schmidt and Sickles (1984) allow inefficiency to be associated with the frontier regressors and avoid distributional assumptions on the inefficiency term by using a fixed-effects time-invariant inefficiency model. Random-effects time-invariant inefficiency models were proposed by Pitt and Lee (1981) and Battese and Coelli (1988). Pitt and Lee (1981) pioneered the use of longitudinal data[31] and ML estimate of the normal-half-normal SF model. Battese and Coelli (1988) suggested that this model should be generalised to the normal-truncated normal situation.

Cornwell, Schmidt, and Sickles (1990) extended the fixed and random-effects panel-data estimators using the quadratic SFA specification to estimate the model parameters. Lee and Schmidt (1993) extended this specification by including time dummy variables. The ML estimate of a time-varying SF model was initially presented by Kumbhakar (1990), and a related model was proposed by Battese and Coelli (1992). The stochastic frontier model by Battese and Coelli (1995) expresses the impacts of inefficiency as an explicit function of a vector of firm-specific variables and a random error. The true fixed-effect (TFE) and true random effects (TRE) models were introduced by Greene (2005a, b) to separate time-varying inefficiency from observation-specific time-invariant unobserved heterogeneity.

SFA has been widely adopted for analysis in various sectors, especially agriculture and banking (Fried, Lovell & Schmidt, 2008). The SFA method has also been used to evaluate the Higher Education sector. For example, Abbott and Doucouliagos (2009) used SFA to estimate an output distance function, with

[31] Longitudinal data (sometimes called panel data) involves repeated observations of the same subjects over time and helps track trends and measure changes over time (Investopedia, 2021a).

a panel data gathered from 36 Australian and 7 New Zealand public universities. Zoghbi, Rocha, and Mattos (2013) applied the SFA to estimate the efficiency of higher education institutions in Brazil. Bolli et al. (2016) estimated a simultaneous two-stage SFA based on a university-level panel dataset across eight European countries. Gralka (2018) provided a systematic review of the literature that applied SFA to measure the efficiency of higher education institutions. Letti et al. (2022) compared the efficiency scores of Brazilian universities using DEA and a distance function in SFA. These studies, and others, are discussed in more detail in Section 3.

2.3.3 *Stochastic Output Distance Function Analysis*

A stochastic output distance function (ODF) considers how the output vector may be proportionally expanded for a given input vector, and this is based on the assumption that a university aims to maximise output for a given level of input (Johnes, 2008).

The ODF seeks the maximum proportional increase in the observed output vector from a given input vector, given that the expanded vector still belongs to the original output set (Grosskopf et al., 1995; Johnes, 2010). As noted in Coelli et al. (2005, p. 47-48), the ODF should satisfy certain economic properties such as convex; non-decreasing, homogeneous of degree one in outputs, $\boldsymbol{y}$; non-increasing and quasi-convex in inputs $\boldsymbol{x}$.

Equation (2.6) can be written compactly for the sake of brevity and clarity as: $\boldsymbol{D_O}(\boldsymbol{x}, \boldsymbol{y}) \leq \mathbf{1}$. A value of one identifying the respective output vector $\boldsymbol{y}$ is produced by a fully efficient university located on the frontier of the production set. A value of less than one indicates inefficiency. Based on the Farrell output-oriented efficiency measures, the measure of output-orientated technical efficiency (TE) is equivalent to the output distance function, as shown in equation (2.7).

Moreover, using the parametric technique to estimate this ODF provides helpful information regarding the underlying production function of tertiary education, the extent of inefficiency, and the factors that contribute to inefficiency. A Cobb-Douglas or a translog ODF is frequently employed. Therefore, the precise Cobb-Douglas and translog specifications of the stochastic output-oriented distance function to be estimated are given by equations (2.32) and (2.33) (Coelli et al., 2005, p. 264):

$$\boldsymbol{lnD_{it}^{O} = \alpha + \sum_{m=1}^{M} \alpha_m \, lny_{mit} + \sum_{k=1}^{K} \beta_k lnx_{kit} + \theta_1 t + \theta_2 t^2} \tag{2.32}$$

$$
\begin{aligned}
\boldsymbol{lnD_{it}^{O}} = \boldsymbol{\alpha} + \sum_{m=1}^{M} \boldsymbol{\alpha_m\, lny_{mit}} \\
+ \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \boldsymbol{\alpha_{mn} lny_{mit} lny_{nit}} \\
+ \sum_{k=1}^{K} \boldsymbol{\beta_k lnx_{kit}} \\
+ \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \boldsymbol{\beta_{kl} lnx_{kit} lnx_{lit}} + \sum_{k=1}^{K}\sum_{m=1}^{M} \boldsymbol{\zeta_{km} lnx_{kit}\, lny_{mit}} + \boldsymbol{\theta_1 t} + \boldsymbol{\theta_2 t^2}
\end{aligned}
\tag{2.33}
$$

where $\boldsymbol{ln}$ denotes the natural logarithm, the subscripts $\boldsymbol{i}$ and $\boldsymbol{t}$ denote the $\boldsymbol{i}^{\text{th}}$ university and time, respectively. $\boldsymbol{D^{O}}$ is the output distance function specified in equation (2.6). There are $\boldsymbol{m}$ outputs ($\boldsymbol{y}$) and $\boldsymbol{k}$ inputs ($\boldsymbol{x}$). Meanwhile, $\boldsymbol{t = 1, \dots, T}$ is a linear time trend.

The translog function is a flexible form and provides a second-order approximation to the unknown function (Coelli et al., 2005). Therefore, using a translog specification has the advantage that cross-terms deliver helpful information on input and output substitution possibilities (Abbott & Doucouliagos, 2009) and allow non-linear causalities (Barra et al., 2018). Hence, this specification is frequently estimated alongside the simplified Cobb-Douglas version, subject to the usual restrictions of homogeneity of degree one in outputs and symmetry[32].

By the homogeneity restriction $\boldsymbol{D(x, \omega y) = \omega D(x, y)}$, one output can be arbitrarily chosen as the normalising variable, so that $\boldsymbol{\omega = \frac{1}{y_M}}$ (Johnes, 2014a, b). In this study, the undergraduate completion is used as the normalised variable. Thus, the output-oriented distance term $\boldsymbol{D_{it}^{O}}$ and the other outputs in Equation (2.33) are divided by the undergraduate completion ($\boldsymbol{i.e., y_M}$) as:

[32] The restrictions required for homogeneity of degree one in outputs are: $\sum_{m=1}^{M} \alpha_m = 1$, $\sum_{n=1}^{M} \alpha_{mn} = 0$ for all n, and $\sum_{k=1}^{K} \zeta_{mk}$=0 for all m. Symmetry restrictions required are: $\alpha_{mn} = \alpha_{nm}$ and $\beta_{kl} = \beta_{lk}$.

$$\ln\left(\frac{D_{it}^{O}}{y_{Mit}}\right) = \alpha + \sum_{m=1}^{M-1} \alpha_m \ln\left(\frac{y_{mit}}{y_{Mit}}\right) + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1} \alpha_{mn} \ln\left(\frac{y_{mit}}{y_{Mit}}\right) \ln\left(\frac{y_{nit}}{y_{Mit}}\right) + \sum_{k=1}^{K} \beta_k \ln x_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{kit} \ln x_{lit} + \sum_{k=1}^{K}\sum_{m=1}^{M-1} \zeta_{km} \ln x_{kit} \ln\left(\frac{y_{mit}}{y_{Mit}}\right) + \theta_1 t + \theta_2 t^2 + v_{it} + u_{it} \quad (2.34)$$

Given that lnD_{it}^{O} is not observable, and the normalising variable (y_{Mit}) is utilised, the dependent variable in Equitation (2.33) becomes $\ln\left(\frac{D_{it}^{O}}{y_{Mit}}\right)$. This can be rewritten as $\ln(D_{it}^{O}) - \ln(y_{Mit})$. Thus, $-\ln(y_{Mit})$ can be used as the dependent variable, transferring $\ln(D_{it}^{O})$ to the residuals (Coelli & Perelman, 2000). The equation (2.34) can be expressed as:

$$-\ln y_{Mit} = \alpha + \sum_{m=1}^{M-1} \alpha_m \ln\left(\frac{y_{mit}}{y_{Mit}}\right) + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1} \alpha_{mn} \ln\left(\frac{y_{mit}}{y_{Mit}}\right) \ln\left(\frac{y_{nit}}{y_{Mit}}\right) + \sum_{k=1}^{K} \beta_k \ln x_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{kit} \ln x_{lit} + \sum_{k=1}^{K}\sum_{m=1}^{M-1} \zeta_{km} \ln x_{kit} \ln\left(\frac{y_{mit}}{y_{Mit}}\right) + \theta_1 t + \theta_2 t^2 + v_{it} + u_{it} \quad (2.35)$$

2.4 Cost Efficiency

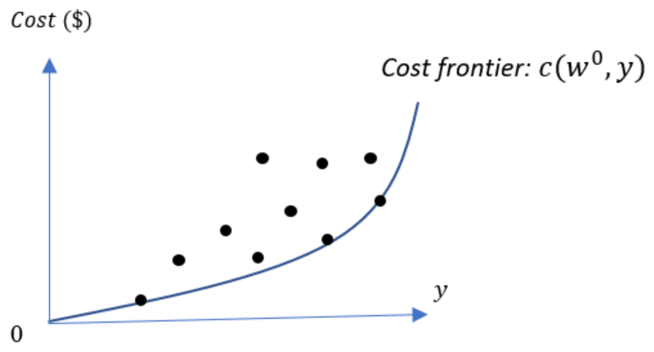
The production function focuses on the physical relationship between inputs and outputs. When multiple inputs exist, universities select the mix of inputs they want to utilise. Commonly, universities are assumed to choose inputs to minimise costs under the assumption of perfectly competitive input markets (e.g., the university is too small to impact input prices), which is said to be perfectly competitive in input markets. In this process, the university looks through all feasible input-output combinations to identify the input quantities that minimise the cost of producing specific quantities of output (Coelli et al., 2005, p. 21). The university's cost minimisation problem can be expressed as:

$$\boldsymbol{c}(\boldsymbol{w}, \boldsymbol{y}) = \min_{\boldsymbol{x}} \boldsymbol{w}'\boldsymbol{x} \quad \text{such that } \boldsymbol{y} = \boldsymbol{f}(\boldsymbol{x}) \qquad (2.36)$$

where $\boldsymbol{c}$ denotes the cost function for producing the output vector $\boldsymbol{y}$ when facing input prices $\boldsymbol{w}$, $\boldsymbol{w} = (\boldsymbol{w_1}, \boldsymbol{w_2}, \ldots, \boldsymbol{w_K})'$ is a K×1 vector of input prices; $\boldsymbol{x} = (\boldsymbol{x_1}, \boldsymbol{x_2}, \ldots, \boldsymbol{x_K})'$ is a K×1 vector of input quantities with the same dimension. The right-hand side of this equation means how to find the input quantities that minimise the cost of producing the output vector $\boldsymbol{y}$ under all technically feasible input-output combinations. Expanding $\boldsymbol{w}'\boldsymbol{x}$ yields: $\boldsymbol{w}'\boldsymbol{x} = \boldsymbol{w_1}\boldsymbol{x_1} + \boldsymbol{w_2}\boldsymbol{x_2} + \cdots + \boldsymbol{w_K}\boldsymbol{x_K} = \boldsymbol{cost}$.

The cost function describes the minimum cost given the current technology as a function of input prices and output volumes. An output level's minimal cost is displayed on a cost frontier for an input price of $\boldsymbol{w^0}$. Each university must be on or above $\boldsymbol{c}\left(\boldsymbol{w^0}, \boldsymbol{y}\right)$, as shown in Figure 2.7 (Kumbhakar & Lovell, 2003, p. 34). A university on the minimum cost frontier is fully cost-efficient (CE). For a university that operates above the frontier, CE can be computed by the ratio of the minimum cost to the actual cost. For instance, if a university's ratio is 0.7 (= minimum cost/actual cost), it could reduce costs by 30% while producing the same output.

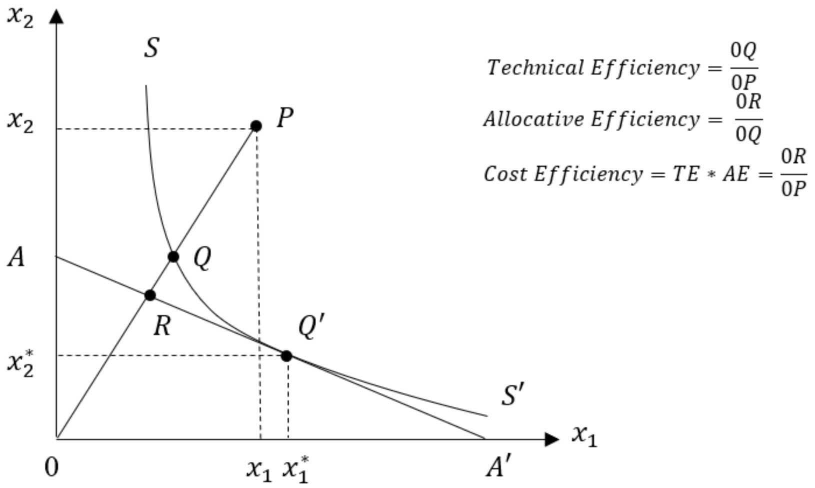
Figure 2.7
A Cost Frontier



Combining input-oriented technical efficiency with allocative efficiency, Figure 2.8 applies the idea of cost efficiency from Coelli et al. (2005, p.53). This illustration assumes that universities only use two inputs $\boldsymbol{x_1}$and $\boldsymbol{x_2}$ with market prices $\boldsymbol{w_1}$ and $\boldsymbol{w_2}$, respectively, to produce a single output $\boldsymbol{y^0}$. The curve $\boldsymbol{SS'}$ represents the $\boldsymbol{y^0}$ output isoquant which defines the minimum combinations of inputs that can produce this output level. The isocost line ($\boldsymbol{AA'}$) represents all input combinations that cost, $\boldsymbol{c} =$

$w_1x_1 + w_2x_2$. AA' is tangent to SS' at point Q' with vertical intercept $A = c/x_2$ and slope $-\left(\frac{w_1}{w_2}\right)$. Using x_1^* units of x_1 and x_2^* units of x_2 is the input bundle that minimises the cost of producing y^0 units of output.

Figure 2.8
Cost Efficiency



In Figure 2.8, a university producing y^0 unit of output and operating at point P, needs to reduce its inputs to point Q (on isoquant SS') to be technically efficient. The input-oriented measure of TE of a university operating at the point P is the ratio of $0Q$ over $0P$, which shows how well physical resources are utilised. To produce using the same input ration as P and minimising costs, the university would need to produce at point R. This means that AE can be measured as the ratio of $0R$ over $0Q$. This ratio expresses how well financial resources are utilised, with a value equal to one representing an efficient operation, and a value between zero and one inefficient operations. CE is a product of technical efficiency and allocative efficiency, $CE = TE * AE = \frac{0Q}{0P} * \frac{0R}{0Q} = \frac{0R}{0P}$.

2.4.1 *Stochastic Cost Frontier Analysis*

Data on the prices of inputs, output quantities, and observed costs for each university can be used to estimate the cost function. This analysis is based on a cost frontier, which can be written in the general form (Kumbhakar & Lovell, 2003, p.137):

$$c_{it} \geq c(w_{1it}, w_{2it}, \dots, w_{kit}, y_{it}; \beta) \qquad i = 1, 2, \dots, K \quad t = 1, 2, \dots, T \qquad (2.37)$$

where c_{it} is the observed costs of university i in period t; w_{kit} is the k-th input price vectors; y_{it} is the output quantities vectors and β is a vector of technology parameters to be estimated. The cost function $\boldsymbol{c}(.)$ should satisfy the following properties, which can confirm the cost-minimising solutions computed in equation (2.36): nonnegative; nondecreasing in input prices and output, homogenous of degree one and concave in input prices (Coelli et al., 2005, p.23). Equation (2.37) represents that the observed cost is greater than or equal to this minimum cost.

As discussed in the above section, cost efficiency can be measured by the ratio of the minimum cost to the observed cost, that is, $\boldsymbol{CE} = \frac{\boldsymbol{c(w_{kit}, y_{it}; \beta)}}{\boldsymbol{c_{it}}}$. Since $\boldsymbol{c_{it}} \geq \boldsymbol{c(w_{kit}, y_{it}; \beta)}$, it follows that $\boldsymbol{CE_{it} \leq 1}$. $\boldsymbol{CE = 1}$ means the observed cost attains its minimum costs.

The cost frontier $\boldsymbol{c(w_{kit}, y_{it}; \beta)}$ is *deterministic* as it ignores the fact that the minimum cost may be affected by random shocks outside the control of the university. Therefore, a stochastic cost frontier can be written as (Kumbhakar & Lovell, 2003, p.137):

$$\boldsymbol{c_{it} \geq c(w_{1it}, w_{2it}, \dots, w_{kit}, y_{it}; \beta) \cdot \exp(v_{it})} \qquad (2.38)$$

where $[\boldsymbol{c(w_{1it}, w_{2it}, \dots, w_{kit}, y_{it}; \beta) \cdot \exp\,(v_{it})}]$ is the stochastic cost frontier (SCFA), which includes two parts: a deterministic part $\boldsymbol{c(w_{kit}, y_{it}; \beta)}$ to all universities and a university-specific random part $\boldsymbol{\exp(v_{it})}$, which obtains the effects of random shocks on each university. $\boldsymbol{v_{it}}$ are independently and identically distributed normal random variables with zero mean and constant variances $\boldsymbol{\sigma_v^2}$, which represent statistical noise.

The observed cost exceeds the stochastic minimum production cost which is attributed to cost inefficiency, and it can be written as:

$$\boldsymbol{c_{it} \geq c(w_{1it}, w_{2it}, \dots, w_{kit}, y_{it}; \beta) \cdot \exp(v_{it} + u_{it})} \qquad (2.39)$$

where $\boldsymbol{u_{it}}$ is a non-negative inefficiency error term that follows certain distributional specification (e.g., half-normal; truncated-normal; exponential; gamma models). When the university is fully efficient, it's inefficiency error term will be zero which means it is operating *on* the stochastic cost frontier. The measure of cost efficiency in a stochastic cost frontier context is provided by the ratio of the stochastic frontier cost to the actual cost (Kumbhakar & Lovell, 2003, p.138):

$$\boldsymbol{CE_{it} = \frac{c(w_{1it}, w_{2it}, \dots, w_{kit}, y_{it}; \beta) \cdot \exp\{v_{it}\}}{c(w_{1it}, w_{2it}, \dots, w_{kit}, y_{it}; \beta) \cdot \exp\{v_{it}\} \cdot \exp\{u_{it}\}} = \exp(-u_{it})} \qquad (2.40)$$

ML estimation can be employed to obtain estimates of the parameters of the two error components $\boldsymbol{v_{it}}$ and $\boldsymbol{u_{it}}$ which are distributed independently of each other and of the regressors (Kumbhakar & Lovell, 2003, p.140). Producer specific cost efficiency can be estimated using the Battese and Coelli (1988) point estimator (Kumbhakar & Lovell, 2003, p.142):

$$\boldsymbol{CE_{it}} = \boldsymbol{E}(\mathbf{exp}(-\boldsymbol{u_{it}})\,|\boldsymbol{v_{it}} + \boldsymbol{u_{it}})) \qquad (2.41)$$

The stochastic cost frontier (SCFA) technique has been used by several studies investigating the efficiency of the higher education sector. For example, Stevens (2005) used SCFA to assess cost efficiency of English and Welsh universities over 1995-1999. Kuo and Ho (2008) employed SCFA to estimate a cost function, with panel data gathered from 34 public universities in Taiwan from 1992 to 2000. Kempkes and Pohl (2010) utilised SCFA and Malmquist index techniques to analyse 72 German public universities from 1998 to 2003. Daghbashyan (2011) applied the SCFA to estimate the efficiency of higher education institutions in Sweden from 2001 to 2005. Gralka (2018) used SCFA to measure the efficiency of German public universities over 2001-2013.

2.4.2 *SCFA in Cobb-Douglas and Translog Models*

This study estimates a cost function to analyse the cost efficiency of Australasian universities. In the cost frontier, the cost variable is the total costs, and the independent variables are the output volume and input price. The Cobb-Douglas and Translog specifications of the stochastic cost functions to be estimated are given by Equations (2.42) and (2.43) (Coelli et al., 2005, p. 266):

$$\boldsymbol{lnC_{it}} = \boldsymbol{\alpha} + \sum_{m=1}^{M} \boldsymbol{\alpha_m lny_{mit}} + \sum_{k=1}^{K} \boldsymbol{\beta_k lnw_{kit}} + \boldsymbol{\theta_1 t} + \boldsymbol{\theta_2 t^2} + \boldsymbol{v_{it}} + \boldsymbol{u_{it}} \qquad (2.42)$$

$$\begin{aligned}\boldsymbol{lnC_{it}} = {} & \boldsymbol{\alpha} + \sum_{m=1}^{M} \boldsymbol{\alpha_m lny_{mit}} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{N} \boldsymbol{\alpha_{mn}}(\boldsymbol{lny_{mit}} * \boldsymbol{lny_{nit}}) + \sum_{k=1}^{K} \boldsymbol{\beta_k lnw_{kit}} \\ & + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{L} \boldsymbol{\beta_{kl}}(\boldsymbol{lnw_{kit}} * \boldsymbol{lnw_{lit}}) + \sum_{m=1}^{M}\sum_{k=1}^{K} \boldsymbol{\zeta_{mk} lny_{mit}} \ln \boldsymbol{w_{kit}} + \boldsymbol{\theta_1 t} + \boldsymbol{\theta_2 t^2} + \boldsymbol{v_{it}} \\ & + \boldsymbol{u_{it}}\end{aligned} \qquad (2.43)$$

where $\boldsymbol{ln}$ denotes the natural logarithm, the subscripts $\boldsymbol{i}$ and $\boldsymbol{t}$ denote the $\boldsymbol{i}$th university and time, respectively. $\boldsymbol{C_{it}}$represents the total expenses in university $\boldsymbol{i}$ and time period $\boldsymbol{t}$. There are $\boldsymbol{m}$ outputs ($\boldsymbol{y}$) and $\boldsymbol{k}$ input prices ($\boldsymbol{w}$). Meanwhile, $\boldsymbol{t = 1, \dots, T}$ is a linear time trend and $\boldsymbol{t^2}$ captures the quadratic trend in the cost function. According to Coelli et al. (2005, pp. 23), a well-behaved cost function is nondecreasing and linearly homogeneous in input prices (e.g., homogeneous of degree one in input prices, that is, the total cost increases proportionally when all prices rise proportionally for a given output level), and nondecreasing in output, and concave in input prices.

2.5 Summary

This chapter has outlined the methodologies used to analyse the efficiency and productivity of New Zealand and Australian universities. Key concepts, such as productivity, efficiency, MPI, TFP, TE, stochastic ODF and SCFA, are introduced as university performance measures.

In an output-oriented framework, TE is measured by comparing the observed output of universities with the maximum possible output for a given input under the current production technology. Distance functions describe production technologies without considering prices or specific behavioural assumptions (e.g., cost-minimisation or profit-maximisation) (Coelli et al., 2005, p. 47). The Farrell output-orientated TE measures are equivalent to the ODF (Shephard, 1970; Färe & Primont, 1995; Coelli et al., 2005, p. 57).

The Malmquist productivity index measures changes in TFP over time, decomposing productivity into technical change and efficiency change. The latter includes pure efficiency change (measuring relative to the VRS frontier) and scale efficiency change (capturing the changes in the deviation between the CRS and VRS technologies). These indexes help evaluate university performance by capturing improvements in output without increased inputs and adjustments toward an optimal scale.

Stochastic ODF is chosen to address the small dataset issue by combining data over time and accounting for technical inefficiency and statistical noise. Including New Zealand data (8 universities) and Australian data (37 universities) enhances the analysis by expanding the dataset and allowing for broader comparison across the two countries. It is particularly relevant in the university sector, where the goal is often to maximise output (e.g., completions) without increasing inputs.

SCFA measures the cost efficiency of universities by measuring the ratio of the stochastic frontier cost to the actual cost. This method allows for identifying inefficiencies to account for external factors that may influence cost performance. SCFA also plays a crucial role in understanding the cost behaviour of universities and optimising resource utilisation.

In summary, the methodologies discussed—Malmquist index, Stochastic ODF and SCFA—are essential for evaluating productivity growth, technical efficiency and cost efficiency in New Zealand and Australian universities. These approaches guide the empirical analysis and interpretation of results in the following chapters.

Chapter 3 Productivity and Efficiency: Literature Review

This chapter reviews the literature on productivity and efficiency in higher education institutions (HEIs), focusing on empirical methodologies and related studies. It focuses on two main approaches: the Malmquist productivity index (MPI) and stochastic frontier methods. These include stochastic frontier analysis (SFA) and stochastic cost frontier analysis (SCFA). The aim is to synthesise existing work, identify research gaps and clarify the objectives of this thesis.

This chapter is structured as follows. Section 3.1 provides an overview of productivity and efficiency studies in HEIs, introducing three recent review studies. Section 3.2 outlines the variables commonly used in these analyses. Section 3.3 discusses the empirical methodologies commonly used in the literature. Section 3.4 reviews MPI applications. Section 3.5 examines SFA and SCFA studies in New Zealand and overseas. Section 3.6 summarises key insights and research gaps. Appendix Chapter 3 provides two summary tables.

3.1 Overview of Productivity and Efficiency Studies

Research on productivity and efficiency in HEIs has grown significantly in recent decades. This expansion has been driven by increased competition and financial pressure (Abbott & Doucouliagos, 2009). Several studies provide comprehensive literature reviews, including Witte and López-Torres (2017), Gralka (2018a), and Ferro and D'Elia (2020). These reviews synthesise empirical methodologies and summarise variables commonly used to assess HEI performance, including inputs, outputs, quality measures, and contextual factors (e.g., environmental variables or inefficiency determinants).

Witte and López-Torres (2017) review efficiency studies in education up to 2015. They categorise input variables into four groups: student-related (e.g., age, gender), family-related (e.g., parental employment status), institutional (e.g., enrollments, expenditures, research income, staff) and community-related (e.g., urban or rural location). Common outputs include the number of graduates, publications, citations, and research income. Contextual or environmental factors, such as dropout rates, faculty composition and geographic location, influence academic outcomes. The study highlights both non-parametric (e.g., DEA, MPI) and parametric (e.g., SFA, SCFA) techniques. Most studies focused on university-level efficiency, followed by school or high school, and district, country or city-level assessments. A smaller number of studies examined national-level performance, while cross-country or multi-country comparisons are relatively scarce.

Gralka (2018a) focuses on SFA-based studies published between 1998 and 2017. The paper systematically reviews 63 peer-reviewed articles and assesses model assumptions, specifications, and variable selections. Frequently used inputs include budgets, academic and administrative staff, students, physical capital, and research activities (e.g., research expenditure or income). Outputs typically include students, graduates, research grants and publications. Some studies include price variables or institutional dummies. Gralka highlights two common SFA models, the Battese and Coelli (1992, BC92) model, which accounts for time-variant efficiency, and the Battese and Coelli (1995, BC95) model, which includes inefficiency determinants, such as student characteristics, subject specialisation and region. The review also notes scarce cross-country analysis and inconsistent reporting of efficiency scores.

Ferro and D'Elia (2020) review 89 empirical studies published between 1997 and 2019, covering both non-parametric (DEA, MPI) and parametric (SFA) methods. They group variables into five categories: inputs (e.g., academic and non-academic staff), outputs (e.g., completions, students, publications, research income), input prices (e.g., labour, capital), quality indicators (e.g., dropout rates), and environmental factors (e.g., international student proportions, student gender composition, geographic region).

Together, these reviews provide a detailed overview of how productivity and efficiency are measured in HEIs. They show the widespread use of DEA, MPI, SFA, and SCFA, highlighting the importance of variable selection and emphasising the growing use of SFA to explore inefficiency determinants. However, several research gaps remain, including scarce cross-country comparisons, inconsistent reporting of efficiency score results, and variation in model specification. These gaps present opportunities for further research.

3.2 Variables Used in the Productivity and Efficiency

Before reviewing the literature in detail, examining the variables commonly used in productivity and efficiency analyses is useful. This section reviews input and output variables commonly used, including labour, capital, student-related factors, input prices, and quality-adjusted indicators. Notably, some variables, such as student numbers or research income, can differ across studies. Depending on the research aims and modelling frameworks, some variables are used as inputs in one study and outputs in another.

There is substantial variation in variable selection across the literature. Some of this variation reflects theoretical considerations, such as reflecting different university functions or attempting to adjust for quality. However, many differences are also driven by practical constraints, such as data availability and consistency across institutions and countries. Therefore, researchers often select variables that fit the context and available data, contributing to the diversity of empirical approaches.

3.2.1 *Output Variables*

Based on Gralka (2018) and the Appendix Chapter 3 tables, this section separates university output variables into six categories: students, graduates, research income, publications, personnel structure, and other outputs. Compared to inputs, outputs show greater variation both within and across studies.

Students—EFTS

A commonly used output measure is equivalent full-time students (EFTS), which adjusts enrolments based on student workload. It accounts for full-time or part-time status and the duration of enrolment (New Zealand Productivity Commission, 2018b). This adjustment supports consistent comparisons of teaching output across institutions and over time. EFTS is widely used in New Zealand and international studies. Gemmell et al. (2017) use EFTS per teaching FTE staff to measure teaching productivity.

However, not all studies apply this adjustment. Some use unadjusted enrolment students (Bolli & Farsi, 2015; Bolli et al., 2016), while others use alternative methods. For instance, Agasisti (2016) analyses the impact of study intensity on cost efficiency by comparing the number of regular students (those who complete courses within the standard timeframe) to total enrolments. The results differ slightly. Agasisti also finds that increasing the number of regular students could significantly reduce unit costs when looking at the marginal costs (Agasisti, 2016, p. 62).

Many studies disaggregate students by educational levels or subjects to reflect output mix. Most studies differentiate students by educational levels, splitting undergraduate, graduate and postgraduate students (Robst, 2001; Abbott & Doucouliagos, 2003; Mensah & Werner, 2003; Stevens, 2005; McMillan & Chan, 2006; Fu, Huang & Tien, 2008; Horne & Hu, 2008; Kuo & Ho, 2008; Johnes, Camanho & Portela, 2008; Johnes, Johnes, & Thanassoulis, 2008; Abbott & Doucouliagos, 2009; Smart, 2009; Mamun, 2011; Sav, 2012c; Sav, 2012d; Sav, 2012f; Sav, 2012h, Sav, 2012j; Bolli & Farsi, 2015; Agasisti & Haelermans, 2016; Gemmell et al., 2017; Titus et al., 2017; Gralka, 2018). This distinction reflects differences in resource intensity, as postgraduate programmes typically require small class sizes, more academic supervision, and research support.

Sav (2012i) further disaggregates undergraduate enrolments by gender, such as total undergraduate enrolments, proportion of female undergraduates, and graduate enrolments. This explores whether more female faculty improves efficiency in producing student graduate rates.

Subject-based classifications are also common, typically distinguishing between science and non-science fields (Johnes & Salas-Velasco, 2007; Johnes & Johnes, 2009; Agasisti & Johnes, 2010; Johnes & Schwarzenberger, 2011; Olivares & Wetzel, 2014; Johnes & Johnes, 2016; Gralka, 2018). This distinction reflects differences in teaching and resource intensity, as science disciplines generally require laboratory space, equipment, and small class sizes. Several studies occasionally identify medicine students as a separate category due to the high cost and complexity of medical training (Agasisti, 2016; Agasisti & Gralka, 2019). Regardless of these classifications, PhD students are frequently treated as an additional output due to their intensive supervision requirements and contributions to institutional research performance (McMillan & Chan, 2006; Johnes & Salas-Velasco, 2007; Johnes, Camanho & Portela, 2008; Agasisti, & Johnes, 2010; Johnes & Schwarzenberger, 2011; Agasisti & Haelermans, 2016).

Several studies with more extensive datasets classify students by both educational level and subject (Izadi et al., 2002; Stevens, 2005; McMillan & Chan, 2006; Horne & Hu, 2008; Johnes, Johnes, & Thanassoulis, 2008; Nemoto & Furumatsu, 2014). For instance, Izadi et al. (2002) and Stevens (2005) disaggregate undergraduate students into arts and science and postgraduate students. McMillan and Chan (2006) similarly distinguish undergraduate science and non-science students, master's students, and doctoral students. Johnes, Johnes, and Thanassoulis (2008) disaggregate undergraduate EFTS into medicine, science, and non-science, and postgraduate EFTS. Nemoto and Furumatsu (2014) use discipline-specific dummy variables to reflect variation across disciplines (such as social sciences or humanity; natural sciences and engineering; medical and health sciences; art, music and others).

Several studies also consider student demographic characteristics. For example, Sav (2011) uses the proportion of students receiving low-income grants to indicate socioeconomic disadvantage. These students are assumed to be more academically at risk and may require additional institutional support and impact cost efficiency. Similarly, Sav (2012c) uses the percentage of minority students (e.g., international students). Universities often provide special programmes and services for these groups, which can increase costs and potentially create inefficiencies.

Graduates

Some studies use the total number of graduates as a measure of teaching output (Flegg et al., 2004; Johnes, 2008; Kempkes & Pohl, 2008; Kempkes & Pohl, 2010; Margaritis & Smart, 2011; and Wang et al., 2020), while others disaggregate graduates by educational level or subject. Differentiating graduates by levels (e.g., undergraduate, graduate and postgraduate) is common (Worthington & Higgs, 2011; Agasisti & Johnes, 2015; Agasisti & Haelermans, 2016). Fewer studies categorise graduates by subject area, such as medical, science or other fields (Agasisti, 2016). Some studies also use undergraduate graduate rates as teaching outputs (Sav, 2012b; 2012i; 2012k).

Some studies that contrast two variables (students vs. graduates) are helpful to see if they lead to a similar assessment. Agasisti and Haelermans (2016) evaluate Italian and Dutch universities using both measures. They find that Dutch universities are more efficient at producing more graduates, while Italian universities appear more efficient based on enrolment measures. Similarly, Agasisti and Gralka (2019) compare students and graduates across disciplines (non-science, science and medical) in Italy and Germany.

Research Grants

In the research context, the literature measures research output through publications, citations, and the amount of research grants or income achieved. Research grants are most commonly used as an output in cost and distance function models but are not used in production functions, likely because these models include only one output (Gralka, 2018a).

Research grant data are typically accessible and reliable, often available from national statistical offices. However, critics emphasise that research grants are spent on research and other facilities, which are an input for production. Additionally, research grants are unequally distributed across subject areas, limiting their comparability between institutions.

Most studies use the overall value of research grants (Izadi et al., 2002; Mensah & Werner, 2003; Flegg et al., 2004; Stevens, 2005; Johnes & Salas-Velasco, 2007; Johnes, Johnes & Thanassoulis, 2008; Johnes & Johnes, 2009; Agasisti & Johnes, 2010; Kempkes & Pohl, 2010; Worthington & Lee, 2008; Worthington & Higgs, 2011; Sav, 2012c; Sav, 2012d; Sav, 2012f; Johnes, 2014a; Johnes, 2014b; Nemoto & Furumatsu, 2014; Agasisti & Johnes, 2015; Agasisti, 2016; Agasisti, Barra & Zotti, 2016; Agasisti & Haelermans, 2016; Johnes & Johnes, 2016; Sav, 2016; Barra, Lagravinese & Zotti; 2018). Few studies disaggregate research grants by discipline. One exception is Olivares and Wetzel (2014), who distinguish science and non-science fields. Kempkes and Pohl (2008, 2010) use normalised measures, such as third-party funds per student and research grants per student.

Research Publications

Research publications are often used as an alternative to research grants. They reflect research performance across academic disciplines, allowing for quality weighting through citations. However, the publication measure has limitations: it is retrospective, spans diverse publication channels, and presents data accuracy challenges.

Johnes and Johnes (1993) first used publications, including the total number of books, articles, and chapters, as a research output measured in efficiency analysis using DEA. Subsequent studies frequently measure publications by the raw publication counts (Johnes, Camanho, & Portela, 2008; Abbott & Doucouliagos, 2009; Parteka and Wolszczak-Derlacz (2013); Yaisawarng and Ng (2014); Bolli et al., 2016).

Few studies specify the types of publications or how they are aggregated institutionally. However, some studies separate among publication types, such as books, book chapters, journal articles, and other publications (Abbott & Doucouliagos, 2009; Worthington & Higgs, 2011; Lu & Chen, 2013). For instance, Lu and Chen (2013) include journal and conference papers as measures of research performance.

Zhang, Bao and Sun (2016) evaluate efficiency using five publication types: total publications, science/engineering publications, non-science/engineering publications, domestic journals, and international journals. Their findings highlight those publications in science/engineering, especially in international journals, are strongly influenced by human resources (e.g., research faculty who teach and conduct research; lectures and instructors who teach only), research expenditure and research equipment. Non-science/engineering publications are influenced by human resources alone. However, since the inputs used are not split according to the same grouping, the interpretation of these findings is scarce.

Although examining both research grants and publications is insightful, no study evaluates their effects on efficiency separately. However, Worthington and Higgs (2011) include both research grants (e.g., Australian national competitive and industry grants in monetary values) and publications (in points) in their model but do not compare them. Instead, they include them both as outputs in the estimation.

Personnel Structure

Personnel-related measures typically include ratios, such as student-to-teacher ratios (Fu, Huang & Tien, 2008; Lenton, 2008; Titus, Vamosiu & McClure, 2017), or percentages, such as the percentage of tenured faculty (Sav, 2011; Sav, 2012c). Mamun (2011) considers the number of both teaching and non-teaching staff.

More precisely, Sav (2011; 2012c) uses the percentage of tenured staff to capture academic staffing characteristics. Fu, Huang and Tien (2008) use the student-to-FTE faculty ratio to reflect output quality, although they acknowledge limitations due to the exclusion of part-time staff. Lenton (2008) finds a significantly negative relationship between the student-to-teacher ratio and total costs, suggesting that larger classes reduce overall costs. Similarly, Titus, Vamosiu, and McClure (2017) find a negative but insignificant relationship between the same ratio and total costs.

Other Output Variables

Several studies also identify additional, less frequently used output variables. Some studies use the number of undergraduate and graduate credit hours (Sav, 2011; Sav, 2012a; Sav, 2012e; Sav, 2012g; Sav, 2016). Other studies focus on financial indicators, particularly revenue, often disaggregated by source (McMillan & Chan, 2006; Johnes, Johnes & Thanassoulis, 2008; Sav, 2011; Sav, 2013). For example, Johnes, Johnes and Thanassoulis (2008) include income from external services provided to entities such as industrial and commercial firms and public corporations. Sav (2011, 2013) includes the proportion of university revenues sourced from government funding (e.g., federal, state and local), suggesting that greater public funding reduces reliance on private funding (e.g., private philanthropy).

Notably, third mission activities[33], such as knowledge transfer and community engagement, are rarely included in university efficiency studies (Gralka, 2018a). Chapple et al. (2005) examine these activities using the number of registered licences and licensing income in U.K. universities and compare their impact on efficiency results.

Some studies use alternative output measures, such as university assets (Mensah & Werner, 2003; Sav, 2016) and infrastructure-related variables (Fu, Huang & Tien, 2008). For instance, Mensah and Werner (2003) use the unrestricted to total net assets ratio to represent institutional financial flexibility, particularly concerning donor restrictions. Sav (2016) uses the total value of capital and

[33] The third mission activity is the service that the university provides to society and a conscious effort on the part of university actors to promote a sense of reciprocal community engagement, address issues that are important to society, and contribute to innovation and social change (Compagnucci & Spigarelli, 2020). Letti et al. (2022) used third mission activities as the output variable, in which professors directly or indirectly impact the community engaged.

other assets as a proxy for infrastructure differences across universities. Fu, Huang and Tien (2008) measure students per square meter of building space as a proxy for congestion in the university's learning and living environment. This reflects that the quality of facilities (e.g., dormitory, recreation, classroom, and library) directly impacts the production of quality undergraduate and graduate education.

3.2.2 *Input Variables*

Following Gralka (2018a) and the review in Appendix Chapter 3 tables, this study categorises the main inputs into six groups: budget, personnel structure, students, physical capital, research funds, and other inputs.

Budget Inputs

Budget inputs typically refer to the total annual expenditure of each institution (Bachan, 2017), operating expenses (Castano & Cabanda, 2007), research expenditure (Zhang et al., 2016; Titus et al., 2017) or student service expenditure (Sav, 2012i; 2012k). Zhang et al. (2016) consider financial resources (e.g., internal and external research expenditure) as inputs directly related to research production. Some studies also include specialised measures such as endowment funds (Sav, 2013).

Several studies distinguish between academic and student-related costs (Sav, 2012a; Sav, 2012b). Johnes (2014a, 2014b) further separates academic expenditure (e.g., on centralised academic services, such as the library and learning resource centres) and administrative expenditure (e.g., on total administration and central services, including staff and student facilities).

Personnel Structure

Personnel inputs are typically measured using full-time equivalent (FTE) staff (Gralka, 2018a). While most studies use overall staff numbers (Chapple et al., 2005; Castano & Cabanda, 2007; Sav, 2012a; Sav, 2012i; Sav, 2012k; Johnes, 2014a; Agasisti et al., 2016), several studies differentiate by staff type, such as teaching versus research (Zhang et al., 2016), or academic versus general staff (Abbott & Doucouliagos, 2009; Sav, 2013). Others focus specifically on academic staff (Johnes, 2014a; Johnes, 2014b; Barra, Lagravinese & Zotti, 2018) or teaching staff (Laureti et al., 2014; Titus et al., 2017).

Some studies use more detailed breakdowns, such as the number of professors (Miranda et al., 2012; Sav, 2013; Erkoc, 2015; Letti et al., 2022) or staff groupings by role and rank. These distinctions reflect differences in experience, responsibilities, and costs—professors are more experienced but more costly than early-career researchers. Staff groupings include the number of professors, lecturers, assistants, and administrative and technical staff (Bolli & Farsi, 2015); the number of professors and assistant professors, other research staff, technical and administrative staff (Bolli et al., 2016); and the number of tenured versus non-tenured positions (Sav, 2012b). Zhang, Bao, and Sun (2016) also distinguish between research faculty (who teach and conduct research) and lecturers/instructors (who teach only) to capture the intensity of academic workload.

Some studies apply staff ratios, such as the professor-to-student ratio (Zoghbi, Rocha & Mattos, 2013) and the staff-to-student ratio (Bachan, 2017), which may reflect teaching intensity or administrative burden. Sav (2016) examines institutional staffing patterns, including the proportion of non-tenure-track staff and the ratio of non-faculty to tenure-track and tenured faculty. The first reflects the trend of replacing higher-wage tenure-track and tenured faculty with lower wage non-tenure track staff. The second captures university decisions to expand lower-wage non-faculty staff relative to higher wage tenure-track and tenured faculty. Carrington et al. (2005) use the proportion of academic staff at or above the associate professor level to indicate institutional research capacity. A higher proportion of senior academic staff may reflect stronger research capacity.

Finally, expenditure on administration and central services, including facilities for staff and students, has also been used to capture non-academic staffing resources (Johnes, 2014a, 2014b).

Students as Inputs

Student numbers are often disaggregated by educational levels (e.g., total, undergraduate, master's and doctoral) or by subject (e.g., science vs. non-science) to reflect differences in source requirements. Postgraduate programmes typically require smaller classes and more supervision than undergraduate courses. Science-based subjects typically incur higher costs due to laboratory and specialised equipment.

Several studies use the total number of enrolled students (Bolli & Farsi, 2015; Bolli et al., 2016), while others focus solely on undergraduate enrolments (Laureti et al., 2014). Many studies commonly distinguish between undergraduate and postgraduate students (Flegg et al., 2004; Johnes, 2008; Johnes & Salas-Velasco, 2007; Kuo & Ho, 2008; Worthington & Lee, 2008; Agasisti & Johnes, 2009; Smart, 2009; Abbott & Doucouliagos, 2009; Mamun, 2011; Margaritis & Smart, 2011; Agasisti & Pohl, 2012; Sav, 2012i; Sav, 2012k; Sav, 2013; Parteka & Wolszczak-Derlacz, 2013; Zhang, Bao & Sun, 2016; Wang et al., 2020). Some studies further disaggregate postgraduate EFTS into master's and doctorate categories (Agasisti & Haelermans, 2016).

Subject specialisation is commonly used to classify student inputs. This allows models to account for cost differences and teaching structures across disciplines. For instance, several studies often separate undergraduate EFTS into science and non-science categories (Johnes & Salas-Velasco, 2007; Johnes & Johnes, 2009) and apply similar groupings to graduates (Graka, 2018; Agasisti & Gralka, 2019). Gralka et al. (2019) classify bachelor's and master's students into science versus non-science disciplines. Stevens (2005) separates undergraduates into science and arts disciplines and identifies postgraduate students. McMillan and Chan (2006) categorise enrolments into science undergraduates, other undergraduates, and master's and doctoral students. Similarly, Daghbashyan (2011) differentiates undergraduate EFTS by subjects: medicine, technical science, humanities, and doctoral-level students.

Kempkes and Pohl (2008) also include subject-specific enrolment ratios, grouping students by faculty, such as engineering, science, and medical/ veterinarian/agrarian fields, with social sciences and languages as the reference category. These variables help control for variation in faculty composition due to cost structures across universities.

Capital Inputs

Capital is an important input in university production, though it appears less frequently in empirical models than in labour. This is largely due to the difficulty of measuring capital services, which ideally reflects the flow of capital services over time. Capital is difficult to measure since accounting-based measures often do not align with economic measures. Therefore, most studies rely on accounting-based proxies, such as book values or depreciation and amortisation, which are more accessible and widely reported.

Physical capital contributes to university production, but it is less frequently used in production and distance function models than financial expenditure (Gralka, 2018a). This is likely due to data limitations and difficulties in measuring capital services. For instance, Johnes (2006) uses total depreciation and interest payable as a proxy for capital input, while Castano and Cabanda (2007) include the value of property, plant and equipment (PPE).

The New Zealand Productivity Commission (2018b) introduced a capital input measure for universities based on physical capital stocks, specifically PPE. Initially, unadjusted capital productivity was calculated as EFTS per PPE. However, this unadjusted measure risked disadvantaging research-intensive universities, where capital resources are more heavily allocated to research activities. To address this, a refined "teaching capital[34]" measure was proposed. This adjusts for the proportion of teaching income relative to total teaching and research income (e.g., *teaching weight*[35]), enabling more equitable comparisons across institutions.

In practice, PPE is typically measured using book values reported in financial accounts. However, this method has several limitations. Leased and owned assets that deliver similar services may be treated differently in accounting records (e.g., depreciation rate). Leased assets are excluded in physical capital stocks measured using accounting values. Moreover, accounting-based measures may reflect accounting rules (e.g., depreciation rules) rather than actual capital services delivered from that stock.

Capital expenditure is widely used in the literature as a proxy for capital inputs, typically capturing non-labour components of total operating expenses (i.e., total expenses minus labour costs) (Glass et al., 1995; Glass et al., 1998; Glass et al., 2002; Abbott & Doucouliagos, 2003; Fu et al., 2008; Worthington & Lee, 2008; Smart, 2009; Kempkes & Pohl, 2010; Margaritis & Smart, 2011; Worthington & Higgs, 2011; Yaisawarng & Ng, 2014; Zhang et al., 2014; Bolli & Farsi, 2015; Tran, 2021).

Definitions of capital inputs vary across studies. Glass et al. (1995), Glass et al. (1998), and Glass et al. (2002) focused on expenditure for equipment, furniture, land, and buildings. Ahn, Charnes, and Cooper (1989) and Ahn and Seiford (1993) included overhead costs, such as the library and general administration expenses. McMillan and Datta (1998) and McMillan and Chan (2006) went further by incorporating total expenditure, including operational expenditure and sponsored research expenditure, although this approach is unusual. Most studies commonly use expenditure-based

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[34] The New Zealand Productivity Commission (2018b) also used *teaching capital flows* as a measure of capital input, including depreciation costs and the teaching capital multiplied by the capital charge rate (below notes), rather than relying on solely physical capital stocks, because not all PPE is equal, and it is depreciating at different rates over time.

Note: Although the New Zealand Government does not impose a capital charge on universities for historical and political reasons, the New Zealand Productivity Commission (2018b) applied a 7% capital charge rate, consistent with the rate applied to other state-sector entities at the time. Additionally, although the legal title has not yet been transferred from the Crown, which still owns the land and buildings, the university has assumed all the normal risks and rewards of ownership (University of Auckland, 2019, p. 62), such as complete control over land and structures and the ability to profit materially and substantially from their usage. Specific information regarding the capital charge rate for Australian universities could not be identified.

[35] New Zealand Productivity Commission (2018b) mentions several implicit assumptions underlying the use of current income data to scale capital stock. First, it assumes that research and teaching have a similar level of capital intensity. Second, it assumes that the current income split has not changed much over time, as the capital stock reflects past decisions. Lastly, it assumes that these assumptions are reasonable within the context of its analysis.

measures, as they maintain continuity and the ability to produce the desired output in higher education institutions (Salleh, 2012).

Likewise, Sav (2012a) explicitly distinguishes between the value of buildings and equipment as separate capital components. Sav (2013) considers the value of art collection and equipment, focusing on the role of private philanthropy (e.g., private gifts) in financing public universities. Sav (2016) uses the total value of capital and other assets as a proxy for infrastructure differences across universities. Johnes (2014a, 2014b) also includes expenditure on centralised academic services, such as library and learning resource centres, central computer and computer networks, and other general academic services.

Other studies use more direct indicators of physical infrastructure. Miranda et al. (2012) utilises library stock (total print collection) and the ratio of academic-purpose computers to students. Similarly, Zoghbi et al. (2013) adopt the number of computers per enrolled student. Laureti et al. (2014) apply specific measures like the number of lecture hall seats, computer laboratories, and books and scientific journals in libraries.

Research Inputs

Research inputs are widely used in production and distance function models, reflecting the importance of research in university operations (Gralka, 2018a). These variables are often monetary, focusing on either research expenditures (Koshal & Koshal, 1999; Robst, 2001; McMillan & Chan, 2006; Kuo & Ho, 2008; Daghbashyan, 2011; Mamun, 2011; Sav, 2012i; Sav, 2012k; Zhang, Bao & Sun, 2016) or research grants (Sav, 2012; Sav, 2012d; Sav, 2012f; Sav, 2012g; Sav, 2013; Bolli & Farsi, 2015; Agasisti, Barra & Zotti, 2016; Barra, Lagravinese & Zotti, 2018).

Sav (2012i; 2012k) examines the proportion of total university expenditure allocated to research, while Zhang, Bao and Sun (2016) also include research equipment as an indicator of research infrastructure and capacity. Similarly, Sav (2012b) uses research revenue per faculty member to link research funding directly to university production, and Sav (2013) employs the awarded value of research grants.

Moreover, Chapple et al. (2005) use total research income as a proxy for universities’ technological stock in production function models. They also consider invention disclosures and external legal intellectual property expenditure. Their results indicate that average technical efficiency remains consistent, regardless of whether they use research income, invention disclosures, or functional form (translog or Cobb-Douglas).

Notably, research-related variables, such as research income or grants, are treated as inputs in some studies and outputs in others, depending on the research objectives and model design.

3.2.3 *Quality Aspect Input and Output Variables*

Incorporating quality adjustments into input and output variables is important to reflect university performance accurately. Common indicators, such as qualification completions, typically measure quantity but do not account for differences in quality across institutions, disciplines, or programmes. This may lead to misleading conclusions, where institutions producing high-quality outcomes appear no more efficient than those delivering lower-quality services. Quality-adjusted measures help account for differences in teaching standards, research impact, and student preparedness. They enhance the validity of efficiency and productivity estimates.

Quality of Staff

Several studies adjust labour inputs to reflect staff quality. Johnes (2014a, 2014b) uses the number of FTE academic staff plus 0.5 times the number of part-time academic staff. Barra and Zotti (2016) adopt an aggregated human capital[36] measure. Similarly, Agasisti, Barra and Zotti (2016) apply a weighted measure combining academic and non-academic staff[37] numbers.

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[36] Barra and Zotti (2016) use the following aggregate measure of human capital input = 1* professors + 0.8* associate professors + 0.6* researchers + 0.4* assistant professors + 0.2*non-academic staff.

[37] Agasisti, Barra and Zotti (2016) have decomposed the academic staff into three categories: professors, associate professors and researchers. They assign weights to each category based on their salary and the amount of institutional, educational and research duties, assuming that a professor is expected to produce more teaching work than an associate professor. They also assign a lower weight to non-academic staff. Thus, they use the aggregate measure of labour input: Equipment personnel 1 = 1*professor + 0.75*associate professors + 0.5*researchers + 0.25* non-academic staff.

They also further test alternative weights given to this variable. Equipment personnel 2 = 0.25*professor + 0.25*associate professors + 0.25*researchers + 0.25* non-academic staff.

And Equipment personnel 3 = 1*professor + 1*associate professors + 0.75*researchers + 0.50* non-academic staff. Finally, they found that all case results were similar.

Letti et al. (2022) weight the number of FTE professors by academic degree level[38]. Miranda et al. (2012) use professors differentiated by contract type, applying a formula[39] that weights staff in proportion to the number of students. They also apply a similar formula to technical and administrative staff[40]. Lu and Chen (2013) use the professor-to-teacher ratio, with higher ratios indicating better teacher and teaching quality indicators.

Mamum (2011) evaluates teaching faculty quality based on educational level, subject specialisation, and teaching experience. Indicators include the number of PhD-qualified teachers and the number of professors and associate professors, reflecting both subject specialisation and teaching experience. These measures capture significant variation in staff quality across universities.

Quality of Students

Several studies incorporate student quality as inputs, recognising that student characteristics affect university efficiency. Johnes (2006, 2014a, 2014b) weights undergraduate EFTS by average A-level entry scores[41] to reflect student preparedness. Stevens (2005) controls student entry quality using average A-level or Higher scores. Similarly, Agasisti and Bianco (2009a) focus on the number of enrolments with a score higher than 9/10 in secondary school to highlight superior student intake quality. Agasisti, Barra and Zotti (2016) and Barra, Lagravinese and Zotti (2018) apply a similar approach: the total number of students weighted by the percentage of enrolments with a score higher than 9/10 in secondary school. Barra, Lagravinese and Zotti (2018) also include the proportion of enrolments from non-vocational secondary schools as a quality indicator.

Bachan (2017) uses lagged median A-level entry scores of graduates across qualifications to improve the precision of entry quality measurement. The author also includes the proportions of domestically domiciled students and students from state schools, both lagged by three years. Sav (2012i, 2012k) uses Reading/Writing and Mathematics admission test scores as an input variable in the U.S. context.

[38] FTE professors weighted by academic degree: doctor = 1; master = 0.6; specialist = 0.4; undergraduate level = 0.2, without undergraduate level = 0.1.

[39] Miranda et al. (2012) proposed the formula for professors = (3* FTE professor + 2* part-time professors + 1* hourly contracted professors) * (students enrolled in the course) / (students enrolled in the HEI)

[40] Miranda et al. (2012) proposed the formula for technical and administrative staff = staff of the HEI * (students enrolled in the course) / (students enrolled in the HEI)

[41] Total EFTS undergraduate students studying for a first degree multiplied by the average A-level points for first year full-time undergraduate students. The A-level score is averaged over 1994/95, 1995/96, 1996/97 and 1997/98. Note that A = 10, B = 8, C = 6, D = 4, and E = 2).

Tyagi et al. (2009) adjust student enrolments [42] based on educational background, study duration, and credits completed. Similarly, Letti et al. (2022) apply weights to undergraduate students by course type, field, duration, and cost, and also include a postgraduate programme quality index. Lu and Chen (2013) incorporate quality indicators, such as the student-to-teacher ratio[43], extended student to total student ratio[44], and the higher-level certificate ratio[45]. Carrington et al. (2005) consider student outcome indicators, including graduate satisfaction (%) from the Course Experience Questionnaire, average graduate starting salary ($), and graduate full-time employment rate (%).

Several studies classify student characteristics as inputs rather than environmental factors (see Section 3.4.6). These include the proportion of female students (Sav, 2012i; Zoghbi et al., 2013), employed students (Daghbashyan, 2011; Zoghbi et al., 2013), non-white students (Zoghbi et al., 2013), students whose mothers attained higher education and student age (Zoghbi et al., 2013). Dropout rates (Zoghbi et al., 2013; Bachan, 2017), retention rates (Sav, 2012d; Sav, 2012i; Sav, 2012j; Sav, 2012k), and graduation rates (Mensah & Werner, 2003; Sav, 2012b; Sav, 2012k; Sav, 2016) are also commonly used.

Zoghbi et al. (2013) compare three specifications, using five to ten different factors to test the effect of student characteristics on efficiency. They find efficiency results are robust to variable selection, but simultaneous variations in determinants of efficiency limit the explanatory power of the results.

Quality of Graduates

Several studies adjust the number of graduates by degree classification to reflect teaching output quality (Agasisti, Barra & Zotti, 2016; Barra, Lagravinese & Zotti, 2018). In Italy, students graduate with final marks ranging from 66 to 110, with 110 (with distinction) being the highest. These studies

[42] Total enrolled students = number of UG students + 1.3 × number of PG students + 2 × number of PhD students.

[43] Lu and Chen (2013) indicate that increasing the student-to-teacher ratio reduces the time each student receives from teachers, negatively affecting knowledge and skill development.

[44] Lu and Chen (2013) use the ratio of students enrolled in extended education programmes to total students, where a higher ratio indicates improved output quality of the extended education.

[45] Lu and Chen (2013) also include the certificate ratio of Level I and Level II certificates awarded to the total certificates achieved, suggesting a higher ratio reflects superior teaching outcomes and higher professional skills students have learned.

apply weightings to graduates based on final degree marks, assigning higher weights to higher classifications[46] to reflect both quantity and quality in teaching outcomes.

Quality of Qualification Completions

Several studies adjust the number of qualification completions to reflect teaching output quality. Johnes (2006a, 2014a, 2014b) weights undergraduate first-degree completions by degree classification to account for quantity and quality of teaching output. While the methods are similar, the weighting schemes[47] differ slightly across these studies.

Alternative approaches include Agasisti (2011), who uses graduate employability[48] as a proxy for the private return to higher education. Gemmell et al. (2017, 2018) develop a method that weights each qualification by the required credits, reflecting study duration and intensity. For instance, bachelor's and doctoral degrees typically require 360 credits. To further adjust for output quality, they apply income-based weights using median graduate earnings by qualification level. This combined credit-and-income-weighted approach is uncommon in the literature, making it a distinctive contribution to this thesis.

Letti et al. (2022) apply weights to undergraduate degrees based on course type, field, duration, and cost and also construct a postgraduate programme quality index to proxy both teaching and research

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[46] Agasisti, Barra and Zotti (2016) describe that Italian student graduates receive final grade marks from 66 to 110, with 110 (with distinction) awarded to top graduates. This grade is measured mainly based on the average grade students have obtained in the exams, and then a certain number of points is added after the final dissertation has been graded. To reflect graduate quality, they apply weighted measures:

Grade marks 1 = 1* (graduates with marks 106-110 with distinction) + 0.75* (graduates with marks 101-105) + (0.5* graduates with marks 91-100) + 0.25* (graduates with marks 66-90). They also test the alternative weights given to the grade marks for robustness.

Grade marks 2: same as above, except the last category (marks 66-90) is weighted at 0.5.

Grade marks 3: total number of graduates without weighting.

They tested three specifications and found that the results were similar.

[47] Johnes (2006a) measures total number of degrees awarded = (number of first degree awarded × 30) + (number of upper seconds × 25) + (number of lower seconds × 20) + (number of thirds × 15) + (number of unclassified × 10). Johnes (2014a, 2014b) measures degree classification weightings are: first class = 30; upper second class = 25; lower second class = 20; third class = 15; unclassified = 10; other undergraduate qualification = 5.

[48] Employment refers to the number of 25–64-year-olds in employment as a percentage of the population aged 25-64 years by level of educational attainment.

quality. Sav (2016) considers the production of undergraduate and graduate education credit hours[49] and also uses the undergraduate degree graduation rate (completion measured at 150% of normal graduation time) as a proxy for educational success.

Quality of Research Publications

Several studies assess research publication quality using weighted measures and citation-based indicators. Carrington et al. (2005) construct a composite index including books, book chapters, journal articles, and conference papers. Tyagi et al. (2009) extended this by constructing a broader research index[50] incorporating research projects and academic conferences. Barra and Zotti (2016) used a similar aggregate approach[51].

Other studies have proposed explicit weighting schemes to reflect the relative importance of different publication types. Worthington and Lee (2008) used the weighted publication points for Australian universities, assigning 5 points to books and 1 point each to book chapters, journal articles, and conference papers. Abbott and Doucouliagos (2009) applied a weighted index for New Zealand and Australian universities, with weights of 0.4 for books, 0.2 for book chapters, 0.3 for journal articles, and 0.1 for other outputs. Worthington and Higgs (2011) also used weighted research points in a cost efficiency analysis, again valuing books at 5 points and assigning 1 point each to book chapters, refereed journal articles and conference proceedings. More recently, Avilés-Sacoto et al. (2020, 2022) adopted a revised system, assigning 2 points to books, 0.5 to book chapters, 1 to journal articles, and 0.5 to conference proceedings.

Lu and Chen (2013) calculate the ratio of journal articles to teachers' research achievement. Higher ratios indicate a stronger quality of research achievement. To capture research impact, Gralka et al. (2019) focus on highly cited publications, identifying the top 10% or 1% of most-cited papers within

[49] A full-time student typically earns 30 credits per year in U.S. universities. A bachelor's degree usually requires 120-130 credits, while a master's degree requires 30-64 credits. One credit hour (also called semester credit hour) generally represents one hour of class time and 2 hours of independent study per week. For instance, a 3-credit course involves 3 hours in class and 6 hours of weekly study. Each credit hour includes 15-16 contact hours over a 15-week semester. Contact hours are the time students spend directly with professors in class or labs. So, a typical 3-credit course includes about 45 contact hours per semester (Wikipedia, 2025).

[50] Tyagi et al. (2009) use the following aggregate index of publications: Research Index = 1* number of papers in journals + 0.5 × number of papers in conferences + 1.2 × number of research projects + 0.7 × number of conferences organised + 0.3 × number of conferences attended by faculty members.

[51] Barra and Zotti (2016) use the following aggregate index of publications: Research Index = 1* articles in international journals + 0.75*articles in national journals + 0.5* articles in international books + 0.25* articles in national books.

Web of Science (WoS) in each subject category based on publication year and percentile-based impact indicators. In contrast, Gemmell et al. (2017, 2018) use Category Normalised Citation Impact[52] (CNCI) scores to adjust publications for quality. This thesis follows a similar approach by using citation-adjusted publications. This is an uncommon method in the literature that also represents a distinctive contribution to this thesis.

3.2.4 *Price Variables*

After achieving technical efficiency (e.g., inputs and outputs are fully used), researchers examine whether inputs are combined optimally, referred to as allocative efficiency. Thus, input prices become an important assessment criterion, typically included in cost or distance function models (Coelli et al., 2005). Prices are generally assumed to be exogenous, with efficiency determined by choosing input levels given these prices. Although uncommon, some production function models include input prices, such as average faculty salaries, as wage variables (Sav, 2012b; Sav, 2012i).

Labour Price variable

Wages are the most frequently used labour price variable in university efficiency studies. They are typically calculated as average annual staff costs, defined as total personnel expenditure divided by the number of employees (Glass et al., 1995; Glass et al., 1998; Stevens, 2004; Stevens, 2005; McMillan & Chan, 2006; Fu et al., 2008; Kuo & Ho, 2008; Kempkes & Pohl, 2008; Kempkes & Pohl, 2010; Daghbashyan, 2011; Mamun, 2011; Sav, 2011; Sav, 2012a; Sav, 2012b; Sav, 2012c; Sav, 2012d; Sav, 2012h; Sav, 2012j; Lu & Chen, 2013; Johnes & Johnes, 2016; Titus et al., 2017; Gralka, 2018b; Gralka et al., 2019). This measure controls for institutional variation in labour cost structures.

Several refinements have been introduced. Sav (2012f; 2012g; 2012i) distinguishes between 9-month and 12-month faculty contracts to reflect salary structure differences. Worthington and Higgs (2011) separate academic and non-academic staff costs into two wage variables, while other studies, such as Zhang et al. (2014) and Tran (2021), have applied similar distinctions. These approaches highlight how staffing arrangements and contractual conditions can affect the measurement of labour input prices.

Capital price variable

[52] CNCI is a measure that compares an article's citations to what would be expected in the given subject area, year of publication, and type of publication (MoE, 2022). This measure only includes citations of journal articles and reviews. For more details, refer to Section 4.1.6.

Capital price is less frequently analysed than labour price, but some proxies have also been proposed in the literature. One common approach is to calculate capital price as capital costs divided by net assets (Glass et al., 1995; Glass et al.,1998; Glass et al., 2002; Stevens, 2004). Glass et al. (1995) note that capital price[53] estimates may be distorted by one-off investments, particularly for small institutions undertaking new large building projects. In their studies, capital costs are defined as expenditures on equipment, furniture, land, and buildings.

Alternative proxies have been suggested. Sav (2011; 2012f; 2012h) uses the year-end value of university buildings as a proxy for capital price, later extending this to include equipment (Sav, 2012a) and collections such as art and libraries (Sav, 2012d). These approaches highlight how differences in local real estate valuations and asset types can affect capital price measures.

Other studies define capital price using proxies based on non-labour expenditure. Fu, Huang, and Tien (2008) define capital price[54] as non-labour expenditure divided by gross fixed capital assets (e.g., total assets), using this ratio to normalise labour prices and total operating costs. Tran (2021) proposes an alternative measure by dividing non-labour costs by academic floor area. Due to the lack of capital pricing data at Australian universities, Worthington and Higgs (2011, p. 394) developed a proxy of university capital[55] (non-labour expenses) related to the full-time undergraduate and postgraduate student load (EFTS enrolments). Zhang et al. (2014, p. 3) later use a similar approach.

3.2.5 ***Determinants of Inefficiency Variables***

According to Coelli et al. (2005), inefficiency determinants should lie outside the production process, neither inputs nor outputs, and beyond institutional control. The determinants differ within and across

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[53] Glass, McKillop and Hyndman (1995) highlighted that 90% of the universities included in this study had an average capital price between £0.08 and £0.2. On the other hand, they utilised the expenses on equipment, furniture, land and buildings and 16% of research grants and contracts, because the expenditure of research funds in the financial statements for individual universities had yet to be subdivided into capital and labour expenses based on a sample of universities. They also included 60% of the value of research grants and contracts in labour expenses.

[54] Non-labour expenditure in Fu, Huang and Tien (2008) includes building and equipment depreciation, library book expenses and other related capital expenses.

[55] This study uses the approach outlined by Worthington and Higgs (2011) to estimate capital price, focusing on non-labour expenditure, which includes the physical support of academic activities and research, libraries, other academic support services, student services, public services, buildings and grounds and administration and other general institution services. The capital price (non-labour input) is proxied by dividing non-labour expenditures by physical capital stock. However, due to the unavailability of data on physical capital stock, a proxy is used where university capital corresponds to the full-time undergraduate and postgraduate student load. The total annual costs for each university are the sum of all labour and non-labour expenditures.

studies. Even when studies use similar variables, the results may differ due to contextual, methodological, or institutional differences.

Gralka (2018) and the studies listed in the Appendix Chapter 3 Tables group these determinants into eight categories: students, personnel structure, budget, institutions, subject specialisation, regional context, and quality of education.

Student Characteristics

A wide range of student-related variables has been examined in the literature as determinants of university efficiency, including enrolment levels, ethnic background, socioeconomic status, retention rate, age structure, gender composition, and engagement measures.

University size (e.g., total EFTS enrolments) is often considered as an efficiency determinant, with studies such as Kuo and Ho (2008) and Laureti et al. (2014) noting that larger institutions may face coordination and administrative challenges that negatively affect performance. Several studies also distinguish students by origin, comparing domestic and international students (Stevens, 2005; Abbott & Doucouliagos, 2009; Daghbashyan, 2011; Agasisti & Bolli, 2013; Bolli & Farsi, 2015), European and non-European (Stevens, 2005), or regional students (Laureti et al., 2014). These distinctions highlight how student diversity may introduce linguistic, cultural or integration challenges that affect institutional resources and outcomes.

International students have received considerable attention. Abbott and Doucouliagos (2009) found that higher proportions of international students improved efficiency in Australian universities but had no impact in New Zealand, attributing this to differences in recruitment strategies. Australian universities actively recruited students abroad through offshore provision and distance learning, whereas many New Zealand international students already resided in the country. Similarly, Bolli and Farsi (2015) used the share of enrolled international students as a proxy for international openness. They indicated a negative but statistically insignificant association with efficiency, possibly due to the broader availability of English language graduate programmes and courses.

Gender composition has also been used (Stevens, 2005; Sav, 2012i; Zoghbi et al., 2013; Laureti et al., 2014; Barra et al., 2018). This may reflect differences in learning preferences, programme selection, or performance outcomes. Zoghbi et al. (2013) reported a positive but insignificant relationship between the percentage of female students and efficiency. In contrast, Barra et al. (2018) found a significant positive effect, suggesting that universities with more female enrolments tend to be more efficient. Stevens (2005) likewise observed that higher female participation was associated with greater efficiency. However, the result was not statistically significant and may be due to some fields of study being more female-dominated.

Other demographic factors have also been explored. Ethnicity is often included as a control, such as the proportion of non-white students (Stevens, 2005; Zoghbi et al., 2013), African American enrolments (Agasisti & Belfield, 2017), or minority enrolments (Sav, 2012; Sav, 2012f). These indicators reflect how demographic diversity and associated support requirements affect university performance. Socioeconomic background is typically proxied by the share of students receiving low-income government grants (Sav, 2011; Sav, 2012; Sav, 2012f; Sav, 2012g; Sav, 2012j; Sav, 2012h) or coming from lower-class backgrounds (Stevens, 2005). These variables capture additional institutional or financial support needs of disadvantaged students, which may increase costs and affect efficiency.

Age-related measures include the proportion of students over 25 (Stevens, 2005), over 22 (Laureti et al., 2014), under 25 (Agasisti & Belfield, 2017), or the average student age (Zoghbi et al., 2013). Such variables may reflect differences in prior academic experience, work-study balance, or engagement levels. The proportion of part-time enrolment has also been used (McMillan & Chan, 2006; Agasisti & Belfield, 2017), indicating reduced student engagement intensity and potentially longer completion times.

Additional measures of engagement and preparedness have been considered. Zoghbi et al. (2013) included the share of students working over 20 hours per week, which may reduce study time, and maternal education, a strong predictor of student success and engagement. Letti et al. (2022) incorporated the proportion of enrolled students who complete their degrees and an index of student participation, reflecting student engagement that may affect technical efficiency. Sav (2012d; 2012f; 2012g; 2012j) used student retention rates (the proportion of entering students returning the following fall term) as a proxy for academic preparedness.

Personnel Structure

Personnel structure is commonly used in inefficiency studies, reflecting labour characteristics, employment conditions, and institutional cost structures. Studies often consider faculty contract type, job level, staff composition, and student-staff ratios as key indicators.

Contract types have been analysed through the proportion of tenured and non-tenure track faculty (Sav, 2011; Sav, 2012c; Sav, 2012j; Sav, 2012d; Sav, 2012; Sav, 2012k), sometimes disaggregated by gender (Sav, 2012i). These variables capture employment stability, staff structure, academic experience and diversity, which may influence institutional performance. Sav (2012g) further distinguished between 9- and 12-month contracts to reflect variations in faculty workload and institutional expectations. Average faculty salary has been used to control for wage differentials across universities (Sav, 2012k).

Job level is another focus. Studies have included the proportion of professors (Stevens, 2005), executive staff (Sav, 2013), senior academic staff (Stevens, 2005; Abbott & Doucouliagos, 2009), and the professor qualification index (Letti et al., 2022). These measures reflect academic strength, particularly research capacity and institutional prestige, which may influence university efficiency.

Student-to-staff ratios are frequently used to capture teaching intensity, staff resource allocation, and institutional support structures (Fu et al., 2008; Daghbashyan, 2011; Sav, 2012c; Sav, 2012d; Lu & Chen, 2013). Sav (2012c) treats the ratio as an overall institutional indicator. Higher ratios may increase costs and inefficiency as more university resources are allocated to individual student attention or small class sizes. Conversely, lower ratios may improve educational quality, attract higher-quality students, and enhance student retention, potentially reducing university costs and improving efficiency. Similar measures (i.e., staff-to-student ratios) are used by Bachan (2017) and Titus et al. (2017). Letti et al. (2022) also distinguished between student-to-employee and student-to-professor ratios and developed indicators of the ratio of equivalent employees by equivalent professors to capture differences in teaching and research effort.

Administrative structure is often measured through the ratio of general to academic staff or the proportion of senior administrative staff, capturing differences in management capacity and operational support (Abbott & Doucouliagos, 2009). A higher general-to-academic staff ratio has been interpreted as a proxy for administrative efficiency, since more general staff can reduce the administrative burden on academics and allow them to focus on teaching and research. However, Abbott and Doucouliagos (2004) noted that expanding the general staff may lower research outputs, all else being equal. Extending this line of inquiry, Letti et al. (2022) examined the professor ratio and the professor’s qualification index, finding that universities with more professors and higher levels of qualification tended to be more efficient.

Budget

Budget-related variables are used as potential sources of inefficiency, particularly the composition of funds and revenues. These measures reflect financial autonomy, funding stability, and resource constraints that may affect institutional performance. Common variables include the share of international public funds (Bolli et al., 2016), private funds (Sav, 2012h; Bolli et al., 2016; Sav, 2016;

Barra et al., 2018), and state funds (Robst, 2001; Mamun, 2011; Sav, 2011; Sav, 2012; Sav, 2012j; Sav, 2016). Other indicators include the share of tuition fees (Agasisti et al., 2016; Bolli et al., 2016; Barra et al., 2018) and the ratio of liabilities to assets (Sav, 2012f; Sav, 2012h).

Institutions

Institutional characteristics are also commonly examined as determinants of efficiency. Studies often classify institutions by type, such as applied universities (Kempkes & Pohl, 2008), research institutions (Robst, 2001), vocational colleges (Agasisti & Belfield, 2017) or Dawkins universities in Australia (Abbott & Doucouliagos, 2009). These classifications reflect varying institutional missions, resource allocation, and output objectives.

The provision of doctoral or master's degrees is used as a proxy for research capacity and academic prestige, which may influence efficiency (Robst, 2001; Sav, 2012k; Sav, 2013). Other factors include the university age (Chapple et al., 2005; Castano & Cabanda, 2007; Mamun, 2011; Barra et al., 2018) and ownership status (Castano & Cabanda, 2007; Sav, 2012f; Zoghbi et al., 2013). Older universities may exhibit lower efficiency due to legacy systems, higher maintenance costs for ageing infrastructure, and more complex administrative structures. The ownership status may affect decision-making autonomy, funding models and governance. Castano and Cabanda (2007) examine the role of institutional autonomy, while Kempkes and Pohl (2008) examine the impact of regulatory environments (e.g., liberal versus restrictive state regulation) on university performance.

Subject specialisation

Subject specialisation is often examined as a determinant of university efficiency to account for differences in cost structures and resource intensity. The presence of a medical school or hospital is the widely used proxy, as they typically require higher expenditure and have distinctive cost patterns (Groot et al., 1991; Abbott & Doucouliagos, 2004; Chapple et al., 2005; Sav, 2013; Kempkes & Pohl, 2008; Barra et al., 2018; Letti et al., 2022).

Empirical findings are mixed. Barra et al. (2018), using a distance function approach, found that universities with medical schools were less efficient, attributing this to the heavy service commitments of medical schools and differences in the health product market. Similar arguments are made by Thursby and Kemp (2002), Chapple et al. (2005), and Anderson et al. (2007). By contrast, Curi et al. (2012) highlighted that the effect of medical schools on university efficiency remained debatable, as variations in production process characteristics and modes may lead to different outcomes across contexts. Kempkes and Pohl (2010), using a cost frontier for German universities, also found that universities with medical faculties had higher cost levels and distinct marginal cost structures.

Region

The regional context is another commonly examined factor in explaining university efficiency differences. Several studies use region-specific dummy variables or socioeconomic indicators to capture geographic variation. For instance, Kempkes and Pohl (2008) include a dummy for former West Germany to account for East/West differences in Germany, while Letti et al. (2022) use regional dummies for Brazil to capture local idiosyncrasies. Other studies incorporate economic and demographic indicators, such as the gross domestic product (GDP) per capita at the state or regional level, to reflect local socioeconomic environments (Chapple et al., 2005; Kempkes & Pohl, 2010; Laureti et al., 2014; Barra et al., 2018). Other controls include educational attainment (e.g., average years of schooling: Zoghbi et al., 2013) and demographic composition, such as the proportion of the population aged 18-35 (Kempkes & Pohl, 2008).

The empirical findings on regional effects are mixed. Zoghbi et al. (2013), using a stochastic production frontier for Brazilian universities, included state income and average schooling years as location-related controls, but found no statistically significant effect on inefficiency. In contrast, Letti et al. (2022) identified regional differences in Brazil, with universities in the Northeast, North, and South showing higher efficiency effects than those in the Southeast. Agasisti et al. (2016), applying a stochastic distance function to Italian universities, also reported regional differences, with universities in the Central North region (North-Western, North-Eastern, and Central) performing more efficiently than those in the South. Kempkes and Pohl (2008) found that Western German universities were more cost-efficient than their Eastern counterparts.

Quality of Education

Education quality is difficult to quantify and is rarely included as an output in efficiency studies (Gralka, 2018). However, several studies include quality-related variables as inefficiency determinants that reflect educational performance. Common proxies use dropout rates (Bachan, 2017) and graduation rates (Sav, 2012g) as academic success and institutional performance indicators. Other indicators of academic quality include the average final degree marks (Laureti et al., 2014) and the proportion of students achieving first- and upper-second-class degrees (Stevens, 2005). These indicators capture variation in learning outcomes and student achievement across institutions.

3.3 Empirical Methodology for Productivity and Efficiency Analysis

This section reviews the main empirical approaches used to assess productivity and efficiency in higher education. It begins by introducing the concept of efficiency and comparing parametric and non-parametric frontier methods. It then discusses the strengths and limitations of Data Envelopment Analysis (DEA) and the Malmquist Productivity Index (MPI). The section concludes with an in-depth discussion of Stochastic Frontier Analysis (SFA), including commonly used model specifications, such as the time-invariant model (e.g., Pitt and Lee 1981 Model, and BC88 Model), time-variant decay model (BC92 Model), and inefficiency determinants (BC95 model).

Concepts of Efficiency in Higher Education

Economic literature defines efficiency as the relationship between inputs and outputs (Titus & Eagan, 2016). In higher education, efficiency is defined as the ability of universities to either maximise outputs from a given set of inputs used (output-oriented) or minimise inputs for given outputs produced (input-oriented). Efficiency is measured relative to a benchmark frontier constructed from the most productive institutions. Deviations from this frontier reflect inefficiency.

Several empirical approaches have been used to assess higher education efficiency (see Johnes, 2015). However, two primary frontier-based methods dominate the literature: non-parametric (e.g., DEA, MPI) and parametric (e.g., SFA, SCFA). These methods assess how well universities maximise outputs with minimum consumption of inputs (Witte & López-Torres, 2017).

Strengths and Limitations of the Non-parametric (DEA, MPI) Approach

Data Envelopment Analysis

DEA constructs a non-parametric, piecewise surface or frontier over the data using linear programming (Charnes et al., 1978). The DEA frontier includes a series of linear segments connecting one efficiency decision-making unit[56] (DMU) to another. The frontier's construction is based on the "best practice frontier", where inefficient DMUs are "enveloped" by the efficiency frontier.

[56] DMU is a term used for not-for-profit entities rather than customary "firm" and "industries" and is not required market prices by Charnes et al. (1978, p. 429).

DEA accommodates multiple inputs and outputs without requiring functional forms or specification of the error terms. It attributes all deviations from the frontier to inefficiency. DEA has been widely applied in higher education (Abbott & Doucouliagos, 2003; Johnes, 2006; Margaritis & Smart, 2011; Duan, 2019). For instance, Johnes (2006) applied DEA to UK universities. Abbott and Doucouliagos (2003) and Duan (2019) examined Australian universities, while Margaritis and Smart (2011) focused on New Zealand universities.

Despite its strengths, DEA has limitations. First, DMUs may be deemed fully efficient even though they are not truly operating on the frontier due to the small sample (few DMUs) (Abbott & Doucouliagos, 2003). Second, DEA lacks statistical significance testing. The DEA results may be sensitive to measurement error, outliers, unobserved heterogeneity of data or the inclusion of environmental variables (Witte & López-Torres, 2017). These issues may lead to biased efficiency scores and misleading conclusions.

The two-step method is a popular approach to address the influence of environmental variables in DEA (Witte & López-Torres, 2017). In the first stage, DEA is applied using only discretionary inputs[57] — that is, inputs that DMUs can control. This produces the initial efficiency scores. In the second stage, a regression is run where non-discretionary variables[58], such as environmental factors outside the control of the DMUs, are used to explain variations in these efficiency scores. However, a limitation of this method is that not all important variables may be identified or included in the regression, which can lead to biased results. To improve the reliability of the results, Simar and Wilson (2007) recommend using a bootstrap procedure. Bootstrapping helps correct serial correlation — a problem that arises because DEA-generated efficiency scores are not fully independent — and provides more accurate estimates of confidence intervals.

Malmquist Productivity Index (MPI)

The MPI builds directly on the DEA framework to measure changes in productivity over time (Caves et al., 1982). While DEA provides a snapshot of efficiency at a single point in time by comparing DMUs to a best-practice frontier, MPI extends this approach by constructing and comparing frontiers

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[57] In education production, discretionary inputs refer to those factors that are under the control of the universities, such as capital and labour (Ruggiero, 2007, p. 86) or those factors that are amenable to managerial control (Witte & López-Torres, 2017, p. 341)

[58] Non-discretionary input variables are beyond the internal control of universities, namely non-discretionary (environmental) variables, which are determinants of educational achievement (Witte & López-Torres, 2017, p. 341).

for different periods. This allows MPI to capture how productivity evolves by assessing changes in both efficiency and technology (Witte & López-Torres, 2017).

Specifically, MPI decomposes total productivity change into two components: efficiency change (how much closer or further a DMU moves relative to the frontier over time) and technological change (how much the frontier itself shifts). Efficiency change can be further broken down into pure efficiency change (efficiency relative to peers) and scale efficiency change (whether the DMU is operating at an optimal scale). This makes the MPI particularly useful in contexts like higher education, where institutions use multiple inputs and outputs, and market prices are often unknown or difficult to observe (Witte & López-Torres, 2017).

Several studies have applied the MPI to higher education to assess productivity dynamics, including Flegg et al. (2004), Worthington and Lee (2008), Margaritis and Smart (2011), Edvardsen et al. (2017), and Wang et al. (2020).

Despite its advantages, the MPI also has limitations. Like DEA, it is sensitive to measurement error, outliers, and unobserved heterogeneity, which can distort results. Moreover, MPI assumes that the technology used by DMUs in different periods is comparable, which may not always hold in practice. Another challenge is that the MPI does not automatically provide statistical tests, and without bootstrapping or other adjustments, the reliability of productivity change estimates may be questionable (Simar & Wilson, 1999; Witte & López-Torres, 2017).

Parametric Method: Stochastic Frontier Analysis (SFA)

SFA is a parametric approach introduced independently by Aigner, Lovell and Schmidt (1977) and Meeusen and Broeck (1977). It is based on econometric techniques to fit a best-practice frontier to the observed data points. SFA differs from DEA in requiring one single explanatory variable and assumptions about the functional form and error structures. The error term consists of two parts: a non-negative random error due to inefficiency and a symmetric random error due to statistical noise (e.g., measurement errors).

SFA's advantage is its ability to separate inefficiency from statistical noise. The need for assumptions about functional form and error structure is both a strength (structure helps deal with noise) and a limitation (wrong assumptions can bias results). This makes SFA particularly useful when measurement errors or random shocks likely affect observed performance.

SFA Framework: Technical and Allocative Efficiency

Production theory provides a conceptual foundation for efficiency studies. It assumes that maximum output is a function of inputs and their prices. The economics literature reflects this relationship between output and inputs in a production function. The concept of economic efficiency of production combines both technical and allocative efficiency (Titus & Eagan, 2016). *Technical efficiency* occurs when universities produce the maximum amount of output (e.g., number of qualification completions, research publications) from a given set of inputs (e.g., staff, capital). *Allocative efficiency* is achieved when the input mix minimises costs for a given output. It is more relevant to cost minimisation for universities. A university is *economically efficient* when it achieves both allocatively and technically efficiency (Titus & Eagan, 2016).

SFA Type of Function

SFA models in higher education typically rely on production, cost, or distance functions[59]. The production function is the mathematical representation of the technology that transforms inputs into outputs. This function is able to compare output to multiple inputs (Gralka, 2018a). Cost functions estimate the minimum cost when universities produce a given quantity of outputs. It involves the comparison of expenditures to outputs and inputs[60] (Gralka, 2018a). As universities are multi-output institutions, typically engaging in teaching and research, a production function that examines only one aspect of university production can be problematic. SFAs built on distance functions have been popular in recent years.

SFA Functional Form

The Cobb-Douglas and translog functions are the most common functional forms used in SFA. Cobb-Douglas functions offer simplicity, while the translog functions allow more flexibility to capture interaction effects. While the translog is flexible, it comes at the cost of increased complexity and may suffer from multicollinearity or estimation difficulties.

Many studies prefer the translog function for its flexibility (Castano & Cabanda, 2007; Johnes, 2014a; Johnes, 2014b; Bolli & Farsi, 2015; Bolli et al., 2016; Letti et al., 2022). Titus and Eagan (2016) find that choosing different functional forms can affect the efficiency values' mean and distribution. The

[59] In the function types, it is generally assumed that the quality of all outputs and inputs is similar, universities use the same technology, and there is linear homogeneity concerning input factor prices (Gralka, 2018a).

[60] Gralka (2018a) notes that in some cases where input prices exhibit minimal variation (consistent with a competitive market) or are unavailable, a cost function can still be estimated by excluding the prices and focusing on technical efficiency only.

authors suggest testing various functional forms when evaluating the efficiency of universities. To test robustness, several studies estimate models using both Cobb-Douglas and translog functional forms (Chapple et al., 2005; Sav, 2011; Zoghbi et al., 2013; Agasisti et al., 2016; Barra et al., 2018).

SFA Model Specification

(a) Time-Invariant Models: Pitt and Lee (1981) Model and BC88 Model

Pitt and Lee (1981) introduced the first panel-data SFA model, assuming that efficiency was constant over time and followed a half-normal distribution. This model is relatively simple but has key limitations. It requires long time periods and attributes all time-invariant effects to inefficiency (Farsi et al., 2006). This can be unrealistic and produce biased estimates if efficiency changes over time. Studies using this model include Erkoc (2015), Agasisti and Haelermans (2016), and Zhang et al. (2016).

Battese and Coelli (1988, named the BC88 model) developed an alternative using a truncated normal distribution. This adds flexibility to the inefficiency term but still assumes efficiency does not change over time. The BC88 model is applied by Johnes (2014a) and Zhang et al. (2016).

(b) Time-Variant Model: BC92 Model

Battese and Coelli (1992, named the BC92 model) proposed a time-varying decay model that allows efficiency to change over time. In this model, inefficiency comprises two parts: a stochastic individual component constant over time and a non-stochastic function of time that is the same for all universities. This model allows for efficiency changes but assumes the same pattern across institutions, which may not reflect reality (Gralka, 2018a). It does not reflect individual university characterises or circumstances. Several studies compare results from the time-invariant and time-variant specifications, such as those of Johnes (2014a), Erkoc (2015) and Zhang et al. (2016). These results conclude that both lead to an overall similar assessment of institutions.

(c) Environmental Variables or Determinants of Inefficiency: BC95 Model

Battese and Coelli (1995, named the BC95 model) introduced a one-step model that integrates inefficiency determinants (exogenous variables, called “z-variables”) directly in the frontier estimation. These z-variables are neither inputs nor outputs of the production process and are outside institutions’ control but may influence performance (Coelli et al., 2005). The BC95 model avoids the bias of two-step methods, where efficiency scores from the first stage are regressed on contextual variables in the second stage (Wang & Schmidt, 2002).

The BC95 model is more advanced by directly modelling inefficiency determinants. However, it still depends on correctly specifying the exogenous variables, which may be hard to observe or measure. Despite this, the BC95 model is widely used in evaluating higher education institutions (Gralka, 2018a). Many studies also compare SFA (using different variables and determinants) with other methods like DEA or Malmquist index (Chapple et al., 2005; Castano & Cabanda, 2007; Kempkes & Pohl; 2010; Barra et al., 2016; Johnes, 2014a; Johnes, 2014b; Zhang et al., 2016; Gralka et al., 2019; Letti et al., 2022). Given their different methodical restrictions, the compositions of the chosen input and output factors differ significantly between the two methods (Gralka, 2018a).

In summary, DEA and SFA offer distinct advantages and limitations for analysing university productivity and efficiency. DEA is flexible in handling multiple inputs and outputs without requiring price data or functional form assumptions. However, it treats all deviations from the frontier as inefficiency and is sensitive to measurement error and outliers. In contrast, SFA accounts for statistical noise and supports formal hypothesis testing but requires assumptions about functional form and error structures. While SFA has the advantage of handling noise, it is often less flexible than DEA when dealing with multiple inputs and outputs without price data.

Due to the advantages and limitations of the different approaches, this thesis applies both the MPI and SFA. The MPI measures productivity change over time, while SFA allows for modelling inefficiency determinants and accounting for stochastic variation. Using both methods provide a more robust and comprehensive analysis of productivity and efficiency in New Zealand and Australian universities.

3.4 Malmquist Productivity Index Literature

Analysing performance using partial productivity—typical labour productivity—can be useful, particularly when data on other inputs are scarce or unavailable. Labour productivity is less data-intensive and easier to calculate, as it does not require the measurement of capital inputs, which are often difficult to capture accurately. However, partial productivity measures can be misleading if the contribution of other inputs changes over time. For instance, if the delivery of teaching or research become more capital-intensive over time, labour productivity may not reflect overall performance. Despite this limitation, labour productivity may still serve as a reasonable proxy in labour-intensive services, such as university outputs (New Zealand Productivity Commission, 2018b). It is therefore important to interpret partial productivity measures with caution.

While partial productivity measures, such as labour productivity, provide useful insights, they only account for a single input. They may overlook changes in the contribution of other inputs, such as capital. This can lead to misleading conclusions, especially when the production process becomes more capital-intensive over time. To address this limitation, multifactor productivity measures are used to account for multiple inputs. One widely adopted method in higher education is the Malmquist productivity index, which tracks changes in total factor productivity over time.

The MPI is particularly useful in higher education, where universities use multiple inputs and operate under different resource constraints. It is suited for analysing longitudinal data and comparing productivity across universities. It allows productivity change to be decomposed into two components: efficiency change, which reflects whether a university is catching up to the best-performing frontier, and technical change, which captures the frontier itself moving outward due to innovation or technological progress. An MPI score greater than one indicates productivity improvement, while a score below one suggests a decline. By capturing both catching-up effects and shifts in technology, the MPI provides a more comprehensive picture of productivity dynamics in the higher education sector.

Key Applications of Partial Productivity and Multifactor Productivity in New Zealand Universities

Smart (2009) examined research performance across New Zealand universities from 1997 to 2007. He used a partial productivity measure: Web of Science (WoS) indexed publications per academic FTE. Research productivity declined in the early 2000s but increased 30% between 2003 and 2006. This rise followed the introduction of Performance-Based Research Funding[61] (PBRF), which linked funding to research performance. In particular, the Quality Evaluation (QE) allocated funding based on peer-reviewed staff portfolios, creating incentives for universities to increase research outputs.

However, the Smart (2009) study has several limitations. The research output measure focused only on the number of articles and reviews indexed in the WoS. Publication counts alone may not fully reflect research productivity since they do not account for quality (e.g., citations, journal impact, or peer recognition). The study also excluded other research outputs, such as books, book chapters, conference papers and creative works. They could be helpful to clarify that non-journal outputs (e.g., books) are particularly important in some disciplines, which further limits the interpretation of the

[61] Established in 2002, the PBRF aims to increase the quality of research by encouraging and rewarding research excellence in New Zealand's degree-granting organisations. It assesses the research performance of TEOs and then funds them based on their performance (New Zealand Tertiary Education Commission, 2024b).

results. WoS may systematically under-represent certain disciplines, which are not just incomplete coverage but potential bias against fields like social sciences, humanities, and creative arts publications. These limitations reduce the accuracy and comparability of the results across disciplines.

Gemmell et al. (2017) measured partial and multifactor productivity for teaching and research in New Zealand's tertiary and university sectors from 2000 to 2015. They produced both unadjusted and quality-adjusted estimates by incorporating measures such as qualification levels, graduate earnings, and research quality into the analysis. They used the number of qualification completions as the teaching output and adjusted it for quality by assigning higher weights to more advanced degrees. They also used applied graduate earnings as additional weights to reflect the value of teaching outputs. The research output was based on publication counts and adjusted using citation rates to capture research quality. On the input side, they adjusted for research staff quality using PBRF scores.

Their results showed that annual growth in teaching labour productivity in the university sector ranged from 0% to 1.6%, depending on the output measure used. The lowest estimate was based on EFTS enrolment per teaching staff FTE. When completions were weighted by credits, the growth rate increased to 1.4%, and when further adjusted for graduate earnings, it reached 1.6%. Research labour productivity showed stronger growth. Annual growth was 3.7% when measured as research publications per research FTE, 6.4% when adjusted for citation-weighted research output per research staff FTE, and 3.8% when further adjusted using citation-weighted output per PBRF-adjusted research FTE. Multifactor productivity growth was modest but still positive overall, especially in research. These findings confirm the importance of quality adjustments when estimating productivity growth.

In addition to studies using partial productivity and multifactor productivity, an important strand of New Zealand research has examined the impact of the PBRF on university research performance. Using anonymized longitudinal individual researcher data (publicly unavailable), Buckle and Creedy (2019a, 2019b, 2020c, 2022b, 2024), Buckle, Creedy and Gemmell (2020a, 2022a), Buckle, Creedy and Ball (2020b, 2021) show that the PBRF has significantly influenced research performance, incentives, and institutional behaviour. One key finding is the substantial tendency towards convergence in research quality across universities and disciplines since introducing the PBRF system.

For instance, Buckle, Creedy and Gemmell (2020a) used the 2003 and 2012 PBRF quality evaluations to assess convergence across eight universities and nine disciplines since introducing the PBRF system. They found evidence of both β-convergence (where initially lower-quality universities and disciplines improved faster than higher-quality ones) and σ-convergence (i.e., reduced overall dispersion of university research quality). Later analyses using the 2018 PBRF round confirmed these patterns, showing that convergence was driven by a combination of staff exits, quality transformations of existing staff, and, to a lesser extent, new entrants (Buckle, Creedy & Gemmell, 2022a). These studies suggest that the PBRF contributed to a movement towards the research "technology frontier" via quality improvement, whereby lower-quality universities could potentially catch up to higher-quality institutions.

This thesis does not use PBRF income as a direct measure of research output (only as the sensitivity analysis to test the robustness of research output), since the focus is on a consistent definition of research income across New Zealand and Australia. Nevertheless, it is important to acknowledge the extensive PBRF literature, as it provides valuable insights into how research evaluation systems influence university performance.

Key Applications of MPI in New Zealand Universities

Only two studies analyse the productivity and efficiency of New Zealand universities. Margaritis and Smart (2011) compared New Zealand and Australian universities from 1997 to 2005. They found that productivity in New Zealand universities grew by only 0.1% per year, much less than Australia's 2.8%. The authors conclude that New Zealand's productivity growth was driven by an advancement in efficiency change due to the introduction of the PBRF and a subsequent increase in research outputs. Australian universities showed larger gains mainly from technology improvements.

Wang et al. (2020) updated this analysis only for New Zealand universities between 2013 and 2018. Their MPI results indicated modest productivity growth (0.6% annually), with five of eight universities achieving MPI scores above one (the exceptions were AUT, Massey University and Victoria University of Wellington). They suggested that these universities' efficiencies could be improved by employing more qualified academic and professional staff. Additionally, the frontier-shift efficiency findings showed slightly improved performance. This result indicates that universities can improve productivity by adopting new technologies, such as offering online learning to domestic and international students.

Level of Analysis

The level of analysis, whether institutional, departmental, national, or international, affects the focus and interpretation of productivity and efficiency studies. Institutional-level analyses capture overall performance trends across entire universities, while department-level studies reveal differences within universities. Cross-country comparisons highlight how national systems, funding systems, institutional structures, and policy environments affect outcomes. Understanding the level at which productivity is assessed is important for interpreting results, identifying drivers of change, and informing relevant policy or institutional responses.

(1) Institutional-Level Studies

The majority of studies are conducted at the institutional level (e.g., Flegg et al., 2004; Carrington et al., 2005; Castano & Cabanda, 2007; Johnes, 2006a; Johnes, 2008; Worthington & Lee, 2008; Sav, 2012b; Yaisawarng & Ng, 2014; Moradi-Motlagh et al., 2016; Edvardsen et al., 2017; Wang et al., 2020). These studies focus on universities as the unit of analysis, examining how individual institutions perform over time.

Several Australian studies have reported consistent productivity growth. Carrington et al. (2005) analysed 35 universities between 1996 and 2000, indicating a 1.8% annual productivity increase, mainly driven by technological progress. Data quality and differences could affect a university's performance. Worthington and Lee (2008) found a 3.3% annual increase in TFP between 1998 and 2003 for 35 universities due to technological advances. Their findings showed that investment in digital infrastructure (e.g., providing electronic library services and educational resources) and expansion of online and multi-campus education delivery contributed to this improvement. They also found minimal technical inefficiency, indicating that most universities operated at or near the best-practice frontier. More recently, Moradi-Motlagh et al. (2016) confirmed these trends. They estimated 2.6% average annual productivity growth across 37 universities from 2007-2013, primarily from technological progress. Overall, Australian studies consistently attribute productivity growth primarily to technological progress. In addition, the studies also find that most Australian universities operate at or near the frontier, leaving limited room for improvements through efficiency gains alone.

UK-based studies show that productivity in English universities has improved over time, mainly due to strong technological progress, despite some declines in technical efficiency (Flegg et al., 2004; Johnes, 2006a; Johnes, 2008). Flegg et al. (2004) found a 51.5% increase in TFP from 1980/81 to 1992/93. This was mainly driven by a 39.1% improvement in technology and an 8.8% increase in technical efficiency. Financial and managerial reforms introduced in the 1980s contributed significantly to these improvements.

Johnes (2006a) analysed 113 English higher education institutions from 1996/97 to 2002/03 and found a 1.5% annual growth in productivity. This was largely due to a 2.3% increase in technology, partially offset by a 0.8% decline in technical efficiency. While this supported earlier findings on technology-led gains, it highlighted a new concern about negative technical efficiency change. Johnes

(2008) extended the analysis to 2004/05 and showed a 1% annual TFP increase. This was again driven by a 6% gain in technology but offset by a 5% decrease in technical efficiency. He suggested that the growing adoption of technologies, such as the increased use of information technology and e-learning and communication improvement on easily collaborative research, improves universities' operations but requires time for staff to adjust to the new technology. Johnes (2006a, 2008) highlighted that these rapid developments in higher education institutions have improved production technologies, albeit at the expense of reducing technical efficiency. Overall, the UK studies also identify technology-driven productivity growth, although they reveal a persistent decline in technical efficiency over time. This suggests that while universities successfully adopted new technologies, efficiency losses may have occurred as staff adapted to new ways of working. This pattern highlights the trade-off between rapid technological adoption and maintaining efficient internal processes.

Other institutional studies have explored university productivity across different countries. In Norway, Edvardsen, Førsund and Kittelsen (2017) investigated productivity development for 49 higher education institutions between 2004 and 2013. Most institutions showed positive productivity growth over time, primarily due to technological improvement. Larger institutions experienced positive and significant productivity growth, while smaller institutions exhibited erratic performance. In Germany, Kempkes and Pohl (2010) compared East and West German universities using the Malmquist indexes (and DEA and SFA) during 1998-2003. They focused on faculty composition of universities (e.g., the presence of engineering and medicine schools). They found that East German universities were less efficient than their West German Counterparts. These studies highlight the value of disaggregated analysis by institution size or faculty type. They also demonstrate how structural differences between institutions can affect productivity outcomes.

In the United States, Sav (2012b) examined graduate rate efficiency across 198 private and 216 public universities during the 2005-2009 financial crisis, using DEA-Malmquist index (and SFA) methods. The Malmquist results showed overall productivity regress in both sectors, with TFP scores of 0.839 for private and 0.816 for public institutions. This decline was mainly due to reduced managerial efficiencies and technological changes during the financial crisis. In China, Yaisawarng and Ng (2014) assessed the impact of recent reforms on 423 Chinese universities by comparing elite Project 211 universities with non-Project 211 counterparts. Project 211 universities indicated a greater decline in productivity (-3.5%), mainly due to technology regress under the financial crisis linked to resource cuts. In contrast, non-Project 211 universities declined only by 1.7%, supported by a 2.8% improvement in managerial efficiency and peer pressure from Project 211 counterparts. Therefore, studies from the US and China highlight external shocks (such as financial crises) as significant drivers of productivity declines. The Chinese case also shows how institutional differences — such as being a Project 211 university — shaped productivity trends during periods of financial constraint.

(2) Department-Level Studies

Bolli and Farsi (2015) and Barra and Zotti (2016), explored productivity at the department or faculty level within universities. Bolli and Farsi (2015) investigated 103 departments across 12 Swiss universities from 1995 to 2012 using SFA and Malmquist index techniques. Since 2002, productivity has declined by 1% per year due to technical regress. However, universities' constant expansion and the resulting economies of scale offset this decline. Productivity changes differed across scientific fields, reflecting potential gains from scale economies.

Barra and Zotti (2016) examined the technical efficiency across departments and faculties at the University of Salerno (an Italian public university) from 2005 to 2009. They implemented separate analyses for teaching and research and categorised departments as either science and technology or humanities and social sciences. They also included quality proxies, such as the student satisfaction index for teaching and the research productivity index for research. Science and technology departments were more efficient in the quality of research, while humanity and social science departments performed better in teaching. Their finding also shows that output specifications, including quality proxies, influence the results.

Department-level studies show that productivity and efficiency differ across disciplines. Science and technology departments perform better in research, while humanities and social sciences perform better in teaching. Findings also depend on how outputs and quality are defined and measured.

(3) Cross-Country Level Studies (Two-Country Comparisons)

Several studies compare university productivity and efficiency across two countries, using methods like the Malmquist index (or DEA of SFA) to explore systemic differences in governance, funding, institutional structures and policy environments (Agasisti & Johnes, 2009; Agasisti & Bianco, 2009; Margaritis & Smart, 2011; Agasisti & Pohl, 2012; Agasisti & Wolszczak-Derlacz, 2016).

Agasisti and Johnes (2009) investigated 57 Italian and 127 English universities between 2002 and 2005. During that period, Italian universities improved significantly in technical efficiency but experienced little technological progress. In contrast, English institutions maintained constant technical efficiency but benefited more from technological advances (e.g., distance learning, information and communications technology). They suggested that institutional size, specialisation and diversification across countries contributed to these differences. Despite being smaller than their

Italian counterparts, English institutions benefited more from scale effects, while larger Italian universities appeared to have reached their maximum potential.

Agasisti and Pohl (2012) compared the efficiency of 53 Italian and 69 German public universities between 2001 and 2007, using MPI and DEA methods. DEA results showed fewer disparities in efficiency scores from a within-country perspective during the period. Both methods indicated that German universities were more efficient than their Italian counterparts. However, from a dynamic viewpoint on MPI analysis, Italian universities increased their efficiency more quickly than German universities. The overall TFP change shows an average rise of 57% per year, with Italy at 70.7% and Germany at 46.5%. Productivity growth was driven mainly by technological progress, with only a minor contribution from efficiency change.

Across Europe, studies largely find modest but positive productivity growth, with larger institutions benefiting more from technological improvements. However, smaller institutions often showed more volatile or erratic performance, possibly reflecting limited capacity to exploit scale economies or adapt to technological change.

(4) Multiple-Country Level Studies

Only a few studies have compared university productivity across multiple countries using the MPI method (Parteka & Wolszczak-Derlacz, 2013; Andersson & Sund, 2022). Parteka and Wolszczak-Derlacz (2013) examined 266 public HEIs in seven European countries between 2001 and 2005, using DEA and MPI methods. They used average values of inputs and outputs to avoid a potential relationship between previous inputs and current outputs (e.g., current outputs produced not only by present inputs but also by past inputs). Their model included two inputs (total staff and total revenues) and two outputs (publications and graduates), aiming to reflect the productivity relationship between students and graduates[62]. The result showed that European HEIs experienced an average annual productivity growth of 4.5%, primarily due to efficiency changes. Performance varied across countries, with German, Italian, and Swiss HEIs achieving the largest productivity improvements.

[62] Parteka and Wolszczak-Derlacz (2013) noted that the relationship between student cohorts (as input) and graduates (as output) was only partially captured by the basic model. Meanwhile, first-year students' enrolment was not expected to influence the number of graduates this year. However, most sampled countries did not have student data broken down by year of university attendance. Since the percentage of first-year students to the total number of students at a particular university was assumed to be steady, a basic DEA model using the total number of students as one input and graduate numbers as one output might better approximate productivity in the teaching process.

Andersson and Sund (2022) evaluated the technical efficiency and productivity of 68 Nordic HEIs (from Denmark, Faroe Islands, Finland, Iceland, Norway and Sweden) between 2011 and 2016, using DEA and MPI methods. Productivity increased by 0.4% per year, on average, driven mainly by technology change (0.9%) rather than efficiency change (-0.4%). Danish and Finnish HEIs achieved the highest productivity change (around 2% per year), while productivity in Norway declined by 0.6% per year.

Overall, institutional-level studies from multiple countries suggest that technological change is the most common driver of productivity improvements, while gains in technical efficiency are less consistently observed. Additionally, the impact of external factors such as financial crises and institutional scale appear to moderate these trends.

3.5 **Stochastic Frontier Analysis Literature**

3.5.1 ***SFA Application in New Zealand***

Although SFA is widely used internationally to assesses university efficiency, its application in the New Zealand context remains scarce, possibly due to data constraints and a smaller higher education system. Only one study has applied SFA to New Zealand universities. Abbott and Doucouliagos (2009) examined 36 Australian public universities (1995-2002) and 7 New Zealand universities (1997-2003), excluding AUT due to it only becoming a university in 2000. The study used a stochastic output distance function to assess the technical efficiency and examined how competition for international students affected university efficiency. Their estimated average technical efficiency score was 0.917 for Australia and 0.80 for New Zealand. This suggests that, on average, New Zealand universities could potentially increase output by 20% given their inputs, compared to only 8% for Australian universities.

The study found that competition for international students improves efficiency in Australian universities. This reflects that Australian universities were more competitive at recruiting international students, likely due to strategies such as offshore provision and distance education. In contrast, no such effect was observed in New Zealand, where universities mainly recruited international students already residing in the country (e.g., from English language schools, foundation programmes, or high schools). This resulted in lower competitive pressure and limited impact on efficiency. The study also found that hiring senior administrators in Australian universities improved efficiency, whereas hiring senior academics reduced it. The reasons for these patterns remain unclear.

3.5.2 *Overseas Stochastic Distance or Production Frontier Analysis*

Country Level Applications

Studies reveal that efficiency patterns vary across countries. For Italian universities, Agasisti, Barra and Zotti (2016) and Barra, Lagravinese and Zotti (2018) used output distance functions and the BC95 model to assess university performance. They tested robustness using Cobb-Douglas and translog functional forms, including various inefficiency determinants. On average, Italian universities were moderately efficient and showed steady efficiency improvements over time.

Agasisti, Barra and Zotti (2016) identified three key factors that positively influenced university efficiency: market share (student enrolment ratio), GDP per capita, and undergraduate fees per student. A larger market share may improve efficiency through scale of operation and a more competitive higher education environment. Higher undergraduate fees per student may make universities more responsive to student needs and more efficient use of resources. Universities in regions with higher GDP per capita also tended to be more efficient, likely due to stronger economic conditions. Barra, Lagravinese, and Zotti (2018) also confirmed these findings and found that universities with medical faculties were less efficient.

For Brazilian universities, Zoghbi, Rocha, and Mattos (2013) assessed the efficiency of 164 Brazilian universities (88 private and 76 public) in 2007, using a Cobb-Douglas production function model. Inputs included capital (computers per enrolled student), labour (professors per enrolled student) and quality indicators (e.g., dropout rate). Inefficiency was affected by university type (public), region, student characteristics (e.g., female student proportion, average age), and state characteristics (e.g., average income). They found that public universities were less efficient than private ones and suggested that allocating resources should be based on their performance.

Letti et al. (2022) studied 56 Brazilian federal universities between 2010 and 2016 using an SFA output distance function. Their findings showed that universities with hospitals tended to be more efficient. They also highlighted that a higher professor-to-student ratio significantly improved efficiency and efficiency varies across regions. The authors concluded that SFA models with appropriate environmental variables, like university hospitals and regions, offered better representations of the reality of Brazilian HEIs than DEA models.

Sav (2012i, 2012k) examined the efficiency of U.S. public universities. The results show that faculty employment characteristics affect efficiency in producing student graduations. Sav (2012i) found that increasing the proportion of female faculty in tenure-track positions offers efficiency gains for improving graduation rates. Higher shares of tenured females had opposite effects, and non-tenure track roles showed unbalanced impacts between male and female student outcomes.

Sav (2012k) further confirmed that employment status matters. A higher proportion of tenured faculty improved efficiency in graduation rates. Tenure-track and non-tenure-track roles showed mixed effects. Non-tenure track staff reduced efficiency in doctoral-level public universities but improved efficiency in the less research-intensive master-level institutions. These findings suggest that reversing the non-tenure track hiring trend and advancing tenure among the faculty ranks could support student academic success and government funding outcomes.

Multi-County studies

Bolli et al. (2016) used an output distance SFA to evaluate the performance of 263 universities across eight European countries between 1994 and 2006. They explored how funding sources (e.g., international public funds[63], private funds[64], and tuition fees[65] acting both as inputs and inefficiency determinants) affect university performance. European governments increasingly adopt competitive university funding to improve performance in higher education. The study found that international public funds reduced the productivity of the best performing universities due to the administrative burden induced by competitive funding. However, these funds also positively impacted efficiency, as the competition for international public funds disciplined universities. The tuition fees improved productivity at the best performing institutions by helping them attract talented students and staff. Tuition fees also widened the gap between high and low-performing universities, creating a strong sorting effect.

Departmental Level Analyses

Bolli and Farsi (2015) examined the productivity of 103 departments across 12 Swiss universities from 1995 to 2012 using an SFA input distance function (and the Malmquist index). The analysis used department-level data, including students and external funds as outputs, various staff types (e.g.,

[63] International public funds refer to grants for specific projects or teaching programmes provided by government and non-government agencies outside the university's home country (Bolli et al., 2016).

[64] Private funds refer to grants and donations from the business sector, non-profit organisations, foundations and other private entities for research, consultancy or contracting teaching (Bolli et al., 2016).

[65] Student tuition fees are charges paid by students for educational purposes, excluding charges for rooms or other services. In most European countries, undergraduate student fees are regulated, present a financial contribution and do not cover the total study costs. In Norway and Finland, undergraduate education is tuition-free (Bolli et al., 2016).

number of professors, lecturers, assistants, admins and technical staff), and non-labour expenditures as inputs.

The study found no major differences in productivity across universities but substantial variation across scientific fields. This indicates that inter-departmental variation is greater than inter-university variation. This suggests that the productivity differences are likely driven by filed-specific factors rather than institutional management. The study also showed that results could be sensitive to the specification of heterogeneity across time and the model (e.g., input/output) orientation.

Comparisons of DEA vs. SFA in Technical Efficiency Estimates

Several studies have also directly compared SFA and DEA to assess the robustness of efficient estimates in higher education. Recall that DEA and SFA may produce different results because DEA does not account for statistical noise, and is deterministic and sensitive to outliers, while SFA allows for random shocks and separates inefficiency from random error.

Johnes (2014b) applied output distance SFA and DEA methods to English universities between 1996/97 and 2008/09. The estimated average efficiency scores varied significantly for each method. The DEA tended to yield higher efficiency scores than the SFA, although both approaches identified similar top and bottom universities. However, mid-ranked institutions showed considerable ranking variations across methods, possibly due to the choice of methodological approach used. Barra et al. (2018) also compared DEA and SFA estimates in the Italian context. Although the average efficiency scores were similar across the two methods, the university rankings varied. This highlights the importance of method selection and suggests combining approaches for robust benchmarking.

3.5.3 *Overseas Stochastic Cost Frontier Analysis*

While SCFA has not yet been applied to New Zealand universities, several international studies provide insights into how this approach has been used to assess cost efficiency in higher education. SCFA has not been used to study New Zealand universities, but they have been applied to analyses of HEIs in several other countries. Sav (2012, 2012d, 2012f, 2012g, 2012h, 2012j, 2016) examined cost efficiency across public and private U.S. institutions and identified several key determinants.

Increases in faculty tenure were associated with higher efficiency (Sav, 2012d). Tenure contributes to cost savings in providing labour force stability, and compared to non-tenure track staff, tenured faculty generate research grant income. Additional faculty employment (especially among 9-month contract staff) tended to reduce cost efficiency, possibly due to the present inability to account for inter-sector differences in teaching loads, faculty governance work, or other work assignments (Sav, 2012g).

Increased government funding improved efficiency in public universities but reduced it in private institutions (Sav, 2012, 2016). Sav (2012) recognised that public ownership varies across public universities, depending on their reliance on government funding. Increased government funding or the degree of publicness reduces efficiency in private universities, but efficiency improves among heavily government-funded public universities. Sav (2016) found that state funding is important for the efficiency of public universities. The results suggest that state funding cuts tend to reduce efficiency.

Sav (2012h) found that student loans and private philanthropy improved efficiency. This may be due to reduced pressure from market forces or improved institutional decision making influenced by external donors. In contrast, institutional debt contributed to inefficiency. If institutional debt reflects internal management, then institutions with weaker managerially skilled, and thus higher debt, tend to be more inefficient.

Kuo and Ho (2008) analysed the effect of adopting the University Operation Fund (UOF—a new semi-private-market financial scheme) on cost efficiency across 34 public universities in Taiwan between 1992 and 2000. The cost frontier model included several dummy variables to capture institutional characteristics. They found that the dummy variable that controls for the existence of research activity is significant and positive, implying a cheaper cost structure when a research activity is present. The coefficient of diversity in the academic fields is significant and positively suggests that increasing diversity of academic fields will increase the complexity of operations and thus increase costs. The year trend and dummy for adopting UOF significantly relate to cost inefficiency, but their effects were opposite. The time trend showed a negative and significant relationship with cost inefficiency, indicating that universities became more cost-efficient over time. However, adopting the UOF had a significantly positive effect on inefficiency, indicating that the reform reduced cost efficiency.

Daghbashyan (2011) examined the cost efficiency of 30 HEIs in Sweden between 2001 and 2005. Inefficiency determinants included university-specific factors (e.g., EFTS per staff, undergraduate EFTS, share of government funding, share of external research income), staff characteristics (e.g., share of professors, proportion of academics aged above 50), and student factors (e.g., share of international students, students below 25). The findings showed moderate variation in cost efficiency across institutions, but no significant change during the period. Results were ambiguous for university-specific variables, such as student-to-staff ratios, university size (undergraduate EFTS), and funding composition. Universities with more professors and young academic staff tended to be more cost efficient.

Stevens (2005) evaluated 80 English and Welsh universities between 1995 and 1998. Cost efficiency was influenced by staff and student characteristics (e.g., age, gender, race). Efficiency increased with a higher proportion of non-white, professors or senior lecturers and active researchers. In contrast, efficiency declined with a greater share of staff aged over 50. Among students, a higher proportion of students who received first and upper-second-class degrees and female students were associated with lower efficiency. However, universities with many older (over 25 years old at the start of their course) or lower social classes (e.g., unemployed parents or guardians) students were typically more cost efficient.

McMillan and Chan (2006) applied DEA and SFA to 45 Canadian universities. They found that cost efficiency was influenced by student-to-faculty ratios, programme specialisation, and the presence of PhD programmes. They highlighted the importance of institutional scale and programme mix in cost structures. The findings suggested that various methods and model specifications might exhibit substantial efficiency scores and rankings differences.

Kempkes and Pohl (2010) assessed cost efficiency in 72 German public universities between 1998 and 2003, using the Malmquist index and SFA methods. Their analysis included comparisons between East and West regions and employed models with and without controls for medical and engineering faculties. They found that cost efficiency was affected by faculty composition and regional economic conditions (e.g., regional GDP per capita). DEA and SFA exhibited broadly similar efficiency patterns. Universities in Eastern Germany and those with medical faculties tended to be less cost efficient.

Summary Tables in Appendix Chapter 3 Tables A3.1 and A3.2

Appendix Table A.3.1 and A3.2 list key studies on efficiency and productivity in higher education from 2004 to 2022. These tables summarise applications of both the Malmquist index and SFA methods. While not a complete list, they offer a fair representation of methodologies used over the past two decades. Comprehensive SFA-based studies are found in Witte and López-Torres (2017), Gralka (2018a) and Ferro and D’Elia (2020). MPI-based studies are reviewed by Witte and López-Torres (2017) and Ferro and D’Elia (2020).

It is also worth noting that, of the 53 studies using the Malmquist index and SFA listed in Appendix Chapter 3, 18 studies apply this method without bootstrapping or 3 studies with bootstrapping. Four studies compare MPI to SFA results, six conduct country-level comparisons, and two make cross-country comparisons. The tables also indicate that most studies focus on university-level efficiency, with relatively few studies conducting country or multi-country comparisons (Witte & López-Torres, 2017; Gralka, 2018a).

3.6 Key Insights from the Literature and Opportunities

The international literature on the efficiency of higher education has developed rapidly, but studies on New Zealand universities remain limited. This section identifies how this thesis aims to address the observed research gaps.

First, only a small number of studies apply either the Malmquist index or SFA to evaluate the efficiency of New Zealand universities. This is because New Zealand has eight public universities, creating challenges for implementing such analyses. Methods like SFA rely on econometric estimation, and small samples reduce the reliability of estimated parameters. MPI and DEA can also suffer in small samples, as too few data points may lead to many units appearing efficient by default. With only eight universities, the frontier may be shaped by a few extreme performers, which can distort results.

To date, only three studies have assessed New Zealand universities' productivity and efficiency: Margaritis and Smart (2011) and Wang et al. (2020) used the Malmquist index; Abbott and Doucouliagos (2009) conducted an SFA using a translog output distance function. Additionally, to the author's knowledge, no prior study has conducted a cost-efficiency analysis for New Zealand universities. Gemmell et al. (2017) applied partial and multifactor productivity analysis to the New Zealand tertiary education sector (not just universities). In addition, Buckle, Creedy and Gemmell (2020a, 2022a) analysed anonymized longitudinal individual researcher-level data from the PBRF to provide further insight into research performance. However, they did not use frontier-based methods such as MPI or SFA.

Second, only a handful of studies (for universities anywhere in the world) conduct both MPI and SFA evaluations. Most previous studies rely on a single approach, DEA/MPI or SFA. Both methods have strengths and limitations (as discussed earlier in this section) and using both methods help to assess the robustness of the results, identify method-sensitive estimates, or capture both deterministic and stochastic elements of efficiency.

This thesis fills this gap by applying the MPI and SFA approaches to the same dataset for New Zealand (and Australian) universities. Secondly, it compares Cobb-Douglas and translog functional forms in the SFA framework to test the sensitivity of efficiency estimates to functional form assumptions and to explore the translog model flexibility.

Third, there is limited use of quality-adjusted input and output measures in the literature. Universities that produce more high-quality outputs may appear less efficient if quality is not accounted for. Adjusting outputs or inputs for quality requires data in addition to quantity values. For instance, teaching output may be measured by the number of completions, while a quality-adjusted measure could account for graduate earnings or student study load. Many studies use "raw" data on inputs or publications. Few studies adjust inputs or outputs for quality, which may lead to biased productivity estimates. An exception is Gemmell et al. (2017), one of the few studies incorporating quality adjustments. They adjusted outputs for qualification levels, graduate earnings, and inputs for staff quality using PBRF scores. However, their analysis did not use frontier methods and focussed primarily on productivity growth rather than efficiency.

Accurately capturing output quality remains a challenge. Most studies use short or middle-term qualification completions rather than quality-adjusted or long-term outputs like graduate employment (Witte & López-Torres, 2017). This thesis addresses this by incorporating quality-adjusted outputs and exploring the joint production of teaching and research in MPI and SFA models.

Fourth, few studies explore inefficiency determinants in New Zealand universities. Establishing the drivers of inefficiency can help improve future resource allocations. It helps identify what factors drive underperformance or enable better resource use. International SFA studies commonly use inefficiency effect models (e.g., BC95) with environmental variables (e.g., faculty composition, student demographics, and regions). These approaches have not been applied to New Zealand universities. Although New Zealand universities are located across region, have heterogeneous student profiles and other dissimilarities, the impact of these differences on inefficiency has not been previously estimated.

This thesis addresses this gap by applying the BC95 model with inefficiency determinants. Specifically, it includes variables such as the presence of medical schools, the proportion of international students and female students, the ratio of general-to-academic staff, and regional indicators. By including these variables, the analysis provides new insights into the structural and demographic factors affecting the performance of New Zealand universities.

Fifth, cross-country SFA comparisons are scarce. Most studies focus on university-level efficiency, with relatively few examining country or multi-country comparisons (Witte & López-Torres, 2017; Gralka, 2018a). Few DEA-based studies have compared New Zealand and Australian universities; one exception is Margaritis and Smart (2011). A rare SFA-based comparison is Abbott and Doucouliagos (2009), who applied a translog output distance function to assess the efficiency of New Zealand and Australian universities from 1997 to 2003.

This thesis extends the analysis by Abbott and Doucouliagos (2009) by using more recent data (2008-2018) and by incorporating consistent quality adjustments (across countries in different universities) that were not included in earlier studies. Importantly, including Australian universities not only enables a cross-country comparison but also addresses the earlier challenge of small sample size in New Zealand by expanding the number of institutions analysed.

This thesis estimates a common frontier using pooled data from New Zealand and Australian universities, enabling cross-country comparisons. This inclusion of Australian universities significantly enlarges the number of institutions available for rigorous empirical analysis. Combining the two countries assumes that their tertiary education systems are sufficiently similar in nature and that a common technological frontier can reasonably be applied to both.

Sixth, many studies do not consider alternative data measurements (e.g., measuring research output using research income versus publications; or using staff headcounts versus FTE staff to measure personnel inputs) to check the robustness of results (efficiency scores can be sensitive to model design and data choices). Titus and Eagan (2016) emphasize that more comparisons of different estimation techniques would be beneficial. Gralka (2018a) found that few studies vary the composition of factors considered, especially how inputs are measured. Studies that vary the explanatory variables often show differences in efficiency values across specifications. Gralka (2018a) recommends that future researchers should consider the robustness of their chosen variables and compare different specifications. Gemmell et al. (2017) incorporated alternative output measures, including credit-weighted and/or income-adjusted completions and citation-weighted indexed publications, which supports the motivation to test different specifications in the MPI and SFA models used in this thesis.

In line with these recommendations, this thesis conducts a range of sensitivity and robustness checks to assess how these choices affect efficiency estimates. These checks include varying the definition of key variables (e.g., research income vs. citation-weighted indexed publications, academic staff vs. teaching and research staff FTE, capital input proxies), testing different functional forms (Cobb-Douglas vs. translog), and using alternative data sources (e.g., national datasets vs. university annual reports). These tests are applied across both the MPI and SFA models.

Seventh, there is inconsistency in the presentation of efficiency scores in the literature. Gralka (2018a) notes that the presentation of efficiency values varies significantly across studies. Efficiency values are either provided in the form of the mean for the whole sample (often as descriptive statistic), for each institution (often relegated to appendices) or as a graph (often as a histogram). This inconsistency can make it challenging to interpret and compare results across studies. In response, this thesis compares the efficiency values of New Zealand and Australian universities, presents them consistently, and discusses the possible drivers behind the differences.

Together, these seven gaps in the literature highlight important limitations in existing research on higher education efficiency, particularly in the New Zealand context. This thesis responds to these gaps by applying both MPI and SFA methods to a consistently constructed dataset covering New Zealand and Australian universities. It incorporates quality-adjusted outputs, tests the robustness of results to alternative measures for variable and model specifications, and examines efficiency determinants using the BC95 model. By expanding the sample to include Australian universities, the analysis addresses challenges associated with the small number of New Zealand universities and enables meaningful cross-country comparisons. Efficiency scores are presented clearly and consistently, with attention given to interpreting differences across institutions and systems across regions. In doing so, this thesis contributes new empirical evidence and methodological insights to studying productivity and efficiency in higher education.

Chapter 4 Data Description

While Chapter 3 provided a broad overview of the categories of variables commonly used in the literature, this chapter specifies the detailed definitions and construction of the variables used in this thesis. The data cover New Zealand and Australian universities and include inputs, outputs, price variables, and determinants of inefficiency. This chapter provides a four-part description of the data used to analyse the performance of Australasian universities using three distinct techniques.

Inputs include full-time equivalent (FTE) staff numbers, further classified into teaching, research, academic, and general FTEs. Capital expenditures are proxies for non-labour expenditure, and capital prices are proxies for non-labour expenditure per equivalent-full-time students (EFTS). The capital price is measured as the total expenses minus labour costs—such as depreciation and amortisation and other non-labour-related expenses—divided by the total number of EFTS, to reflect the average capital cost per student (Worthington & Higgs, 2011, p. 394). Staff price is defined as the average labour costs per FTE. Outputs include qualification completions, adjusted for quality based on credit or/and income weights, and research income. This chapter also will discuss several measurement issues related to these variables.

The data sources are publicly accessible and include annual observations from eight New Zealand universities and 37 Australian public universities from 2008 to 2018.New Zealand data are collected from the Tertiary Education Commission (TEC), Ministry of Education (MoE), university annual reports, and the New Zealand Qualifications Framework (2016). Australian data are obtained from the Australian Government Department of Education (DoE) and the Australian Qualifications Framework (2013).

As noted in Chapter 1, Australian universities are grouped into five groups: Group of Eight (Go8) universities, Innovative Research Universities Australia (IRU), Regional University Network (RUN), Australian Technology Network (ATN) universities, and Non-aligned (Non-aligned) universities. Further details on this classification are presented in Table 1.3 of Section 1.4.

The chapter is structured as follows. Sections 4.1 and 4.2 present the data for the partial labour productivity analysis and the Malmquist productivity index (MPI). Section 4.3 introduces the data used for the stochastic frontier analysis (SFA) with an output distance function (ODF). Section 4.4 describes the data for the stochastic cost frontier analysis (SCFA). Section 4.5 presents the mean values of the variables used in each model specification. Appendix Chapter 4 provides additional figures for unadjusted teaching (e.g., undergraduate and postgraduate qualification completions) and research outputs (WoS-indexed articles and reviews).

4.1 **Partial Labour Productivity Analysis**

This section discusses the variables used to analyse partial labour productivity in teaching and research. Section 4.1.1 outlines the teaching and research labour input variables, and Section 4.1.2 discusses the adjustments for quality in labour inputs. Sections 4.1.3 and 4.1.4 introduce the data for teaching outputs and their quality adjustments. Sections 4.1.5 and 4.1.6 focus on research outputs and adjustments for research quality. Finally, Sections 4.1.7 provides a summary of the variables used in the partial labour productivity analysis.

4.1.1 ***Teaching and Research Input Variables***

Universities typically have two main missions: teaching and research. The variables used for inputs and outputs in the university of productivity and efficiency analysis generally reflect these functions (Kempkes & Pohl, 2010).

For labour productivity analysis, the main input variables are teaching FTE staff and research FTE staff. However, an issue is that there is no breakdown of academic staff time into separate teaching and research components. A starting point for allocating total academic FTEs into separate teaching and research FTEs is the "40:40:20 model" (University of Waikato, n.d.). This model is commonly used in New Zealand universities and allocates academic staff time to 40% teaching, 40% research, and 20% service/administrative activities, on average.

Various surveys of university staff find that the 40:40:20 model is a good approximation of how academic staff spend their time—for instance, Sutherland (2018) reported that academics at New Zealand universities reported a 44:35:21 allocation of their time across research, teaching, and service. Internationally, Ćulum (2015, p. 143) reported data from junior academics in 12 European countries, which showed that junior academics spent 16.7 hours per week on research work, 14.6 hours on teaching, and 7.1 hours on service and administration – a 44:38:18 allocation. Similarly, Bentley, Goedegebuure and Meek (2014, p. 366) found that academics at Australian Go8 universities spent 44% of their time on research, 31% on teaching, and 25% on service and administration, suggesting a 44:31:25 allocation.

Based on the 40:40:20 model, Gemmell et al. (2017., p. 9) allocates 50% of academic FTEs to teaching and 50% to research by evenly splitting the 20% service time between services that support teaching and services that support research. This study adopts the same 50:50 allocation to teaching and research. This allocation assumes that academic staff equally divide their time for administrative services between teaching and research. To test the sensitivity of the results to this assumption, a "40:60" model is also used, where all administration time (20%) is allocated to research, leading to a teaching-to-research FTE ratio of approximately 40:60. This follows the sensitivity analysis proposed by Gemmell et al. (2017) to test teaching and research allocation.

Comparison of New Zealand and Australian data

Tertiary Education Commission (TEC) data on FTE staff for New Zealand universities are decomposed into three categories: (1) academic/tutorial staff[66] (excluding research-only staff), (2) general staff[67], and (3) research-only staff [68]. Using the 50:50 allocation assumption discussed earlier, this study assumes that teaching FTE staff constitute 50% of academic/tutorial FTEs, while research FTE staff include 50% of academic/tutorial FTEs plus research-only staff.

In contrast, Australian staff data sourced from the Australian Government Department of Education (DoE) classify FTE staff by function into four categories: (1) teaching only, (2) teaching and research, (3) research only, and (4) other FTEs[69]. As the New Zealand data does not distinguish teaching-only staff,

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[66] New Zealand TEC's Academic/tutorial staff FTE refers to the annual cumulative total of staff who are teaching staff engaged in delivery of education and training. This category includes teaching staff who also participate in research but excludes persons only engaged in research or technical roles.

[67] New Zealand TEC's General staff refers to all staff other than those engaged in the teaching process, including librarians, IT staff, general and administrative and managerial staff, but excluding researchers and technicians. These staff focus on non-teaching and non-research roles essential for university operations.

[68] The University of Auckland only has two years of data for research-only staff. The average of these two years was used to estimate the data for the remaining years for the University of Auckland. No research-only FTE are recorded for AUT, which appears to be a data limitation rather than reflective of AUT not having any research-only FTE.

[69] Australian General staff include academic support staff, student services staff, and public services staff (Australian Government Department of Education, n.d.c).

this could present a challenge when comparing the productivity of New Zealand and Australian universities.[70]

Table 4.1 shows the average shares of teaching-only FTE as a proportion of (1) teaching and research staff, and (2) total staff for Australian universities. For both Australian and New Zealand universities, the table also shows (3) academic and research only staff as a proportion of total staff, and (4) other staff as a proportion of total staff. By design, for each university, the numbers in (3) and (4) sum to one.

The table reveals that teaching-only FTE staff represent a small fraction of teaching and research staff and total staff, with Go8 universities averaging 5.7% and 1.4%, respectively. This suggests that the effect of teaching-only staff on academic staff or total staff is small, and consequently, their effects on productivity measurements are expected to be minor. Notably, the proportions of academic and research-only staff versus other staff are similar across New Zealand and most Australian university groups, further reinforcing the expectation that teaching-only staff have a minimal impact on productivity comparisons.

Table 4.1
Average Proportions (%) of Teaching-Only (TO), Teaching and Research (T&R), Research-Only (RO) And Other Staff as Proportions of Total FTE, 2008-2018

	(1)	(2)	(3)	(4)
University	TO/ (TO+T&R)	TO/Total	(TO+T&R+RO)/Total	Other/Total
University of Auckland			0.432	0.568
University of Waikato			0.407	0.593
Massey University			0.533	0.467
Victoria University of Wellington			0.470	0.530
University of Canterbury			0.407	0.593
Lincoln University			0.437	0.563
University of Otago			0.475	0.525
AUT			0.499	0.501
Go8	0.057	0.014	0.480	0.520
IRU	0.073	0.024	0.418	0.582
RUN	0.151	0.049	0.375	0.625
ATN	0.098	0.028	0.421	0.579
Non-Aligned	0.112	0.038	0.429	0.571

Source: New Zealand TEC, and Australian Government DoE.

[70] New Zealand universities do not categorise staff as teaching-only staff, such as teaching fellows or tutorial staff, likely because academic staff are expected to engage in teaching and research. Although teaching fellows likely exist, they might not be classified as a distinct "teaching-only" category in New Zealand's data. Additionally, teaching fellows or tutorial staff might play a role that differs from those of full-time research-track teaching staff.

Table 4.2 reports the number of teaching FTE staff, research FTE staff, as well as the shares of teaching, research in teaching and research FTE staff. Averaged across New Zealand universities, the teaching and research shares are 0.42 and 0.58, respectively. AUT shows a balanced emphasis on teaching and research (0.50 each). For Australian universities, the Go8 have the lowest teaching share (0.31) and the highest research share (0.69), emphasising their research intensity. The RUN universities have the highest teaching focus, with the lowest research share.

Table 4.2 also shows size differences across the universities in terms of FTE numbers. For New Zealand universities, University of Auckland has the most teaching FTE staff (1,034), which is about 10 times as many as the smallest university, Lincoln University (105). Similarly, University of Auckland has the most research FTE staff (1,314), followed closely by University of Otago (1,247), while Lincoln University has the smallest number (194).

Table 4.2

Teaching and Research FTEs across Australasian Universities in 2018

University	Teaching FTE	Research FTE	Teaching FTE / (Teaching + Research FTE)	Research FTE/ (Teaching + Research FTE)
Auckland	1,034	1,314	0.44	0.56
Waikato	264	334	0.44	0.56
Massey	637	921	0.41	0.59
VUW	463	627	0.42	0.58
Canterbury	351	426	0.45	0.55
Lincoln	105	194	0.35	0.65
Otago	613	1,247	0.33	0.67
AUT	589	589	0.50	0.50
New Zealand Average	***507***	***706***	***0.42***	***0.58***
Go8	790	1,768	0.31	0.69
IRU	380	488	0.44	0.56
RUN	271	234	0.54	0.46
ATN	533	800	0.40	0.60
Non-Aligned	424	554	0.43	0.57
AUS average	***478***	***770***	***0.43***	***0.57***

Source: New Zealand TEC, and Australian Government DoE.

Note: 1. The FTE numbers for Australian groupings represent the average number of FTEs for those university groupings.

2. “AUS average” refers to the average number of FTEs for an individual Australian university, rather than average university groups.

Teaching and research FTEs trends over time

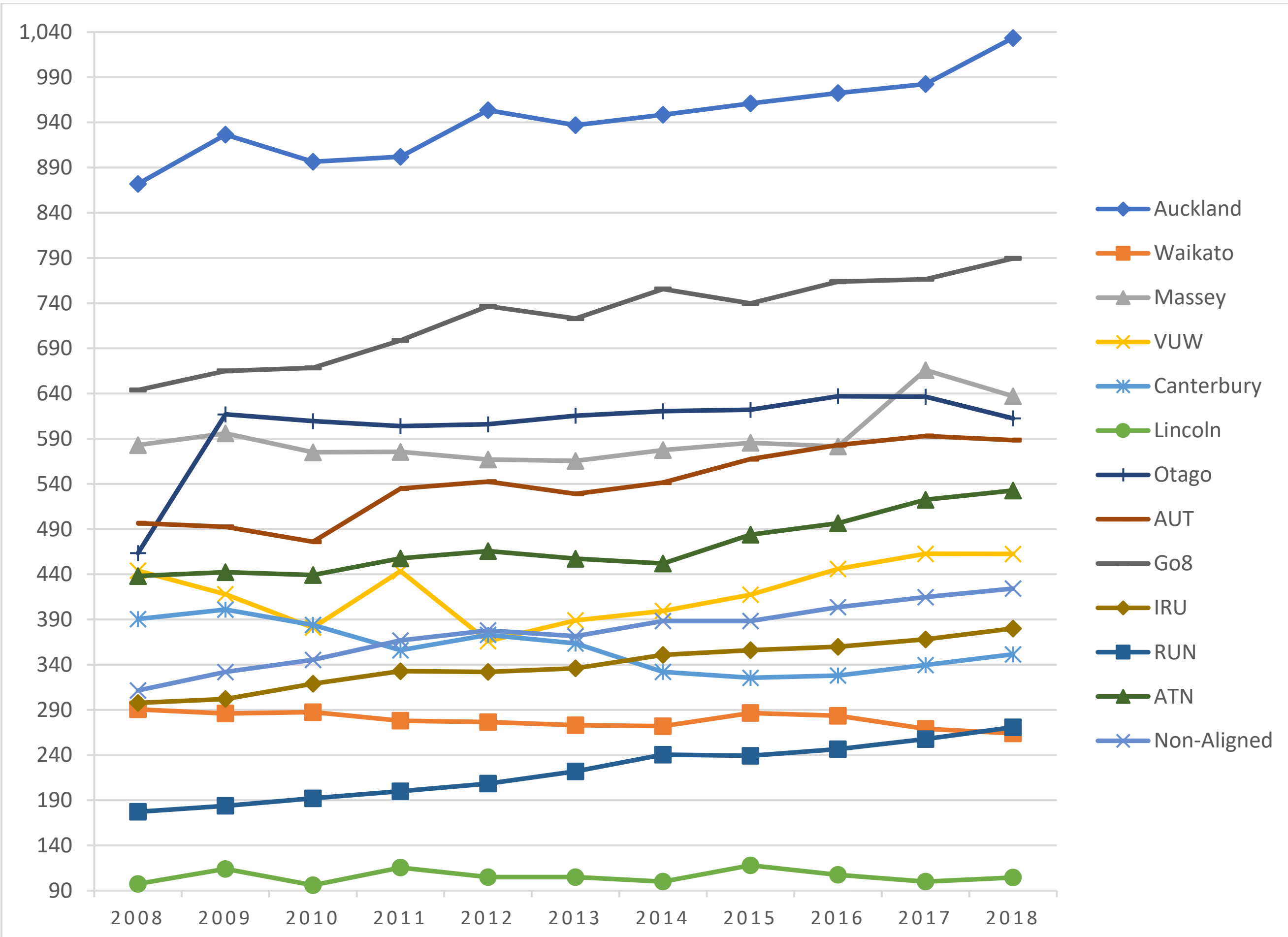
Figures 4.1 and 4.2 show the trends over time in teaching and research FTE staff by university, respectively. The University of Auckland and the average Go8 university have the most teaching FTE staff, with a gradual and steady increase over the decade from 2008 to 2018. The average Go8 university has the highest number of research FTE staff, followed by University of Auckland and University of Otago.

Some New Zealand universities, such as Massey University and University of Canterbury, show fluctuations in teaching and research FTE staff. Massey University experienced a sharp drop in research FTE staff in 2016, reached a peak of 1,176 in 2017 and then declined again in 2018. There was a decline in teaching and research FTE at University of Canterbury after the 2011 Canterbury earthquake, before staffing numbers recovered by 2018. Lincoln University exhibits the most volatility in teaching and research FTEs, possibly due to its smaller size, specialist land-based characteristics and resource constraints.

In Australia, Go8 universities, exhibited stronger increases in the absolute number of research FTE than teaching FTE staff from 2008 to 2018. For instance, Go8 research FTE increased by 61, from 1,707 to 1,768, while teaching FTE rose by 146, from 644 to 790. Similarly, the ATN universities also show a significant rise in research FTE staff, with an increase from 610 to 800, an absolute increase of 190. In contrast, IRU, RUN and non-aligned universities exhibited a slight increase in research staff. The IRU’s research FTEs rose by 38 (from 450 to 488), RUN universities increased by 46 (from 188 to 234), and non-aligned universities experienced an increase of 126 (from 428 to 554).

Figure 4.1

New Zealand vs. Australian Universities: Teaching FTE staff with 50:50 weights, 2008-2018

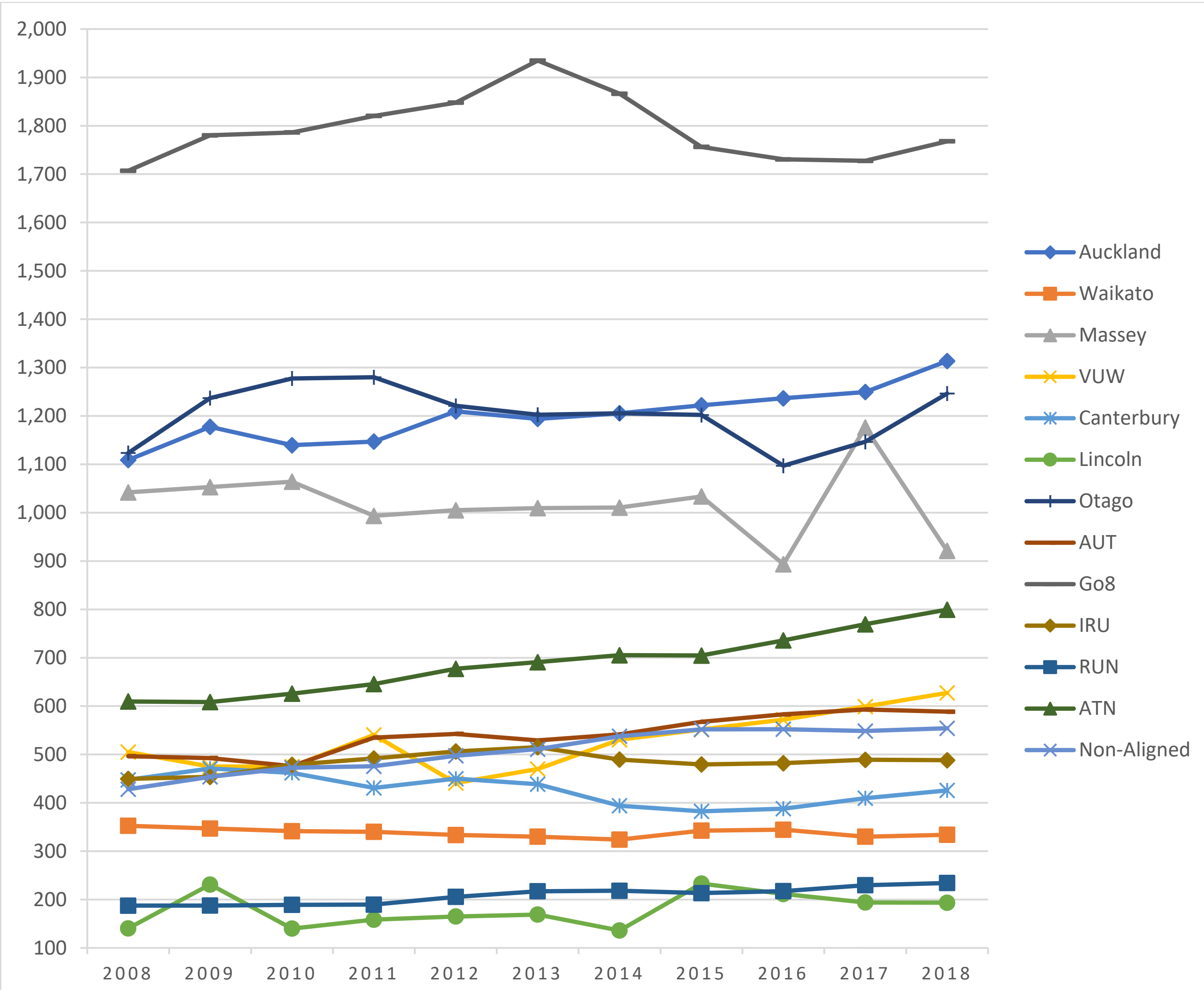


Source: New Zealand TEC, and Australian Government DoE.

Note: The numbers for Australian groupings are the averages for the universities within the groupings.

Figure 4.2

New Zealand vs. Australian Universities: Research FTE staff with 50:50 weights, 2008-2018



4.1.2 *Quality-Adjusted Labour Input Variable*

Quality-Adjusted Teaching Staff Labour Input

Teaching inputs should ideally be adjusted to account for changes in teacher quality over time. Gemmell et al. (2017) proposed using salary-based adjustments to capture changes in staff composition across various skill or experience levels, such as professors and lecturers. Similarly, York (2010) proposed weighting teaching inputs by wage rates to form a time series of total labour inputs, such as FTE weighted by mean teacher salaries in each tertiary institution type. This adjustment captures changes in teaching staff qualifications and experience over time. For example, increasing junior staff would reduce the weighted labour input index due to their lower salaries. However, this approach does not detect differences in teaching quality among staff with equal qualifications and experience who are paid the same amount.

While New Zealand universities provide salary scale data, they lack detailed publicly available information on academic staff by specific positions, such as the number of professors, senior lecturers, etc. They typically report only the total number of academic and general FTE staff without a further breakdown by specific positions. In contrast, Australian universities provide more detailed classifications of academic staff, including the number of above senior lecturers (e.g., professors, associate professors), Level C senior lecturers, Level B lecturers, and Level A below lecturers (e.g., associate lecturers, tutors, research associates). This difference in data availability limits the ability to compare quality-adjusted teaching inputs between the two countries. Therefore, this study does not apply quality adjustments to teaching staff inputs.

Quality-Adjusted Research Staff Labour Input

There is no simple indicator to adjust the quality of research staff. Although several potential adjustments were considered, data limitations made them unsuitable for this study. For instance, using the PBRF as a proxy for research quality was considered. However, PBRF evaluates research quality only twice (2012 and 2018) within the study periods, providing no continuous measure of research quality over time. Another limitation of undertaking a PBRF-based quality adjustment is that research-inactive staff are not counted as active research inputs, despite being included in wage expenses. This exclusion could overestimate research labour productivity measures, particularly in cases where universities with a higher share of R-ranked researchers have similar wage expenses to those with a lower share of R-ranked researchers. Thus, PBRF-ranked staff were not used to quality-adjust labour input.

In Australia, there are no equivalent individual-researcher-level quality assessments like PBRF. Rather than assessing individual researchers' portfolios, Australia's research quality is assessed at the institutional level through the Excellence in Research for Australia (ERA), Australia's national research assessment administered by the Australian Research Council (ARC). ERA is a comprehensive evaluation that uses a combination of indicators and expert review, but it does not provide continuous assessments of quality over time. It was conducted in four rounds (2010, 2012, 2015 and 2018), and focused on the set of discipline-specific indicators at the institutional level. Therefore, ERA is less suitable for quality-adjusting research staff inputs in this study.

Although data on Australian academic staff categorised by academic rank (e.g., professor, senior lecturer, etc.) is available, using these ranks for quality adjustment is problematic. For instance, a professor at a RUN university may have different qualifications or responsibilities compared to a professor at a Go8 university due to different standards and criteria. This disparity could affect productivity comparisons, potentially artificially reducing productivity in the RUN universities due to the absence of quality considerations. Additionally, the Australian DoE only provides classifications for academic and general staff costs without detailed data on staff wages by specific categories, further limiting the ability to assess staff quality.

Given these issues and the lack of an equivalent quality assessment system like PBRF in Australia, this study does not apply quality adjustments to research staff inputs.

4.1.3 *Teaching Output Variables*

Qualification Completions

Student qualification completions are widely considered an important measure of tertiary sector output (Gemmell et al., 2017, p. 12). They provide a more accurate reflection of a university's success in achieving its educational mission than equivalent full-time student (EFTS) enrolments, since enrolment counts do not capture whether students complete their studies. A university with high non-completion rates will have low teaching productivity, regardless of enrolment levels. Hence, completion data offers a clearer picture of teaching productivity than enrolment data.

In New Zealand, the teaching output most commonly used is the qualification completions at New Zealand Qualification Framework (NZQF) levels. The NZQF recognises ten levels of qualifications, but completion data published by the Ministry of Education (MoE) are aggregated across groups of levels, including Levels 1, 2, 3, 4 certificates[71]; Level 5-7 certificates and diplomas[72]; Level 7 bachelor's degrees; Level 7 graduate certificates and diplomas[73]; Level 8 honours and postgraduate certificates and diplomas[74]; Level 9 master's degree; Level 10 doctorates. This range of qualification levels highlights the diversity in educational programmes offered by New Zealand universities, providing important context for comparing teaching outputs across universities.

In Australia, completion data is sourced from the Australian Government Department of Education (DoE) and based on the Australian Qualifications Framework (AQF) (2013). The AQF also covers ten levels, but universities only offer qualifications from Levels 5 to 10[75]. The completion data is more aggregated than AQF specifications, including Level 5-6 undergraduates (i.e., Level 5 diploma and Level 6 advanced diploma); Level 6 associated degrees; Level 7 bachelor's degrees; Level 8 honours and graduate certificates and diplomas; Level 9 master's degrees; Level 10 doctorates.

This study aggregates qualification completions into undergraduate and postgraduate levels. In New Zealand, undergraduate completions include Level 1-4 certificates, Level 5-7 certificates and diplomas, Level 7 bachelor's degrees, and Level 7 graduate certificates and diplomas. Postgraduate completions include Level 8 honours and postgraduate certificates and diplomas, Level 9 master's and Level 10 doctorate degrees. In Australia, undergraduate completions cover Level 5 diplomas, Level 6 advanced diplomas and associate degrees, and Level 7 bachelor's degrees. Postgraduate completions consist of Level 8 honours and graduate certificates and diplomas, Level 9 master's degrees, and Level 10 doctorates.

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[71] All New Zealand universities produce completions for Level 4 certificates, while the University of Waikato and AUT additionally produce Level 3 certificates. Lincoln University is also unique in producing completions across certificates at Levels 1, 2, 3, and 4, although the completion numbers at Levels 1 and 2 certificates are quite small.

[72] Certificates and diplomas at Levels 5 to 7 are available for students' completed qualifications. These include certificates at Levels 5 and 6 and diplomas at Levels 5, 6, and 7.

[73] Graduate certificates or diplomas Level 7 for students' completions relate to graduate certificates and graduate diplomas Level 7.

[74] Honours and postgraduate certificates and diplomas at Level 8 for students who have completed their qualifications include completions at Level 8 in Bachelor's honour degrees, Postgraduate certificates, and Postgraduate diplomas.

[75] The Australian Qualifications Framework (AQF) (2013) includes ten levels, ranging from certificates to doctoral degrees. Some qualifications are offered in more than one sector. Higher education is provided at AQF Levels 5 to 10, while vocational education and training (VET) are offered from AQF Levels 1 to 8. The university provides undergraduate to doctorate completions at AQF Levels 5 to 10.

A notable distinction is that New Zealand universities also award Levels 1-4 qualifications, which Australian universities do not offer. These lower-level completions highlight the broader educational role of New Zealand universities and should be considered when comparing teaching outputs between the two systems.

Undergraduate Completions Trends: 2008-2018 in Appendix Chapter 4 Figures A4.1

The University of Auckland, the Australian ATN (especially RMIT) and Go8 universities (especially Monash) consistently show the highest number of undergraduate completions, indicating their largest number of bachelor's degrees produced. In contrast, smaller universities like Lincoln University and the Australian RUN universities have the lowest undergraduate completions, due to their specialised land-focus programmes for Lincoln and smaller size for RUN.

The University of Canterbury experienced a notable decline in undergraduate completions after the 2011 earthquake, with recovery beginning around 2016. In contrast, Lincoln, which is also based in Canterbury but was relatively unaffected by the 2011 earthquake, has a large increase in completions from 2011, before falling again in 2014. AUT produced the largest number of undergraduate completions in 2008 and showed fluctuations due to many changes in the number of Level 1 to 4 certificates and level 5-7 certificates and diplomas produced.

Postgraduate Completions Trends: 2008-2018 in Appendix Chapter 4 Figures A4.2

The Australian Go8 (especially Melbourne and Sydney) and ATN universities (especially RMIT and University of Technology Sydney) show significant increases, particularly in master's degrees by coursework and research-based doctorates. In New Zealand, the University of Auckland and Otago, as leading research universities, display steady increase, especially in honours and postgraduate certificates and diplomas and master's degrees. Conversely, smaller universities, like the University of Waikato and Lincoln University in New Zealand, and RUN universities in Australia, show more stable but lower postgraduate completion trends, possibly reflecting their focus on smaller and more specialised programmes.

Overall, using qualification completion at undergraduate (including Levels 1-7) and postgraduate (including Levels 8-10) levels to measure teaching output provides a more accurate reflection of a university's educational performance compared with EFTS numbers. More details on EFTS can be found in Section 4.2.1 Malmquist analysis.

4.1.4 *Quality-Adjusted Teaching Output Variables*

The New Zealand Productivity Commission (2018a) recommends that outputs should account for costs (e.g., depreciation and capital charges) and describe expected performance, such as quantity, quality, cost, time, and place of delivery. This study adopts two methods of weighting the quality-adjusted completions to provide a more accurate measure of teaching outputs: qualification credits or/and income expectations associated with different qualification levels.

Adjustment for Credit Weighted Completions

An issue with raw completion data is that it does not account for differences in the number of credits a qualification involves, which relates to the length of time it takes to complete. For example, a Level 7 diploma typically involves 120 credits and takes one year of full-time study, while a Level 7 bachelor's degree typically involves 360 credits and takes three years of full-time study. Thus, Gemmell et al. (2017) uses credit-weighted completions as a quality-adjusted teaching output measure, providing a more accurate reflection of the educational effort associated with each qualification.

Thus, the first quality-adjusted teaching output is the number of completed qualifications, weighted based on the number of credits assigned to each qualification level by the NZQA. For example, a bachelor's degree and doctorate are assigned 360 credits.

Comparison with the Australian Qualifications Framework

The Australian Government Department of Education collects completion data that is more aggregated than the AQF specifications. For instance, Level 8 postgraduate completions, which include bachelor's honours degrees, graduate certificates, and diplomas, follow similar credit weights as NZQF (2016). Level 6 associated degrees, typically requiring two years of learning, are assigned 240 credits. Additionally, credits for Level 5 and 6 diplomas are assigned 120 credits (reflecting 1-2 years of learning for diplomas at Level 5, and 1.5-2 years for advanced diplomas at Level 6), as opposed to the 90 credits in NZQF (2016). Table 4.3 provides an overview of the credit weightings assigned to different qualifications in New Zealand and Australian universities, reflecting the comparison of credits across qualification levels.

Table 4.3
New Zealand and Australian University Credit weights by Qualification Level

NZ Qualification	Credit Weight	Australia Qualification	Credit Weight
Certificate 1	40		
Certificate 2	40		
Certificate 3	40		
Certificate 4	40		
Certificates/Diplomas 5-7	90	Diplomas 5-6	120
Graduate Certificates and Diplomas 7	90	Associated Degree 6	240
Bachelor’s Degree 7	360	Bachelor’s Degree 7	360
Honours and Postgraduate Certificates/Diplomas 8	120	Honours and Graduate Cert/diplomas 8	120
Master’s Degrees 9	180	Master’s Degrees 9	180
Doctorates 10	360	Doctorates 10	360

Source: New Zealand Qualification Authority (NZQA), New Zealand Qualification Framework (2016), Australian Government of Department of Education, and Australian Qualification Framework (AQF) (2013).
Notes: In some cases, completion data is more aggregated than the NZQF and AQF specifications, leading to averaged weightings for categories Level 5-7, Level 7 and Level 8.

This study differs from Gemmell et al. (2017), which develops quality-adjusted productivity measures for the tertiary education sector. This study adjusts the credit weights for qualification at Levels 5-8 to more accurately reflect their structural and academic differences, based on the average credits awarded upon completion. For instance, Level 8 postgraduate completions (e.g., honours and postgraduate certificates and diplomas) are assigned 120 credits, whereas certificates and diplomas at Levels 5 to 7 are weighted at 90 credits. This adjustment contrasts with Gemmell et al. (2017), who assigned 90 credits to Level 8 qualifications and 120 credits to Levels 5 to 7 qualifications. Additionally, the credit weighting for a master’s degree is set at 180 credits in this study, compared to the 240 credits used by Gemmell et al. (2017). These adjustments aim to provide a more accurate reflection of the academic value of the qualifications. However, this method has limitations, such as the use of 360 credits for bachelor’s or doctorate degrees, and these limitations are accounted for in the income adjustment.

Unlike the more detailed data from the NZQA specifications, the completion data provided by the New Zealand MoE is more aggregated. For instance, Level 8 qualifications, including bachelor’s honours degrees, postgraduate certificates, and diplomas, are assigned an average credit value of 120, which aligns with the Australian Qualifications Framework (AQF), which also assigns 120 credits to equivalent qualifications [76].

For Levels 5 to 7 certificates and diplomas, this study applies an average credit weighting of 90 credits, calculated as the average of the credit requirements for Levels 5 and 6 certificates (40 credits each), and Levels 5, 6, and 7 diplomas (120-credit each). For master's degrees, the NZQA specifies credit requirements ranging from 120 to 240 credits, depending on the programme type and length. The AQF identifies three categories of master's qualifications: (1) research-based master's degree (typically takes 1-2 years), (2) coursework-based master's degree (1-2 years), (3) extended[77] master's degrees (3-4 years). Given these variations, this study uses an average weighting of 180 credits for master's degrees.

Further differences in approach arise from the scope and timeframe of the research. Gemmell et al. (2017) analysed the period from 2000 to 2015, whereas this study focuses on the period from 2008 to 2018. While they examine both the tertiary education sector and the university sector, this study exclusively focuses on the university sector. Moreover, this study incorporates Australian universities and compares them with their New Zealand counterparts, necessitating adjustments to achieve consistency across both systems, such as aligning credit weightings with the AQF.

However, a limitation of this approach is that it does not adjust for the relative academic levels of qualifications with the same credit values. For instance, a 360-credit bachelor's degree and a 360-credit PhD are treated equivalently regarding credit weighting, despite their substantial differences in academic level and research intensity. This limitation emphasises the importance of supplementing credit-weighted completions with income weights (discussed below) to better capture the economic value and productivity differences across qualification levels.

Adjustment for Credit and Income-Weighted Completions

[76] The AQF, rather than based on credits, emphasises the "volume of learning", which represents the amount of equivalent full-time years of study required to achieve learning outcomes specified for an AQF qualification type (Australian Qualifications Framework, 2013). For example, Australian Level 8 bachelor's honours degrees generally require one year of full-time study, graduate certificates require 0.5 to one year, and graduate diplomas take 1-2 years.

[77] In Australia, there are three types of master's degree (AQF, 2013): (1) Research Master's degree is to produce research or add new knowledge in a specific field. (2) Course Master's degree focuses on professional practice or the academic field of study. (3) Extended Master's degree focuses on professional practice.

The second weighted adjustment measure reflects expected incomes associated with different qualification levels. More precisely, the second adjustment for quality-adjusted teaching output involves weighting qualification completions by credits and expected income levels. This approach aims to capture not just the quantity of educational output but also the contribution of different levels of qualifications to lifetime or early career earnings (Gemmell et al., 2017, p. 12).

For New Zealand universities, the number of completions is first weighted by the credits assigned to each qualification level, following New Zealand Qualification Authority rankings (as above). Then, these credit-weighted completions are further adjusted by the median income associated with each qualification level. The New Zealand MoE provides data on median earnings for domestic graduates by qualification levels in the first to eleven years (1-11 years) after completing their studies.

Gemmell et al. (2017) proposed that earnings could be used as a proxy for the stock of human capital and thus were widely used to assess returns to education. They used census-based income weights to capture qualification premiums and compared these with MoE (2016) "5 years after graduates" income weights, which related to median earnings in 2015 by qualification level.

To align with the available income data for Australian graduates, this study uses earnings data for full-time employees by educational attainment levels from 2012. Specifically, the Melbourne Institute (2015, p. 72) data focuses on the earnings of full-time employees based on their educational attainment levels in 2012. The income weights by qualification level are derived from the average earnings of male and female FTE employees in 2012, measured six years post-study (Gemmell et al., 2017, p. 43; Melbourne Institute, 2015, p. 72). This is comparable to the MoE (2021) data used in this study, which tracks the median earnings of New Zealand domestic graduates six years post-study (for those who graduated in 2012) and relates it to median earnings in 2018 by qualification level. By aligning the timeframes and data sources, this study ensures consistency in calculating income weights for New Zealand and Australian graduates.

These income weights are shown in Table 4.4, expressed relative to the median earnings of domestic bachelor degree graduates. It is important to note that income data is not available for individual universities but is aggregated by qualification level. Thus, Australia has results for Certificate Levels 1-4 even though Australian universities do not offer these qualifications as they are offered through other types of institutions.

Table 4.4

Summary of Estimated Income Weights by Qualification Level, Relative to a Bachelor's Degree

<table>
<tr><th>Qualification</th><th>Gemmell et al. (2017)</th><th>MoE (2016) after 5-years</th><th>MoE (2021) after 6-years</th><th>Australia: HILDA Survey 2012</th></tr>
<tr><td>Certificate Levels 1-3</td><td>0.50</td><td>0.70</td><td>0.77</td><td></td></tr>
<tr><td>Certificate Level 4</td><td>0.60</td><td>0.71</td><td>0.87</td><td></td></tr>
<tr><td>Diploma Levels 5-7</td><td>0.70</td><td>0.76</td><td>0.79</td><td>0.83</td></tr>
<tr><td>Bachelor's Level 7</td><td>1.00</td><td>1.00</td><td>1.00</td><td>1.00</td></tr>
<tr><td>Graduate certificates or diplomas Level 7</td><td>1.10</td><td>1.12</td><td>1.02[78]</td><td>1.03</td></tr>
<tr><td>Honours or postgrad certi/dipl. Level 8</td><td>1.20</td><td>1.14</td><td>1.16</td><td rowspan="3">} 1.12</td></tr>
<tr><td>Master's Level 9</td><td>1.30</td><td>1.15</td><td>1.20</td></tr>
<tr><td>Doctorates Level 10</td><td>1.40</td><td>1.42</td><td>1.38</td></tr>
</table>

Source: Author's estimates, Gemmell et al. (2017), MoE (2016), MoE (2021), Melbourne Institute (2015, Table 7.4, p. 72) and Gemmell et al. (2017, p. 43).
Note: New Zealand MoE (2016) data related median earnings in 2015 by qualification level, while New Zealand MoE (2021) provides data related median earnings in 2018. The Melbourne Institute (2015, Table 7.4, p. 72) calculated the average earnings for male and female full-time employees aged 25-59 in 2012.

The qualification income weights show an explicit ordering of graduate earnings by qualification levels (MoE, 2021). In New Zealand, domestic graduates with "Certificate Level 4" qualifications earn significantly more than those with "Diploma Levels 5 to 7". This may be because many Level 4 certificates are trade-oriented, with trade-related skills and services in high demand during this period (Scott, 2020). However, Australian graduates with Level 4 certificates have slightly higher income weights than those with Level 5 to 7 diplomas.

Interestingly, Australian graduates with higher-level degrees (above Level 7) have income weights lower than those of corresponding New Zealand graduates[79]. One possible explanation is that Australian

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[78] Level 7 graduate certificates/diplomas between MoE (2016) data (1.12) and MoE (2021) data (1.02) differ so much, possibly due to MoE (2016) data reflecting 2015 median earnings, while MoE (2021) data based on 2018 median earnings, or possibly due to bachelor's median earnings increased much but Level 7 remained relatively stable. In other words, the earnings gap between Level 7 certificates/ diplomas and bachelor's degrees narrowed in the MoE (2021) data. Changes in the economic environment, wage inflation, and shifts in labour market demand for different qualification levels likely affect the median earnings.

[79] In this study, the earnings data for New Zealand graduates focuses on young domestic graduates aged 21 to 29 who are classified as employed. *Employment status* is defined as receiving wages and salary, paid parental leave and/or ACC compensation for at least four months or more in the tax year and/or receiving any self-employment income (PAYE, withholding payments and/or annual earnings), with graduates doing further study, overseas or in

postgraduate degrees may not have as high a return relative to bachelor's degrees, compared to New Zealand. However, it may also be due to measurement differences. For example, Australian earnings data aggregates honours, master's and doctorate degrees. Even the aggregate returns for these postgraduate degrees relative to a bachelor's degree in Australia (1.12) are lower than those for an honour's degree or post-graduate certificate or diploma, which are the lowest-level post-graduate degrees (1.16, according to MoE, 2021). There may also be differences in the field of study composition between Australian and New Zealand postgraduate students, with Australian students more likely to study in lower return areas.

Additionally, the Australian income data is limited to full-time employees aged 25-59 (Melbourne Institute, 2015, p. 73). This focus may lead to underestimating the returns for postgraduate qualifications if a significant proportion of postgraduate graduates are employed part-time or in less stable employment, as their income would not be captured in the full-time data. In contrast, bachelor's degree holders are more likely to be employed full-time, which could result in higher observed returns. However, if postgraduate graduates are more likely to work full-time, their returns could be higher than those of bachelor degree holders. Therefore, the scope of the data may limit the accuracy of the income return estimates for Australian postgraduate qualifications.

A notable limitation of this method is its inability to account for university-specific returns to education. For example, the job market value of a degree from Auckland may differ significantly from that of a degree from Massey University, potentially ignoring the impacts of university reputation and graduate employability on income outcomes. Nevertheless, the income weighting measure provides a valuable framework for understanding the broader link between qualification levels and earnings potential, reflecting the economic advantages of higher education attainment.

Credit and Income-Weighted Undergraduate Completions Trends: 2008-2018 in Figure 4.3

Australian universities, particularly those in the ATN (like RMIT and Curtin University) and Go8 (e.g., Monash University, the University of Melbourne and Sydney) universities, consistently have the highest credit and income-weighted completions. This is driven by their large enrolments and a significant

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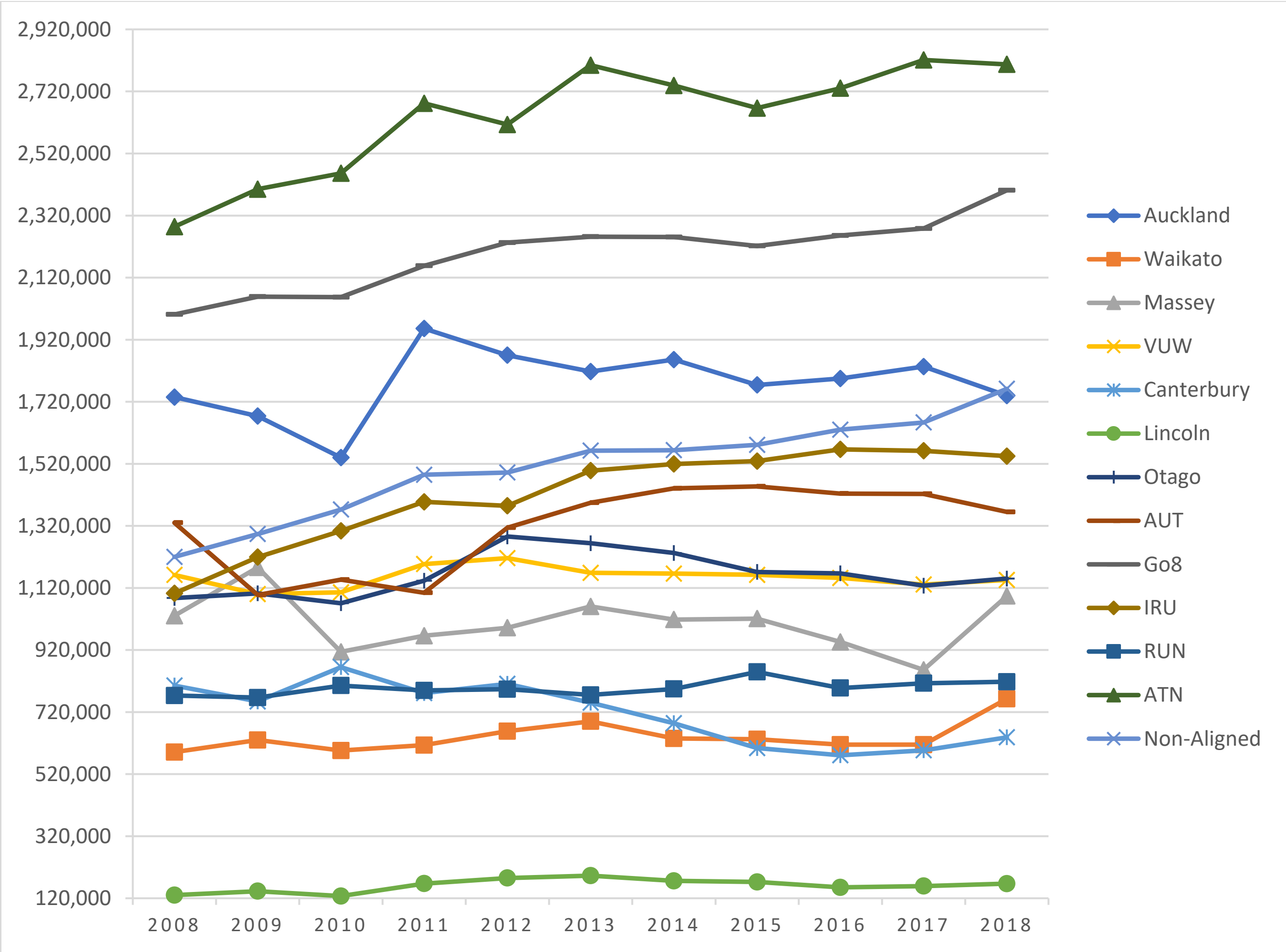
the other/known category excluded (Ministry of Education, n.d.b). For more details, please refer to https://www.educationcounts.govt.nz/statistics/beyond-study.

Australian income weighting data was sourced from two sources: pre-calculated values provided by Gemmell et al. (2017) and raw data from the Melbourne Institute report (Melbourne Institute, 2015). However, the Melbourne Institute report offers limited details about the dataset, only noting that the sample for the earnings model is full-time employees aged 25-59.

number of undergraduate qualifications, particularly certificates and diplomas with higher relative income weights and bachelor's degrees with larger credit weightings. In contrast, the University of Auckland and AUT in New Zealand produce larger completions, although they are still lower than the Australian Go8 universities. AUT experienced a significant decline in level 5 to 7 certificate and diploma completions between 2008 and 2011.

Figure 4.3

New Zealand vs. Australian Universities: Undergraduate Credit-And-Income-Weighted Completions, 2008-2018



Source: New Zealand TEC, New Zealand MoE, NZQF (2016), New Zealand MoE (2021), Australian Government DoE, Australian Qualification Framework (2013), Melbourne Institute (2015, Table 7.4, p. 72) and Gemmell et al. (2017, p. 43).

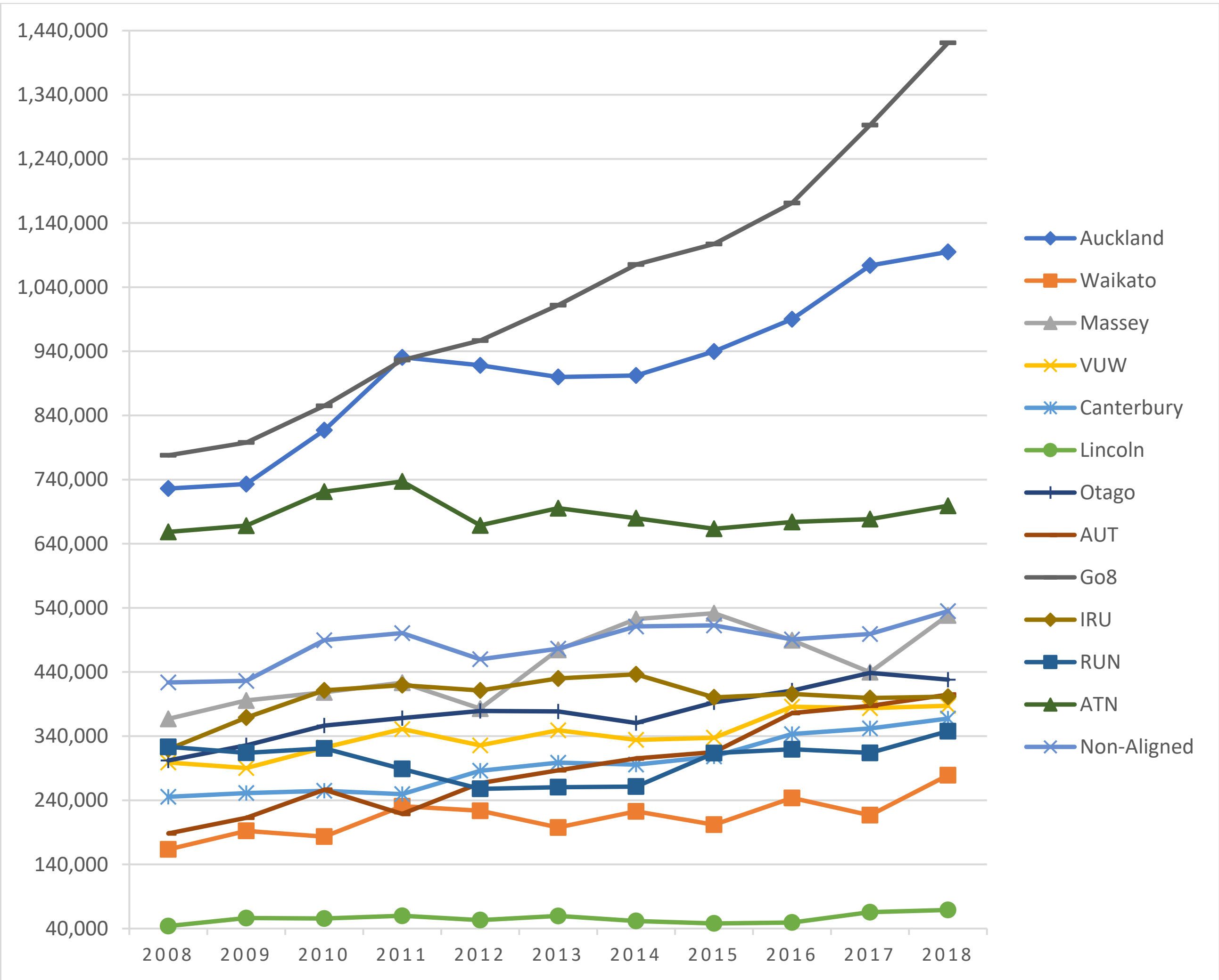
Note: The numbers for Australian groupings are the averages for the universities within the groupings.

Credit and Income-Weighted Postgraduate Completions Trends: 2008-2018 in Figure 4.4

Australian Go8 universities have the highest credit and income-weighted completions, with an especially large number of master's and doctorate degrees, reflecting both higher credit weights and the higher income premiums associated with postgraduate qualifications. In contrast, the University of Auckland, Otago and Massey University in New Zealand perform reasonably well but still have room to catch up with Australian universities. Smaller universities in both countries, such as New Zealand's Lincoln University, the University of Waikato, and Australian RUN universities, show relatively stable trends in postgraduate completions adjusted for quality.

Figure 4.4

New Zealand vs. Australian Universities: Postgraduate Credit and Income-Weighted Completions, 2008-2018



Source: New Zealand TEC, New Zealand MoE, NZQF (2016), New Zealand MoE (2021); Australian Government DoE, Australian Qualification Framework (2013), Melbourne Institute (2015, Table 7.4, pp. 72) and Gemmell et al. (2017, p. 43).

Note: The numbers for Australian groupings are the averages for the universities within the groupings.

It is a common belief that acquiring a qualification boosts earnings potential, and employers pay a premium to those who have completed a qualification (MoE, 2021). The premium for earning a qualification below degree level increases with the level of qualification. Moreover, domestic graduates with higher-level degree completions typically earn more than those with lower ones. The largest jump in earnings is between graduates with qualifications below degree level and those with degrees. These results are also consistent with Scott's (2020) studies, in which degree and higher-level education give graduates higher earnings and earnings growth in New Zealand.

However, as highlighted by the New Zealand Productivity Commission (2017, p. 248), qualification completion rates, and graduate salaries and employment rates, may not be reliable indicators of provider or system performance. This is because they are not adjusted for differences in the student intake, such as prior achievement, socioeconomic background, or parents' qualifications. Such limitations may impact the EFTS and completion data, as they can influence the quality of incoming students and subsequently the completion outcomes.

Moreover, the New Zealand Ministry of Education (n.d.b) proposed that factors beyond universities' control impact graduates' outcomes, such as occupation, age, experience, personal factors, regional labour markets, individual choices, and possible workplace inequalities. The failure to account for input quality and factors beyond universities' control could provide an imprecise measure of university teaching output and make comparisons of university value-added potentially misleading, since the universities or New Zealand MoE, TEC or Australian Government do not provide data on the quality of the students enrolling in universities.

This study adopts this "adjusted" income data, which, although imperfect, offers insights into how New Zealand universities assist students in achieving outcomes that influence their post-graduation earnings. However, several limitations remain. First, the income adjustments do not account for differences in the field of study. For instance, a university with a medical school is likely to produce graduates with bachelor's degrees who earn more, on average, than a university focusing on arts degrees. This may lead to underestimating the teaching output of universities with medical schools relative to those without. Second, the adjustment does not consider that returns to qualifications may differ across universities. For instance, employers may value degrees from the University of Auckland more than those from AUT, which may result in underestimating the teaching outputs of Auckland relative to others. These limitations reflect the challenges in accurately capturing the value added by universities in affecting graduate outcomes.

In conclusion, New Zealand universities, in general, have relatively stable credit and income completions, while Australian Go8 universities far outpace them due to larger enrolments and higher income premiums for their graduates. The income-weighted completions analysis emphasises the economic returns of the university, demonstrating that the combination of large enrolments and significant income returns leads to more teaching output and productivity, particularly at the postgraduate levels.

4.1.5 *Research Output Variables*

Two key research outputs are used to analyse the performance of Australasian universities' performance over time: research income (measured in real terms deflated using the 2018 general CPI) and the number of research publications (articles and reviews) indexed on the Web of Science (WoS). These data are sourced from the New Zealand TEC, the Australian Government of Department of Education (DoE), and WoS.

Research Income as a Proxy for Research Output

Universities play an essential role in research and development, which conducts basic (e.g., knowledge-creating) and applied research (through collaborations with government and industry). Research income is often used as a proxy for research output because it is easily accessible and closely correlated with prior research performance (Johnes, 2014). Research income provides a valuable, up-to-date information reflection of both the quantity and quality of research based on market prices (Flegg et al., 2004; Kempkes & Pohl, 2010; Worthington & Lee, 2008).

For New Zealand universities, total income data reported in university annual reports includes categories such as "government grants and funding", "student tuition fees", "research income (e.g., PBRF and research contracts)", and "other income (e.g., dividends, interest, donations etc.)". Alternative income data from the TEC provides detailed data on "government tuition funding", "student fees and charges (including international and domestic tuition fees, student service levy and other student-related fees)", "research income (e.g., PBRF income; external research grants from agencies and foundations; TEC funded research capability and initiatives excl. PBRF; and other research-derived income)" and "other income (e.g., interests, dividends)". Therefore, this study uses research income from TEC data due to its consistent categories across New Zealand universities[80].

For Australian universities, total income data is sourced from the Australian Government DoE and includes a variety of funding streams, such as the Commonwealth Grant Scheme[81] and other grants, the Higher Education Loan Program (HELP)[82], and fees and charges[83] etc. Australian research income comprises Australian Government research grants (e.g., Australian Research Council[84] (ARC), Education Research Grants, other Australian Government Financial Assistance, State and Local Government Financial Assistance etc.), and research contract income (e.g., royalties, trademarks and licences, consultancy and contracts). Lastly, other income (e.g., investment income) is also included in the total income for Australian universities.

Financial variables, such as research income, are deflated to 2018 prices using the consumer price index (CPI), calculated as the average of the four quarterly CPI values for each year. CPI data are sourced from Stats NZ and the Australian Bureau of Statistics. CPI values are necessary to adjust for inflation and ensure that the financial variables accurately reflect the real value over time. This study compares New Zealand universities with Australian universities and examines the performance of New Zealand universities over time, aligning with the approach used by Gemmell et al. (2017). Moreover, to enable comparison of financial variables between New Zealand and Australia, the real Australian financial variables are converted into New Zealand dollars, using OECD estimates of Gross Domestic Product

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[80] Gemmell et al. (2017) proposed an alternative approach for calculating research income, as they considered that university staff funded by tuition and student fees also devote time to research, using the "40:40:20" academic time allocation model. Thus, they redefined income for teaching purposes, assigning 40% of tuition and student fee income to teaching. Adjusted research income is then calculated by adding 40% of tuition/fee income to the New Zealand TEC research income category. Lastly, the remaining 20% of tuition/fee income is added to "other income".

[81] The Australian Government provides the Commonwealth Grant Scheme (CGS) to subsidise tuition costs for students pursuing higher education in various subject areas and qualification levels. More details see https://www.education.gov.au/higher-education-funding/commonwealth-grant-scheme-cgs.

[82] The Australian Government also offers financial support to students through the Higher Education Loan Program (HELP), which provides income-contingent loans. HELP eliminates upfront cost barriers to tertiary education. It includes HECS-HELP (Government paying student contribution amount), FEE-HELP (paying student tuition fees), OS-HELP (paying some overseas study expenses), and SA-HELP (paying student services and amenities fees). Further information sees https://www.education.gov.au/higher-education-funding/help.

[83] Australian university's student fees and charges include fee-paying domestic and overseas, student services and amenities, and other non-course fees and charges.

[84] The Australian Research Council (ARC) is competitively awarded to research working in all academic fields except health and medical research. More information can be found in Section 1.4.

(GDP) purchasing power parity (PPP). The OECD recommends this methodology for comparing financial variables across countries (Schreyer & Koechlin, 2002; Smart, 2009; Margaritis & Smart, 2011).

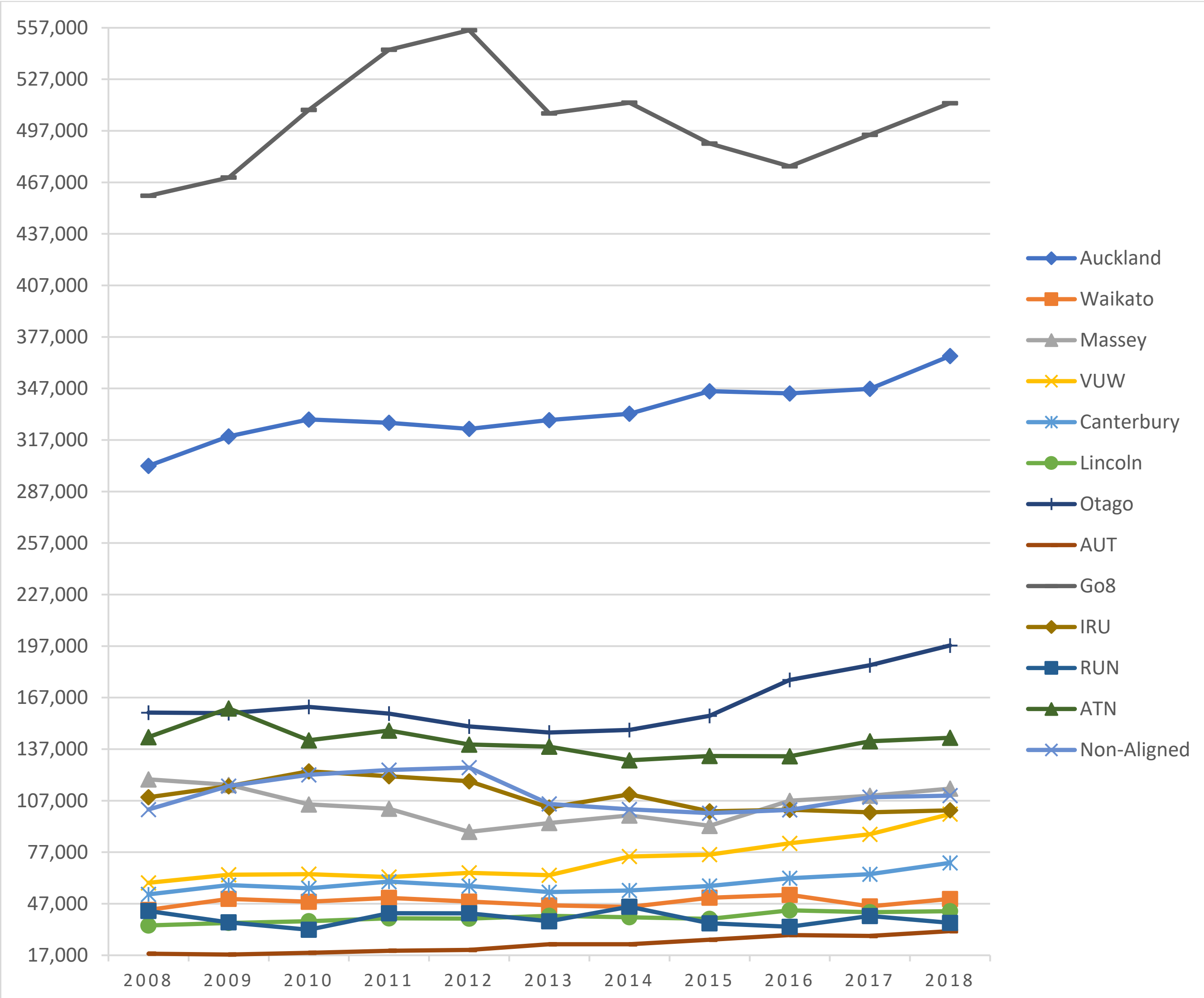
Research Income Trends: 2008-2018 in Figure 4.5

The Australian Go8 universities consistently have the highest research income, with substantial increases over the period. While the Go8 universities experienced a peak in 2012, followed by a slight decline and stabilization, they maintained a significant advantage over other universities. The Australian ATN and Non-aligned universities show stable increases, but their research income remains significantly lower than the Go8 universities.

In contrast, New Zealand's leading research university, Auckland, shows a steady increase and consistently has the highest research income. However, the funding gap in both countries remains substantial. University of Otago also consistently performs well with stable and moderate increases, reflecting its status as the second leading research university in New Zealand. As a younger and more teaching-focused university, AUT has the lowest research income, but it demonstrates stronger growth throughout the period.

Figure 4.5

New Zealand vs. Australian Universities Research Income (in 2018 $000), 2008-2018



Source: New Zealand TEC and Australian Government DoE.
Note: The numbers for Australian groupings are the averages for the universities within the groupings.

In summary, there are significant disparities in research income between New Zealand and Australian universities. The Australian Go8 universities have a significant research income advantage over their New Zealand counterparts (Smart, 2011). New Zealand universities, including the top performers, such as the University of Auckland, exhibit more modest increases in research incomes.

Given that research funds (in general) support current research, it is indicative of the current research output (Stevens, 2005). Research income reflects recent research contributions, and highlights research that is not necessarily traditional publications, indicating universities' broader contributions to research.

Furthermore, universities that are good at attracting research funding also appear to produce high-quality research publications; therefore, both research indicators (publications and research grants) can be used interchangeably in evaluating a university's performance (Gralka et al., 2019).

Research Publications—Number of WoS Indexed Articles and Reviews

Measuring the research output for New Zealand universities by research publications as reported by the universities can be problematic due to the inconsistent ways that they report their outputs. While universities have routinely reported the number of research outputs in their annual reports for several years, the categories and thresholds used vary considerably, and some have modified their reporting methods over time. Some universities like University of Auckland and VUW, have stopped reporting research output numbers in their annual reports. These limitations make year-on-year comparisons of research outputs across universities over any extended period problematic. Furthermore, when publications have multiple authors from several universities, it can lead to double counting of research results.

To better understand the research labour productivity of New Zealand universities, bibliometric databases provide an alternative, more consistent measure of research outputs (Smart, 2009). One such database is Web of Science (WoS), owned by Clarivate (previously Thomson Reuters). This study focuses on articles and reviews indexed by WoS under the name of New Zealand universities. However, the research labour productivity derived from these raw output numbers implicitly assumes that the quality of publications has remained constant over time (Smart, 2009).

Meanwhile, it is essential to note the time lag between submitting a journal article and its publication. Research publications for a given year are likely to be generated by labour inputs from previous years. Therefore, comparing research outputs and inputs within the same year is inappropriate. To account for this, this study utilises a one-year lag between the articles and reviews and corresponding labour inputs, as supported by Smart (2009, 2009a) and Margaritis and Smart (2011). For instance, the WoS articles and reviews published in 2009 are related to inputs used in 2008.

Trends in the Number of WoS-Indexed Articles and Reviews: 2008-2018 in Appendix Chapter 4 Figures A4.3

Australian Go8 universities showed a clear and significant lead in research publications throughout the period. Their outputs exhibited a sharp and consistent increase, particularly after 2013, reaching over 8,000 in 2018. This trend highlights these universities' strong research capabilities and financial resources. Australian ATN and Non-aligned universities also show upward trends in research publications, but their increase is more modest than that of Go8 universities.

In contrast, New Zealand's top research universities, such as Auckland and Otago, displayed steady but more moderate increases in research publications. Auckland's indexed articles and reviews increased from approximately 1,700 in 2008 to over 4,200 in 2018, while Otago's research outputs increased from 1,400 to 2,800 over the same period. Although these figures reflect the growing research contributions of New Zealand's top universities, the gap between them and the Australian Go8 universities remain significant. While New Zealand's leading universities have made notable progress, significant gaps remain when compared to the research intensity of Australian Go8 universities. Despite Auckland's average of 944 research FTEs, which exceeds the Go8 universities' average of 723, the gap in research output remains substantial, reflecting the need for further enhancement in research capacity and resources beyond just staff numbers. AUT exhibits relatively low research publications, but with encouraging recent trends. Publications by AUT staff increased from 215 in 2008 to over 1,050 by 2018, reflecting its growing role as a research-oriented university.

In summary, this study utilises articles and reviews indexed in the WoS with a one-year lag to ensure consistency in adjusting research publications by citation weights (CNCI), which measures only the citation impact of articles and reviews. This approach provides a targeted representation of research quality by focusing on articles and reviews. It distinguishes it from methods that include a broader range of publication types, such as books and book chapters. Section 4.1.6 will elaborate this adjusted method unlike Gemmell et al. (2017, 2018), who utilised an average number of indexed publications—articles, books, and book chapters— from SCOPUS and WoS to measure research productivity.

4.1.6 *Quality-Adjusted Research Output Variables*

Citation-Weighted Research Publications

The number of WoS-indexed articles and reviews, with a one-year lag, is used as a proxy for research output. A quality-adjusted research output is calculated by multiplying the number of articles and reviews by their corresponding citation weights. The citation weight is known as Category Normalised Citation

Impact (CNCI), which is a measure that compares an article's citations to what would be expected in the given the subject area, year of publication, and type of publication (MoE, 2022a). This measure only includes citations of journal articles and reviews. Table 4.5 presents the average CNCI for articles and reviews published by academics at New Zealand and Australian universities.

Table 4.5
Citation Rates of Research Publications by New Zealand and Australian Universities, 2008-2018

Countries	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
NZ	1.12	1.15	1.18	1.24	1.29	1.32	1.36	1.31	1.32	1.35	1.34
AUS	1.18	1.20	1.22	1.24	1.27	1.30	1.33	1.36	1.39	1.42	1.44

Source: Web of Science (Clarivate), New Zealand Ministry of Education (MoE, 2022a). https://www.educationcounts.govt.nz/statistics/research. Research Performance, Table RSP.11.
Note: The annual series for CNCI is sourced from New Zealand MoE (2022a) data available only as five-year averages for 1980-84 to 2016-20. This study treats these numbers as estimates for the middle year of five, such as the 2008 citation weight, using the data from the time frame 2006-10.

A CNCI value of one implies that the academic impact of the research is equal to the world average. A value greater than one for the CNCI means that the average citation rate of university research is above the world average and vice versa. The citation rates for research from New Zealand and Australian universities have generally increased over time compared with the world average. From the 2006-2010 five-year period to 2016-20, New Zealand's CNCI improved from 1.12 to 1.34.

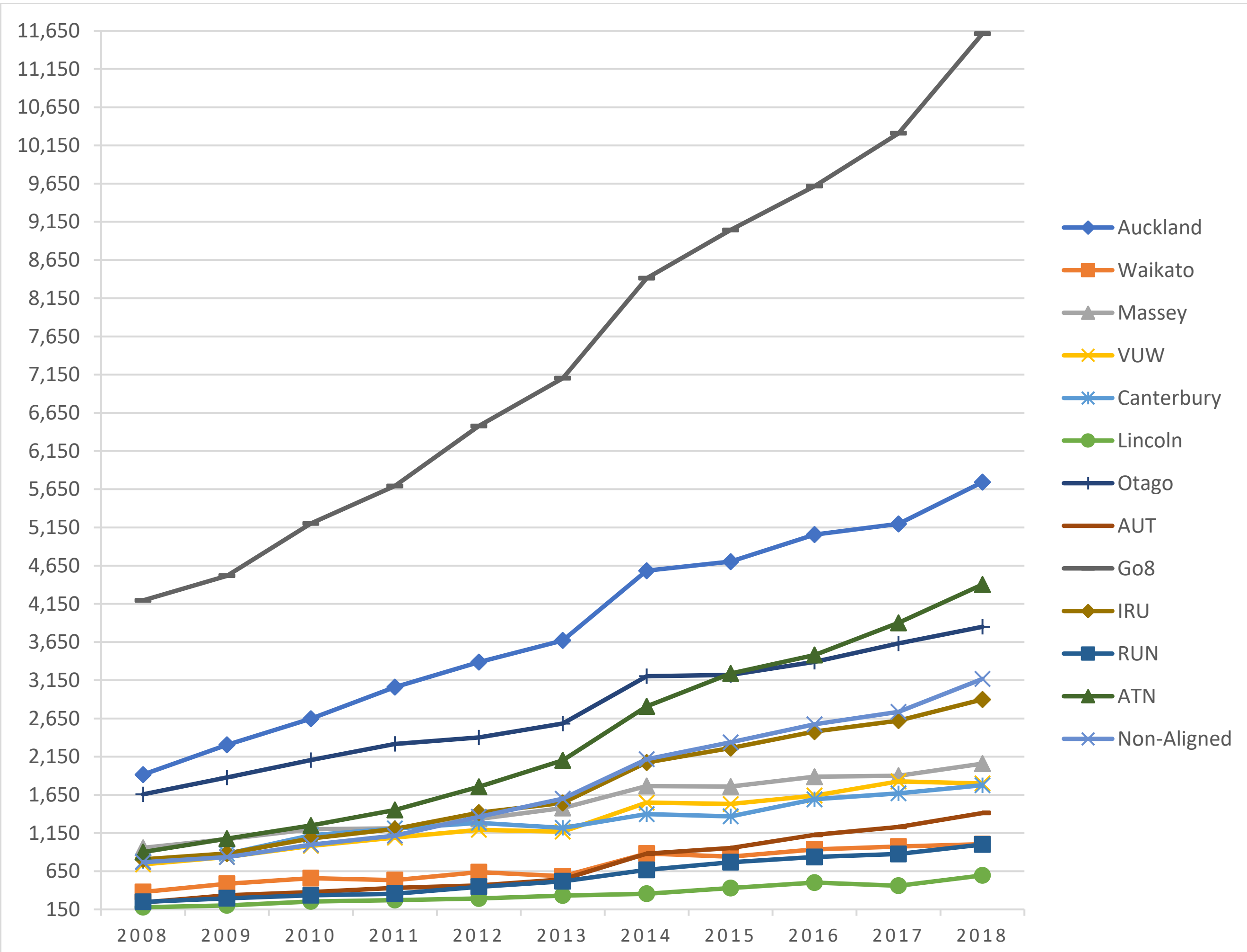
Between 2006-2010 and 2009-2013, the gap between CNCI values for New Zealand and Australian universities has narrowed. Between 2010-2014 and 2012-2016, the CNCI for New Zealand universities was slightly higher than for Australian universities, partly due to a number of highly cited papers in the field of physics (Ministry of Education, n.d.a). However, in most recent periods, New Zealand's CNCI has fallen below Australia's as the highly cited papers are no longer included in the more recent five-year windows (Ministry of Education, n.d.a).

Trends in the Number of Adjusted WoS-Indexed Articles and Reviews: 2008-2018 in Figure 4.6

The data shows that Australian universities, particularly Go8 universities, consistently outperform their New Zealand counterparts in the quantity and quality of research outputs. Go8 universities show a much larger and faster-growing research output, maintaining a strong dominance in research outputs compared to other universities. On the New Zealand side, the University of Auckland and Otago consistently rank as the top research universities in terms of WoS-indexed articles and reviews adjusted for quality. Lincoln University and AUT have lower publications, but show accelerated increase after 2013, especially AUT.

Figure 4.6

New Zealand vs. Australian Universities: Adjustment for the Number of WoS Indexed Articles and Reviews, 2008-2018



Source: Web of Science (Clarivate), New Zealand MoE (2022a). https://www.educationcounts.govt.nz/statistics/research. Research Performance, Table RSP.11.

Note: 1. The annual series for CNCI is sourced from MoE (2022a) data available only as five-year averages for 1980-84 to 2016-20. This study treats these numbers as estimates for the middle year of five, such as the 2008 citation weight using the data from the time frame 2006-10.

2. The numbers for Australian groupings are the averages for the universities within the groupings.

Caveats and Considerations

Several caveats should be considered when using bibliometric data and their citation impacts, such as CNCI. Gemmell et al. (2017, p. 19) noted that adjusting publications by average citations (e.g., CNCI) involves approximating actual, unknown annual values. This is because the available data is based on five-year averages from 2006-2010 to 2016-2020, treated as estimates for the middle year of each five-year period. Therefore, caution is required when treating these numbers. When citations are used as a proxy for quality, highly cited publications are assumed to contribute more knowledge and higher quality than those with fewer or no citations (Smart, 2009, p. 19).

The New Zealand Ministry of Education (2022a) further notes that bibliometric data is limited to articles and reviews in the Clarivate's Essential Science Indicators (ESI) dataset (one of the Web of Science datasets). The Clarivate's database is the most commonly used source of citation data. However, social sciences and humanities coverage is less extensive than the natural and medical sciences. New Zealand's applied fields of research and social science research are more likely to appear in local journals and may be excluded from WoS (MoE, 2022a).

Smart (2009, 2009a, 2019) also noted some important caveats in using bibliometric data, which is *limited* to indexed journal articles and reviews. This would be ignored by many research outputs produced by universities, particularly in areas like social science and humanities. Smart (2019) recommended treating bibliometric data as *indicative* rather than *comprehensive*.

4.1.7. *A Summary of Variables Used for the Partial Labour Productivity Analysis*

Table 4.6 summarises the input and output variables used in the partial labour productivity analysis. The variables measure both teaching and research-related inputs and outputs, which allows the analysis in the next chapter to evaluate universities across the key functions of academic institutions. Note that it would ideally quality-adjust both inputs and outputs, but due to data limitations, only quality-adjusted outputs are used in this study.

Table 4.6
Summary of Input and Output Measures Used in the Partial Labour Productivity

Category	Variables	Description
Inputs	Teaching FTE staff	NZ: 50% of academic/tutorial FTE for teaching FTEs
		AUS: 50% of teaching and research FTEs plus teaching-only FTEs

	Research FTE staff	NZ: 50% of academic/tutorial FTEs plus research-only FTEs
		AUS: 50% of teaching and research FTEs plus research-only FTEs
	General FTE staff	NZ: All staff other than those engaged in the teaching process, including librarians, IT staff, general and administrative and managerial staff, but excluding researchers and technicians.
		AUS: Academic support staff, student services staff, and public services staff
Teaching Outputs	Undergraduate Completions	NZ: Qualification completions at Levels 1-4 certificates, Levels 5-7 certificates and diplomas, Level 7 bachelor's degree and Level 7 graduate certificates and diplomas
		AUS: Qualification completions at Levels 5 and 6 undergraduates, Level 6 associated degrees and Level 7 bachelor's degrees
	Postgraduate Completions	NZ: Qualification completions at Levels 8 honours and postgraduate certificates and diplomas; Level 9 master's degree and Level 10 doctorate degrees
		AUS: Qualification completions at Level 8 honours and graduate certificates and diplomas; Level 9 master's degrees; Level 10 doctorates
Adjusted Teaching Outputs	Credit-weighted UG Completions	Qualification completions weighted by credits associated with different undergraduate qualification levels
	Credit-weighted PG Completions	Qualification completions weighted by credits associated with different postgraduate qualification levels
	Credit- and income-weighted UG Completions	Qualification completions weighted by credit and income levels associated with different undergraduate qualification levels
	Credit- and income-weighted PG Completions	Qualification completions weighted by credit and income levels associated with different postgraduate qualification levels
Research Outputs	Research Income	NZ: PBRF income, external research grants and other research-derived income (NZD$000) in 2018 New Zealand Dollars
		AUS: Australian Government research grants (e.g., ARC etc.) and research contract income (e.g., royalties, trademarks and licences, consultancy and contracts) (NZD$000) in 2018 New Zealand Dollars
	WoS-indexed articles and reviews	Number of research publications (articles and reviews) indexed in the Web of Science (WoS)
Adjusted Research Outputs	Adjusted WoS-indexed articles and reviews	Number of research publications weighted by citation rates (Category Normalised Citation Impact, CNCI)

4.2 Malmquist Productivity Index Analysis

4.2.1 *Input Variables*

Labour Costs: Teaching, Research and General FTE staff

As noted in Section 4.1.1, this study assumes a 50:50 allocation of academic staff time across teaching and research activities in the partial labour productivity analysis. For consistency, the same weighting is used in the Malmquist index analysis. This assumption allows comparability between New Zealand and Australian universities and provides a consistent approach to analysing productivity differences across these universities. A 40:60 weighting is used in some estimations to test the robustness of the findings and explore alternative staff allocation models. The measure for general FTE staff is the same as in Section 4.1.

Capital Costs: Non-labour expenditure

Capital inputs are more complicated than labour inputs since it is challenging to distinguish and quantify capital service flows from capital stocks at any given time. Universities' capital stock, measured by book value, can vary depending on when assets were acquired, potentially reflecting the age of the university. The age and composition of capital stock may differ significantly across universities, when comparing older universities with established infrastructure and newer universities that may rely on leased or recently acquired assets. Older universities possess fully depreciated assets, and may appear to have low capital inputs, despite still using these assets for teaching or research purposes. This difference could lead to an underestimation of capital input in older universities. In contrast, universities with newly acquired assets would report higher depreciation, potentially affecting capital input comparisons.

Additionally, universities may vary in their propensity to lease or own assets. Leased assets may not appear in accounting records as part of the capital stock, even though they provide capital services equivalent to owned assets. Excluding leased assets may bias capital input estimates, making universities with more owned assets appear to have higher capital inputs than those that rely more on leasing. The capital input measure should ideally treat leased assets on an equivalent basis to owned assets (New Zealand Productivity Commission, 2018b, p. 67).

Another concern is how depreciation is measured. Since all property, plant, and equipment are not created equal, different classes of assets depreciate at different rates over time, such as buildings, laboratory equipment, or IT infrastructure. If property, plant and equipment differ significantly across universities, then a failure to include depreciation could make universities whose assets depreciate more quickly than their counterparts appear to be more productive (New Zealand Productivity Commission, 2018b).

Unfortunately, data from universities' annual reports, the New Zealand Ministry of Education (TEC), or the Australian Government Department of Education do not provide explicit information on capital expenditures. To address this, this study uses New Zealand TEC and Australian Government DoE data on total costs minus labour costs as a proxy for the non-labour expenditure/costs when analysing the productivity and efficiency of higher education institutions.

Table 4.7 indicates the differences in the average share of capital costs to total costs across New Zealand and Australian universities from 2008 to 2018, sourced from New Zealand TEC and Australian Government DoE data and university annual reports.

Table 4.7
Average Share of Capital Costs to Total Costs from TEC and University Annual Reports Data, 2008-2018

University	New Zealand TEC/AUS DoE data		University Annual Report	
	Non-labour exp/Total	Depreciation & Amortisation/Total	Non-labour exp/Total	Depreciation & Amortisation/Total
Auckland	0.447	0.116	0.424	0.126
Waikato	0.414	0.094	0.419	0.091
Massey	0.409	0.104	0.413	0.104
VUW	0.446	0.106	0.432	0.115
Canterbury	0.434	0.121	0.462	0.119
Lincoln	0.475	0.081	0.467	0.089
Otago	0.393	0.094	0.393	0.095
AUT	0.373	0.117	0.372	0.118
New Zealand Average	***0.424***	***0.104***	***0.423***	***0.107***
Go8	0.441	0.066	0.443	0.067
IRU	0.41	0.065	0.411	0.065
RUN	0.423	0.059	0.421	0.058
ATN	0.393	0.072	0.398	0.071
Non-aligned	0.407	0.064	0.405	0.063
AUS Average	***0.417***	***0.064***	***0.417***	***0.064***

Note: 1. The numbers for Australian groupings are the averages for the universities within the groupings.
2. "Depreciation and amortisation" are presented here as an alternative measure of capital costs to enhance the robustness of the empirical result in the subsequent chapters.

The share of non-labour expenses in total expenses for New Zealand universities averages 42.4%, based on TEC data, closely aligned with the 42.3% observed in university annual reports. Depreciation and amortisation as a share of total expenses also show minor differences between TEC (10.4%) and university reports (10.7%), indicating relative consistency in capital expense reporting across data sources.

In contrast, Australian universities have a slightly lower average non-labour expense share (41.7%, the same in Australian DoE data and university annual reports). The average depreciation and amortisation shares are also lower than those in New Zealand, potentially reflecting differences in assets estimated useful life, depreciation rates or capital investment structures between the two countries.

Trends in the Non-Labour Expenditures (in 2018 $000): 2008-2018 in Figure 4.7

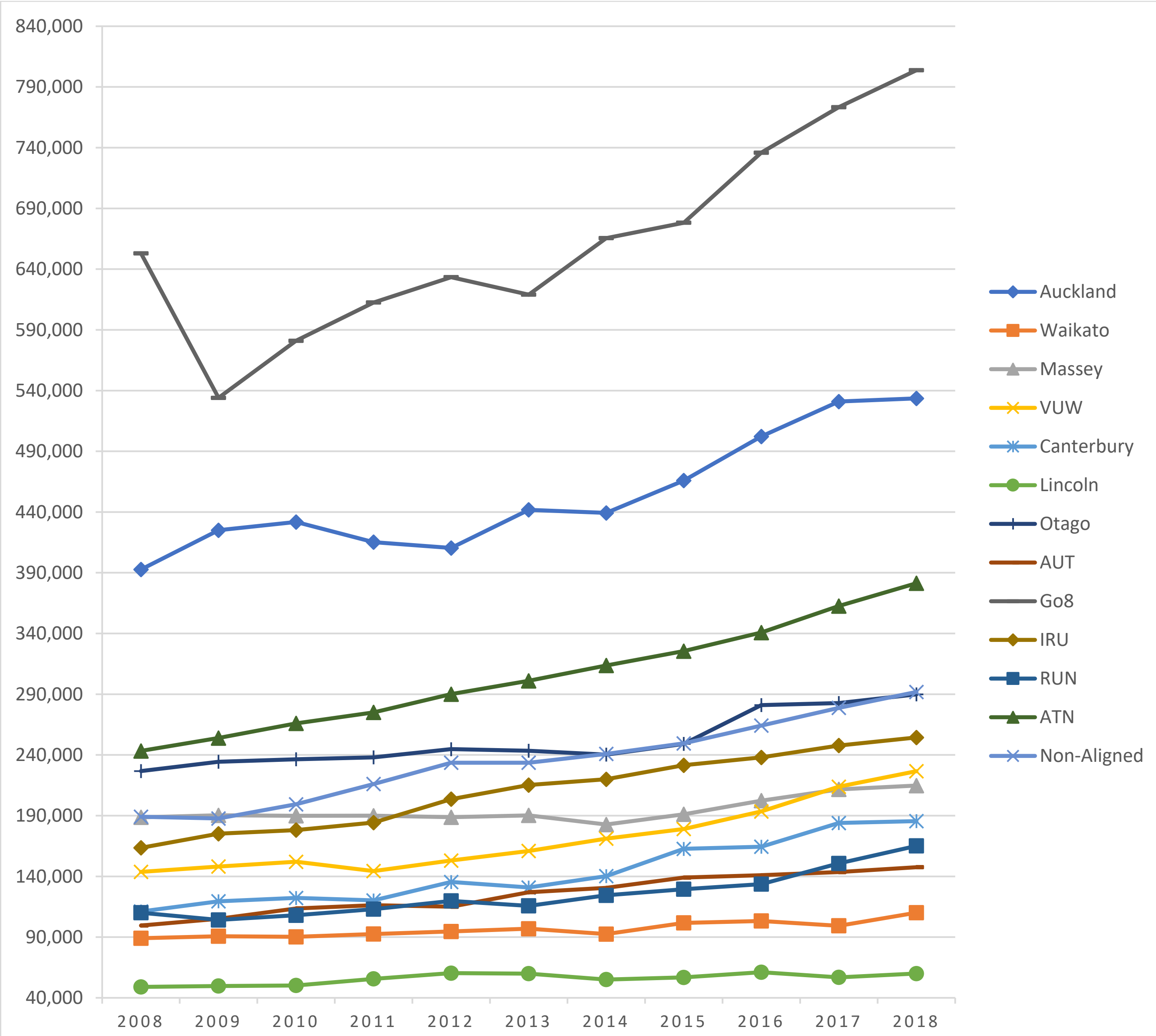
Trends in non-labour expenditure highlight significant disparities between New Zealand and Australian universities. The Go8 universities consistently allocated the highest resources to non-labour expenditures, increasing from NZD 653 million in 2008 to over NZD 800 million in 2018. This trend may reflect that these universities were larger and experiencing faster increases, which afforded them the potential for greater resources to invest in infrastructure, property, and other non-labour relative expenses. Such investment could support these universities in sustaining or even enhancing their teaching and research output levels. In contrast, Australian ATN and Non-aligned universities exhibited a more modest but steady increase in non-labour expenditures during the period.

In New Zealand, the University of Auckland stands out for its steady increase in non-labour spending, increasing from approximately NZD 392 million in 2008 to around NZD 533 million in 2018. The University of Otago, Massey University and VUW show moderate increases during the period. However, New Zealand universities remain behind their Australian counterparts, particularly the well-funded Go8 universities. Lincoln University and the University of Waikato display much lower levels of non-labour expenditures, reflecting their smaller size. AUT experienced large increases, reflecting its efforts to improve infrastructure and resources.

The financial gap in non-labour expenditures between New Zealand and Australian universities remains evident, with Australian universities consistently possessing greater resources for investment in their physical assets and infrastructure that support their teaching and research activities. The larger market size and scale of Australian universities may partially explain this difference. And financial security is also a crucial factor, such as the steady operating margins and strong cash flows of Australian universities allow them to make sustained investments in campus infrastructure, including research facilities, buildings, and advanced technologies, which in turn enhances their capacity to maintain or improve their teaching and research outputs.

Figure 4.7

New Zealand vs. Australian Universities: Non-labour Expenditures (in 2018 $000), 2008-2018



Source: New Zealand TEC and Australian Government DoE.
Note: The numbers for Australian groupings are the averages for the universities within the groupings.

EFTS Enrolments

The final input variable used in the MPI analysis is EFTS enrolments, representing the number of students enrolled in universities. According to the New Zealand National Qualifications Framework (NZQF), EFTS are calculated based on a student taking 120 equivalent credits (typically eight courses of 15 credits) in a single academic year. For this study, EFTS data in New Zealand is sourced from the New Zealand MoE and aggregated across the ten levels of the NZQF, ranging from certificates (Level 1-4) to doctoral degrees (Level 10). For Australian universities, the EFTS data collected by the Australian Government DoE is more aggregated than AQF specifications, with universities covering AQF Levels 5 to 10.

Using EFTS as an input captures the scale of educational services delivered by each university and reflects the demand for teaching resources, such as academic staff time, classrooms and administrative support. The more students enrolled, the greater need for teaching resources and support. EFTS serve as a proxy for student load, reflecting the total teaching capacity required by a university.

EFTS is commonly used as an input variable in MPI analysis in New Zealand (Smart, 2009; Wang et al., 2020) and international studies (Flegg et al., 2004; Johnes, 2008; Worthington & Lee, 2008; Agasisti & Johnes, 2009; Margaritis & Smart, 2011; Agasisti & Pohl, 2012; Parteka & Wolszczak-Derlacz, 2013).

EFTS enrolments can also be used as a teaching output measure (Abbott & Doucouliagos, 2003; Kuo & Ho, 2008; Smart, 2009 and DEA model in section 3.5.4 (Bolli & Farsi, 2015; Gemmell et al., 2017; New Zealand Productivity Commission, 2018b). However, using EFTS as an output has several limitations due to exogenous factors, such as labour market conditions or changes in government policies and funding, which may cause fluctuations in enrolment numbers. Given these considerations, EFTS is used here solely as an input variable to analyse university performance in the MPI analysis.

This study adopts EFTS enrolments at undergraduate and postgraduate levels. This separation allows for a fairer and more accessible comparison of university performance, as postgraduate students typically require more resources and are associated with higher teaching costs.

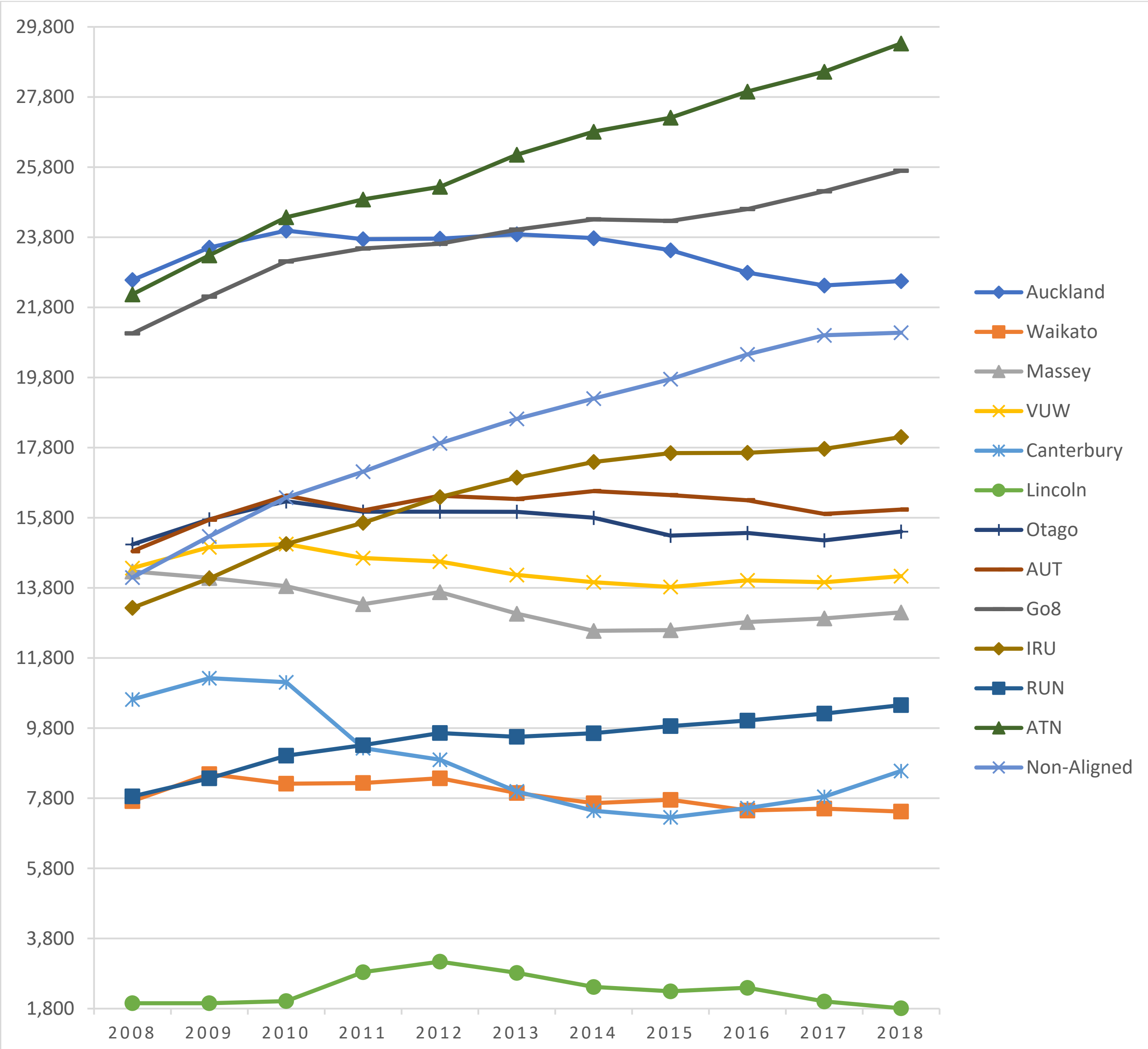
Trends in Undergraduate and Postgraduate EFTS: 2008-2018 in Figures 4.8 and 4.9

Both countries experienced relatively stable increases in undergraduate enrolments. The University of Auckland and the Australian ATN and Go8 universities exhibited the highest enrolments, while smaller universities, such as Lincoln University and Australian RUN universities, had lower numbers. The University of Canterbury showed a decrease in enrolments after the 2011 earthquake, with recovery starting around 2016. Overall, New Zealand universities demonstrated moderate, steady increases in undergraduate EFTS, while Australian universities consistently maintained high enrolment numbers, particularly the Go8 and non-align universities.

Postgraduate enrolments showed more variation, with Australian Go8 universities exhibiting significant increases over time. In New Zealand, the University of Auckland and Otago, recognised for their research excellence, showed notable rises in postgraduate enrolments. However, smaller New Zealand universities like Lincoln University, the University of Waikato, and Australian RUN universities displayed more stable but lower postgraduate enrolments.

Figure 4.8

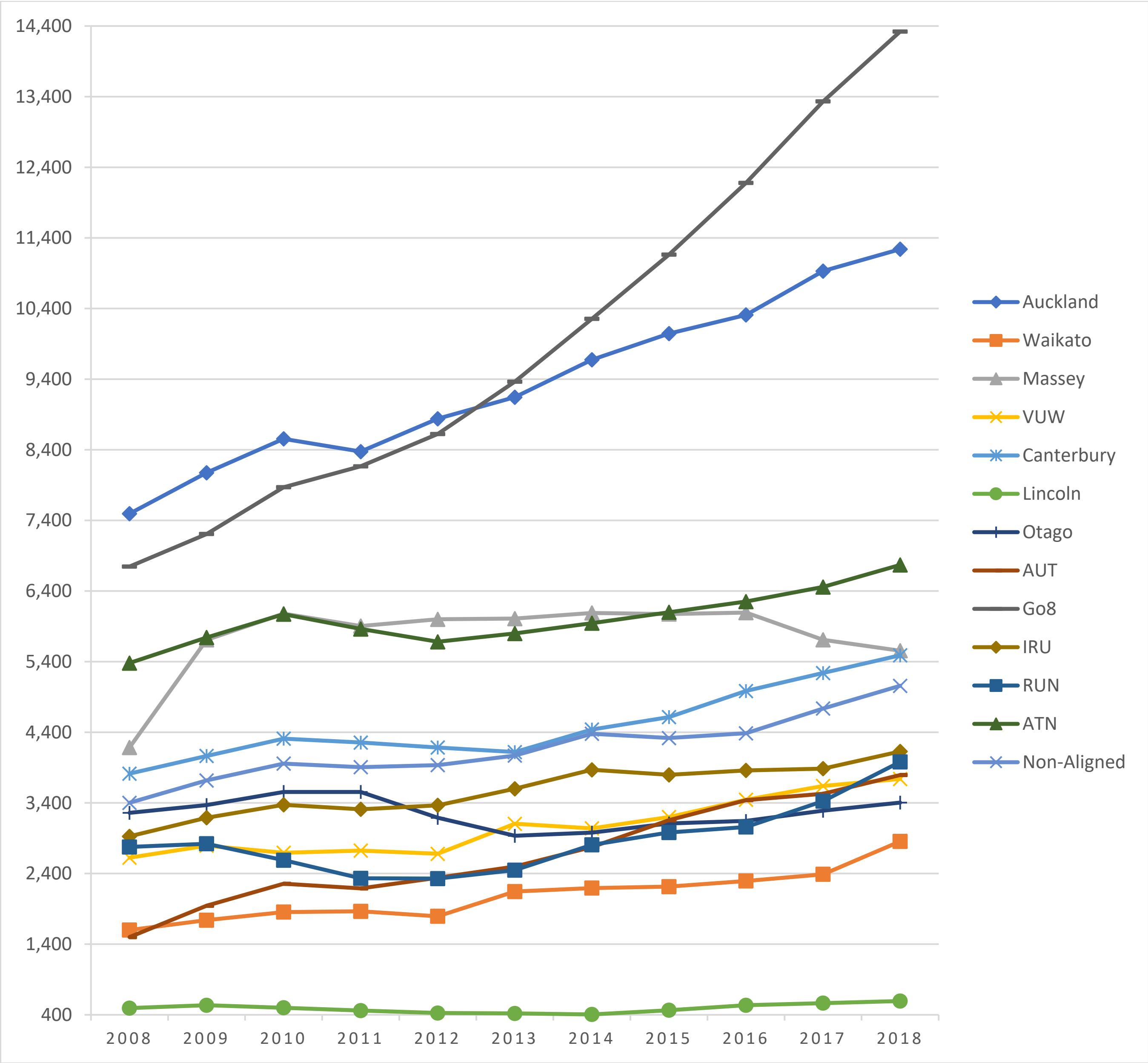
New Zealand vs. Australian Universities: Undergraduate EFTS Enrolments, 2008-2018



Source: New Zealand MoE, and Australian Government DoE.

Note: The numbers for Australian groupings are the averages for the universities within the groupings.

Figure 4.9
New Zealand vs. Australian Universities: Postgraduate EFTS Enrolments, 2008-2018



Source: New Zealand MoE, and Australian Government DoE.
Note: The numbers for Australian groupings are the averages for the universities within the groupings.

Robustness for Capital Costs Measures

(1) Alternative proxy for capital costs

To provide the robustness check of capital input measures, this study utilises the TEC data as an alternative proxy for capital inputs for New Zealand universities. This proxy includes expenses related to depreciation and amortisation[85], occupancy and property costs[86], and non-property leases[87]. TEC data provides consistent and detailed capital-related cost information, which estimates the proportion of non-labour expenses attributed to capital costs. These categories represent a broad range of capital expenditures in maintaining and utilising physical capital stock across universities.

For Australian universities, similar data is sourced from the Australian Government DoE. This includes expenses such as depreciation and amortisation, repairs and maintenance, impairment of assets, and net loss on disposal of property, plant, equipment, and non-capitalized equipment.

Other expenses in New Zealand and Australia are determined by deducting labour and capital expenses from total expenses. More precisely, in New Zealand universities, other expenses include faculty support and related costs, finance costs and other expenses. In Australian universities, other expenses include finance costs, investment losses and other expenses.

Table 4.8 reports the shares of total expenses allocated to staff, capital, and other costs across New Zealand universities and Australian university groups. On average, New Zealand universities allocate 55.8% of their total expenses to staff expenses, comparable to the 54.5% observed in Australian university groupings. While the shares are similar, the unit for labour costs differ significantly (Auckland: NZD 112,651 vs Sydney: NZD 175,563 vs NSW: NZD 162,338 vs Melbourne: NZD 155,735). These variations may reflect differences in financial resources, and the scale of operations, particularly in larger Australian universities such as the University of Sydney and Melbourne compared to their New Zealand counterparts.

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[85]TEC defines depreciation and amortisation as follows:

1) Depreciation is on fixed assets (and intangible software asset amortisation), excluding amortisation of capitalised course development costs and profit or loss on asset disposal.
2) Amortisation refers to course/programme amortisation costs, and amortisation costs of leasehold improvements.

[86] The definition provided by TEC for occupancy and property costs includes rent, rates, energy, maintenance and all other property-related costs, including lease payments and any property impairment expense.

[87] Based on TEC's definition, non-property leases include equipment leases. This could include IT leases or leasing equipment such as computers, software and servers. For instance, the AUT annual report (2020) lists equipment lease operating costs. VUW annual report mentions IT leases. It is noted that Lincoln and Otago report zero values for non-property leases. Non-property leases provide capital services equivalent to those of owned assets, which should be included in capital stock calculations.

Table 4.8
Cost Shares (%) by Expense Category, 2008-2018

University	Staff expenses	Capital expenses	Other expenses
Auckland	53.2	18.4	28.4
Waikato	55.6	13.9	30.5
Massey	58.1	15.6	26.4
VUW	53.1	18.3	28.5
Canterbury	55.8	17.6	26.6
Lincoln	53.1	11.8	35.1
Otago	57.6	15.2	27.2
AUT	59.9	18.4	21.8
New Zealand Average	*55.8*	*16.1*	*28.1*
Go8	52.6	12	35.4
IRU	54.9	10.5	34.6
RUN	53.9	10.2	36
ATN	56.1	9.8	34.1
Non-aligned	55.4	10.5	34.1
Australia Average	*54.5*	*10.7*	*34.8*

Source: New Zealand TEC and Australian Government DoE.
Note: 1. The other expenses in New Zealand and Australia are determined by deducting labour and capital expenses from total expenses.
2. The numbers for Australian groupings are the averages for the universities within the groupings.

It is crucial to note the limitations and potential biases in this approach. The Australian DoE does not explicitly define these capital expense categories. Instead, these categories are derived from accounting definitions and similar related capital expenses in university annual reports. Therefore, these shares used in the robustness analysis represent an estimate of capital costs, which may provide a more specific representation compared to the broader non-labour expenditure category as a proxy for capital costs. On average, 16.1% of total expenditure is attributed to capital expenses in New Zealand universities, compared to 10.6% for Australian universities.

(2) Depreciation and Amortisation as Capital Costs

Following Johnes (2006), this study utilises depreciation and amortisation as a proxy for capital costs. Although Johnes (2006) also includes interest payments in the estimation of capital costs, such data is unavailable in the TEC data. Thus, this study relies solely on depreciation and amortisation as a measure of capital costs. These data are derived from the New Zealand TEC dataset and Australian MoE data, as previously detailed above (1).

(3) Adjusting Physical Capital Stock (e.g., Plant, Property and Equipment)

This approach uses teaching weights the New Zealand Productivity Commission (2018b, p. 64) constructed a simple indicator of capital productivity, measured as EFTS per thousand dollars of physical capital stocks (e.g., property, plant, and equipment, PPE). However, this raw measure has limitations. Universities engage in teaching and research, with significant resources devoted to research outputs. The proportion of research to teaching varies across universities, the raw capital productivity may present research-intensive universities unfairly. Although the TEC data do not include an output variable for research, the data does split university income into teaching and research categories. The ratio of teaching income to total teaching and research income serves as a weight representing a proxy for the teaching intensity of the university. This *teaching weight*[88] is applied to the value of property, plant, and equipment to derive "*teaching capital*[89]", ensuring a more equitable comparison across universities.

The teaching and research income data are sourced from New Zealand TEC and Australian DoE.
In New Zealand, teaching income includes government tuition funding, student fees and charges. Teaching income for Australian universities includes the Commonwealth Grant Scheme and other grants, the Higher Education Loan Program (HELP), and fees and charges, etc. More details on teaching and research income can be found in Section 4.1.5.

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[88]The New Zealand Productivity Commission (2018b) mentions several implicit assumptions underlying the use of current income data to scale capital stock. First, it assumes that research and teaching have a similar level of capital intensity. Second, it assumes that the current income split has not changed too much over time, as the capital stock reflects past decisions. Lastly, it assumes that these assumptions are reasonable within the context of its analysis.

[89] The New Zealand Productivity Commission (2018b) also used *teaching capital flows* as a measure of capital input, including depreciation costs and the teaching capital multiplied by the capital charge rate (below notes), rather than relying on solely physical capital stocks, because not all PPE is equal, and it is depreciating at different rates over time.

Note: 1. Although the New Zealand Government does not impose a capital charge on universities for historical and political reasons, the New Zealand Productivity Commission (2018b) applied a 7% capital charge rate, consistent with the rate applied to other state-sector entities at the time. Additionally, although the legal title has not yet been transferred from the Crown, which still owns the land and buildings, the University has assumed all the normal risks and rewards of ownership (The University of Auckland, 2019, p. 62), such as complete control over land and structures and the ability to profit materially and substantially from their usage.

2. Specific information regarding the capital charge rate for Australian universities could not be identified. To maintain consistency with the data available for Australian universities, this study uses only teaching capital as the measure of capital input.

Therefore, in the robustness check for capital costs, the non-labour costs proxy for capital costs is replaced by (1) the capital-related categories provide a specific view of capital expenditures associated with the maintenance and utilisation of physical capital assets within universities, such as depreciation and amortisation, occupancy and property costs, and non-property leases etc., (2) depreciation and amortisation—this measure exclusively focuses on depreciation and amortisation as proxies for capital costs, (3) adjusted teaching capital is physical capital stock (e.g., plant, property and equipment) adjusted by teaching income as a proportion of teaching and research income. These alternative measures are in the econometric estimations detailed in Section 4.2.1 to enhance the robustness of the analysis.

4.2.2 *Output Variables*

Research Output—Research Income

This study employs research income data as a proxy for research output, consistent with its use in the partial labour productivity analysis. Research income data is collected from New Zealand's TEC and Australia's DoE and enables comparisons between New Zealand and Australian universities. Detailed information on research income is provided in Section 4.1.5.

Teaching Output—Adjustment for Credit and Income-Weighted Completions

This study adjusts qualification completions for quality by weighting credits and expected income levels, reflecting expected incomes associated with different qualification levels. The teaching outputs include undergraduate and postgraduate credit and income-weighted completions. To ensure consistency, the data used for these adjustments are the same as those described in Section 4.1.4, sourced from the New Zealand MoE and the Australian Government DoE.

Robustness Check for Research Outputs

In the robustness check for research output, research income is replaced by the citation-weighted number of WoS-indexed articles and reviews in the econometric estimations outlined in Section 4.1.6. The quality-adjusted research publications are calculated by multiplying the number of articles and reviews by their corresponding citation weights. The citation weight is known as Category Normalised Citation Impact (CNCI).

4.2.3. *A Summary of Variables Used for the Malmquist Productivity Index Analysis*

Table 4.9 summarises the input and output variables used in the Malmquist productivity index analysis. Some of the variables are the same as those used in the partial labour productivity analysis (see Section 4.1.7). They are repeated here for completeness.

Table 4.9
Summary of Input and Output Measures used in the Malmquist Productivity Index

Category	Variables	Description
Inputs	Teaching FTE staff	NZ: 50% of academic/tutorial FTE for teaching FTEs
		AUS: 50% of teaching and research FTEs plus teaching-only FTEs
	Research FTE staff	NZ: 50% of academic/tutorial FTEs plus research-only FTEs
		AUS: 50% of teaching and research FTEs plus research-only FTEs
	General FTE staff	NZ: All staff other than those engaged in the teaching process, including librarians, IT staff, general and administrative and managerial staff, but excluding researchers and technicians
		AUS: Academic support staff, student services staff, and public services staff
	Capital Expenses	NZ and AUS: Total costs minus labour costs
	UG EFTS enrolments	NZ: EFTS enrolments at Certificates levels 1 to 4, Certificates & Diplomas levels 5 to 7, Bachelor's Degree level 7, and Graduate Certificates/Diplomas level 7
		AUS: EFTS enrolments at other undergraduates at Levels 5 to 7, Associated Degree Level 6, and Bachelor's Degree level 7
	PG EFTS enrolments	NZ and AUS: EFTS enrolments at Honours or Postgraduate Certificates or Diplomas, Master's Degree and Doctorate Degree.
Outputs	Credit and income-weighted UG Completions	Qualification completions weighted by credit and income levels associated with different undergraduate qualification levels
	Credit and income-weighted PG Completions	Qualification completions weighted by credit and income levels associated with different postgraduate qualification levels
	Research Income	NZ: PBRF income, external research grants and other research-derived income (NZD$000) in 2018 New Zealand Dollars

		AUS: Australian Government research grants (e.g., ARC etc.) and research contract income (e.g., royalties, trademarks and licences, consultancy and contracts) (NZD$000) in 2018 New Zealand Dollars

4.3 Stochastic Distance Function Analysis

While the previous subsection described the data used in the labour productivity and MPI analysis, this subsection focuses on the data used in the SFA analysis. Sections 4.3.1 and 4.3.2 discuss the inputs and outputs utilised in the SFA output distance function (ODF) analysis, while section 4.3.3 introduces the variables employed in the SFA inefficiency effect model. Section 4.3.4 provides a summary of the variables used in the SFA ODF analysis.

Although the MPI and SFA methodologies utilise the same teaching output variable (from the same data source)—adjusted completions—they are used in distinct methodologies and thus are discussed in their respective sections and corresponding literature. Additionally, MPI analysis focuses on teaching and research functions, using respective FTE staff data from the New Zealand TEC, which also provides research-only FTEs, to analyse productivity changes and trends for partial labour productivity and MPI.

Conversely, the SFA analysis relies on university annual report data to calculate academic and general staff prices, as some New Zealand universities provide detailed personnel cost data. For instance, universities such as the University of Auckland, Canterbury, Otago, Waikato, and AUT separate total staff costs into academic and general salaries, enabling more precise calculations. However, other universities, including Lincoln University, Massey University and VUW (and TEC), only report total personnel costs in their annual reports, which limits the staff price level of detail available for SFA cost frontier analysis.

These differences in data availability necessitate using different data sources across methodologies in this study, resulting in variations in key variables, such as FTE staff, non-labour expenses and research income, based on the specific data source. To address these discrepancies, this study conducts sensitivity analyses within each empirical results section, using alternative data sources to assess the robustness of the findings.

4.3.1 *Output Variables*

Universities ideally should utilise the long-term added value of their research and education on society's human capital in evaluating their final outputs (Bolli & Farsi, 2015). Since insufficient outcome measures are available, empirical studies often rely on simple measures of intermediate outputs, such as the number of completions (Johnes, 2014b; Letti et al., 2022), enrolments (Stevens, 2005; McMillan & Chan, 2006; Kuo & Ho, 2008; Bolli & Farsi, 2015), publications (Abbott & Doucouliagos, 2009; Bolli et al., 2016), or financial grants (Agasisti et al., 2016; Barra et al., 2018).

Teaching Output: Completions vs. Credit and Income-Weighted Completions

Letti, Bittencourt and Vila (2022) used the number of undergraduate and postgraduate degree completions as teaching output variables in a stochastic output distance function with a translog specification, also testing alternative error term models by Battese and Coelli (1992, 1995). They argued that degree completions could more accurately capture the costs incurred by higher education institutions, specific results related to the accumulation of human capital, and the purpose of "teaching" to prepare professionals, compared to student enrolment measures (Letti et al., 2022, p. 58). Building on this approach, this study uses the number of undergraduate and postgraduate completions weighted by credits assigned to each qualification under the NZQA and AQF frameworks, providing a quality-adjusted measure of teaching outputs, as detailed in Section 4.1.4.

Research Output: Research Income

Research income is used in efficiency analysis as a proxy for the universities' research reputation, reflecting its ability to attract competitive funds and maintain research quality (Agasisti & Haelermans, 2016). It also measures the market value of research, allowing for an ingenious combination of quantity and quality of research effort (Johnes, 1997; Worthington, 2001; Agasisti & Johnes, 2010; Agasisti & Gralka, 2019). This is also in line with SFA models utilised in previous studies (Kempkes & Pohl, 2010; Kempkes & Pohl, 2008; Bolli & Farsi, 2015; Gralka et al., 2019).

In the SFA ODF analysis, research income for New Zealand universities, is sourced from university annual reports and includes PBRF income[90] and research contract income (e.g., external research income and consulting and commercial revenue). For Australian universities, research income, is also derived from university annual reports, and includes Australian Research Council (ARC) grants, Research Block

[90] Further information on PBRF is provided in Section 4.2.2.

Grants (RBG) and research contracts income (e.g., royalties, trademarks and licences, consultancy and contract income). It should be noted that variations in the classification of research income between the TEC and financial statements for university annual reports may lead to inconsistencies in the reported data across universities. Thus, based on university annual reports data, the SFA ODF calculations of research income may differ from the figures reported by the TEC.

Robustness Check for Research Outputs

In the robustness check for research output, research income is replaced by the citation-weighted number of WoS-indexed articles and reviews in the econometric estimations outlined in Section 4.1.6. The quality-adjusted research publications are calculated by multiplying the number of articles and reviews by their corresponding citation weights, referred to as the Category Normalised Citation Impact (CNCI).

Additionally, for the robustness check for research output, research income changes to data resources from the New Zealand TEC data and Australian Government DoE, as outlined in Section 4.1.5. This ensures the reliability of the findings by incorporating alternative data resources.

4.3.2 *Input Variables*

Labour Inputs—Academic and General FTE staff

University annual reports data on FTE staff for New Zealand universities are divided into two categories: (1) academic FTE staff[91] and (2) general FTE staff[92]. Similarly, Australian universities categorise staff data from university annual reports into (1) academic FTEs[93] and (2) general FTEs[94], providing a

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[91] Only some New Zealand universities provide the details of academic and general staff categories in their annual reports. These staff categories are based on the details of annual reports from the University of Auckland and the University of Otago. The academic FTE staff from annual reports include professors, associate professors, senior lectures, lectures, other teaching and research staff.

[92] 3. Only the University of Otago's annual reports provide details of general staff categories, and this description comes from Otago's annual reports, which include executives, technicians, librarians, administrators and general services staff.

[93] Australian academic full-time and fractional full-time staff.

[94] Australian's total number of FTE general staff includes academic support, student services, public services FTE staff etc.

comparable basis for labour inputs across both countries. Data for these two staff types is used in the SFA ODA analysis.

Capital Input—Non-Labour Expenses

Due to the lack of explicit capital expenditure information in the university annual reports, non-labour expenses are used as a proxy for capital inputs in the SFA ODF analysis. These expenses are calculated as total costs minus labour costs (Worthington & Higgs, 2011; Bolli & Farsi, 2015; and Letti, Bittencourt & Vila, 2022). A more detailed explanation of capital costs is provided in Section 4.2.1.

4.3.3 *Variables Used in the Inefficiency Effects Model (Battese and Coelli (1995) Model Specification)*

The inefficiency effects model (Battese & Coelli, 1995, named BC95 model) examines the factors that may influence university inefficiency by incorporating specific exogenous variables into the stochastic frontier framework. These exogenous variables, also known as "Z-variables" or "determinants of efficiency", are included in the model to account for their impact on performance. While these variables are neither inputs nor outputs in the production process, they may impact producer performance (Gralka, 2018a; Huang et al., 2022, p. 763).

In this study, the observable explanatory variables in the inefficiency effects model are used to capture differences in university characteristics that may influence inefficiency. These variables include region dummies, characteristics of EFTS (such as the proportions of international or domestic female EFTS enrolments), medical school dummies and staff composition (ratio of general to academic FTE staff). The use of these variables in the international studies is discussed in Chapter 3.2.5. Descriptive statistics for these variables are shown in Table 4.15.

Location Effect—Region Dummies

To account for location effects, this study includes regional dummies for New Zealand and state territory dummies for Australia. These variables capture the potential influence of geographic location on university efficiency. The classification of New Zealand universities by region is presented in Table 1.2, and Australian universities by state territory in Table 1.4.

EFTS Demographics—Proportion of International EFTS

This study includes the proportion of international EFTS as a determinant of inefficiency. The variable reflects the socio-demographic composition of the enrolled students and the potential effect of international EFTS on university efficiency (Kempkes & Pohl, 2008). It is calculated as the ratio of international EFTS to total EFTS at each university.

EFTS Demographics—Proportion of Domestic Female EFTS

The proportion of domestic female EFTS is also included as a determinant of inefficiency. This variable reflects the gender composition of the student population and is measured as the ratio of domestic female EFTS to total EFTS at each university.

Faculty Composition—Medical School

This study includes a dummy variable for the presence of a medical school to capture the potential impact of faculty composition on university efficiency. Medical schools entail higher operational costs and unique service demands, such as clinical training and specialised equipment. Focusing on medical schools ensures consistency with previous research, which commonly examines medical faculties to analyse university inefficiency.

In New Zealand, only the University of Auckland and Otago operated medical schools during 2008-2018, while all universities offered engineering courses. In Australia, the number of universities with medical schools increased from 16 in 2008 to 19 in 2018. As of 2008, all Go8 universities had medical schools, one RUN university, three Non-aligned universities, four IRU universities, and none in the ATN universities. By 2018, medical schools had expanded to two additional Non-aligned universities and one ATN university.

Staffing Structure: Ratio of General to Academic FTE Staff

This study uses the ratio of general to academic FTE staff as a determinant of inefficiency. The ratio is calculated as the number of general FTE staff divided by the academic FTE staff at each university. It captures differences in staffing structure, which may affect how universities allocate resources between teaching, research and administrative support.

Although universities can adjust their staffing mix to some extent, the ratio is also influenced by external factors such as budget constraints, historical staffing arrangements, and employment regulations. For example, staff dismissals must follow fair and proper procedures (Employment New Zealand, 2024), which could be time-consuming and may influence the efficiency of university operations. In addition, personnel costs per FTE, which are expected to be consistently measured across universities, may also vary across institutions depending on staffing composition (e.g., a different staff mix). Thus, this study measures how staffing structures influence university efficiency.

4.3.4 *A Summary of Variables Used for SFA—Distance Function Analysis*

Table 4.10 summarises the input and output variables used in the SFA ODF analysis. Some of the variables are the same as those used in the MPI analysis (see Section 4.1.7). They are repeated here for completeness.

Table 4.10
Summary of Input and Output Measures used in the SFA—Distance Function Analysis

Category	Variables	Description
Inputs	Academic FTE staff	New Zealand academic FTE staff include professors, associate professors, senior lectures, lectures, other teaching & research staff.
		Australian academic full-time and fractional full-time staff.
	General FTE staff	New Zealand general FTE staff includes executives, technicians, librarians, administrators and general services staff.
		Australian total number of FTE general staff includes academic support, student services, public services FTE staff etc.
	Capital Expenses	The non-labour expenditure (e.g., total expenses minus personnel costs) as a proxy for capital costs.
Outputs	Credit and income-weighted UG Completions	Qualification completions weighted by credit and income levels associated with different undergraduate qualification levels
	Credit and income-weighted PG Completions	Qualification completions weighted by credit and income levels associated with different postgraduate qualification levels
	Research Income	NZ: Performance-based research funding (PBRF) income and research & contract income (NZD$000) in 2018 New Zealand Dollars
		AUS: Australian Government research grants (e.g., ARC., etc.) and research contract income (e.g., royalties, trademarks and licences, consultancy and contracts) (NZD$000) in 2018 New Zealand Dollars
	Medical school	Dummy variable of existence of medical school in university.

Inefficiency Effects Model	Share of overseas	The ratio of international to the total EFTS enrolments.
	Region dummies	New Zealand South Island Region dummy variable, e.g., South Island dummy equals 1 if the university is located in the South Island and 0 otherwise (where North Island New Zealand is the reference region).
	Ratio of general to academic staff	The ratio of general to academic FTE staff.
	Share of female students	The ratio of domestic female to the total EFTS enrolments.

4.4 Stochastic Cost Frontier Analysis

This section details the data employed in the stochastic cost frontier analysis (SCFA). Sections 4.4.1, 4.4.2 and 4.4.3 outline the data used for cost, output and input variables, respectively. The SCFA also utilises the Battese and Coelli (1995) model (BC95 model), with the variables for the inefficiency effect model outlined earlier in Section 4.3.3. Descriptive statistics for the SCFA variables are presented in Table 4.14.

4.4.1 *Cost Variables (Dependent Variable)*

In cost efficiency analysis, the dependent variable is commonly a university's annual total costs (Stevens, 2005; Kuo & Ho, 2008). Studies of German universities have also utilised this approach while applying normalised costs and related output variables to account for differences across universities. For instance, Kempkes and Pohl (2008, 2010) normalised total costs, third-party funds (from industry) and graduate numbers by student enrolments. In contrast, Gralka (2018b) and Agasisti and Gralka (2019) [95] normalised total expenditures, third-party funds and students by the number of graduates.

Normalisation accounts for differences in student non-completion rates, which can distort cost comparisons even when postgraduate and undergraduate activities are correlated (Johnes, 2014; Gralka, 2018). Agasisti and Haelermans (2016) further demonstrated that efficiency results are sensitive to the choice of output variables, such as whether research income, student numbers or graduate numbers are included.

[95] Gralka (2018b) and Agasisti and Gralka (2019) assume that third-party funding should be excluded from the total costs because it represents an output. In this study, "total costs net of third-party funds" is not used as the cost variable, due to unavailable third-party funds data for New Zealand universities.

This study defines the cost variable as total annual costs, normalised by the number of EFTS enrolments to ensure comparability across universities of different sizes.

4.4.2 Output Variables (Independent Variables)

Consistent with previous studies (Kempkes & Pohl, 2008, 2010; Gralka, 2018b; Agasisti & Gralka, 2019) and the cost variables Normalisation approach, the output variables in this study include credit- and income-weighted undergraduate and postgraduate completions, and research income. The number of EFTS normalises these variables. Specific details on undergraduate and postgraduate completions and research income are found in Section 4.3.1.

4.4.3 Input Price Variables (Independent Variables)

Labour and capital input prices are the essential variables in the SCFA, as they reflect the costs of university operations. Generally, labour and capital prices are assumed to be exogenous, and efficiency is assessed by selecting the input levels.

Labour Price: Total Personnel Costs per FTE

In this study, the labour price is measured as the ratio of total personnel costs to the total number of FTE staff at each university (Stevens, 2004, 2005; McMillan & Chan, 2006; Kuo & Ho, 2008; Kempkes & Pohl, 2008, 2010; Daghbashyan, 2011; Johnes & Johnes, 2016; Gralka, 2018b; Gralka et al., 2019). This aggregate measure is used because separate data for academic and non-academic staff costs are unavailable, particularly for Massey University, Victoria University of Wellington and Lincoln University.

The labour price serves as a proxy for the average cost of labour inputs and reflects differences in staffing structures across universities. For instance, some universities may hire more assistant professors and fewer professors, while others may employ more professors with fewer total research or teaching employees (Kempkes & Pohl, 2010). In other words, universities with a higher proportion of senior professors may report higher average personnel costs than those employing proportionally more junior staff.

Capital Price—Non-labour Expenditure per EFTS

Similarly, data on the capital price (which refers to the cost associated with utilising capital assets—such as machinery, plant and equipment—in the production process (Investopedia, 2023)) is still unavailable. This study measures the capital price as the total expenses minus labour costs (including depreciation, amortisation and other non-labour-related expenses), divided by the total EFTS. This provides a proxy for the capital price, following the approach of Worthington and Higgs (2011, p. 394) and Zhang et al. (2014, p. 3).

The measure reflects differences in resource use and cost structures across universities. As Glass et al. (2006, p. 131) noted, capital expenditure per student reflects the higher resource demands of science-oriented teaching programmes, which require greater investment in equipment and facilities.

4.4.4 A Summary of Variables Used for SCFA—Cost Frontier Analysis

Table 4.11 summarises the variables used in the SCFA. New variables introduced in this section include the cost variable normalised by EFTS, output variables (unadjusted and adjusted undergraduate and postgraduate completions, and research income) normalised by EFTS, and input price variables, such as labour price (personnel costs per FTE staff) and capital price (non-labour expenditure per EFTS). Variables previously outlined in the inefficiency effects model (also used in SFA ODF analysis) include the medical school dummy, the share of overseas students, the share of female students, region dummies, the ratio of general to academic staff. Some of the variables are the same as those used in the SFA ODF analysis (see Section 4.3.4). They are repeated here for completeness.

Table 4.11
Summary of Input and Output Measures used in the SCFA—Cost Frontier Analysis

Category	Variables	Description
Cost	Total costs/EFTS	Total expenses (CPI 2018 base year in NZD$000) divided by the number of EFTS enrolments.
Outputs	Unadjusted UG Completions/EFTS	The number of qualification completions at undergraduate levels divided by the number of EFTS enrolments.
	Unadjusted PG Completions/EFTS	The number of qualification completions at postgraduate levels divided by the number of EFTS enrolments.
	Adjusted UG Completions/EFTS	The number of credit and income-weighted undergraduate completions divided by the number of EFTS enrolments.

	Adjusted PG Completions/EFTS	The number of credit and income-weighted postgraduate completions divided by the number of EFTS enrolments.
	Research Income/EFTS	NZ: Performance-based research funding (PBRF) income and research & contract income (CPI 2018 base year in NZD$000) per EFTS.
		AUS: Research Council Grants, Research Block Grants, research & contracts income, Other Australian Government Financial Assistance and State and local government Financial Assistance (CPI 2018 base year in NZD$000) per EFTS.
Input Price	Price of FTE staff	Personnel costs are divided by FTE staff (CPI 2018 base year in NZD$000).
	Price of Capital input	Non-labour expenditure per EFTS enrolment as a proxy for capital price.
Inefficiency Effects Model[1]	Medical school	Dummy variable of existence of medical school in university.
	Share of overseas	The ratio of international to the EFTS enrolments.
	Region dummies	New Zealand Region dummy variables, e.g., South Island dummy equals 1 if the university is located in the South Island and 0 otherwise (where the North Island is the reference region).
	Ratio of general to academic staff	The ratio of general to academic FTE staff.
	Share of female students	The ratio of domestic female to total EFTS enrolments.

Note: The variables used in the SCFA inefficiency effects model are the same as the SFA output distance function analysis.

4.5 Mean of Variables in Each Model Specification Analyses

Tables 4.12 and 4.13 show the mean of variables utilised in partial labour productivity and MPI analyses, reflecting distinct operational characteristics between New Zealand and Australian universities. Each university operates in a very different manner. Except for teaching staff, New Zealand universities show lower average values across all variables compared to their Australian counterparts.

However, certain variables for specific New Zealand universities (e.g., the University of Auckland) are larger than those for groupings of Australian universities (except for Go8). For instance, Auckland has the largest number of teaching staff, more research income, and more indexed publications than other New Zealand universities, although it still falls behind the Australian Go8 universities in several variables. On average, New Zealand universities have about half or fewer indexed publications than the Go8 universities.

All variables in New Zealand are, on average, lower than those in Australia, except for the number of teaching staff. In both countries, teaching FTEs represent a smaller workforce than the general staff.

However, Australian universities benefit from significantly higher financial resources, with an average research income nearly 1.5 times that of New Zealand universities and double the adjusted undergraduate completions.

There are significant differences in the operation of each university. On average, Lincoln University, the smallest university in New Zealand, has 106 teaching FTE staff, whilst the University of Sydney employs the largest number of teaching staff (968). New Zealand's largest university, the University of Auckland, has 9,335 postgraduate EFTS enrolments, close to the Australian Go8 (9,930 EFTS). The number of credit and income-weighted postgraduate completions at the University of Auckland remains lower than in Australian Go8 universities.

Table 4.12

Mean of Variables for Australasian Universities over 2008-18

University	Teaching Staff	Research Staff	TEC General Staff	UG Completion	PG Completion	Completion	UG Credit weighted Completion	PG Credit weighted Completion	Credit weighted Completion
Auckland	944	1,201	2830	5,850	4,910	10,624	1,782,055	754,009	2,536,064
Waikato	279	338	898	2,572	1,110	3,608	643,673	176,645	820,318
Massey	592	1,019	1412	4,030	2,412	6,376	1,016,400	373,691	1,390,091
VUW	421	526	1069	3,942	1,664	5,493	1,157,873	280,555	1,438,427
Canterbury	359	427	1142	2,518	1,509	3,973	717,832	242,155	959,986
Lincoln	106	179	367	1,062	236	1,251	168,005	44,400	212,405
Otago	604	1,204	1999	3,544	1,877	5,304	1,164,659	306,164	1,470,823
AUT	541	541	1093	5,556	1,580	7,021	1,339,391	243,627	1,583,018
NZ average	***481***	***679***	***1,351***	**3,634**	**1,912**	***5,456***	***998,736***	***302,656***	***1,301,392***
Go8	723	1,793	2,745	6,168	5,054	11,227	2,199,281	935,171	3,134,452
IRU	340	484	1,169	4,026	2,172	6,198	1,422,996	365,201	1,788,196
RUN	222	208	708	2,354	1,709	4,063	805,999	276,095	1,082,095
ATN	472	689	1,599	7,543	3,625	11,176	2,648,029	622,803	3,270,832
Non-aligned	375	508	1,169	4,330	2,612	6,943	1,514,803	441,236	1,956,039
AUS average	***425***	***744***	***1,469***	***4,644***	***2,996***	***7,641***	***1,633,842***	***522,034***	***2,155,876***

Table 4.13

Mean of Variables for Australasian Universities over 2008-18

University	UG Credit- and income-weighted completion	PG Credit- and income-weighted completion	Credit- and income-weighted completion	TEC Research Income ($000)	Indexed publication	CNCI weighted Indexed publication	TEC Capital Expenses (Non-Labour Exp)	UG EFTS	PG EFTS	Total EFTS
Auckland	1,780,914	911,456	2,692,370	333,061	2,978	3,842	453,532	23,312	9,335	32,647
Waikato	639,924	214,079	854,003	48,115	552	711	96,447	7,888	2,086	9,975
Massey	1,007,622	451,239	1,458,861	104,293	1,177	1,511	194,584	13,301	5,765	19,066
VUW	1,155,251	342,340	1,497,591	72,502	1,014	1,305	171,472	14,331	3,063	17,394
Canterbury	715,594	295,672	1,011,267	58,758	1,013	1,299	143,283	8,884	4,502	13,386
Lincoln	161,492	55,657	217,149	39,015	273	352	55,873	2,332	491	2,823
Otago	1,163,876	376,455	1,540,332	163,424	2,139	2,749	251,526	15,636	3,254	18,890
AUT	1,317,075	292,527	1,609,602	23,128	558	727	125,259	16,095	2,675	18,770
New Zealand average	***992,718***	***367,428***	***1,360,147***	***105,287***	***1,213***	***1,562***	***186,497***	***12,722***	***3,896***	***16,619***
Go8	2,197,105	1,035,728	3,232,833	502,928	5,634	7,471	662,709	23,762	9,930	33,703
IRU	1,420,711	400,367	1,821,078	109,643	1,313	1,751	210,136	16,355	3,574	19,936
RUN	797,858	301,938	1,099,796	38,248	432	577	124,912	9,452	2,868	12,331
ATN	2,637,225	685,799	3,323,024	141,332	1,787	2,397	304,835	25,993	6,006	32,004
Non-aligned	1,510,575	484,083	1,994,658	110,735	1,332	1,783	234,955	18,263	4,170	22,437
AUS average	***1,628,974***	***574,867***	***2,203,841***	***184,921***	***2,138***	***2,845***	***309,482***	***18,259***	***5,255***	***23,522***

Source: New Zealand TEC; Australian Government DoE.

Note: 1. The numbers for Australian groupings are the averages for the universities within the groupings.

2. Australian average numbers are the average of each Australian university.

Tables 4.14 and 4.15 show the average values for the input, output and explanatory variables associated with inefficiency used in the SFA ODF and SCFA, covering individual New Zealand universities and Australian university groupings from 2008 to 2018. These tables provide an overview of Australasian universities' personnel and financial structures.

On average, Australian universities are larger than their New Zealand counterparts. For instance, the average number of academic staff and unadjusted and adjusted postgraduate completions at New Zealand universities are two-thirds of those in Australian universities. Australia also has nearly double the average number of adjusted undergraduate completions, capital expenses and research income compared to New Zealand. Australian universities generally employ more academic staff, while New Zealand universities recruit a higher ratio of general staff. For example, the University of Auckland has nearly twice the number of general staff compared to Australian Go8 universities.

There are significant differences in the average size of New Zealand universities. The largest, University of Auckland, consistently produces the largest average number of teaching output (undergraduate and postgraduate completions), hiring the highest average for academic and general staff and spending the highest average capital costs. Lincoln University experiences the exact opposite situation. As New Zealand's newest university, AUT produces the second-highest average number of (adjusted) undergraduate completions and the lowest average research income, with a higher average academic and general staff employed. The University of Otago employs the second-highest average academic and general staff numbers and capital costs but yields the highest average research income. Massey University employs the third-highest academic and general staff and produces the second-highest average number of (adjusted) postgraduate completions (with higher credit and income weights).

On average, Australian universities have more resources per student than their New Zealand counterparts (the costs per student averaging around NZD 29,888 compared to NZD 26,360 in New Zealand). The average staff price in Australian universities is approximately twice that in New Zealand universities (NZD 161,767 versus NZD 95,248). Moreover, the capital price (non-labour expenses per student) is higher in Australian universities (NZD 12,622), compared to New Zealand (NZD 11,275). However, New Zealand universities show encouraging signs in certain variables, such as the average EFTS enrolments at the University of Auckland (32,647), which are close to the highest enrolments for Go8 universities (33,703). New Zealand universities maintain a higher ratio of undergraduate completions per enrolment, while Australian universities have a higher ratio of postgraduate completions to enrolment, with greater adjusted teaching output per enrolment based on higher credit and income weights.

Significant variations exist within New Zealand universities. On average, Lincoln has the lowest total expenses and enrolments and delivers the fewest teaching and research outputs, though it has the highest costs per enrolment (NZD 36,937). In contrast, AUT has the lowest costs per enrolment (NZD 17,776) while the University of Auckland enrolls the largest proportion of EFTS and spends the largest expenditure, ranking third in costs per student (NZD28,214) among New Zealand universities.

Regarding average staff price, the University of Auckland (NZD 106,588) and Otago (NZD 99,979) spend the highest average personnel price whereas Lincoln University's lowest average personnel price (NZD 84,297) is roughly half of the Australian average (NZD 161,767). Differences in the ratios of general to academic staff possibly lead to these variations in average personnel price across universities.

Regarding teaching output per enrolment, Lincoln has the highest ratio of undergraduate completions per enrolment, whilst Auckland experiences the reverse case, possibly due to their drastically different enrolments and completions[96]. However, the University of Auckland and Massey University have the largest ratio of postgraduate completions (and adjusted for quality) per enrolment. Auckland and Massey enrolled the largest number of postgraduate students (particularly international postgraduates) and produced the largest postgraduate completions. In contrast, AUT produces the smallest ratios due to its undergraduate programme focus, such as certificate levels 3 or 4 and cert/diplomas levels 5 to 7.

Regarding research output per enrolment, Otago has the highest research income per student due to its larger PBRF income and high-quality research staff, while AUT has the lowest ratio due to its lowest average research income with higher enrolments. This trend aligns with its status as the newest university, granted in 2000, which began with a focus on teaching rather than research.

Regarding the explanatory factors related to the inefficiency levels, New Zealand universities exhibit a higher average proportion of female students (0.473) than Australian universities (0.419), indicating minor variation in domestic female-to-male student ratios. Notably, Massey University (0.537), the University of Otago (0.507), and AUT (0.507) have over half female EFTS, compared with Lincoln (0.323), Go8 (0.369), and ATN (0.356) universities, which have fewer female students. This aligns with

[96] For instance, Lincoln University specialized in primary sector-based subjects while the University of Auckland specialized in the clinical medicine area as it has the medical school.

Lincoln University's distinct agricultural focus, which may account for its lowest proportion of female students.

Moreover, New Zealand universities, except Lincoln University, maintain an average foreign enrolment ratio significantly lower than Australian universities (0.158 vs. 0.271). This means that, on average, one-third of students in Australian universities are international, with Lincoln University (0.261) and AUT (0.171) showing the highest proportions in New Zealand universities.

Only the University of Auckland and Otago offered medical schools in New Zealand during the period. In Australia, the number of universities with medical schools increased from 16 in 2008 to 19 in 2018. All Go8 universities had medical schools as of 2008, compared to one RUN university, three Non-aligned universities, four IRU universities, and none ATN universities. In 2018, they were added to two medical schools of non-align universities and one ATN university.

New Zealand has five universities (University of Auckland, AUT, University of Waikato, Victoria University of Wellington and Massey University) in the North Island as the benchmark and three others (Otago, Canterbury and Lincoln) on the South Island. In contrast, Australia's 37 public universities span eight States Territories. This study utilises the different region or state territory dummies to assess the location effect on university inefficiency. Note that Australian Catholic University has seven campuses, which are located in the multi-states. Most campuses are located in Sydney and so it is put into NSW State. It belongs to non-align group.

The average general-to-academic staff ratio exceeds one in all New Zealand universities (except for Lincoln University), with Canterbury having the highest ratio (1.498). This suggests that New Zealand universities hire more general staff and fewer academics. In contrast, Australian universities have ratios below one. Specifically, Go8 universities have fewer general staff than academics, with a ratio of 0.418.

Table 4.14

Mean of variables for Australasian Universities over 2008-18

University	AR Research income ($000)	AR Academic FTE	AR General FTE	AR Capital costs (non-labour exp $000)	AR Total expenses ($000)	Total expenses per EFTS ($000)	UG completions per EFTS	PG Completions per EFTS	Adjusted UG completions per EFTS	Adjusted PG completions per EFTS	AR Research income per EFTS ($000)	AR Average costs per FTE staff ($000)	AR Capital price (non-labour exp per EFTS) ($000)
Auckland	218,831	2,144	2,830	391,785	922,365	28.214	0.179	0.15	54.586	27.855	6.689	106.588	11.977
Waikato	48,118	633	876	97,288	231,764	23.247	0.258	0.111	64.129	21.441	4.824	89.202	9.757
Massey	110,972	1,450	1,642	195,364	472,750	24.825	0.211	0.127	52.874	23.724	5.822	89.704	10.258
VUW	68,258	945	1,072	152,552	351,465	20.201	0.227	0.096	66.459	19.678	3.924	98.585	8.767
Canterbury	58,758	762	1,138	164,025	348,695	26.335	0.188	0.114	53.541	22.39	4.422	97.117	12.482
Lincoln	32,171	340	312	48,353	103,280	36.937	0.362	0.086	57.523	20.08	11.51	84.297	17.224
Otago	239,518	1,589	2,229	247,590	629,267	33.346	0.188	0.099	61.655	19.951	12.692	99.979	13.123
AUT	23,090	1,085	1,090	124,506	334,522	17.776	0.298	0.083	70.19	15.451	1.223	96.511	6.612
NZ Average	***99,964***	***1,118***	***1,399***	***177,683***	***424,264***	***26.36***	***0.239***	***0.108***	***60.12***	***21.321***	***6.388***	***95.248***	***11.275***
Go8	502,409	3,731	1,530	664,062	1,482,515	46.39	0.184	0.151	65.423	30.804	16.428	154.491	20.714
IRU	109,592	1,115	878	210,784	516,545	29.145	0.195	0.111	68.936	20.062	8.092	165.104	12.139
RUN	38,352	571	567	125,483	296,143	24.092	0.185	0.132	63.027	23.419	3.398	150.651	10.218
ATN	147,650	1,710	1,049	312,258	780,996	24.512	0.232	0.117	81.569	22.12	4.714	168.695	9.743
Non-aligned	111,510	1,250	801	235,284	573,821	25.303	0.195	0.118	67.808	21.595	5.065	169.894	10.293
AUS Average	***185,732***	***1,682***	***956***	***310,906***	***729,323***	***30.275***	***0.195***	***0.126***	***68.089***	***23.698***	***7.741***	***161.887***	***12.822***

Source: New Zealand university annual reports, New Zealand MoE, Australian university annual report and Australian Government DoE.

Note: 1. The numbers for Australian groupings are the averages for the universities within the groupings.

2. Australian average numbers are the average of each Australian university.

Table 4.15

Mean of variables for Australasian Universities over 2008-18

University	North Island New Zealand	South Island New Zealand	Victoria State	New South Wales State	Queensland State	Northern Territory	Western AUS State	South AUS State	Tasmania State	AUS Capital Territory	Medical school (dummy)	Share of overseas	Ratio of general to academic FTE	Ratio of Female students
Auckland	1	0	0	0	0	0	0	0	0	0	1	0.138	1.319	0.48
Waikato	1	0	0	0	0	0	0	0	0	0	0	0.17	1.384	0.493
Massey	1	0	0	0	0	0	0	0	0	0	0	0.157	1.136	0.537
VUW	1	0	0	0	0	0	0	0	0	0	0	0.127	1.138	0.484
Canterbury	0	1	0	0	0	0	0	0	0	0	0	0.119	1.498	0.453
Lincoln	0	1	0	0	0	0	0	0	0	0	0	0.261	0.924	0.323
Otago	0	1	0	0	0	0	0	0	0	0	1	0.117	1.404	0.507
AUT	1	0	0	0	0	0	0	0	0	0	0	0.171	1	0.507
NZ Average	***0.63***	***0.38***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.25***	***0.16***	***1.23***	***0.47***
Go8	0	0	0.25	0.25	0.125	0	0.125	0.125	0	0.125	1	0.295	0.418	0.369
IRU	0	0	0.143	0.143	0.286	0.143	0.143	0.143	0	0	0.714	0.23	0.8	0.474
RUN	0	0	0.143	0.429	0.429	0	0	0	0	0	0.143	0.241	1.002	0.462
ATN	0	0	0.25	0.25	0	0	0.25	0.25	0	0	0.143	0.343	0.622	0.356
Non-aligned	0	0	0.364	0.364	0.091	0	0.091	0	0.091	0.091	0.455	0.248	0.746	0.435
AUS Average	***0***	***0***	***0.22***	***0.35***	***0.19***	***0.03***	***0.11***	***0.08***	***0.03***	***0.05***	***0.46***	***0.26***	***0.72***	***0.43***

Source: New Zealand MoE and Australian Government DoE.

Note: 1. The numbers for Australian groupings are the averages for the universities within the groupings.

2. Australian average numbers are the average of each Australian university.

3. Australian Catholic University has 7 campuses, which is located in the multi-states. Most campuses are located in Sydney and so put it into NSW State. It belongs to non-align group.

Chapter 5 Empirical Results: Partial Labour Productivity and Malmquist Productivity Index

This chapter presents the empirical results of partial labour productivity (LP) and the Malmquist productivity index (MPI). Section 5.1.1 introduces the empirical model of partial LP. Section 5.1.2 provides and discusses the results, and Section 5.1.3 concludes the LP analysis.

Section 5.2.1 outlines the empirical model for MPI. Section 5.2.2 presents the results and discussion. Section 5.2.3 provides a sensitivity analysis of MPI using alternative model specifications, and Section 5.2.4 concludes the MPI analysis. Appendix Chapter 5 provides supplementary and additional tables for robustness analyses.

5.1 Partial Labour Productivity Analysis

5.1.1 *Empirical Model*

Productivity measures how well a university converts inputs into outputs. Partial productivity measurements focus on one single input, such as labour, capital, or consumables. Partial labour productivity, measured as output per full-time equivalent staff (FTE), is widely used. It offers advantages, including the ability to be more easily carried out due to its lower data requirements and the ability to highlight the influence of changes in one particular factor on total productivity (New Zealand Productivity Commission, 2018b, p. 47).

Building on Gemmell et al. (2017), which established quality-adjusted productivity indexes for the tertiary education sector, this study explores the quality-adjusted labour productivity across Australasian universities from 2008 to 2018. Teaching and research outputs are adjusted using credit, income, and citation weights. A summary of alternative weights for these adjustments is provided. More robust productivity measures account for changes in quality-adjusted teaching and research outputs, such as qualification completions weighted by credit and/or income weights and citation weights from bibliometric databases (e.g., Web of Science, WoS). Details of variables in the equations in this section are provided in Table 4.6.

The following equations display the measures of partial teaching labour productivity (in levels):

$$\boldsymbol{Teaching\ Labour\ Productivity_1} = \frac{\boldsymbol{Completions}}{\boldsymbol{Teaching\ FTEs}} \qquad (5.1)$$

$$\textbf{Teaching Labour Productivity}_2 = \frac{\textbf{Credit-weighted completions}}{\textbf{Teaching FTEs}} \quad (5.2)$$

$$\textbf{Teaching Labour Productivity}_3 = \frac{\textbf{Credit \& income-weighted completions}}{\textbf{Teaching FTEs}} \quad (5.3)$$

The corresponding annual growth rates[97] (AGR) for each measure are calculated using the following general formula:

$$\textbf{Annual Growth Rate} = \frac{\textbf{Teaching Labor Productivity1}_t}{\textbf{Teaching Labour Productivity1}_{t-1}} - \mathbf{1} \quad (5.4)$$

where $\textbf{Teaching Labor Productivity1}_t$ represents the level of $\textbf{Teaching Labour Productivity}_1$ in the current year (e.g., 2009), and $\textbf{Teaching Labour Productivity1}_{t-1}$ represents the level in the previous year (e.g., 2008). The Average Annual Growth Rate[98] (AAGR) is measured as the mean of annual growth rates from 2008 to 2018.

Partial research labour productivity (in levels) is measured as follows:

$$\textbf{Research Labour Productivity}_1 = \frac{\textbf{Research income}}{\textbf{Research FTEs}} \quad (5.5)$$

$$\textbf{Research Labour Productivity}_2 = \frac{\textbf{Number of WoS-indexed articles and reviews}}{\textbf{Research FTEs}} \quad (5.6)$$

$$\textbf{Research Labour Productivity}_3 = \frac{\textbf{Citation weights} * \textbf{Number of WoS} - \textbf{indexed articles and reviews}}{\textbf{Research FTEs}} \quad (5.7)$$

The AGRs and the AAGR for research labour productivity are calculated similarly for teaching labour productivity.

Subsections 5.1.2 and 5.1.3 provide a statistical summary of the variables and the empirical results. The focus is on the impact of quality adjustments on partial labour productivity and how they differ across universities.

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[97] The AGR measures year-to-year changes in labour productivity, reflecting specific annual fluctuations. And AGR is sensitive to short-term variations and outliers, which may fail to reflect long-term trends. For instance, AUT's completions peaked at 7,780 in 2008 but exhibited annual fluctuations, ultimately declining to 7,230 in 2018.

[98] The AAGR is used in this study to capture sustained trends and smooth year-to-year volatility, reflecting long-term performance. This approach aligns with Gemmell et al. (2017), who used AAGR to evaluate labour and multifactor productivity across distinct periods.

Along with the empirical results presented below, prepare a clear picture of changes in each TLP and RLP over time, using the key graphs to illustrate these trends.

5.1.2 *Empirical Results and Discussion*

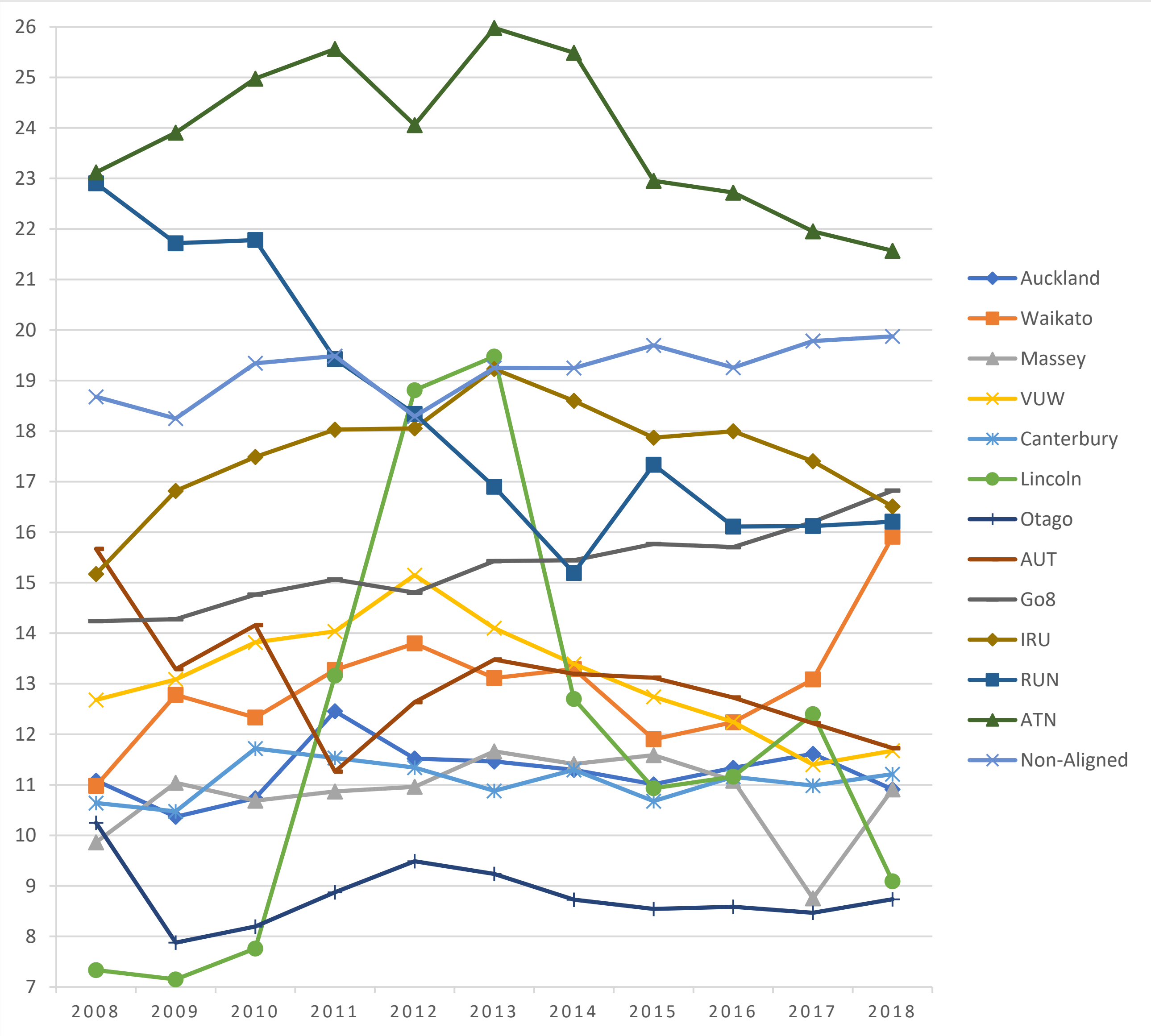
This section analyses partial labour productivity for teaching and research in New Zealand and Australian universities from 2008 to 2018. Three measures are used for both teaching labour productivity (TLP) and research labour productivity (RLP). More precisely, TLP is measured by (1) completions per teaching FTE, (2) credit-weighted completions per teaching FTE, and (3) credit and income-weighted completions per teaching FTE. RLP is measured by (1) research income per research FTE, (2) WoS-indexed articles and reviews per research FTE, and (3) citation-weighted WoS-indexed publications per research FTE. Lastly, the analysis of the AAGR of each teaching and research labour productivity are shown.

Teaching Labour Productivity 1

Completions per Teaching FTE from 2008 to 2018 are shown in Figure 5.1. All New Zealand universities show lower teaching productivity levels than their Australian counterparts, particularly Australian Technology Network (ATN) achieving the highest levels of teaching labour productivity.

Figure 5.1

Completions per Teaching FTE by New Zealand and Australian Universities, 2008-18



Source: New Zealand Ministry of Education (MoE), Tertiary Education Commission (TEC); Australian Government Department of Education (DoE).

Note: 1. The numbers for Australian groupings are the averages for the universities within the groupings.

2. Australian average numbers are the average of each Australian university.

In New Zealand, Lincoln showed significant fluctuations in its productivity levels, following the 2011 Canterbury earthquake, with a notable spike in 2011 (13.2) and 2013 (19.5), but it declined sharply to 9.1 in 2018. This variation is attributed to a sharp rise in completions at Certificates 1 to 3, followed by a dramatic decline in 2014. The 2011 merger with Telford Rural Polytechnic, the quick recovery of Lincoln's operations after the earthquake, and labour market conditions[99] in the Canterbury region, contributed to the surge in qualification completions between 2011 and 2013.

[99] Several factors might explain the productivity surge at Lincoln during this period:

The University of Waikato exhibited the highest teaching labour productivity increase, from 11.0 in 2008 to 15.9 in 2018. This steady upward trend was driven by a strong financial performance (4% surplus in 2012) (University of Waikato Annual Report, 2012), enabling investments in facilities and resources. Despite challenges in international enrolments, domestic enrolments grew steadily, boosting completions. The University of Waikato's relatively high international ranking (see Table 1.2) likely contributed to attracting high-quality staff, students and research opportunities.

In contrast, several New Zealand universities experienced declined completions per teaching FTE. AUT experienced the most significant drop, from 15.7 in 2008 to 11.7 in 2018, due to a 30.2% decrease in undergraduate completions and an 18.5% increase in teaching staff. Similarly, the University of Auckland's completions per teaching FTE declined from 11.1 to 10.9 over the same period, reflecting a 2.6% reduction in completions and an 18.5% increase in teaching staff. These trends suggest that not all New Zealand universities were able to sustain or improve their productivity during the period.

For Australian universities, the ATN consistently exhibited the highest teaching productivity levels among Australian university groups, peaking at 26.0 completions per teaching FTE in 2013. This reflects the efficient use of teaching staff and the largest average undergraduate and second-largest postgraduate completions (among Australian groups). Teaching FTEs increased by 21.6% from 438 in 2008 to 533 in 2018, and undergraduate completions averaged 7,543 and postgraduate completions averaged 3,625. This strong performance is linked to several factors: financial stability, enabling

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First, the 2011 merger with Telford Rural Polytechnic significantly contributed to the increase in completions, bringing in a substantial number of students enrolled in sub-degree and entry-level qualifications, especially in agricultural and land-based sectors. Integrating Telford's educational programmes into Lincoln's structure expanded the university provision, particularly at the secondary school level, to the doctoral level across the full ambit of agricultural and land-based sector provision (Lincoln University Annual Report, 2011, p. 4).

Second, despite the negative impact of the earthquake on student recruitment and retention, Lincoln benefited from stable short-term government funding that helped to drop temporary enrolments (Lincoln University Annual Report, 2011, p. 4). Some students might have enrolled at Canterbury chose Lincoln due to its ability to maintain operations during the post-earthquake period. Moreover, the post-earthquake labour market conditions in Canterbury possibly played a role in driving the increase in enrolments, particularly in short certificate-level courses. The region experienced a downturn in employment opportunities immediately following the earthquake, which may have resulted in more people pursuing further education and training in agriculture and land-based sectors, areas in which Lincoln was well-positioned to offer practical qualifications. This increase in enrolments at the certificate level directly contributed to the rise in completions between 2011 and 2013.

However, by 2013, the surge in completions began to decline as the immediate effects of the earthquake on student demand decreased, and the temporary spike in enrolments returned to more normal levels. Moreover, stabilizing the labour market and recovering the University of Canterbury's enrolment capacities possibly contributed to the final decrease in Lincoln's certificate-level completions in 2014.

investments in infrastructure, facilities, technologies, and student support systems (Curtin University Annual Report, 2011, p. 7; RMIT University Annual Report, 2013, p. 5; University of Technology Sydney Annual Report, 2018, p. 24). A significant contributor could be the strategic partnerships with international universities. ATN institutions may deliver courses collaboratively through offshore campuses or partner institutions[100].

With international students comprising around one-third of their enrolments, these partnerships may enable universities to increase completions without a corresponding rise in staff. Additionally, ATN universities emphasise a strong industry focus[101] through practice-based teaching and learning models (e.g., vocational training). These approaches enhance graduate employability and streamline resource utilisation, contributing to optimised productivity levels.

Teaching Labour Productivity 2

Figure 5.2 illustrates credit-weighted completions per teaching FTE from 2008 to 2018, with credit weights outlined in Table 4.3. Australasian universities generally exhibit similar productivity levels when completions are credit weighted. However, Lincoln University stands out with reduced fluctuations compared to unweighted completions per teaching FTE.

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[100] Australian universities provide offshore delivery of Australian higher education courses, allowing students worldwide to study Australian courses without travelling to Australia. These courses are offered through overseas Australian campuses, partnerships with foreign institutions, or online delivery, with courses recognised under the Australian Qualifications Framework.

While overseas enrolments combine offshore and inshore students, the Australian Government Department of Education reports only distinguish between domestic and overseas enrolments and completions without separating offshore and onshore data. Offshore delivery locations include China, Singapore, Malaysia, Vietnam and other countries (Australian Government Department of Education, 2024).

[101] RMIT University, established in 1887, is one of Australia’s original education institutions and the nation’s largest tertiary institution. It offers flexible pathways between vocational and higher education qualifications, supported by various scholarships, contributing to its strong performance in undergraduate completions and productivity.

Curtin University is Western Australia’s largest and Australia’s third largest international student population. Its courses have a strong practical focus, with many involving vocational or work experience components, ensuring students gain valuable hands-on experience.

The University of Technology Sydney (UTS) is the top-ranked young university in Australia, offers a variety of degrees in traditional and emerging disciplines, and provides a range of extracurricular programmes, industry placements, and internships.

The University of South Australia is the largest in South Australia and offers more than 400-degree programmes designed with a strong professional emphasis and in close consultation with industry.

In New Zealand, the University of Waikato consistently experienced the highest credit-weighted completions per teaching FTE over the periods. By 2018, the University of Waikato reached the highest productivity level of 3,769. Specifically, it indicates that each teaching FTE supported the completion of 3,769 credit courses. This is approximately equivalent to 10 completions of 360-credit courses (e.g., bachelor's or doctorate degrees) or 20 completions of 180-credit courses (e.g., master's degrees)[102]. This reflects its strong postgraduate completions, which increased from 920 in 2008 to 1,340 in 2018, with higher credit weights assigned to qualifications (e.g., honours postgraduate certificates and diplomas and master's and doctorates).

Lincoln University also displayed a notable recovery following the Canterbury earthquakes, with credit-weighted completions per teaching FTE increasing from 1,715 to 2,156 by 2018. This increase was less volatile than the unadjusted measures between 2010 and 2014. The use of credit-weighted completions results in a smoother evolution of teaching labour productivity over time compared with the unadjusted productivity measure.

Despite a slight decrease (from 3,187 in 2008 to 3,164 in 2018), Victoria University of Wellington (VUW) was the top performer among New Zealand universities in all years except 2018. This indicates that, even with minor declines, its adjusted teaching labour productivity remained relatively strong. AUT experienced a declining trend until 2011, followed by a rapid increase, peaking at 3,164 in 2014 due to a rise in the completion of undergraduate and doctoral degrees with large credit weights (360 credits) and then falling again to 2,902 in 2018.

Australian universities exhibited consistency between adjusted and unadjusted teaching labour productivity measures. The Go8 universities experienced a steady increase in credit-weighted completions per teaching FTE, from 4,084 in 2008 to 4,575 in 2018, driven by their large number of postgraduate completions with high credit weights. ATN universities maintained the highest productivity levels due to a large number of undergraduate and postgraduate completions.

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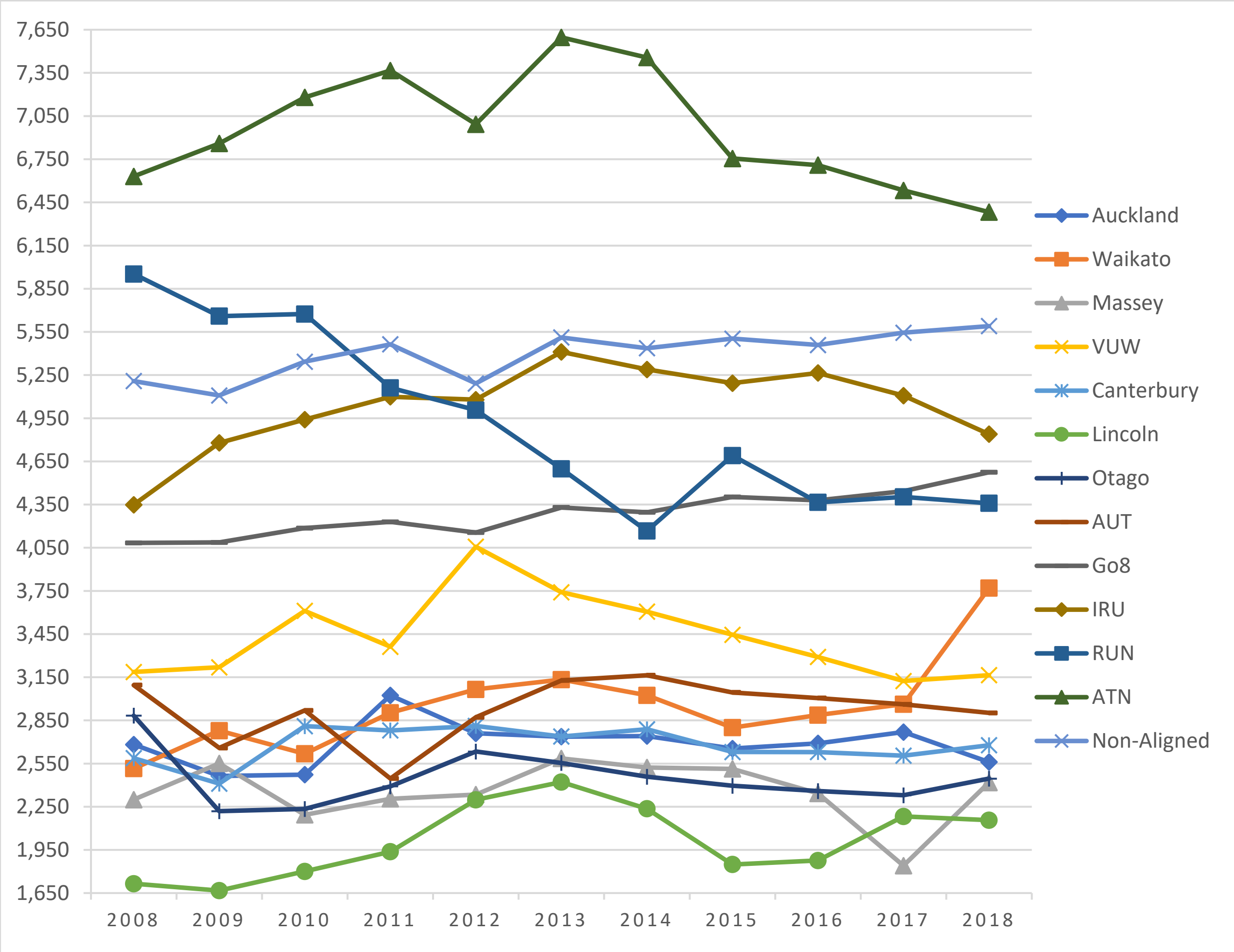
[102] The completions per teaching FTE for Waikato in 2018 were 15.9, indicating that each teaching FTE supported approximately 15.9 total qualification completions. These completions include undergraduate and postgraduate but are not weighted by their credit size. For instance, this could reflect the completion of lower-level qualifications (e.g., more diplomas or certificates) or a mix of qualification types.

In contrast, the credit weighting reflects the relative workload or size of the qualification or the "volume of learning represents the amount of equivalent full-time years of study required to achieve learning outcomes specified for an AQF qualification type (Australian Qualifications Framework, 2013)". For instance, the credit-weighted completion per teaching FTE for Waikato in 2018 was 3,769. This reflects the weighting of qualifications based on their credit values (e.g., 360 credits for a bachelor's degree or doctorate; 180 credits for a master's degree), reflecting the greater contribution of higher-level qualifications, such as bachelor's or master's degrees. Since the bachelor's or doctorate degrees are assigned the same credit value, it is necessary to incorporate income weights to account for the financial impact of different qualification types on teaching productivity.

Figure 5.2

Credit-weighted Completions per Teaching FTE by New Zealand and Australian Universities, 2008-18



Source: New Zealand MoE, TEC, New Zealand Qualification Framework (NZQF) (2016), New Zealand Qualification Authority (NZQA); Australian Government DoE, Australian Qualification Framework (AQF) (2013).

Notes: 1. In some cases, completion data is more aggregated than the NZQF and AQF specifications, and thus using averaged weightings for categories Level 5-7, Level 7 and Level 8. Credit weights by qualification level are described in Table 4.3.

2. The numbers for Australian groupings are the averages for the universities within the groupings.

3. Australian average numbers are the average of each Australian university.

Overall, the trends between adjusted and unadjusted measures of teaching labour productivity were relatively similar across universities (except Lincoln University). This approach highlights the importance of adjusting for credit weights in analysing labour productivity to capture better-detailed information on teaching labour productivity across universities. However, it does not fully account for the quality of completions, particularly as the credit-income weight one goes further.

Moreover, the results show a significant gap between New Zealand and Australian universities, with all Australian universities groupings outperforming their New Zealand counterparts. Australian universities particularly produce a greater number of postgraduate completions with higher credit weights, further contributing to their better productivity performance.

Teaching Labour Productivity 3

Figure 5.3 shows credit and income-weighted completions per teaching FTEs from 2008 to 2018. The measure incorporates both the credit weight of completions, and the impact of graduates' median earnings associated with qualifications. This approach offers a clearer view of productivity, particularly for higher-level qualifications such as master's and doctorate degrees, which have larger credit and income weights.

For New Zealand universities, the University of Waikato consistently exhibited the highest productivity levels, increasing from 2,597 in 2008 to 3,947 in 2018[103]. This is due to an increase in postgraduate completions from a relatively low base with higher weights and a decrease in teaching FTEs. Lincoln University also showed improved productivity, increasing from 1,786 to 2,260 during the period, despite remaining the lowest among the universities. This might be due to its mix of certificate and postgraduate completions. The University of Canterbury experienced moderate productivity at 2,863 in 2018, with significant growth in master's and doctoral completions (121% and 52%, respectively) from 2011 to 2018, despite declines in degree and below-degree completions.

The University of Auckland's productivity remained relatively stable, slightly decreasing from 2,822 in 2008 to 2,743 in 2018, indicating no significant improvement. The University of Otago and AUT experienced decreased teaching labour productivity using these adjusted measures, although by a lower amount than when completions are only credit weighted.

In Australia, Go8 universities maintained consistently high productivity levels, increasing from 4,194 in 2008 to 4,741 in 2018. This reflects their ability to maintain high postgraduate completion levels with high-income weights. Similarly, IRU and Non-aligned universities exhibited increased

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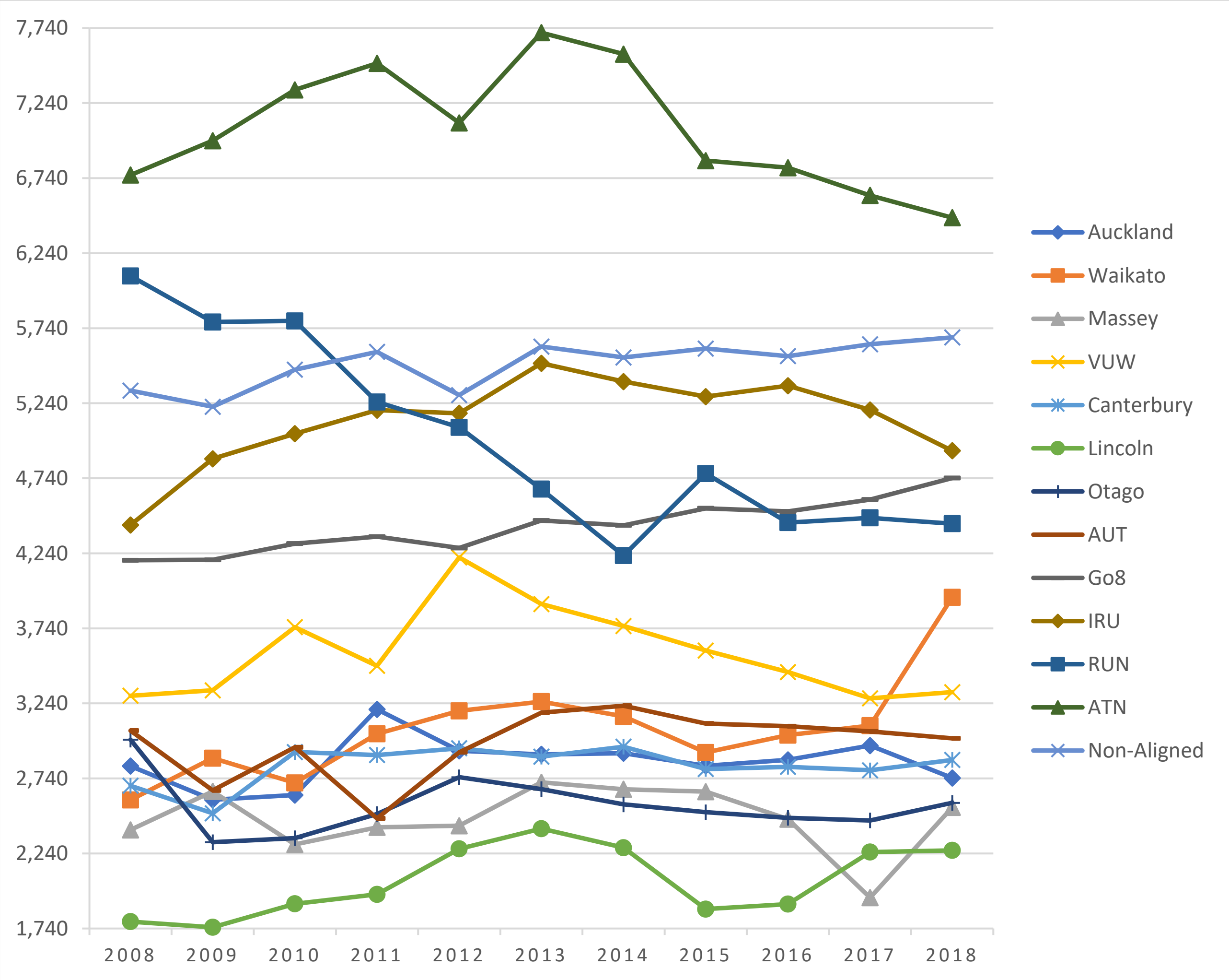
[103] The income weights reflect the financial contribution of each qualification type. For example, the income weight for a doctorate in New Zealand is 1.38 (relative to a bachelor's degree normalised to 1.0), indicating its higher financial contribution due to greater earnings potential. The credit and income-weighted completions account for the size of qualifications (credit value) and their economic value (income weights). For instance, postgraduate qualifications such as doctorates (360 credits) involve larger workloads (credit weights) and generate higher financial returns (income weights).

In 2018, the University of Waikato's teaching productivity was 3,947, indicating that each FTE teaching staff supported 3,947 credit-income weighted completions. This high value reflects the increasing number of high-credit, high-income qualifications (e.g., master's or doctorate degrees) in the University of Waikato's completions. For instance, if a teaching FTE supported approximately eight doctoral completions, the calculation would be 8*360 credits*1.38 (doctorate income weight) =3,974.

productivity, with 4,924 and 5,679 in 2018, respectively. ATN universities remained at the highest productivity levels among Australian university groups, driven by their focus on undergraduate and substantial postgraduate completions.

Figure 5.3

Credit and Income-weighted Completions per Teaching FTE by New Zealand and Australian Universities, 2008-2018



Source: New Zealand MoE, TEC, NZQA, NZQF (2016); Australian Government DoE, Australian Qualification Framework (AQF) (2013); author's estimates, Gemmell et al. (2017), MoE (2016), MoE (2021), Melbourne Institute (2015, Table 7.4, p. 72).

Notes: 1. In some cases, completion data is more aggregated than the NZQF and AQF specifications, leading to averaged weightings for categories Level 5-7, Level 7 and Level 8.

2. Credit weights and income weights by qualification level are described in Tables 4.3, and 4.4, respectively.

3. New Zealand MoE (2016) reports median earnings by qualification level for 2015, while MoE (2021) provides data related median earnings in 2018. The Melbourne Institute (2015, Table 7.4, p. 72) calculated the average earnings for male and female full-time employees in 2012.

4. The numbers for Australian groupings are the averages for the universities within the groupings.

5. Australian average numbers are the average of each Australian university.

The weights assigned to degree completions, particularly for master's and doctorate completions, significantly affect teaching labour productivity across universities. These higher-level degrees are weighted more heavily on credit and income, contributing to higher adjusted teaching outputs and productivities. For instance, for the University of Waikato, a substantial increase in higher-level degree completions (46% at postgraduate levels), combined with a 9% reduction in teaching FTE, resulted in a sharp increase in productivity.

The results also highlight a consistent gap between New Zealand and Australian universities. Australian universities, particularly Go8, continue to exhibit increase productivity due to their focus on postgraduate completions with substantial credit and income weights. Despite these differences, the general trends in credit and income-weighted completions per teaching FTE remain consistent across both countries.

Research Labour Productivity 1

Research Income per Research FTE from 2008 to 2018 is shown in Figure 5.4. New Zealand universities generally demonstrated more stable and consistent increases, while Australian universities (except for Go8) exhibited declines and considerable fluctuations in research labour productivity.

In New Zealand, AUT exhibited the most significant proportional increase, from NZD 36,000 in 2008 to NZD 53,000[104] in 2018, despite starting from the lowest base and maintaining the lowest productivity. This sharp rise reflects AUT's concentrated efforts to enhance its research capacity over time. The University of Canterbury experienced many fluctuations, especially following the 2011 Canterbury earthquake. Its research income per FTE dropped to NZD 123,000 in 2013 but recovered to NZD 166,000 by 2018. Victoria University of Wellington maintained a relatively stable increase, reaching NZD 158,000 in 2018, indicating a steady improvement in research capacity.

The University of Waikato significantly increased its research income per FTE from NZD 123,000 to NZD 149,000, indicating enhanced research performance. The University of Otago maintained stable, peaking at NZD 162,000 in 2016-2017. The University of Auckland also experienced relatively stable research income per FTE, reaching a peak of NZD 279,000 in 2018. Massey University fluctuated, starting at NZD 115,000 in 2008, declining to NZD 88,000 in 2012, and increasing to NZD 124,000

[104] The unit of research income per research FTE represents the amount of research income (expressed in thousands of dollars) generated by each FTE staff member engaged in research.

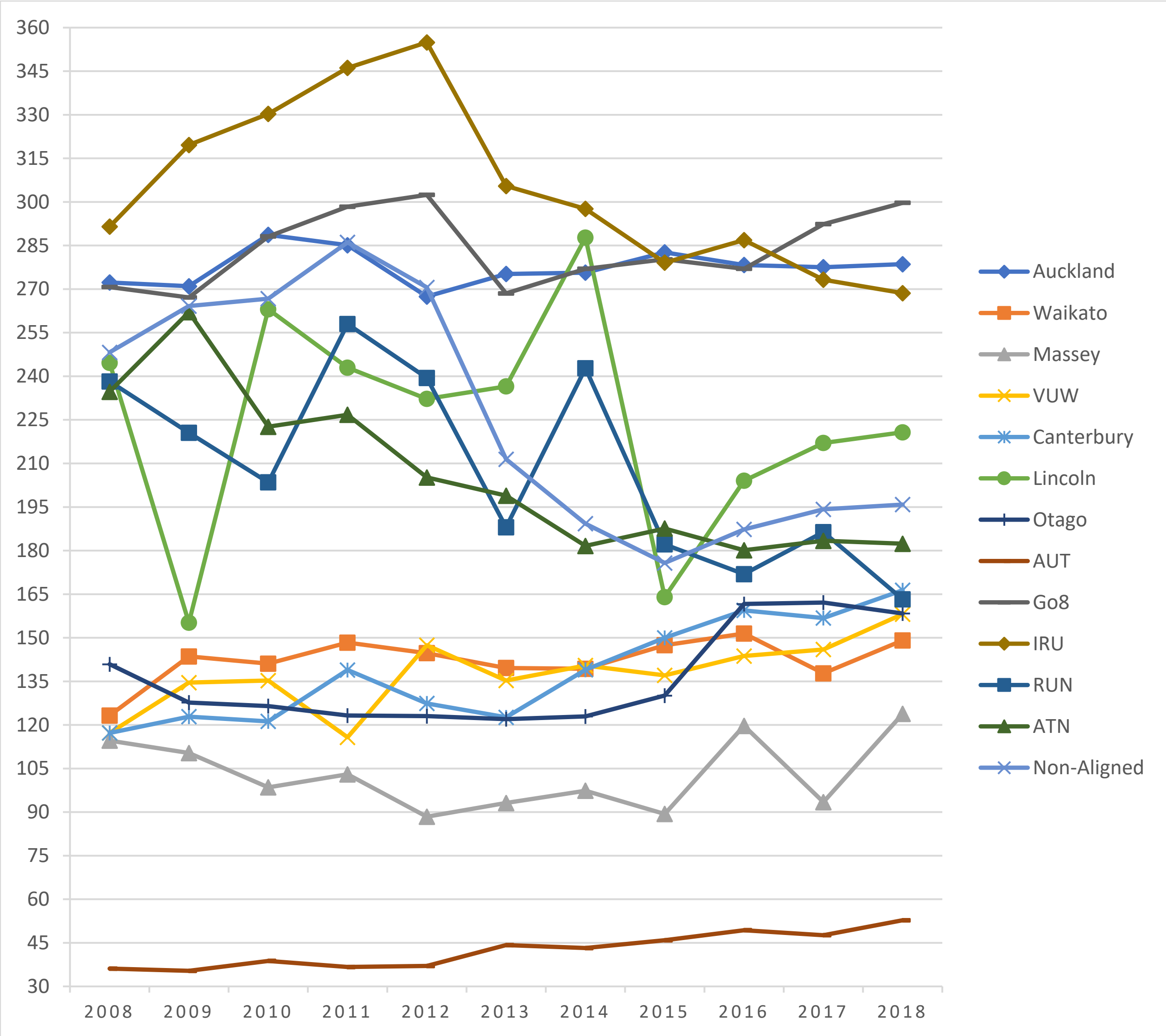
AUT's research income per research FTE in 2018 was NZD 53,000, indicating that each research FTE at AUT generated NZD 53,000 in research income.

in 2018. Lincoln University also experienced fluctuations, ending at NZD 221,000 in 2018, due to a steady increase in research income but variations in research FTEs.

In Australia, Go8 universities showed consistently high and stable research labour productivity, increasing slightly from NZD 271,000 in 2008 to NZD 300,000 in 2018, reflecting their research-intensive universities with a strong focus on postgraduate education and research. The IRU group exhibited a stable increase in research labour productivity until 2012, peaking at NZD 355,000, but declined gradually in the remaining years due to reduced research income and growing research FTEs. RUN universities declined sharply from NZD 238,000 to NZD 163,000 due to research income failing to keep pace with large increases in research staff numbers. ATN and non-aligned universities also declined. ATN fell from NZD 235,000 in 2008 to NZD 182,000 in 2018, and non-aligned universities dropped from NZD 248,000 to NZD 196,000, driven by smaller increases in research income relative to increases in research staff.

Figure 5.4

Research Income ($000) per Research FTE by New Zealand and Australian Universities, 2008-2018



Source: New Zealand TEC; Australian Government DoE.

Note: 1. The numbers for Australian groupings are the averages for the universities within the groupings.

2. Australian average numbers are the average of each Australian university.

These data highlight significant disparities in research labour productivity across the two countries. New Zealand universities generally showed stable increases, while many Australian universities, except for Go8, experienced declines in research income per research FTE, with significant fluctuations for some universities. These findings indicate that research productivity differs across universities.

Research Labour Productivity 2

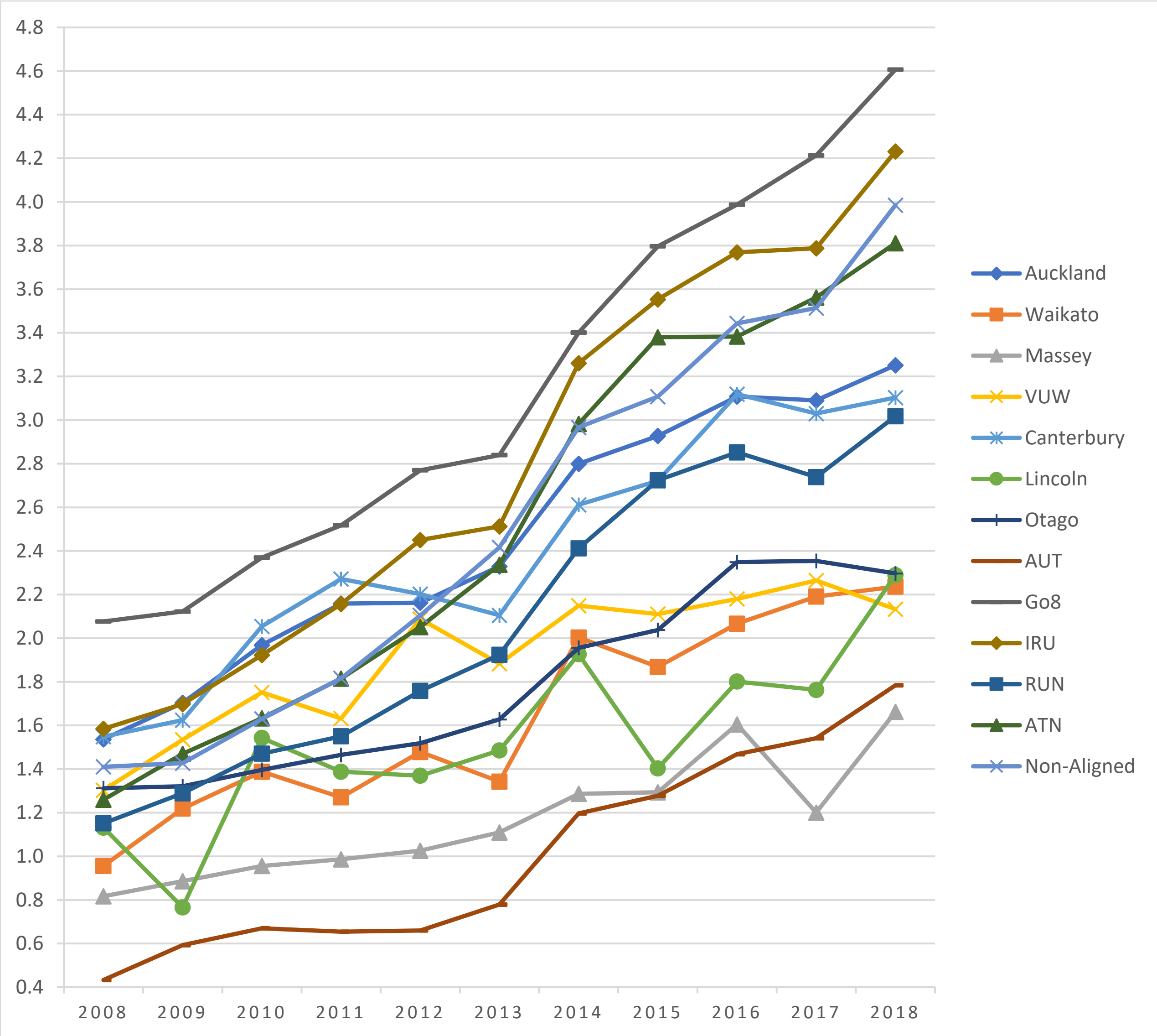
Articles and Reviews per Research FTE between 2008 and 2018 are shown in Figure 5.5. In New Zealand, all universities displayed a considerable increase in research labour productivity. The University of Auckland maintained the highest levels, increasing from 1.54 to 3.25[105] articles and reviews per research FTE. The University of Waikato and AUT also showed significant improvements. AUT, in particular, experienced the largest proportional increase (from 0.43 in 2008 to 1.78 in 2018), albeit from a very low base, reflecting its efforts to enhance research capacity. The University of Canterbury's productivity doubled from 1.55 to 3.10 due to its increased research outputs and reduced research staff, despite the disruptions caused by the 2011 earthquake. Lincoln University exhibited large fluctuations, but overall, its research labour productivity increased substantially. The University of Otago maintained a steady increase in research publications per FTE. Although New Zealand universities improved over time, their productivity remained below Australian levels, with some exceptions (e.g., research productivity at the University of Auckland was higher than that of RUN universities during the sample period).

Australian universities consistently displayed the highest research productivity over the period. Particularly in Go8, their average increased from 2.08 to 4.61 articles and reviews per research FTE, highlighting their dominant position in research outputs. Other Australian universities, such as ATN and Non-aligned universities, also showed substantial increases. ATN more than tripled its productivity from 1.26 to 3.81, reflecting its focus on research performance and industry collaboration. Similarly, Non-aligned universities showed steady progress, with the research productivity measure rising from 1.41 to 3.99.

[105] The unit of research labour productivity 2 is the number of articles and reviews published per research FTE. The research productivity of the University of Auckland in 2018 was 3.25, indicating that each research FTE produced three scholarly articles and reviews.

Figure 5.5

Articles and Reviews per Research FTE by New Zealand and Australian Universities, 2008-2018



Source: New Zealand TEC; Australian Government DoE; Web of Science (Clarivate).
Note: 1. The numbers for Australian groupings are the averages for the universities within the groupings.
2. Australian average numbers are the average of each Australian university.

These findings indicate a steady increase in articles and reviews per research FTE across both countries, reflecting a broader effort to enhance research capabilities, but disparities remain in productivity levels. Although research labour productivity has improved across both New Zealand and Australian universities, especially the Go8 in Australia continues to outperform, maintaining higher research productivity levels.

Research Labour Productivity 3

Citation-weighted articles and reviews per research FTE between 2008 and 2018 are shown in Figure 5.6. As noted in Section 4.1.6 (Table 4.5), this measure accounts for research quality when measuring research productivity. A general upward trend is observed across all universities, indicating an overall improvement in research labour productivity over the period.

All New Zealand universities showed steady increases in research labour productivity using this indicator, with rankings remaining consistent between unadjusted and adjusted measures. The University of Auckland's productivity increased from 1.73 in 2008 to 4.37[106] in 2018, consistently maintaining its position as the top performer. The University of Canterbury also significantly increased research productivity from 1.74 to 4.17. Despite the challenges posed by the 2011 earthquake, the university focused on enhancing its research output but reduced its research staff. This strategic focus on research performance facilitated a strong recovery, with the University of Canterbury's research productivity from 2016 to 2018 approaching that of the University of Auckland.

AUT experienced the largest proportional increase, from a very low base of 0.49 in 2008 to 2.40 in 2018, driven by efforts to build research capacity from a low base. The University of Waikato and Lincoln University also showed strong improvements, with the University of Waikato nearly tripling its productivity to 3.01 in 2018 and Lincoln University increasing from 1.27 to 3.08.

Australian universities, especially the Go8, again had the highest research labour productivity with adjusted research publications per research FTE, increasing from 2.45 to 6.64. This highlights their leading position in research performance across the universities. Other Australian university groupings also exhibited substantial productivity increases.

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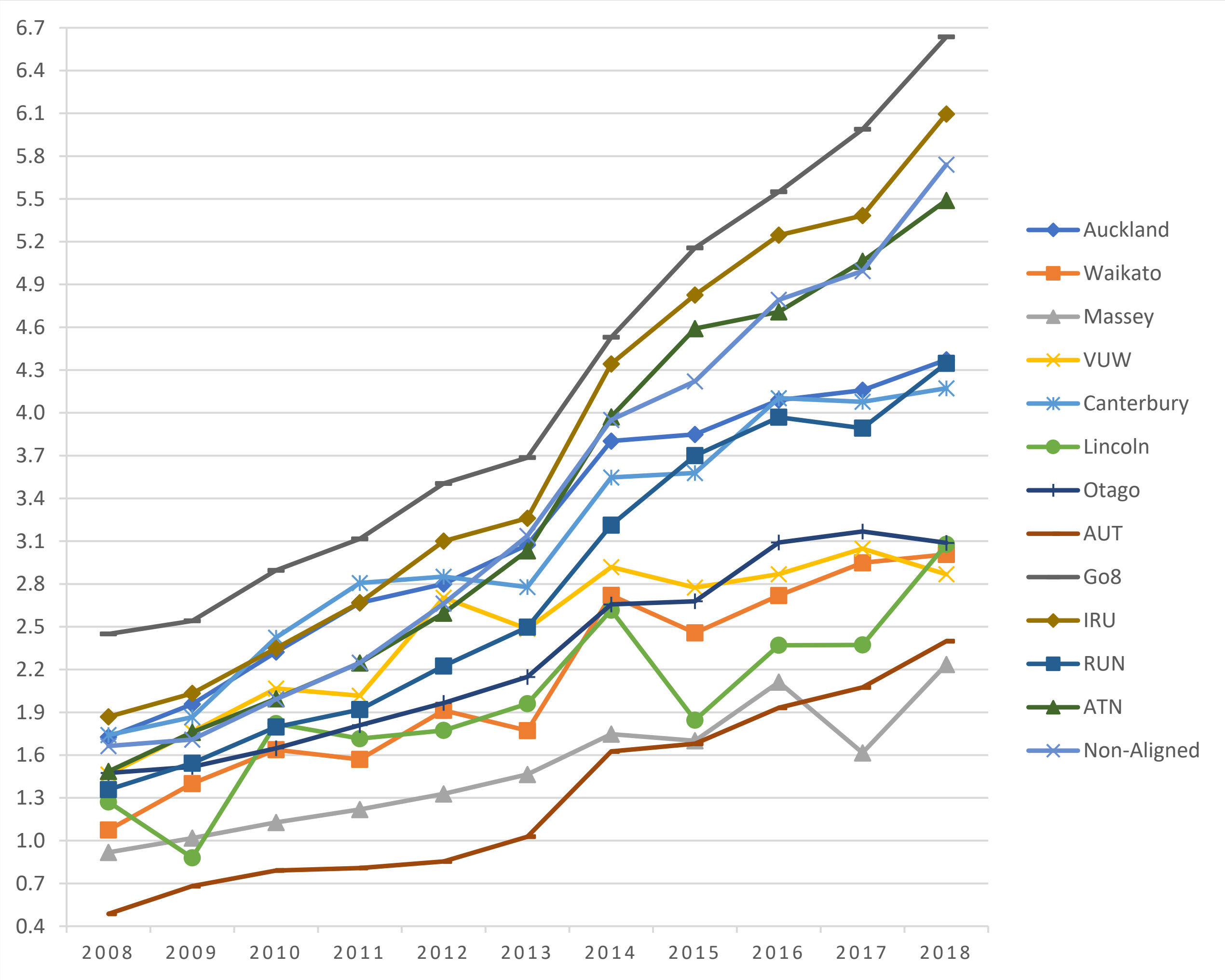
[106] Research labour productivity 3 is measured as citation-weighted articles and reviews per FTE. This indicator captures the quantity and quality of research outputs through the Category Normalised Citation Impact (CNCI). A CNCI number larger than 1 indicates that the university research citation rate is higher than the world average and vice versa. Research outputs are weighted by their CNCI, with higher weights for articles and reviews with citation rates exceeding the global average. The citation rates for research from New Zealand and Australian universities have generally increased over time compared with the world average. For instance, New Zealand's CNCI improved from 1.12 to 1.34 during the period (details in Table 4.5).

The University of Auckland's 2018 productivity of 4.37 indicates that each research FTE staff produced 4.37 citation-weighted articles and reviews, reflecting both the volume and the high citation impact of its research outputs.

Figure 5.6
Citation-Weighted Articles and Reviews per Research FTE by New Zealand and Australian Universities, 2008-2018



Source: New Zealand TEC; Australian Government DoE; Web of Science (Clarivate), New Zealand MoE (2022). https://www.educationcounts.govt.nz/statistics/research. Research Performance, Table RSP.11.
Note: 1. Citation weight is based on the CNCI, detailed in Table 4.5. The annual series for CNCI from MoE (2022) is available only as 5-year averages for 1980-84 to 2016-20. This study treats these numbers as estimates for the middle year of five, such as the 2008 citation weight, using the data from the time frame 2006-10.
2. The numbers for Australian groupings are the averages for the universities within the groupings.
3. Australian average numbers are the average of each Australian university.

These findings indicate that research labour productivity still differs across universities. While both New Zealand and Australian universities have further improved, the Go8 remains at the forefront of research outputs and productivity. The steady increase in citation-weighted outputs per FTE across both countries indicates broader efforts to enhance research capabilities. However, the persistent gap in productivity levels between them is still evident. These findings suggest that while New Zealand universities have made significant progress, further efforts may be required to close the productivity gap with their Australian counterparts, particularly the research-intensive universities like the Go8. Additionally, these trends underline the varying capacity of universities across both countries to produce research publications relative to their research staff numbers, reflecting differences in research strategies, funding environments, and the university's focus on research performance.

Labour Productivity Average Annual Growth Rates (AAGR)

AAGR for teaching and research labour productivity between 2008 and 2018 are presented in Table 5.1. Averaged across universities, AAGRs for the three teaching productivity measures and research income per research FTE staff (RLP1) in New Zealand are larger than those in their Australian counterparts. Conversely, Australian universities experienced higher AAGRs for research productivity measures based on WoS-indexed outputs (RLP2 and RLP3).

Table 5.1
Annual Average Growth Rates (%) of Labour Productivity for Australasian Universities, 2008-2018, based on FTE 50:50 allocation

University	TLP 1	TLP 2	TLP 3	RLP 1	RLP 2	RLP 3
Auckland	0.05	-0.13	0.03	0.28	7.96	9.96
Waikato	4.17	4.54	4.71	2.1	10.13	12.26
Massey	1.63	1.44	1.52	2.21	8.56	10.46
VUW	-0.6	0.28	0.43	3.62	5.69	7.74
Canterbury	0.64	0.52	0.79	3.80	7.69	9.68
Lincoln	5.99	2.84	2.87	3.39	12.48	14.65
Otago	-1.19	-1.23	-1.11	1.49	5.96	7.91
AUT	-2.39	-0.15	0.31	4.13	16.25	18.38
New Zealand Average	*1.03*	*1.01*	*1.19*	*2.63*	*9.34*	*11.38*
Go8	2.00	1.40	1.49	1.62	8.64	10.84
IRU	1.93	2.18	2.17	0.07	11.05	13.30
RUN	-1.55	-1.39	-1.42	4.13	11.50	13.76
ATN	-0.72	-0.40	-0.44	-1.42	12.09	14.36
Non-aligned	1.47	1.42	1.37	0.47	12.57	14.86
AUS Average	*0.86*	*0.832*	*0.826*	*1.13*	*11.18*	*13.43*

Note:1. TLP1 = Completions/Teaching FTE; 2. RLP1 = Research income/Research FTE.
2. TLP2 = Credit weighted completions /Teaching FTE; RLP2 = WoS indexed articles and reviews/Research FTE.
3. TLP3 = Credit & income weighted completions /Teaching FTE; RLP3 = CNCI-weighted WoS indexes articles and reviews/Research FTE.
4. The numbers for Australian groupings are the averages for the universities within the groupings.
5. Australian average numbers are the average of each Australian university.

AAGR—Teaching Labour Productivity (TLP)

The University of Waikato experienced a substantial and gradual increase in all TLPs, with a 4.71% increase in credit and income-weighted completions per teaching FTE, driven by a gradual rise in completions and a decrease in teaching staff. The University of Canterbury also showed positive growth in TLP3 (0.79%) despite the disruptions caused by the 2011 earthquake. This was primarily due to a significant increase in postgraduate completions (48%), offsetting a 28% decline in undergraduate completions. In contrast, the University of Otago experienced negative TLP growth across all three measures. TLP declined by 1.11%, mainly due to the imbalance between the minor increase in completions and a larger rise in teaching staff.

Lincoln University stands out for its high average growth rate in TLP, particularly in completions per teaching FTE (5.99%). This dramatic increase was largely due to a 186% surge in completions between 2008 and 2013, especially at the sub-degree (mainly Levels 1 to 4) and postgraduate levels (except bachelor's degrees and postgraduate certificates and diplomas). At the same time, teaching FTEs only grew by 1.4% due to the 2011 merger with Telford Rural Polytechnic.

AUT's TLP1 and TLP2 declined by 2.39% and 0.15%, respectively, due to a significant decline in undergraduate completions, from 6,930 in 2008 to 4,835 in 2018. However, its modest 0.31% increase in TLP3 mitigated the negative growth in teaching productivity, possibly due to growth in postgraduate completions (103%) and teaching FTEs (19%).

The University of Auckland experienced positive growth in unadjusted completion per teaching staff measures, while there was negative growth in credit-weighted completions per teaching staff. This is due to small annual increases in enrolments and completions (despite the gradual decline in completions between 2011 and 2014), while teaching staff increased more sharply.

A rise in completion numbers, particularly at the master's and doctoral degrees, with higher corresponding credit or/and income weights, significantly impacts teaching outputs and productivity measures. This effect is evident at the University of Waikato, where productivity increased due to higher completions and a concurrent decline in teaching staff. The adjusted teaching output, which considers credit or/and income weights, further amplified this productivity growth. However, at universities like the University of Canterbury, Lincoln University and Massey University, the increase in TLP was more modest when income weights were used, compared to the larger increase observed under credit-weighted completions. This suggests that the impact of income weights may not be substantial in these universities, indicating that the results are sensitive to the types of weights used when measuring teaching productivity.

TLP in Australian university groupings followed a different trend than New Zealand universities. The AAGR of Australian teaching productivity is approximately half that of New Zealand on average. The difference stems not only from absolute productivity levels but from different growth patterns over time. Australian universities tend to experience more gradual and steady increases in completions and teaching staff numbers. However, New Zealand universities show more significant fluctuations, like the sharp increase in completions with a decrease in teaching staff at the University of Waikato, leading to a high productivity growth rate. The lower AAGR does not imply that Australian universities perform worse, as they started with a higher level of TLP than New Zealand universities, such as credit-weighted completions per teaching FTE (in Figure 5.2) and credit and income-weighted completions per teaching FTE (in Figure 5.3)—all Australian university groupings experienced higher TLP levels than their New Zealand counterparts.

For instance, the Go8 universities have the highest AAGR in completions per teaching staff across Australian universities, reflecting their strong focus on teaching quality and steady increase in student completions. Similarly, the IRU universities show substantial improvements in adjusted output per teaching staff, possibly due to their large increase in undergraduate completions and smaller increase in teaching staff. By contrast, the RUN universities experienced negative growth rates in TLP due to fewer completions and an increase in teaching staff (like Southern Cross University and Charles Sturt University), which reduced their productivity levels.

AAGR—Research Labour Productivity (RLP)

All New Zealand universities had high RLP growth rates, particularly in measures based on WoS data. AUT exhibited the highest growth despite starting from a very low base. AUT's RLP1 measure increased by 4.13% per year, while its RLP2 and RLP3 increased by 16.25% and 18.38% per year, respectively. This growth may be attributed to AUT's strategic investments in research infrastructure and its growing focus on research performance. AUT also started with the lowest level of research productivity (see Figures 5.5 and 5.6), so it had more scope for growth than other universities. VUW and the University of Canterbury also experienced positive RLP growth. VUW's RLP1 increased by 3.62% per year, with RLP2 and RLP3 growing by 5.69% and 7.74% per year, respectively. The University of Canterbury showed an RLP1 growth of 3.8%, RLP2 at 7.69% and RLP3 at 9.68% per year, indicating substantial improvements despite challenges such as the 2011 Canterbury earthquake.

Lincoln University achieved significant growth, with RLP1 at 3.39%, RLP2 at 12.48%, and RLP3 at 14.65% per year. These figures reflect Lincoln University's success in increasing research income and the volume and impact of its research publications, particularly in areas of strength such as agriculture. The University of Waikato also displayed notable improvements across all RLP measures, with RLP1 growing by 2.15%, indicating a steady increase. Its research productivity for the RLP2 and RLP3 measures increased by 10.13% and 12.26%, respectively, possibly due to its effective strategies to attract research funding and enhance postgraduate research completions. Massey University's performance followed a similar track, with productivity growing at 2.21% (RLP1), 8.56% (RLP2) and 10.46% (RLP3) per year.

In contrast, the University of Auckland experienced modest growth in research income per research FTE (RLP1) at 0.28% per year but showed substantial increases in research publications, with RLP2 growing by 7.96% per year and RLP3 by 9.96% per year. Although the University of Auckland experienced modest growth in research income, it substantially improved the quality and quantity of its research publications. The University of Otago exhibited a similar pattern, with RLP1 at 1.49%, RLP2 at 5.96%, and RLP3 at 7.91% per year on average.

In Australia, on average, RLP measures based on WoS data were higher than those for New Zealand universities, except for research income-based measures. The Go8, known for its research intensity, maintained solid growth rates, with RLP1 at 1.62%, PLP2 at 8.64%, and RLP3 at 10.84% per year on average. This moderate growth reflects their already high base in research income and publications. However, the ATN universities suffered negative growth in research income per research FTE (RLP1: -1.42%), potentially due to a larger increase in research staff that outpaced research income growth, particularly at RMIT and Curtin University. The ATN achieved significant growth in RLP2 (12.09%) and RLP3 (14.36%), indicating improvements in research publications and impacts. This growth may be partially attributed to their focus on strengthening collaborations between universities, governments, industry partners and international organisations (Australian Technology Network of Universities, n.d.).

Results for research productivity growth rates also highlight that research productivity quality adjustments have a significant impact. When research outputs are weighted by citation as a proxy for quality, AAGRs for research productivity are much higher than unweighted research outputs used.

A Robustness Check for an Alternative Teaching and Research FTE Allocation

This section examines labour productivity AAGRs using a 40:60 teaching-to-research FTE allocation displayed in Table 5.2. In New Zealand, AAGRs for both teaching and research productivity under a 40:60 allocation are similar to those under the 50:50 baseline (see Table 5.1). The University of Waikato and Lincoln University continued to indicate steady TLP growth, while AUT and the University of Otago experienced declining AAGRs, possibly due to reduced teaching staff.

Turning to RLP, New Zealand universities continued to perform exceptionally well across all research measures. The University of Auckland and AUT displayed similar growth rates across three RLP measures. Additionally, the University of Waikato, VUW and the University of Canterbury exhibited consistent increases in RLP under the 40:60 allocation. Changing the staff allocation assumption did not significantly affect WoS-based RLP measures.

In Australia, the TLP measures under a 40:60 staff allocation were smaller than those based on a 50:50 allocation, particularly for Australian RUN and ATN universities, while the RLP measures were larger. The 40:60 allocation slightly decreased TLP growth rates for all Australian universities, especially ATN and IRU, suggesting a trade-off between teaching and research outputs under research-focused allocation.

While the 40:60 split increases the proportion of research FTE staff, which theoretically should increase the denominator and lead to a decrease in RLP, the actual results show an increase in Australian RLP measures. The unexpected results suggest that the additional research staff may have contributed significantly to enhancing research outputs, possibly offsetting the effects of a larger denominator.

Table 5.2
Annual Average Growth Rates (%) for Labour Productivity for Australasian Universities, 2008-2018 based on FTE 40:60 allocation

University	TLP 1	TLP 2	TLP 3	RLP 1	RLP 2	RLP 3
Auckland	0.05	-0.13	0.03	0.28	7.95	9.96
Waikato	4.16	4.53	4.70	2.22	10.19	12.32
Massey	1.62	1.42	1.51	1.82	8.17	10.08
VUW	-0.70	0.28	0.42	3.88	5.97	8.03
Canterbury	0.63	0.51	0.78	3.89	7.79	9.78
Lincoln	5.97	2.78	2.81	3.14	12.20	14.34
Otago	-1.18	-1.23	-1.11	1.33	5.79	7.74
AUT	-2.40	-0.16	0.30	4.13	16.26	18.38
New Zealand Average	*1.02*	*1.00*	*1.18*	*2.59*	*9.29*	*11.33*
Go8	1.66	1.07	1.16	1.57	8.58	10.78
IRU	1.50	1.74	1.74	0.09	11.07	13.33
RUN	-1.92	-1.77	-1.79	4.42	11.84	14.11
ATN	-1.17	-0.85	-0.89	-1.10	12.45	14.73
Non-aligned	1.19	1.13	1.08	0.75	12.89	15.18
AUS Average	*0.51*	*0.47*	*0.46*	*1.30*	*11.37*	*13.63*

Note:1. TLP1 = Completions/Teaching FTE; 2. RLP1 = Research income/Research FTE.
2. TLP2 = Credit weighted completions /Teaching FTE; RLP2 = WoS-indexed articles and reviews/Research FTE.
3. TLP3 = Credit & income weighted completions /Teaching FTE; RLP3 = Citation-weighted WoS-indexed articles and reviews/Research FTE.
4. The numbers for Australian groupings are the averages for the universities within the groupings.
5. Australian average numbers are the average of each Australian university.

This comparison highlights that a 50:50 allocation supports consistent growth across TLP and RLP. In contrast, a research-oriented allocation (40:60 split) appears advantageous for enhancing research outputs, such as research income, particularly in universities with a strong research focus. However, note that the absolute levels of RLP decrease under the 40:60 staff allocation due to the larger denominator caused by an increased proportion of research FTE staff. Additionally, interpreting the AAGR also requires caution. A high AAGR does not always equal a high output volume. For instance, AUT had the highest growth in doctoral completions, averaging 19.24%, but started from a very low base number of PhD students. In general, both the level and growth rates of productivity measures should be considered when assessing labour productivity.

5.1.3 *Conclusion*

This chapter analysed partial labour productivity in Australasian universities from 2008 to 2018, using various input and output variables, including quality-adjusted teaching and research outputs. By utilising different weights on teaching and research outputs to account for quality adjustments, the analysis reveals distinct productivity trends across universities in New Zealand and Australia, with further comparison across Australian groupings. The findings indicate that the teaching and research productivities varied across institutions. The differences between teaching and research labour productivity were also interesting and often as expected (e.g., ATN universities focus more on teaching and less on research).

For teaching labour productivity, New Zealand universities consistently exhibited lower TLP levels than their Australian counterparts across all measures, indicating a gap between the two countries. Australian universities, particularly ATN universities, achieved the highest TLP levels in all measures, driven by financial stability and strategic partnerships with international universities. Among New Zeeland universities, Lincoln University exhibited significant fluctuations in quality-adjusted measures due to structural changes (e.g., merger) and external disruptions (e.g., the Canterbury earthquake), although adjusted outputs showed reduced volatility. VUW and the University of Waikato consistently achieved relatively high TLP levels among New Zealand institutions.

For research labour productivity, New Zealand universities showed steady improvements, but their absolute levels remained lower than Australian universities. The University of Auckland consistently maintained the highest RLP levels, while AUT achieved the largest proportional increase despite starting from the lowest base of research productivity across all measures. In Australia, Go8 universities showed consistently high and stable RLP levels, indicating their research-intensive focus on postgraduate education and research outputs. Other Australian universities also exhibited substantial productivity growth. However, the gap in productivity levels between them remained evident. These trends highlight variations in research capacity to produce research outputs relative to their researchers, possibly affected by different research strategies, funding environments, and institutional priorities.

For TLP Annual Average Growth Rates, New Zealand universities exhibited higher AAGRs for all three TLP measures than Australian universities, driven by increases in master's and doctoral completions with higher credit or/and income weights. The University of Waikato experienced increased productivity due to increased completions and reduced teaching staff. Lincoln University, Massey University and the University of Canterbury showed more modest increases, indicating the sensitivity of TLP growth to weighting methods (e.g., income weights). In contrast, Australian universities maintained higher absolute TLP levels despite lower AAGRs. For instance, the Go8 had the highest AAGR in completions per teaching staff among Australian universities, reflecting their strong focus on teaching quality and steady increase in completions.

For RLP Annual Average Growth Rates, New Zealand universities had higher AAGRs in research income per research FTE staff, while Australian universities performed better on publication-based RLP. AUT, starting from the lowest productivity levels, exhibited more scope for growth than other universities. VUW and the University of Canterbury also experienced a steady increase. Lincoln University achieved significant increases by its increased research income and outputs, particularly in agriculture. The University of Auckland and Otago showed modest growth in RLP1 but significant increases in research publication quantity and quality. Australian universities, particularly Go8, were higher than New Zealand universities based on publication measures. Quality adjustments (e.g., citation-weighting) for research publications substantially increase growth.

For the robust analysis of FTE staff allocation 50:50 vs. 40:60, New Zealand universities showed similar AAGRs for TLP under both allocations. The University of Waikato and Lincoln University maintained steady TLP increases, while AUT and the University of Otago experienced declines due to reduced teaching staff. RLP measures for New Zealand universities remained strong, with similar growth observed in the University of Auckland and AUT. Changing staff allocation assumptions had minimal impact on WoS-based RLP measures. In Australia, a 40:60 allocation slightly reduced TLP growth rates, especially for ATN and IRU universities, indicating a trade-off between teaching and research outputs under the research-focused allocation. However, Australian RLP measures increased despite a larger FTE denominator, implying that additional research staff possibly enhanced research outputs. Overall, a 50:50 allocation supports consistent growth across TLP and RLP, while a 40:60 allocation favours research output in research-focused institutions. Both growth rates and absolute productivity levels should be considered when interpreting results.

These findings indicate the importance of weighting methods and staff allocation assumptions in analysing labour productivity trends across Australasian universities.

5.2 **Malmquist Productivity Indexes Analysis**

5.2.1 ***Empirical Model***

This section is structured as follows. Section 5.2.1 presents the empirical estimates for MPI. Section 5.2.2 provides the empirical results and discussion. Section 5.2.3 summarises the sensitivity analysis. Section 5.2.4 shows the conclusions. Additional robustness results are provided in Appendix Chapter 5.

The section applies output distance functions to derive output-oriented MPI measures, which are widely used to analyse productivity changes over time. The MPI measures are suitable for multi-input, multi-output production technology and do not require assumptions about specific behavioural objectives (e.g., cost minimisation or profit maximisation) (Coelli et al., 2005, p. 47). For detailed methodology, refer to Section 2.1.1 in Chapter 2. The decomposition of MPI is summarised in Table 2.1.

As presented in equation (2.6), the output distance function measures how much the output vector $\boldsymbol{y}^{\boldsymbol{t}}$ can be proportionally expanded, given the input vector $\boldsymbol{x}^{\boldsymbol{t}}$, within the feasible production set. The distance function equals one, only if the input-output combination $(\boldsymbol{x}^{\boldsymbol{t}}, \boldsymbol{y}^{\boldsymbol{t}})$ lies on the production frontier, indicating technical efficiency. A value less than one implies that the input-output combination lies inside the frontier, representing technical inefficiency. These functions serve as the basis for constructing the MPI.

The output-input ratio defines productivity. The total factor productivity (TFP) index measures productivity change between two periods, $\boldsymbol{t}$ and $\boldsymbol{t+1}$. The Malmquist TFP measures the TFP changes between two time periods by comparing the performance of each university, as captured by the ratio of output distances relative to a reference technology (either from period $\boldsymbol{t}$ or $\boldsymbol{t+1}$). The comparisons of these indexes allow for assessing which university has experienced greater productivity growth or decline.

The MPI decomposes TFP changes into two key components:

1. Efficiency Change:

- This component captures changes in how production moves closer to or further from the production frontier, reflecting improvements or declines in resource utilisation or productivity scale.
- This component can be further subdivided into:
  - Pure efficiency change: Represents improvements in the ability to produce more outputs without increasing inputs, indicating better resource utilisation.
  - Scale efficiency change: Measures whether a university operates closer to the technically optimal productive scale.

2. Technical Change:
   - This component reflects shifts in the production frontier between periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$ (calculated relative to a constant return to scale (CRS) technology), reflecting technological progress or regress.
   - A positive technical change indicates that universities can produce more output using the same input levels due to innovations or improvements in production technology.

The MPI is calculated as the geometric mean of period-specific productivity indexes based on the production frontiers in periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$. A value greater than one indicates productivity improvement/progress over time. It indicates positive TFP growth between periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$. For instance, a value of 1.01 for an index indicates that productivity increases by 1%. A value less than one indicates a decline in productivity. For instance, A value of 0.99 indicates that productivity decreases by 1%. A value of one shows no change in productivity between periods $\boldsymbol{t}$ and $\boldsymbol{t+1}$. The same interpretation applies to the components of TFP change, technical change, efficiency change, pure efficiency change, and scale efficiency change. Note that overall productivity improvements may coincide with deterioration in one or more component measures and vice versa.

The input variables for the MPI analysis, which are detailed in Section 4.2 and summarised in Table 4.9, include:

1. Teaching FTE staff,
2. Research FTEs,
3. General FTEs,
4. Capital expenses (non-labour expenditure),
5. Undergraduate equivalent full-time student (EFTS) enrolments,
6. Postgraduate EFTS enrolments.

The output variables include:

1. Research income,

2. Undergraduate credit and income-weighted qualification completions,
3. Postgraduate credit and income-weighted qualification completions.

Analysing the cumulative effects of changes in TFP helps identify factors influencing TFP change (Margaritis & Smart, 2011). Using chained indexes provides a way of quantifying these cumulative effects (Flegg et al., 2004). The cumulative change scores allow for tracking the direction of productivity change trends (Moore, 2021, p. 120), enhancing the interpretability of results and exposing anomalies in data (Moore, 2020, p. 161).

To calculate cumulative TFP change for each year between 2008 and 2018, the base year 2008 is normalised to a value of 1. The value of change in TFP or TFP growth in the calculation of the Malmquist TFP method refers to the value between periods 2008 and 2009. For example, the 2009 cumulative TFP is the 2008 base value multiplied by the 2008/09 TFP change or TFP growth. A 2010 cumulative value of 1.102 indicates a 10.2% increase in productivity relative to the base year 2008.

5.2.2 *Empirical Results and Discussion*

Partial labour productivity measures only consider the ratio of a single input and (an adjusted) output and, therefore, ignore the functional relationship between multiple inputs and outputs for a given process. The Malmquist TFP index in this section facilitates more detailed estimates of productivity changes in New Zealand and Australian universities from 2008 to 2018. As noted above, this approach enables the decomposition of productivity changes into efficiency change (catching-up effect) and technical change (frontier shift). Moreover, efficiency change is further decomposed into pure and scale efficiency changes.

Table 5.3 summarises the results for the geometric mean changes in the Malmquist TFP index and its components for Australasian universities. Appendix Chapter 5 Tables A5.1—A5.6 present the results of the MPI components for individual universities.

The geometric mean TFP change across all years indicates a distinct contrast between New Zealand and Australian universities in Table 5.3. On average, New Zealand universities experienced a slight decline in TFP change (0.993), indicating an annual productivity reduction of 0.7%. Conversely, Australian universities achieved an average productivity change of 1.6% per year. Decomposing this TFP change for New Zealand universities into technical and efficiency changes, technical change showed a modest improvement of 0.6% annually, indicating modest technological progress. However, this progress was outweighed by a 1.4% annual decline in efficiency change, indicating the efficiency frontier shifted inwards. Efficiency change can be further divided into pure and scale efficiency changes. Pure efficiency change declined slightly (average 0.992 per year). Similarly, scale efficiency change decreased (averaged 0.995 per year), reflecting challenges in achieving optimal operational scale. The results contrast with Margaritis and Smart (2011), who examined New Zealand university productivity during the early 2000s. It attributed the TFP growth to positive changes in efficiency change, especially for scale efficiency change[107].

In contrast, Australian universities experience greater technical change than their New Zealand counterparts, with an average rise of 1.3% per year and slight improvements in efficiency change at an average of 0.3 % per year. The efficiency change components, pure efficiency change (Pure EfficiencyΔ=1.001) and scale efficiency change (Scale EfficiencyΔ=1.002), indicate modest improvements in resource utilisation and scale operations.

Table 5.3 also shows that New Zealand universities experienced productivity improvements in specific periods, such as 2008/09 (1.030), 2009/10 (1.001), 2013/14 (1.005), 2014/15 (1.047), and 16/17 (1.021), primarily due to advancements in technical change. However, productivity regressed significantly in 2010/11 (0.921) and 2017/18 (0.958). In contrast, Australian universities displayed more consistent productivity growth across the period, with exceptions in 2008/09 (0.998) and 09/10 (0.973), possibly influenced by the global financial crisis.

Among New Zealand universities, AUT ($\boldsymbol{TFP}\Delta$ =1.033) exhibited the highest average TFP change of 3.3% per year, driven by positive technical change (and no efficiency change). Similarly, VUW ($\boldsymbol{TFP}\Delta$ =1.008) achieved a modest productivity change of 0.8% annually due to higher technology change combined with positive efficiency change.

In contrast, productivity at Massey University declined over the period, with an average annual decrease of 1.8% ($\boldsymbol{TFP}\Delta$ =0.982). This decline was driven by a significant decline in efficiency change of 1.9% on average per year, including a 1.5% decrease in pure efficiency and a 0.4% decline

[107] The differences between this study and Margaritis and Smart (2011) might be attributed to variations in the time frame, input and output variables, funding policies, and structural changes within New Zealand's university sector. Margaritis and Smart (2011) analysed the period 1997-2005, during the early implementation of the PBRF, while this study focused on 2008-2018, when the PBRF was fully operational and influencing university operations. The transition receiving research funding for New Zealand tertiary education organisations (TEOs) from research top-ups based on domestic student enrolments at the degree level or higher to the PBRF (more details can be found in Section 1.3.3.1).

Margaritis and Smart (2011) used academic and general FTE as labour inputs and research publications (the number of WoS-indexed articles and reviews) as research outputs. In contrast, this study employs teaching, research and general FTE as labour inputs and research income as research outputs. The New Zealand university sector experienced structural changes during the early 2000s. For instance, AUT's transition to university status in 2000 entered the research funding and performance landscape, contributing to a shift in competitive dynamics and resource allocation.

in scale efficiency. Similar trends occurred at the University of Otago and Waikato. The University of Otago's TFP declined by 2.4% annually ($\boldsymbol{TFP}\Delta$ =0.976), as the decrease in efficiency (-2.8%) was larger than the increase in technology (0.4%). Lincoln University experienced the largest decline, with TFP decreasing by 2.8% per year ($\boldsymbol{TFP}\Delta$ =0.972). This was caused by a large decline in scale efficiency (-3.2%), which offset a slight positive contribution from technology change (0.3%). The University of Auckland exhibited a slight decline in TFP of 0.3%, due to a decrease in technology change of 0.2%, with no efficiency change.

For Australian universities, all groupings experienced TFP improvements, with the RUN universities achieving the highest average (3.3% per year), followed by Non-aligned universities (1.7% annually), ATN universities (1.6% annually), IRU universities (1.1% annually), and Go8 universities (0.3% annually). The strong performance of RUN universities was driven by large increases in both efficiency change and technical change.

Table 5.3
Geometric Mean Changes in Total Factor Productivity, Technical, Efficiency, Pure Efficiency and Scale Efficiency of Australasian Universities, 2008/09 to 2017/18

	TFPΔ	*Technical Δ*	*Efficiency Δ*	*Pure Efficiency Δ*	*Scale Efficiency Δ*
New Zealand					
08/09	1.030	1.053	0.978	1.011	0.967
09/10	1.001	0.980	1.022	1.016	1.006
10/11	0.921	1.008	0.914	0.925	0.987
11/12	0.974	1.025	0.950	0.962	0.987
12/13	0.988	0.976	1.012	0.984	1.028
13/14	1.005	1.020	0.986	1.000	0.986
14/15	1.047	1.042	1.005	1.014	0.991
15/16	0.990	0.993	0.996	0.995	1.001
16/17	1.021	1.005	1.016	1.013	1.003
17/18	0.958	0.966	0.991	1.000	0.991
All Years	*0.993*	*1.006*	*0.986*	*0.992*	*0.995*
Auckland	0.997	0.998	1.000	1.003	0.997
Waikato	0.984	1.013	0.971	0.974	0.997
Massey	0.982	1.001	0.981	0.985	0.996
VUW	1.008	1.005	1.003	1.003	1.000
Canterbury	0.991	0.995	0.996	0.994	1.002
Lincoln	0.972	1.003	0.968	1.000	0.968
Otago	0.976	1.004	0.972	0.974	0.998
AUT	1.033	1.033	1.000	1.000	1.000
New Zealand Mean	*0.993*	*1.006*	*0.986*	*0.992*	*0.995*
Australia					
08/09	0.998	1.005	0.992	0.988	1.005
09/10	0.973	0.976	0.997	0.997	1.000
10/11	1.002	1.008	0.994	0.997	0.997
11/12	1.063	1.060	1.003	1.009	0.995
12/13	1.020	1.017	1.003	0.995	1.009
13/14	1.031	1.030	1.000	1.004	0.996

14/15	1.011	1.025	0.987	0.988	0.998
15/16	1.029	1.004	1.025	1.007	1.018
16/17	1.026	1.028	0.998	1.006	0.991
17/18	1.010	0.981	1.029	1.015	1.014
All Years	*1.016*	*1.013*	*1.003*	*1.001*	*1.002*
Go8	1.003	1.005	0.998	1.001	0.998
IRU	1.011	1.020	0.991	0.992	0.999
RUN	1.033	1.016	1.017	1.004	1.013
ATN	1.016	1.014	1.002	1.002	1.000
Non-aligned	1.017	1.013	1.005	1.004	1.001
Australian Mean	*1.016*	*1.013*	*1.003*	*1.001*	*1.002*

Source: New Zealand TEC, MoE, NZQF (2016) and New Zealand's university annual reports. Australian Government DoE and AQF (2013).

Note: 1. All means are geometric means.

2. $\boldsymbol{TFP}\Delta$ (e.g., TFP change) $= \boldsymbol{Technical}\Delta \times \boldsymbol{Efficiency}\Delta$, $\boldsymbol{Efficiency}\Delta = \boldsymbol{PureEfficiency}\Delta \times \boldsymbol{ScaleEfficiency}\Delta$

3. The numbers for Australian groupings are the geomean for the universities within the groupings.

4. New Zealand or Australian mean numbers are the geometric means across all New Zealand or Australian universities.

5. "All Years" refer to geomeans across all years.

Cumulative TFP changes

The analysis of cumulative TFP changes for the universities provides valuable insights into the factors influencing productivity change over time (Margaritis & Smart, 2011). As described in Section 5.2.1, cumulative changes are computed by successively applying annual changes starting the base year, 2008.

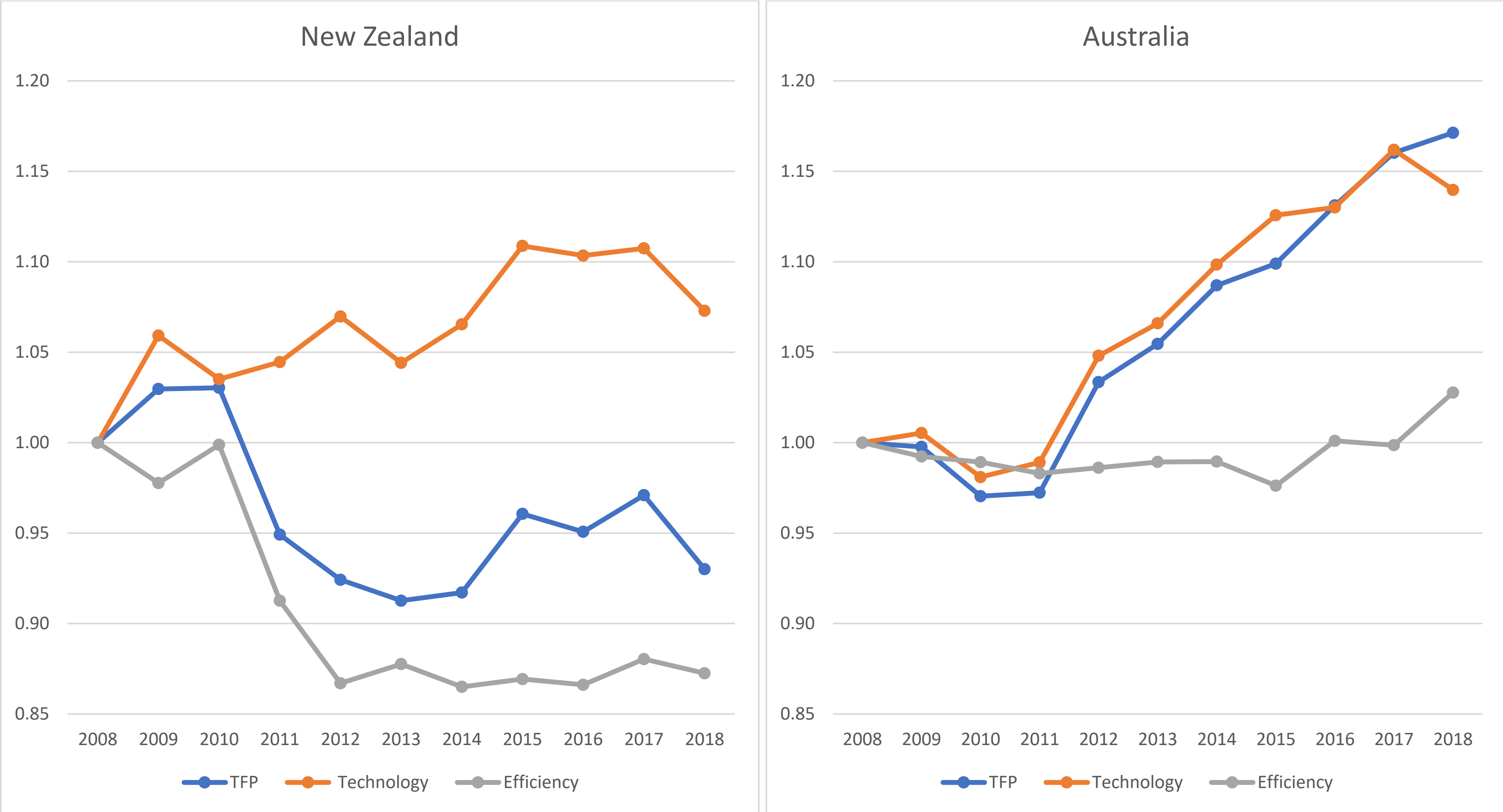
Figure 5.7 illustrates the cumulative TFP, technology and efficiency trends for New Zealand and Australian universities between 2008 and 2018. The results support early findings in Table 5.3, showing that productivity changes in New Zealand were caused by strong technological improvements, offset by declining efficiency. This provides a broader picture of productive efficiency in New Zealand universities compared to Australian universities, offering insights into the factors affecting TFP changes before exploring individual New Zealand university results.

More precisely, in New Zealand, cumulative TFP decreased by 7.0% on average, primarily driven by a 12.7% fall in efficiency, which outweighed a 7.3% improvement in technology. This substantial efficiency loss was mainly driven by declines of 8.0% in pure efficiency and 5.1% in scale efficiency.

In contrast, Australian universities experienced a 17.1% increase in cumulative TFP during the same period. This was mainly driven by a significant 14.0% improvement in technology, complemented by a modest 2.8% gain in efficiency. The efficiency improvement consisted of a 0.5% increase in pure efficiency and a 2.2% enhancement in scale efficiency.

Figure 5.7

Cumulative Changes in TFP, Technology and Efficiency for New Zealand and Australian Universities, 2008-2018



Source: New Zealand TEC, MoE, NZQF (2016) and New Zealand's university annual reports. Australian Government DoE and the AQF (2013).

Note: 1. The base year, 2008 is set to a value of one.

2. The annual figures for New Zealand and Australia are geometric mean of cumulative changes in TFP, technology and efficiency relative to the base year 2008.

From 2008 to 2018, New Zealand and Australian universities displayed contrasting productivity trends. New Zealand universities experienced fluctuating TFP, with an initial peak in 2009 followed by a steady decline, leading to cumulative TFP falling below its 2008 base level by 2018. In contrast, Australian universities consistently grew in cumulative TFP, steadily progressing throughout the period.

The decomposition of cumulative TFP shows different drivers of productivity across the two countries. New Zealand universities relied mainly on technological improvements, which increased until 2015 but declined slightly towards 2018. However, persistent efficiency declines largely offset these technological gains. In contrast, Australian universities achieved balanced cumulative productivity change, driven by both continuous technological progress and moderate efficiency improvements, resulting in better overall productivity.

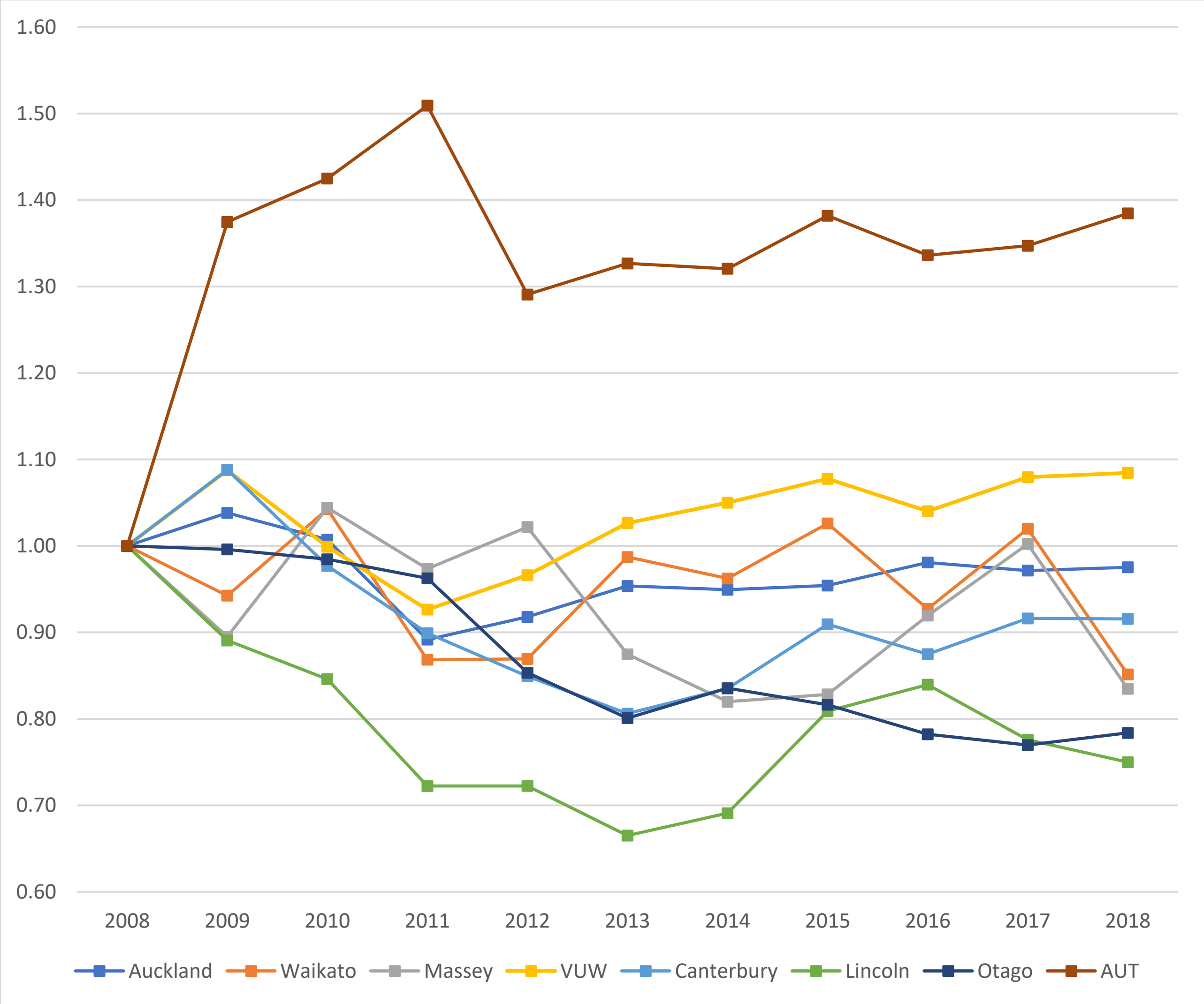
Australian universities experienced a temporary decline in technology change between 2009 and 2010, attributed to reduced undergraduate completions, practically in Go8 universities. However, after 2010, technological progress accelerated, driven by a sharp increase in postgraduate completions and high research earnings. These gains were further strengthened by active collaboration with international universities, increasing international students without an increase in staff.

New Zealand universities showed a sharp decline in efficiency between 2010 and 2012, primarily due to decreased research income and increased teaching and research staff. While there was a modest improvement in technology, it was outweighed by a substantial decline in efficiency. As a result, TFP declined significantly.

The performance of individual New Zealand universities is hidden by the cumulative change in TFP of the New Zealand university grouping depicted in Figure 5.7. For each New Zealand university from 2008 to 2018, the cumulative TFP changes are shown in Figure 5.8.

Figure 5.8

Cumulative Change in TFP by Individual New Zealand University, 2008-2018



Source: New Zealand TEC, MoE, NZQF (2016) and New Zealand's university annual reports.

Note: 1. The base year, 2008 is set to a value of one.

2. The annual figures for New Zealand are geometric mean of cumulative change in TFP relative to the base year 2008.

Auckland University of Technology (AUT)

AUT experienced the fastest rise in cumulative TFP (by 38.5%) among New Zealand universities during the period. This was due to a 73.1% rise in research income, albeit from the lowest research income among all New Zealand universities. The increase reflects AUT's opportunity to enhance its research capability from a low base. A significant component of AUT's TFP increase stemmed from its credit and income-weighted completions, including bachelor's, master's and doctoral degrees with high income weights.

AUT also had numbers of completions at sub-degree levels, reflecting its polytechnic origins before becoming a university in 2000. However, the rapid productivity growth from a low base became harder to maintain as inefficiency was eliminated, shifting the focus to technological improvements. This aligns with Worthington and Lee (2008), who noted a slowdown in TFP growth after 2012.

The University of Auckland

The University of Auckland experienced fluctuating cumulative TFP over time. Its TFP peaked between 2008 and 2010, primarily due to an 8.9% increase in research income. However, from 2011 to 2013, cumulative TFP declined, particularly in 2011, mainly due to reduced completions weighted by variable credit and income. Between 2013 and 2014, TFP increased, driven by increased completions at master's and doctoral levels and increased research income. From 2016 to 2018, TFP declined again, mainly due to the continuously falling EFTS enrolments and completions.

The University of Auckland responded by redeveloping and expanding its facilities[108] to attract both domestic and international students. This response addressed a slight 0.1% decrease in undergraduate EFTS and a 50.0% increase in postgraduate EFTS. It increased its teaching staff by 18.5% to meet the growing demand. As New Zealand's largest and top-ranked university, it benefits from its provision of faculty-focused subjects across six campuses (e.g., the Faculties of Medical and Health Science), which enhances its ability to attract research staff, PhD students, and more research income, sustaining its competitive position.

The University of Waikato

The University of Waikato's cumulative TFP mainly benefited from a 14% improvement in technical change, possibly due to its international collaborations, offshore programme delivery, and a 9.1% decrease in teaching staff. However, efficiency declined by 25.3%, mainly due to a 23.0% fall in pure efficiency, which led to a decrease in cumulative TFP. Fluctuations in completions, particularly in undergraduate levels (e.g., Levels 3 certificates to Level 7 certificates and diplomas) and postgraduate levels (e.g., master's and doctorates weighted by high credit and income) and decreasing research income, also contributed to this decline. Since 2013, cumulative TFP improved due to a rise in research income in 2015 and increased completions in 2017. However, it declined again, primarily driven by a sharp fall in pure efficiency in 2018.

[108] In 2009, the University of Auckland embarked on a NZ$1 billon 10-year plan to develop and expand its facilities (Wikipedia, 2024). The university upgraded the Grafton Campus in 2011; purchased and moved to the new facilities in Newmarket for the Faculty of Engineering and the School of Chemical Science in 2015; opened the new Science Centre in 2017; and completed the new Engineering Building in 2019.

Massey University

Massey University's TFP showed notable fluctuations during the period. Between 2008 and 2012, TFP growth was driven by increased undergraduate (such as Level 4 certificates, graduate diplomas, and bachelor's degrees) and postgraduate completions, weighted by high credit and income, along with having the third-largest research income. However, from 2013 onward, TFP declined significantly due to reduced efficiency, particularly in pure efficiency. After 2015, TFP partially recovered due to an increase in research income of 23.4% and undergraduate completions of 7.1%. However, postgraduate completions declined by 0.6%, while teaching staff increased by 8.8% between 2015 and 2018. The large TFP decline by 2018 may reflect congestion, where increased inputs (e.g., FTE staff) yielded decreased outputs (Worthington & Lee, 2008). Its specialisation in primary sector-based subjects (Smart, 2019b), such as agriculture and horticulture, which are labour-intensive, may further explain this decline.

Victoria University of Wellington (VUW)

VUW achieved the second-highest cumulative TFP among New Zealand universities, due to substantial productivity improvements since 2011. Between 2009 and 2011, productivity declined due to a 2.1% drop in research income, a 2.1% decrease in undergraduate EFTS enrolments and a 2.5% fall in postgraduate EFTS, and a 6.1% increase in teaching staff. From 2012 onward, VUW's TFP rose sharply, driven by a 19.0% increase in postgraduate completions and a 52.6% rise in research income between 2012 and 2018. This indicates that the university performs more effectively using limited resources (New Zealand Tertiary Education Commission, 2019). This suggests VUW has improved by moving closer to its best-practice frontier—increasing outputs relative to inputs given the available technology—which contributed to improved TFP.

The University of Canterbury

After a spike in 2009, driven by increased postgraduate completions and research income, the University of Canterbury experienced a gradual decrease in productivity over time. However, the 2011 Canterbury earthquake significantly disrupted its operations, leading to a decrease in undergraduate enrolments and completions by 16.9% and 9.7%, respectively. Despite these challenges, the earthquakes led to the development of over 200 earthquake-related research projects across disciplines by 2012, including geosciences, engineering, social science, education and business. To further support these efforts, the university established new PhD scholarships for earthquake-related research (University of Canterbury, 2012), highlighting its significant academic response to the disaster.

Lincoln University

Lincoln University exhibited substantial fluctuations in cumulative TFP over time, with the lowest levels between 2009 and 2015. In 2018, it experienced the lowest TFP across New Zealand universities, mainly due to a steady decrease in undergraduate enrolments and completions at Levels 1 to 4 certificates, Levels 5 to 7 certificates and diplomas, and Level 7 bachelor's degrees. The 2011 merger with Telford Rural Polytechnic, the quick recovery of its operations after the earthquake, and labour market conditions in the Canterbury region contributed to a surge in completions between 2011 and 2013. In particular, the completions at Certificate Levels 1 and 2 continuously declined and even disappeared in 2018. However, the completions of graduate certificates and diplomas at Levels 7, bachelor's, master's and doctoral degrees, steadily increased between 2013 and 2016, supporting improvements in TFP. Lincoln University relies heavily on international students, who comprise around one-third of enrolments, and its specialisation in agricultural-focused disciplines also affects its TFP trends.

The University of Otago

The University of Otago experienced a steady decline in TFP, particularly after 2010, likely driven by reductions in undergraduate completions and enrolments. This reflected inefficiencies in resource utilisation and difficulties in maintaining outputs relative to inputs. During this period, substantial increases in labour and capital inputs further contributed to the decline in productivity. Although postgraduate completions rose by 3.7% and research income increased by 2.4%, the university struggled to sustain productivity growth, particularly in the face of increasing labour and capital costs, reflected in annual growth of 3.3% in teaching staff, 1.2% in research staff, and 2.6% in capital expense. Reliance on capital-based improvements was insufficient to offset productivity decline. A modest recovery in 2014 was attributed to improved teaching productivity by developing online student management systems and providing distance education. However, these measures were insufficient to sustain long-term TFP growth as rising labour and capital costs continued to outpace output gains.

5.2.3 *Sensitivity Analysis of Alternative Variables Measurements on the Base Model*

Sensitivity analysis, summarised in Table 5.4 (with further details in Appendix Chapter 5 Tables A5.7—A5.12), explores the robustness of the Malmquist index for Australasian universities under alternative variable measurements, compared to those used to generate the based model results in Table 5.3. This comparison highlights how changes in input variables (e.g., labour and capital), research output (e.g., research publications), and data sources affect the results. The key findings are as follows:

1. Labour inputs: Staff Allocation (base model 50:50 vs 40:60): Shifting to a 40:60 FTE allocation had minimal impact on productivity results for New Zealand universities. Slight TFP improvements were observed at the University of Auckland (base model 0.997 vs. 0.998) and the University of Canterbury (base 0.991 vs 0.992). The University of Auckland showed improved scale efficiency but reduced pure efficiency. Conversely, Lincoln University's TFP declined slightly under the 40:60 allocation (base model 0.972 vs. 0.971). The average TFP for New Zealand (0.993) and Australian (1.016) universities remained unchanged, indicating stable results across staff allocation models. However, Australian universities showed slight declines in pure efficiency under the 40:60 allocation. These results indicate that variations in FTE allocation have a limited impact on productivity changes for most universities.

2. Capital cost variations were tested using four specifications: the base model (non-labour expenditure), specific capital categories, depreciation and amortisation, and teaching capital adjusted by teaching income[109]. Different types of capital costs had different impacts on university productivity:

    2.1 Specific Capital Categories, including property-related costs (e.g., rent, energy, maintenance, property impairment expenses, and equipment leases) alongside depreciation and amortisation, resulted in an overall TFP increase of 0.1% for New Zealand universities (0.994 vs. base model 0.993). In contrast, Australian universities experienced a TFP decline (1.014 vs. base 1.016). These differences suggest that variations in the classifications of capital cost affect TFP outcomes.

    2.2 Using only depreciation and amortisation, TFP estimates for New Zealand universities were generally reduced compared to the base model. For example, the University of Auckland's fell by 0.1% (base model 0.997 vs. 0.996), and Massey University's declined by 0.9% (base model 0.982 vs. 0.973). However, the University of Waikato and AUT showed slight improvements of 0.3% (base model 0.984 vs. 0.987) and 0.5% (base 1.033 vs. 1.038), respectively. Australian universities exhibited a modest TFP increase of 0.1% (base model 1.016 vs. 1.017). These differences may reflect variations

[109] Variations in capital cost are detailed in the Data Summary, Section 4.2.1.

in asset types (e.g., buildings, laboratory equipment, or IT infrastructure) and respective depreciation rates across the two countries.

2.3 Adjusting physical capital for teaching weights (e.g., PPE adjusted for teaching income) offered a new perspective by accounting for the teaching intensity of universities. Australian universities exhibited a 0.1% TFP increase due to strong technical progress, while New Zealand universities showed no change in TFP, with improved efficiency possibly offsetting reduced technology. For example, AUT's TFP increased by 0.7% under this measure, driven by efficiency gains. This adjustment allows for a relatively fair comparison across universities with different research and teaching intensities, reflecting the impact of resource allocation and productive efficiency specific to teaching functions.

3. Research output variations (base model: research income vs citation-weighted research publications): when citation-weighted research publications are used as an output variable, there are notable changes in results. All universities (except for the University of Canterbury) experienced decreases in TFP and technical changes compared to the base case. This impact was undeniable for Australian universities, which exhibited reductions in all components of productivity. In contrast, New Zealand universities showed increased efficiency change, reflecting the effect of quality-adjusted research outputs on productivity. For instance, the University of Auckland's TFP decreased from 0.997 to 0.973, due to declines in both technical and efficiency changes, while the University of Otago's TFP fell from 0.976 to 0.958, driven solely by technical regress. Despite these variations, AUT's TFP consistently remained above one in both models and across all changes, reflecting its relatively high and consistent performance across specifications. This research alternative measure reflects the interplay between research quality and productivity, highlighting the importance of carefully selecting research output variables in productivity analysis.

4. Data source variations (base model: New Zealand TEC data/Australian DoE data vs. Universities' annual reports): Using alternative data sources for academic (combining teaching and research FTEs) and general FTEs affects productivity results. For New Zealand universities, the average TFP deteriorated from 0.993 to 0.991, driven by technological regress, while Australian universities experienced a slight improvement from 1.016 to 1.017 due to technological gains. VUW's TFP increased from 1.008 to 1.012, and the University of Otago's also rose from 0.976 to 0.996. However, other universities experienced declines in TFP. The University of Auckland's decline was mainly due to reduced efficiency, particularly pure efficiency, while other universities faced declines primarily due to technological regress. AUT's TFP remained stable at 1.033, reflecting consistent productivity performance across data sources. These results indicate that data source

variation impacts productivity estimates, mainly through technical change, while efficiency changes are relatively stable for both countries.

Table 5.4
Geometric Mean Changes in Total Factor Productivity, Technical, Efficiency, Pure Efficiency and Scale Efficiency of Australasian Universities, 2008/09 to 2017/18

Model Specification	University	TFP Δ	Technical Δ	Efficiency Δ	Pure efficiency Δ	Scale efficiency Δ
0. Base Model	Auckland	0.997	0.998	1.000	1.003	0.997
	Waikato	0.984	1.013	0.971	0.974	0.997
	Massey	0.982	1.001	0.981	0.985	0.996
	VUW	1.008	1.005	1.003	1.003	1.000
	Canterbury	0.991	0.995	0.996	0.994	1.002
	Lincoln	0.972	1.003	0.968	1.000	0.968
	Otago	0.976	1.004	0.972	0.974	0.998
	AUT	1.033	1.033	1.000	1.000	1.000
	New Zealand	***0.993***	***1.006***	***0.986***	***0.992***	***0.995***
	Australia	***1.016***	***1.013***	***1.003***	***1.001***	***1.002***
1. FTE staff allocation: 40:60	Auckland	0.998	0.998	1.000	1.002	0.998
	Waikato	0.984	1.013	0.971	0.974	0.997
	Massey	0.982	1.001	0.981	0.985	0.996
	VUW	1.008	1.005	1.003	1.003	1.000
	Canterbury	0.992	0.995	0.996	0.994	1.002
	Lincoln	0.971	1.003	0.968	1.000	0.968
	Otago	0.976	1.004	0.972	0.974	0.998
	AUT	1.033	1.033	1.000	1.000	1.000
	New Zealand	***0.993***	***1.006***	***0.986***	***0.991***	***0.995***
	Australia	***1.016***	***1.014***	***1.002***	***1.000***	***1.002***
2.1 Capital Costs (TEC specific categories)	Auckland	0.996	1.000	0.996	1.007	0.989
	Waikato	0.986	1.009	0.978	0.976	1.001
	Massey	0.974	0.987	0.986	0.986	1.001
	VUW	1.007	1.005	1.002	1.002	1.000
	Canterbury	0.994	0.993	1.001	0.996	1.005
	Lincoln	0.981	0.999	0.981	1.000	0.981
	Otago	0.975	1.005	0.970	0.970	1.000
	AUT	1.037	1.021	1.016	1.016	1.000
	New Zealand	***0.994***	***1.002***	***0.991***	***0.994***	***0.997***
	Australia	***1.014***	***1.010***	***1.004***	***1.001***	***1.003***
2.2 Capital Costs (Depreciation and Amortisation)	Auckland	0.996	1.000	0.996	1.004	0.992
	Waikato	0.987	1.013	0.975	0.974	1.001
	Massey	0.973	0.991	0.982	0.982	1.000
	VUW	1.007	1.005	1.002	1.002	1.000
	Canterbury	0.993	0.995	0.998	0.994	1.004
	Lincoln	0.970	1.003	0.967	1.000	0.967
	Otago	0.975	1.005	0.970	0.970	1.000
	AUT	1.038	1.021	1.016	1.016	1.000
	New Zealand	***0.992***	***1.004***	***0.988***	***0.993***	***0.995***
	Australia	***1.017***	***1.014***	***1.003***	***1.000***	***1.002***
2.3 Capital Costs (Adjusted	Auckland	1.001	1.006	0.996	1.004	0.992
	Waikato	0.984	1.011	0.973	0.972	1.001
	Massey	0.973	0.991	0.982	0.982	1.000

Teaching Capital (e.g., PPE) by teaching income)	VUW	1.008	1.006	1.002	1.002	1.000
	Canterbury	0.996	0.998	0.998	0.994	1.004
	Lincoln	0.969	1.002	0.967	1.000	0.967
	Otago	0.975	1.005	0.970	0.970	1.000
	AUT	1.040	1.024	1.016	1.016	1.000
	New Zealand	***0.993***	***1.005***	***0.988***	***0.992***	***0.995***
	Australia	***1.017***	***1.015***	***1.002***	***1.001***	***1.002***
3. Research output: Adjusted Research Publications	Auckland	0.9727	0.975	0.998	0.998	1.000
	Waikato	0.9734	0.999	0.975	0.978	0.996
	Massey	0.9731	0.989	0.984	0.987	0.996
	VUW	0.997	0.983	1.014	1.013	1.000
	Canterbury	0.992	0.972	1.020	1.018	1.002
	Lincoln	0.948	0.976	0.971	1.000	0.971
	Otago	0.958	0.967	0.990	0.991	0.999
	AUT	1.027	1.027	1.000	1.000	1.000
	New Zealand	***0.980***	***0.986***	***0.994***	***0.998***	***0.996***
	Australia	***0.979***	***0.977***	***1.002***	***1.000***	***1.002***
4. Data Source changed to Universities' Annual Reports (Academic and General FTEs)	Auckland	0.987	1.005	0.982	0.983	1.000
	Waikato	0.981	1.011	0.971	0.973	0.997
	Massey	0.978	0.997	0.981	0.983	0.998
	VUW	1.012	1.005	1.007	1.006	1.001
	Canterbury	0.978	0.983	0.995	0.992	1.003
	Lincoln	0.969	0.997	0.972	1.000	0.972
	Otago	0.996	1.010	0.987	0.999	0.988
	AUT	1.033	1.033	1.000	1.000	1.000
	New Zealand	***0.991***	***1.005***	***0.987***	***0.992***	***0.995***
	Australia	***1.017***	***1.014***	***1.003***	***1.001***	***1.002***

Source: New Zealand TEC, MoE, NZQF (2016) and New Zealand's university annual reports. Australian Government DoE and AQF (2013).

Note: 1. All means are geometric means.

2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.

Overall, while the sensitivity analysis produces some quantitative differences, the qualitative results observed in the base model are robust. This highlights the importance of selecting appropriate input, output and data measures in productivity analysis.

Changes in labour input allocations had minimal impact on TFP changes, indicating stable productivity trends. Variations in capital costs had different effects: specific capital categories improved TFP in New Zealand universities but reduced it in Australia due to the technical regress. Depreciation-focused measures lowered TFP for New Zealand universities, but increased it for Australian universities, reflecting their technical progress. Teaching income-adjusted capital improved Australian TFP due to their technical progress but had no effect in New Zealand.

Using citation-weighted research publications instead of research income reduced TFP for most universities. Australian universities showed declines in all components, while New Zealand universities experienced efficiency improvements. Similarly, using alternative data sources, such as university annual reports, slightly reduced TFP for New Zealand universities, due to technological regress, while Australian universities showed modest gains due to technological progress.

5.2.4 *Conclusion*

Partial labour productivity captures single output-input ratios but cannot reflect the functional relationship between multiple inputs and outputs in university operations. This chapter used a Malmquist index approach to further analyse productivity trends in New Zealand and Australian universities. This approach also enabled the decomposition of TFP into efficiency and technical change.

Throughout the study, TFP in New Zealand universities decreased by an average of 0.7% per year. This was driven by a 0.6% annual improvement in technical change and a 1.4% annual decline in efficiency change. The technology change was an important component of the Malmquist index in New Zealand universities, consistent with Wang et al. (2020) but contrasting with Margaritis and Smart (2011). While New Zealand universities have attempted to respond to the government's desire for expansion in the tertiary education sector by changing technologies, they are doing so at the price of efficiency (Johnes, 2006a, 2008).

In contrast, Australian universities experienced an average annual TFP increase of 1.6%. This was due to a 1.3% increase in technology change and a 0.3% rise in efficiency. The finding that technology change was a significant driver of TFP change in Australian universities, aligns with previous studies (Carrington et al., 2005; Worthington & Lee, 2008; Margaritis & Smart, 2011).

The cumulative TFP analysis from 2008 to 2018 reveals that New Zealand universities initially experienced faster TFP growth (3%) than Australian universities (-3%) between 2008 and 2010, primarily driven by technological improvements (3.5%). However, this trend reversed after 2010. New Zealand universities experienced a 7% cumulative decline in TFP by 2018, mainly due to a significant 12.7% drop in efficiency. In contrast, Australian universities exhibited steady TFP growth from 2010 onward, achieving a 17.1% increase, driven by technological progress (14.0%) and modest efficiency gains (2.8%). These results reflect the divergence in productivity trends and the widening performance gap between New Zealand and Australian universities over the period.

Smaller and younger universities (e.g., AUT) often exhibit the highest productivity improvements across TFP, its components, and its cumulative TFP, due to starting from a lower base and having more scope for progress than larger and older institutions. This suggests that these universities are more likely to pursue some of the critical drivers of productivity development, such as expanding production scale and improving the quality of inputs (Worthington & Lee, 2008). For instance, AUT is a typical example that has improved its quality of labour input (e.g., a 37.7% rise in PBRF FTEs from 2012 to 2018) and an increase in its output levels (e.g., a 114.9% increase in postgraduate completions).

Some New Zealand universities exhibit distinct areas of specialisation, which may enhance their performance by focusing on specific fields and gaining a comparative advantage (Smart, 2019b). For instance, the University of Auckland and Otago specialise in clinical medicine due to their medical schools, while Massey University and Lincoln University focus on primary sector subjects such as agriculture. However, courses like engineering or medicine are more resource-intensive and costlier to deliver than fields like commerce. The New Zealand Productivity Commission (2018b) suggests that universities specialising in such capital-intensive courses may appear less productive due to higher delivery costs. This may partly explain the observed declines in TFP changes and cumulative TFP at Auckland and Otago.

Universities generally prefer recruiting more international students, as they pay higher tuition fees than domestic students. A decline in international enrolments may significantly affect institutions that rely heavily on this revenue. For instance, from 2008 to 2018, Lincoln University had the highest proportion (one-third) of overseas students among New Zealand universities. The large decline in Lincoln University's enrolment between 2008 and 2014 was driven by reduced international students and completions and the impacts of the Christchurch earthquake. These factors likely contributed to Lincoln University having the lowest cumulative TFP.

The analysis examined the sensitivity of changes in TFP and its components to alternative input and output measures. The robustness check included adjusting for credit and income-weighted completions. Shifting the labour input allocation from 50:50 to 40:60 resulted in minor changes in TFP for New Zealand universities, with slight improvements observed for the University of Auckland and Canterbury and a slight decline at Lincoln University.

Variations in capital cost measures had a notable effect on TFP changes. Replacing non-labour expenditure with specific capital costs led to improved TFP change in New Zealand universities, while solely using depreciation and amortisation as a proxy for capital costs decreased TFP change, likely due to differences in asset depreciation rates. Adjusting physical capital for teaching intensity improved TFP change in Australian universities due to strong technical progress but had no overall effect in New Zealand. Despite variation in capital measures, New Zealand universities consistently exhibited efficiency-driven improvements, but technical regress persisted compared to the base model. These findings highlight the critical role of capital measurement choices in shaping productivity change outcomes.

When research outputs were measured using quality-adjusted research publications rather than research income, all universities (except the University of Canterbury) exhibited a decrease in TFP and technical change relative to the base case. This effect was undeniable for Australian universities, which exhibited reductions across all components. In contrast, New Zealand universities experienced efficiency improvements. These results reflect the importance of selecting research output variables, significantly affecting productivity analysis.

Lastly, using alternative data sources, such as universities' annual reports data, impacted TFP change, primarily through technical change. For New Zealand universities, mean changes in TFP deteriorated from 0.993 to 0.991, driven by technological regress. In contrast, Australian universities showed a slight improvement from 1.016 to 1.017 due to technological progress.

It is important to distinguish between productivity levels and productivity growth when interpreting these results. A university may appear more or less productive or efficient compared to others in the sample (44 universities), depending on its ability to generate outputs given its inputs. However, productivity growth reflects the proportional change in productivity over time relative to a base period. Worthington and Lee (2008) noted that a larger university may generate higher output levels and thus appear more productive, but its productivity growth may remain low if its input growth matches or exceeds output growth. This appears to be the case for the University of Otago.

Chapter 6 Empirical Results: Stochastic Output Distance Frontier Analysis

This chapter examines the technical efficiency of Australasian universities using the stochastic output distance function (ODF) approach. This analysis builds on the theoretical framework in Section 2.3.3 and the data analysis in Section 4.3. It investigates the relationship between outputs (postgraduate completions and research income) and inputs (academic staff, general staff and capital costs), with undergraduate completions as the dependent variable. This analysis uses the Battese and Coelli (1995, BC95) model, which simultaneously estimates the stochastic frontier and inefficiency effect, allowing the identification of key factors influencing inefficiency.

Section 6.1 specifies the empirical model, including the Cobb-Douglas (CD) and translog functional forms. The CD model provides a simple structure, while the translog model is more flexible and commonly used for capturing complex relationships between inputs and outputs (e.g., interaction terms). Additionally, Section 6.1 outlines the sources of inefficiency, referred to as "z-variables" or "determinants of efficiency". Determinants of efficiency include the presence of a medical school, the proportion of international or female enrolments, regional dummies, and the ratio of general to academic full-time equivalent (FTE) staff. The analysis also examines the cross-effects via interaction terms to explore complementary relationships between inputs or between outputs, and their effects on university performance.

Section 6.2 presents and discusses the empirical findings, including ODF estimates, technical efficiency scores and sensitive analyses for the robustness checks. Section 6.3 concludes the chapter by summarising the main insights. Appendix Chapter 6 provides supplementary and additional tables for robustness analyses.

6.1 Empirical Model Specification

Stochastic Output Distance Function Framework

The stochastic ODF evaluates the potential proportional expansion of outputs for a given input vector, assuming universities aim to maximise outputs for a given input level (Johnes, 2008). As discussed in Section 2.3.3, the ODF framework satisfies specific economic properties, including convexity, non-decreasing behaviour in outputs, homogeneous degree one in outputs, and non-increasing behaviour in inputs (Coelli et al., 2005, pp. 47-48).

The dependent variable is $-\boldsymbol{lny_{UG}}$, where $\boldsymbol{y_{UG}}$ represents undergraduate completions. The transformation ensures that the distance from the efficiency frontier is reflected in the residuals, with a value less than one indicating inefficiency. The transformation is based on the homogeneity of degree one in outputs, where undergraduate completions ($\boldsymbol{y_{UG}}$) serve as the normalizing variable. Refer to Equations 2.32-2.35 in Section 2.3.3 for details.

The negative sign of the dependent variable implies that the estimated parameters in the ODF equations have opposite signs compared to those in standard production functions. This reflects the focus on distance from the efficiency frontier rather than the absolute output level.

Cobb-Douglas and Translog Model Specifications

Two widely used functional forms for estimating the ODF are the Cobb-Douglas (CD) and translog models:

Cobb-Douglas Model

The Cobb-Douglas model (Equation 6.1) provides a simple, linear structure for estimating the input-output relationships. It assumes constant elasticities and no interaction effects. The empirical model for this study is expressed as:

$$\begin{aligned} -\boldsymbol{lny_{UG_{it}}} &= \boldsymbol{\alpha_0} + \sum_{m=2}^{3} \boldsymbol{\alpha_m} \, \boldsymbol{ln}\left(\frac{\boldsymbol{y_{mit}}}{\boldsymbol{y_{UG_{it}}}}\right) + \sum_{k=1}^{3} \boldsymbol{\beta_k lnx_{kit}} + \boldsymbol{\theta_1 t} + \boldsymbol{\theta_2 t^2} + \boldsymbol{v_{it}} + \boldsymbol{u_{it}} \\ &= \boldsymbol{\alpha_0} + \boldsymbol{\alpha_2} \, \boldsymbol{ln}\left(\frac{\boldsymbol{y_{PG_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right) + \boldsymbol{\alpha_3} \, \boldsymbol{ln}\left(\frac{\boldsymbol{y_{RI_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right) + \boldsymbol{\beta_1 lnx_{Aca_{it}}} + \boldsymbol{\beta_2 lnx_{Gen_{it}}} + \boldsymbol{\beta_3 lnx_{Cap_{it}}} \\ &\quad + \boldsymbol{\theta_1 t} + \boldsymbol{\theta_2 t^2} + \boldsymbol{v_{it}} + \boldsymbol{u_{it}} \end{aligned} \tag{6.1}$$

Translog Model

The translog model (Equation 6.2) extends the Cobb-Douglas model by adding second-order interaction terms. This allows greater flexibility in capturing nonlinear relationships and interaction effects. The translog model is expressed as:

$$
\begin{aligned}
-\boldsymbol{lny_{UG_{it}}} = {} & \boldsymbol{\alpha_0} + \sum_{m=2}^{3} \boldsymbol{\alpha_m\, ln}\left(\frac{\boldsymbol{y_{mit}}}{\boldsymbol{y_{UG_{it}}}}\right) \\
& + \frac{\mathbf{1}}{\mathbf{2}}\sum_{m=2}^{3}\sum_{n=2}^{3} \boldsymbol{\alpha_{mn}\, ln}\left(\frac{\boldsymbol{y_{mit}}}{\boldsymbol{y_{UG_{it}}}}\right)\boldsymbol{ln}\left(\frac{\boldsymbol{y_{nit}}}{\boldsymbol{y_{UG_{it}}}}\right) \\
& + \sum_{k=1}^{3} \boldsymbol{\beta_k lnx_{kit}} \\
& + \frac{\mathbf{1}}{\mathbf{2}}\sum_{k=1}^{3}\sum_{l=1}^{3} \boldsymbol{\beta_{kl} lnx_{kit} lnx_{lit}} + \sum_{k=1}^{3}\sum_{m=2}^{3} \boldsymbol{\zeta_{km} lnx_{kit}\, ln}\left(\frac{\boldsymbol{y_{mit}}}{\boldsymbol{y_{UG_{it}}}}\right) + \boldsymbol{\theta_1 t} + \boldsymbol{\theta_2 t^2} + \boldsymbol{v_{it}} \\
& + \boldsymbol{u_{it}} \\
& = \boldsymbol{\alpha_0} + \boldsymbol{\alpha_2\, ln}\left(\frac{\boldsymbol{y_{PG_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right) + \boldsymbol{\alpha_3\, ln}\left(\frac{\boldsymbol{y_{RI_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right) \\
& + \left\{\mathbf{0.5}\boldsymbol{\alpha_{22}} * \left[\boldsymbol{ln}\left(\frac{\boldsymbol{y_{PG_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right)\right]^2 + \boldsymbol{\alpha_{23}} * \left[\boldsymbol{ln}\left(\frac{\boldsymbol{y_{PG_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right)\boldsymbol{ln}\left(\frac{\boldsymbol{y_{RI_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right)\right] + \mathbf{0.5}\boldsymbol{\alpha_{33}} \right. \\
& \left. * \left[\boldsymbol{ln}\left(\frac{\boldsymbol{y_{RI_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right)\right]^2\right\} + \left(\boldsymbol{\beta_1 lnx_{Aca_{it}}} + \boldsymbol{\beta_2 lnx_{Gen_{it}}} + \boldsymbol{\beta_3 lnx_{Cap_{it}}}\right) \\
& + \left[\mathbf{0.5}\boldsymbol{\beta_{11}} * (\boldsymbol{lnx_{Aca_{it}}})^2 + \mathbf{0.5}\boldsymbol{\beta_{22}} * (\boldsymbol{lnx_{Gen_{it}}})^2 + \mathbf{0.5}\boldsymbol{\beta_{33}} * (\boldsymbol{lnx_{Cap_{it}}})^2 + \boldsymbol{\beta_{12}} \right. \\
& \left. * \left(\boldsymbol{lnx_{Aca_{it}} lnx_{Gen_{it}}}\right) + \boldsymbol{\beta_{13}} * \left(\boldsymbol{lnx_{Aca_{it}} lnx_{Cap_{it}}}\right) + \boldsymbol{\beta_{23}} * \left(\boldsymbol{lnx_{Cap_{it}} lnx_{Gen_{it}}}\right)\right] \\
& + \left\{\boldsymbol{\zeta_{12}} * \left[\boldsymbol{lnx_{Aca_{it}} ln}\left(\frac{\boldsymbol{y_{PG_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right)\right] + \boldsymbol{\zeta_{13}} * \left[\boldsymbol{lnx_{Aca_{it}} ln}\left(\frac{\boldsymbol{y_{RI_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right)\right] + \boldsymbol{\zeta_{22}} \right. \\
& * \left[\boldsymbol{lnx_{Gen_{it}} ln}\left(\frac{\boldsymbol{y_{PG_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right)\right] + \boldsymbol{\zeta_{23}} * \left[\boldsymbol{lnx_{Gen_{it}} ln}\left(\frac{\boldsymbol{y_{RI_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right)\right] + \boldsymbol{\zeta_{32}} * \left[\boldsymbol{lnx_{Cap_{it}} ln}\left(\frac{\boldsymbol{y_{PG_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right)\right] \\
& \left. + \boldsymbol{\zeta_{33}} * \left[\boldsymbol{lnx_{Cap_{it}} ln}\left(\frac{\boldsymbol{y_{RI_{it}}}}{\boldsymbol{y_{UG_{it}}}}\right)\right]\right\} + \boldsymbol{\theta_1 t} + \boldsymbol{\theta_2 t^2} + \boldsymbol{v_{it}} + \boldsymbol{u_{it}}
\end{aligned}
\tag{6.2}
$$

where:

- $\boldsymbol{-lny_{UG}}$ represents undergraduate completions and is the dependent variable,

$\boldsymbol{y_m}$ represents outputs, including postgraduate completions ($\boldsymbol{y_{PG}}$) and research income ($\boldsymbol{y_{RI}}$), respectively, to measure the teaching and research performance of universities;

- $\boldsymbol{x_k}$ represents inputs, including academic FTE staff ($\boldsymbol{x_{Aca}}$), general FTE staff ($\boldsymbol{x_{Gen}}$), and capital costs ($\boldsymbol{x_{Cap}}$) using the non-labour expenditure as a proxy for unavailable capital expenses data (Worthington & Higgs, 2011);
- $\boldsymbol{\alpha, \beta, \zeta, \theta}$ are unknown parameters to estimate;
- $\boldsymbol{t}$ represents time trend variables to capture technological change;
- $\boldsymbol{v_{it}}$ represents random errors;

- $\boldsymbol{u_{it}}$ represents technical inefficiency.

The $\boldsymbol{v_{it}}$ terms represent random errors, assumed to be independently and identically distributed $\boldsymbol{N(0, \sigma_v^2)}$, and independent of $\boldsymbol{u_{it}}$. The term $\boldsymbol{u_{it} = -lnD_{it}^{O} = -lnTE_{it}}$ represents non-negative random errors that measure the technical inefficiency of the university i and time t and need to be estimated.

Normalisation and Mean-Scaling

Before estimation, all input and output variables are normalised by dividing them by their respective geometric means. This approach allows the first-order coefficients of each variable to be interpreted as distance elasticities, evaluated at the geometric means of the data (Cuesta & Orea, 2002; Cuesta & Zofo, 2005; Cuesta et al., 2009; Johnes, 2014a; Johnes, 2014b; Minviel & Sipiläinen, 2021; Letti et al., 2022). Linear homogeneity on the ODF is imposed by using undergraduate completions ($\boldsymbol{y_{UG}}$) as the numeraire (Letti et al., 2022).

Quality Adjustment of Teaching Outputs

Undergraduate and postgraduate completions are weighted by credit and income to reflect both the quantity and quality of teaching outputs. This adjustment serves as proxies for the knowledge and skills acquired by students upon graduation.

Inefficiency Effects Model: Battese and Coelli (1995, BC95) Model

The inefficiency term ($\boldsymbol{u_{it}}$) is estimated using the BC95 model, which allows for simultaneous[110] estimation of the stochastic frontier and inefficiency effects. The model accommodates panel data[111] and accounts for time-varying efficiencies and universality-specific inefficiency determinants. The BC95 model specification has been widely used in empirical studies, such as Abbott and

[110] Pitt and Lee (1981) adopted a two-stage approach, in which the first stage estimated the stochastic frontier production function and predicted the technical inefficiency effects, assuming that these inefficiency effects are identically distributed. The second stage regresses the predicted technical inefficiency effects upon the specific variables, inconsistent with the assumptions regarding the independence of the inefficiency effects in the two estimation stages (Coelli, 1996).

[111] The panel data includes observations on several universities across multiple years and allows for the analysis of differences across universities and changes within each university over time. On the other hand, the type of data also has cross-sectional data, which is collected at one point in time for multiple universities.

Doucouliagos (2009), Zoghbi, Rocha and Mattos (2013), Johnes (2014a, 2014b), Bolli and Farsi (2015), Bolli et al. (2016), Agasisti, Barra and Zotti (2016), Barra et al. (2018), and Letti et al. (2022).

Source of Inefficiency

The BC95 model specification identifies whether certain explanatory variables contribute to inefficiency by specifying the error term as $\boldsymbol{u_{it} = \delta Z_{it} + w_{it}}$, where $\boldsymbol{Z_{it}}$ is a vector of observable explanatory variables associated with the technical inefficiency of the production of universities over time. These variables, often called “z-variables”, are not inputs or outputs, but significantly impact performance (Coelli et al., 2005). The parameter $\boldsymbol{\delta}$ represents a vector of unknown coefficients to be estimated. The random term, $\boldsymbol{w_{it}}$, follows a truncated normal distribution with zero mean and variance $\boldsymbol{\sigma_u^2}$, ensuring truncation at $\boldsymbol{-\delta Z_{it}}$, e.g., $\boldsymbol{w_{it} \geq -\delta Z_{it}}$, that is,

$$\boldsymbol{u_{it} \sim N\left(\delta Z_{it}, \sigma_u^2\right)} \tag{6.3}$$

The inefficiency term $\boldsymbol{u_{it}}$ for this study is specified as:

$$\begin{aligned} \boldsymbol{u_{it}} = {} & \boldsymbol{\delta_0 + \delta_1 Medical\ school_{it} + \delta_2 Share\ of\ Overseas_{it} + \delta_3 Region_i} \\ & \boldsymbol{+ \delta_4 Ratio\ of\ General\ \ to\ Academic\ FTE\ staff_{it}} \\ & \boldsymbol{+ \delta_5 Ratio\ of\ Female\ EFTS_{it}\ + \omega_{it}} \end{aligned} \tag{6.4}$$

where:

- $\boldsymbol{Medical\ school_{it}}$ is a dummy variable equaling 1 if the university has a medical school and 0 otherwise, which accounts for the specificity of the faculty composition and controls for structural differences of universities with or without a medical school;
- $\boldsymbol{Share\ of\ Overseas_{it}}$ is the ratio of international to total EFTS enrolments, reflecting the impact of international enrolments on university efficiency;
- $\boldsymbol{Ratio\ of\ Female\ EFTS_{it}}$ is the ratio of domestic female equivalent full-time students (EFTS) to total domestic EFTS, proxying for differences in qualification composition among universities. These two enrolment ratios reflect the influence of the socio-demographic composition of the student population;
- $\boldsymbol{Region_i}$ are dummy variables for New Zealand regions (with the North Island of New Zealand as the benchmark) and Australian state territories where universities are located as a proxy for the location effects to account for geographic differences (e.g., local economic conditions) and institutional differences (e.g., variations in government funding, research intensity and student demographics);

- $\boldsymbol{Ratio\ of\ General\ \ to\ Academic\ FTE\ staff_{it}}$ serves as an indicator of administrative efficiency (Abbott & Doucouliagos, 2009), reflecting variations in staff composition and expenses across universities.

Estimation with FRONTIER Version 4.1

This analysis employs the computer program FRONTIER Version 4.1 to estimate stochastic frontier production and cost functions using maximum-likelihood estimation (Coelli, 1996). The program supports panel data analysis and allows for flexible model specifications, including Cobb-Douglas and translog functional forms with a logged dependent variable and several independent variables, and accommodates half-normal and truncated normal distributions. The program was written to estimate the BC95 model, enabling simultaneous estimation of the stochastic frontier and inefficiency effects and thus incorporating time-varying efficiencies and university-specific determinants of inefficiency.

Inefficiency measure (γ)

According to Coelli et al. (2005, p. 246), the proportion of deviations from the frontier attributable to inefficiencies is measured as:

$$\boldsymbol{\gamma = \frac{\sigma_u^2}{\sigma_v^2 + \sigma_u^2}} \tag{6.5}$$

This parameter, $\boldsymbol{\gamma}$, ranges from zero to one. A $\boldsymbol{\gamma}$ value of zero indicates that all deviations from the frontier are due to random errors ($\boldsymbol{v_{it}}$), while a $\boldsymbol{\gamma}$ value of one means that all deviations are caused by inefficiency ($\boldsymbol{u_{it}}$).

First-Order Elasticities and Scale Elasticities

The individual first-order elasticities, derived from Equation (6.2), capture the contribution of specific inputs and outputs to university performance. According to Paul and Nehring (2005), the first-order elasticities with respect to outputs are expressed as:

$$\boldsymbol{-\varepsilon_{D^o,y_m} = -\frac{\partial lnD^o}{\partial lny_m} = \frac{\partial(\ln y_{UG})}{\partial \ln y_m} = \frac{\partial y_{UG}}{\partial y_m} * \frac{y_m}{y_{UG}} = \varepsilon_{y,y_m} = \alpha_m + \sum_{n=2}^{3} \alpha_{mn} lny_n + \sum_{k=1}^{3} \zeta_{km} lnx_k} \tag{6.6}$$

and with respect to inputs:

$$\boldsymbol{-\varepsilon_{D^o,x_k} = -\frac{\partial lnD^o}{\partial lnx_k} = \frac{\partial(\ln y_{UG})}{\partial \ln x_k} = \frac{\partial y_{UG}}{\partial x_k} * \frac{x_k}{y_{UG}} = \varepsilon_{y,x_k} = \beta_k + \sum_{l=1}^{3} \beta_{kl} lnx_l + \sum_{m=2}^{3} \zeta_{km} lny_m}$$

(6.7)

These elasticities represent the percentage change in undergraduate completions ($\boldsymbol{y_{UG}}$) due to a 1% change in an output ($\boldsymbol{y_m}$) or an input ($\boldsymbol{x_k}$), holding other factors constant. These elasticities represent how efficiently resources are used and the returns generated by specific inputs and outputs.

Specifically, the elasticities with respect to outputs ($\boldsymbol{y_m}$) in Equation (6.6) illustrate the percentage change in undergraduate completions ($\boldsymbol{y_{UG}}$) due to a 1% change in $\boldsymbol{y_m}$ (e.g., postgraduate completions or research income), holding all inputs constant. On the other hand, the elasticities for input ($\boldsymbol{x_k}$) in Equation (6.7) reflect the percentage change in undergraduate completions ($\boldsymbol{y_{UG}}$) from a 1% change in $\boldsymbol{x_k}$ (e.g., academic staff, general staff, or capital expenses), holding all output ratios ($\frac{y_m}{y_{UG}}$) constant. Such elasticities show the returns to or output contributions from changes in input $\boldsymbol{x_k}$. Moreover, if the marginal product of $\boldsymbol{x_k}$ ($\boldsymbol{MP_k}$) is calculated as $\frac{\partial y_{UG}}{\partial x_k}$ and represents an increase in overall output from an increase in $\boldsymbol{x_k}$, $\boldsymbol{\varepsilon_{y,x_k}}$ can be regarded as the "output share" of $\boldsymbol{x_k}$ (relative to $\boldsymbol{y_{UG}}$), that is, $\boldsymbol{\varepsilon_{y,x_k}} = \frac{MP_k * x_k}{y_{UG}}$.

The scale elasticities (SE) are the sum of the input elasticities for all inputs, indicating how overall output changes in response to a proportional increase in all inputs. Following Färe and Primont (1995), the SE can be expressed as:

$$SE = -\varepsilon_{D^o,x} = -\sum_k \frac{\partial lnD^o}{\partial lnx_k} = \sum_k \frac{\partial(\ln y_{UG})}{\partial \ln x_k} = \sum_k \varepsilon_{y,x_k} = \varepsilon_{y,x} \quad (6.8)$$

- $\boldsymbol{SE > 1}$ implies increasing returns to scale (IRS), which means output increases more than proportionally with input increases.
- $\boldsymbol{SE = 1}$ reflects constant returns to scale (CRS), which means output changes proportionally with input increases.
- $\boldsymbol{SE < 1}$ indicates decreasing returns to scale (DRS), where output increases less than proportionally with input increases. For instance, if $\boldsymbol{SE = 0.5}$, it implies that a 1% increase in all inputs might yield only a 0.5% rise in undergraduate completions, possibly signalling inefficiencies or resource underutilization.

Second-Order Elasticities of interaction terms: Complementarity effect

The first-order elasticities can be further decomposed into second-order effects, which reveal how input or output composition changes as the scale expands (Paul & Nehring, 2005). These second-order effects in the ODF provide insights into the joint behaviour of input and output in production systems. This indicates how the $\boldsymbol{x_k}$ output elasticity or share of one input ($\boldsymbol{\varepsilon_{y,x_k}}$) responds to changes in another input. Complementarity between outputs (or inputs) means that an increase in one enhances the contributions of another, thus improving overall performance.

Specifically, for the ODF, the second-order elasticity of inputs $\boldsymbol{\varepsilon_{yx_k,x_l}} = \frac{\boldsymbol{\partial \varepsilon_{y,x_k}}}{\boldsymbol{\partial ln x_l}}$ measures how a change in one input ($\boldsymbol{x_l}$) affects the contribution of another input ($\boldsymbol{x_k}$). If the two inputs ($\boldsymbol{x_l}$ and $\boldsymbol{x_k}$) are complementary, $\boldsymbol{\varepsilon_{yx_k,x_l}} > \boldsymbol{0}$ (a positive value), an increase in $\boldsymbol{x_l}$ enhances the contribution and marginal product of $\boldsymbol{x_k}$. In the translog specification, this corresponds to the cross-input coefficient ($\boldsymbol{\beta_{kl}}$), where symmetry ensures $\boldsymbol{\varepsilon_{yx_k,x_l}} = \boldsymbol{\beta_{kl}} = \boldsymbol{\varepsilon_{yx_l,x_k}}$(Paul & Nehring, 2005).

The output perspective is assessed through interaction terms for output ratios. $\frac{\boldsymbol{-\partial D^o}}{\boldsymbol{\partial y_m}} = \frac{\boldsymbol{\partial y_{UG}}}{\boldsymbol{\partial y^*_m}} = \boldsymbol{r^*_m}$ ($\boldsymbol{y^*_m} = \frac{y_m}{y_{UG}}$) indicates the (negative) shadow value of $\boldsymbol{y_m}$ relative to $\boldsymbol{y_{UG}}$. $\boldsymbol{\varepsilon_{y,y_m}} = \frac{\boldsymbol{\partial ln y_{UG}}}{\boldsymbol{\partial ln y^*_m}} = \frac{\boldsymbol{r^*_m y^*_m}}{\boldsymbol{y_{UG}}}$, thus reflects the "shadow share" or relative contribution of $\boldsymbol{y_m}$ (e.g., postgraduate completions or research income) to $\boldsymbol{y_{UG}}$ (undergraduate completions). The second-order coefficient $\boldsymbol{\alpha_{m^*n^*}} = \frac{\boldsymbol{\partial \varepsilon_{y,y_m}}}{\boldsymbol{\partial ln y^*_n}}$ reflects how changes in one output ratio ($\boldsymbol{y^*_n}$) alter the relative contribution of another ($\boldsymbol{y_m}$) to undergraduate completions ($\boldsymbol{y_{UG}}$). Positive second-order elasticities ($\boldsymbol{\alpha_{m^*n^*}} > \boldsymbol{0}$) imply that an increase in one output ratio ($\boldsymbol{y^*_n}$) enhances the contribution of another, indicating complementary relationships between outputs.

Therefore, positive second-order elasticities (e.g., input $\beta_{kl} > 0$ or output $\alpha_{m^*n^*} > 0$) imply that two outputs or two inputs are complementary. This indicates that an increase in one output (or input) enhances the contributions of another output (or input), improving overall universities performances, as measured by the dependent variable (undergraduate completions).

6.2 Empirical Results and Discussion

This section shows the empirical findings on the efficiency of Australasian universities using the stochastic frontier analysis (SFA) approach with an ODF. The analysis applies both Cobb-Douglas and translog functional forms. Outputs include undergraduate and postgraduate completions (both unadjusted and quality-adjusted) and research income. Inputs include academic and general FTE staff, capital costs and time trend variables. The SFA models explicitly account for inefficiency effects, while the OLS models exclude them. Inefficiency effects are modelled using explanatory factors such as the presence of a medical school, the proportion of international and female students, regional locations, and the ratio of general to academic staff.

6.2.1 ***Results and Discussion***

Table 6.1 presents a summary of the variables used in the empirical analysis. The initial step involves testing four model specifications to identify the appropriate functional form and assess the presence of inefficiency. Models 1 and 3 use OLS estimations and exclude inefficiency terms, while Models 2 and 4 extend the analysis by incorporating inefficiency terms. The models also differ in how they measure outputs: Models 1 and 2 measure output using the number of undergraduate and postgraduate completions. Models 3 and 4 use quality-adjusted completions, weighted by credit and income. The inputs remain the same across all models.

Table 6.1
Specifications of Output Distance Functions and Determinants of Inefficiency

Outputs, Inputs, and Determinants of Inefficiency	Distance Function Models			
	1	2	3	4
Output: No. of undergraduate completions (UG)	√	√		
Adjusted Output: No. of credit-and income-weighted UG completions			√	√
Postgraduate completions (PG)	√	√		
Adjusted PG completions: No. of credit-and income-weighted PG completions			√	√
Research income (RI)	√	√	√	√
Academic FTE (Aca FTE)	√	√	√	√
General FTE (Gen FTE)	√	√	√	√
Capital expenses (Cap exp)	√	√	√	√
Inefficiency effect model				
Medical School		√		√
Region/State Territories dummies		√		√
Share of Overseas students		√		√
Ratio of general to academics		√		√
Rate of Female students		√		√

Following the study by Battese and Broca (1997) to test the proper model specification and functional form, and due to the nested nature of the models, log-likelihood ratios (LR) tests were used to evaluate model fit when comparing OLS with SFA models. The results from the hypotheses tests in Table 6.2 show that the Cobb-Douglas functional form is rejected in favour of the more flexible translog form, which better captures the complexity of input-output relationships. The second null hypothesis of no technical inefficiency is also rejected, confirming that inefficiency is present in the data. Therefore, the translog models with inefficiency effects (Models 2 and 4) are preferred for further analyses.

Table 6.2
Hypothesis Tests

Null hypothesis (H_0)		L(H_0)	L(H_1)	LR-test statistic	Critical value ($x^2_{0.95}$)	Decision
Model 1 and 2: Output is the number of undergraduate and postgraduate completions and research income with academic, general FTE staff, capital costs as inputs used						
(1) Cobb-Douglas frontier is an adequate representation	$H_0: \alpha_{mn} = 0, \beta_{kl} = 0$ *and* $\zeta_{km} = 0$	541.670	515.665	-52.009	30.144	Reject H_0
(2) There is no technical inefficiency (e.g., OLS estimation is valid)	$H_0: \gamma = 0$	541.670	519.305	-44.730	20.410	Reject H_0
Model 3 and 4: Output is the number of credit undergraduate and postgraduate completions and research income with academic, general FTE staff and capital costs as inputs used						
(3) Cobb-Douglas frontier is an adequate representation	$H_0: \alpha_{mn} = 0, \beta_{kl} = 0$ *and* $\zeta_{km} = 0$	568.319	544.454	-47.729	30.144	Reject H_0
(4) There is no technical inefficiency (e.g., OLS estimation is valid)	$H_0: \gamma = 0$	568.319	550.741	-35.156	20.410	Reject H_0

Notes:

1. The LR-test statistic is given by -2[log likelihood (H_0)-log likelihood (H_1)], where H_0 denotes the model with the explanatory variables related to the inefficiency effects in the Cobb-Douglas estimation and H_1 denotes the model including the explanatory variables in the Translog estimation. The Cobb-Douglas model test uses regular chi-square distributions (Chapple et al., 2005) in which the degree of freedom is 19. The log likelihood can be obtained from the Table.
2. The critical values for $\gamma = 0$ are obtained from Table 1 of Kodde and Palm (1986) due to the mixed chi-square distribution with a degree of freedom of 12 (Battese & Broca, 1997). H_0 denotes the model without the explanatory variables related to the inefficiency effects (e.g., OLS) in the Cobb-Douglas estimation and H_1 denotes the model including the explanatory variables in the Cobb-Douglas estimation.

The maximum likelihood estimation results for the stochastic ODF using Cobb-Douglas and translog specifications from 2008 to 2018 are shown in Tables 6.3 and 6.4. To ensure consistent interpretation, all variables are normalised by their geometric means, allowing the first-order parameters to be directly interpreted as distance elasticities evaluated at the geometric mean (Cuesta & Orea, 2002; Johnes, 2014a; Johnes, 2014b; Letti et al., 2022). Undergraduate completions, y_{UG}, are used as the numeraire to impose Linear homogeneity in the ODF.

First-Order Parameters in Translog Model Estimation

The estimation results reveal that all first-order parameters have the expected signs: outputs' coefficients are positive, while those for inputs are negative. Most coefficients are statistically significant at the 1% level, except capital expenses in the adjusted translog model, which is significant at the 10% level. Positive output elasticities at the geometric mean indicate that the estimated ODF increases with outputs, while the negative input elasticities suggest that the ODF decreases with inputs. In other words, increases in teaching completions and research income improve universities' technical efficiency, while more labour and capital inputs reduce efficiency. These expected signs confirm that the monotonicity conditions for the ODF are satisfied at the sample mean (Cuesta & Zofío, 2005; Cuesta et al., 2009; Minviel & Sipiläinen, 2021).

Labour input elasticities, such as academic and general staff, are negative and statistically significant. This implies that increasing staff numbers, holding other factors constant at the mean, reduces efficiency by moving universities further away from the frontier and increasing the distance function. In the adjusted translog model with quality-adjusted completions, a 1% increase in academic FTE staff increases the distance from the frontier by 0.349%, implying that the universities move away from the efficient frontier, thereby reducing efficiency. In contrast, increasing outputs (holding others constant) enhances efficiency as universities move closer to the frontier and reduce the distance to the frontier. Specifically, a 1% increase in credit and income-weighted postgraduate completion reduces the distance from the frontier by 0.204%, indicating an efficiency improvement.

A notable finding is the trade-off between the dependent variable (negative adjusted undergraduate completions) and independent variables (positive adjusted postgraduate completions and research income, and negative labour and capital inputs). A significant negative relationship between adjusted undergraduate and postgraduate completions suggests that universities focusing on postgraduate completions tend to reduce undergraduate completions, holding other factors constant. In adjusted translog model 4, on average, a 1% increase in research income reduces undergraduate completions by 0.242%, indicating universities prioritising research activities might do so at the expense of teaching. This reflects the resource constraints universities face when balancing teaching and research priorities.

However, the results also indicate that hiring more academic and general staff enhances undergraduate completion. Similarly, capital expenses positively affect undergraduate completion, suggesting that investment in learning infrastructure, such as advanced technologies and improved facilities, contributes to more undergraduate completion.

Second-order Parameters in Translog Model Estimation and Interaction Effects

The translog models include interaction terms to capture input-output interdependencies. However, fewer than half of the interaction terms are statistically significant. When these terms are statistically significant, they indicate complex relationships between independent variables (e.g., postgraduate completions, research income, labour inputs, or capital input) and the dependent (undergraduate completions) variables. These interactions show that a change in one input or output influences the contribution of others, thereby providing insights into the degree of complementarity within university production processes (Abbott & Doucouliagos, 2004). In other words, second-order elasticities represent production complementarities that reflect the effects of joint output or input production on universities' performance.

Complementarity between Academic and General Staff

The coefficient of the interaction term between academic and general staff is positive and significant, indicating that they are complementary in producing undergraduate completions. This means that they jointly enhance undergraduate completion. This finding aligns with prior studies highlighting the complementarity between academic and professional staff (Conway, 2012; Knight & Trowler, 2001; Kwiek, 2008; Szekeres, 2006, 2011; Gray, 2015). Conway (2012) emphasises partnerships at the interface of professional and academic staff roles, highlighting the importance of being open to learning about each other's ways of working today. Additionally, Pace et al. (2006) and Veles et al. (2023) note that partnership is used interchangeably with or as a complement to collaborative approaches. Pedagogical partnerships between academic and professional staff are effective for collaboration (Graham & Regan, 2016; Veles et al., 2023), supporting student learning, experiences and outcomes.

Substitution between Staff and Capital Inputs

The negative and significant interaction terms suggest a degree of substitutability between specific inputs in university operations. Specifically, the negative and significant interaction between academic staff and capital expenses indicates that universities may offset rising labour costs by increasing capital investments in teaching delivery. This substitution may be particularly relevant in institutions where personnel costs represent a large share of total expenditure. For instance, the average labour costs account for 57.7% of total expenditure in New Zealand universities and 58.3% in Australian universities (see Table 4.7). In response to financial pressures, universities may rely more on capital-intensive teaching methods, such as using larger lecture theatres, increasing computer technology, and adopting more online teaching.

However, the precise substitution relationship between academic staff and capital in the Australian university sector remains unknown and unaddressed in the existing literature. While earlier studies discuss potential substitution effects (Avkiran, 2001; Abbott & Doucouliagos, 2003; Carrington et al., 2005; Worthington & Lee, 2008), recent evidence is scarce. In contrast, research on English higher education suggests that academic staff and capital exhibit high substitutability (Johnes, 2014b, p. 12). Johnes (2022, p. 1206) also cites Worthington and Higgs (2008), noting that Australian universities substitute capital more readily for labour.

Time Trend Impact

The translog model uses time trend variables to account for technological change over time (Coelli et al., 2005, p. 213). In this study, the translog models capture the effects of technological change improvements[112] over time (e.g., technological progress). These findings imply that while universities may initially face challenges in adapting to new technologies, they gradually overcome them, leading to an accelerating rate of technological advancement. Abbott and Doucouliagos (2004) noted that this progression may be due to various factors, such as increased adoption of new technologies, enhanced computing capabilities, and improved access to library resources.

Scale Elasticities

The estimated scale elasticities (SE) in translog models 2 and 4 are -0.534 and -0.591, indicating that universities operate under decreasing return to scale. This means that increasing all inputs proportionally yields a smaller increase in overall output. This indicates potential inefficiencies in scaling up university operations. Thus, it reflects the extent to which overall output increases from a 1% increase in all inputs. Specifically, an SE of 0.534 implies that a 1% increase in academic staff, general staff and capital expenses might yield only a 0.534% increase in undergraduate completions. These findings highlight the importance of strategic resource management and suggest that universities should focus on optimising resource use rather than merely expanding inputs to enhance efficiency.

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[112] The percentage change in ($1/y_{UG}$) due to technological change at each period, as derived from Equation 6.2, is given by the derivative in the unadjusted translog model 2: $\frac{\partial \ln\left(\frac{1}{y}\right)}{\partial t} = \theta_1 + 2\theta_2 t = -0.150 + 0.11t$.

This expression highlights the quadratic nature of technological change, where the negative and significant $\theta_1 = -0.150$ indicates an initial phase of technological regress, possibly due to challenges in adapting to new technologies. However, the positive and significant $\theta_2 = 0.11$ suggests that the rate of technological progress increases over time.

Table 6.3

Stochastic Output Distance Specification: Cobb-Douglas Models

Measure of output: number of UG completions (models 1&2) vs adjusted number of UG completions (models 3&4)								
Dependent variable	Number of undergraduate completions				Number of adjusted undergraduate completions			
Model	1		2		3		4	
Stochastic Frontier		se		se		se		se
Constant	0.053***	(0.018)	0.090***	(0.018)	0.049***	(0.017)	0.097***	(0.019)
Postgraduate completions (PG)	0.247***	(0.022)	0.283***	(0.023)	0.165***	(0.024)	0.215***	(0.025)
Research income (RI)	0.285***	(0.018)	0.276***	(0.019)	0.223***	(0.017)	0.217***	(0.016)
Academic FTE (Aca FTE)	-0.272***	(0.045)	-0.248***	(0.044)	-0.329***	(0.042)	-0.312***	(0.042)
General FTE (Gen FTE)	-0.136***	(0.041)	-0.181***	(0.040)	-0.175***	(0.039)	-0.196***	(0.036)
Capital expenses (Cap exp)	-0.120***	(0.039)	-0.094**	(0.039)	-0.091**	(0.037)	-0.070*	(0.038)
t	-0.093***	(0.029)	-0.121***	(0.028)	-0.077***	(0.028)	-0.112***	(0.027)
t^2	0.032***	(0.011)	0.042***	(0.011)	0.024**	(0.011)	0.035***	(0.010)
Inefficiency effect:								
Constant			-0.506***	(0.131)			-0.991***	(0.297)
Medical School			-0.060**	(0.023)			-0.115***	(0.037)
Share of Overseas students			1.201***	(0.210)			2.040***	(0.484)
NZ_South Island			-0.017	(0.102)			0.053	(0.069)
AUS_NewSouthWales			-0.087	(0.100)			-0.199***	(0.069)
AUS_Victoria			-0.099	(0.105)			-0.201***	(0.072)
AUS_Queensland			-0.041	(0.100)			-0.113*	(0.061)
AUS_Western			-0.114	(0.103)			-0.195***	(0.072)
AUS_South			-0.068	(0.103)			-0.140**	(0.064)
AUS_Tasmania			0.020	(0.104)			0.029	(0.071)
AUS_NorthTerritory			-0.055	(0.113)			-0.156	(0.108)
AUS_capitalTerritory			-0.041	(0.106)			-0.084	(0.061)
Ratio of general to academics			-0.158***	(0.045)			-0.182***	(0.057)
Rate of Female students			0.841***	(0.192)			1.535***	(0.475)
Log Likelihood	497.782		515.665		526.707		544.454	
sigma-squared	0.008		0.008		0.007		0.010	
gamma			0.132***				0.404***	
Likelihood ratio test of the one-sided error			35.767				35.495	
Mean efficiency			0.979				0.972	
Observations	495		495		495		495	

Note: 1. Standard errors are in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

2. Model 1 is an OLS estimation and output is number of undergraduate and postgraduate completions, and research income with academic, general FTE and capital costs as inputs used. Model 2 adds the variable used in the inefficiency model. Model 3 uses the adjusted undergraduate and postgraduate completions. Model 4 adds the inefficiency explanatory variables.

Table 6.4

Stochastic Output Distance Specification: Translog Models

Measure of output: number of UG completions (models 1&2) vs adjusted number of UG completions (models 3&4)								
Dependent variable	Number of undergraduate completions				Number of adjusted undergraduate completions			
Model	1		2		3		4	
Stochastic Frontier		se		se		se		se
Constant	0.068***	(0.021)	0.113***	(0.021)	0.061***	(0.020)	0.103***	(0.022)
PG	0.247***	(0.023)	0.294***	(0.022)	0.163***	(0.024)	0.204***	(0.024)
RI	0.299***	(0.019)	0.280***	(0.018)	0.263***	(0.018)	0.242***	(0.018)
Aca FTE	-0.285***	(0.047)	-0.290***	(0.046)	-0.334***	(0.044)	-0.349***	(0.044)
Gen FTE	-0.118***	(0.043)	-0.145***	(0.042)	-0.157***	(0.041)	-0.173***	(0.041)
Cap exp	-0.132***	(0.040)	-0.099**	(0.039)	-0.102***	(0.038)	-0.069*	(0.038)
t	-0.118***	(0.033)	-0.150***	(0.032)	-0.099***	(0.031)	-0.134***	(0.030)
t^2	0.044***	(0.013)	0.055***	(0.012)	0.034***	(0.012)	0.045***	(0.012)
PG^2	-0.222	(0.155)	0.000	(0.154)	-0.367**	(0.178)	-0.275	(0.168)
RI^2	-0.077	(0.089)	-0.079	(0.089)	-0.047	(0.087)	0.013	(0.091)
PG * RI	0.063	(0.090)	-0.026	(0.087)	0.039	(0.100)	0.024	(0.098)
$Aca\ FTE^2$	0.385	(0.624)	0.128	(0.581)	0.038	(0.584)	-0.272	(0.733)
$Gen\ FTE^2$	0.241	(0.390)	0.408	(0.382)	0.143	(0.362)	0.486	(0.367)
$Cap\ exp^2$	0.753**	(0.341)	0.503	(0.323)	0.742**	(0.320)	0.520	(0.317)
Aca FTE * Gen FTE	0.864***	(0.320)	1.069***	(0.327)	0.550*	(0.293)	0.863***	(0.308)
Aca FTE * Cap exp	-0.878***	(0.334)	-0.738**	(0.309)	-0.629**	(0.310)	-0.596*	(0.350)
Gen FTE * Cap exp	-0.725**	(0.310)	-0.942***	(0.296)	-0.513*	(0.288)	-0.787***	(0.283)
Aca FTE * PG	0.031	(0.244)	0.270	(0.239)	-0.485*	(0.252)	-0.395*	(0.233)
Gen FTE * PG	0.347*	(0.187)	0.019	(0.185)	0.310	(0.193)	0.123	(0.192)
Cap exp * PG	-0.631***	(0.167)	-0.514***	(0.161)	-0.403**	(0.169)	-0.347**	(0.163)
Aca FTE * RI	0.338*	(0.181)	0.305*	(0.178)	0.316*	(0.180)	0.442**	(0.182)
Gen FTE * RI	-0.254*	(0.154)	-0.351**	(0.166)	-0.218	(0.150)	-0.112	(0.174)
Cap exp * RI	0.457***	(0.165)	0.446***	(0.172)	0.387**	(0.165)	0.245	(0.176)
Inefficiency effect:								
Constant			-1.655***	(0.386)			-0.400	(0.273)
Medical School			-0.035	(0.057)			-0.049	(0.033)
Share of Overseas students			2.877***	(0.526)			1.117***	(0.388)
NZ_South Island			-0.050	(0.193)			-0.047	(0.061)
AUS_NewSouthWales			-0.154**	(0.067)			-0.131**	(0.060)
AUS_Victoria			-0.218**	(0.097)			-0.202***	(0.065)
AUS_Queensland			-0.134	(0.099)			-0.066	(0.049)
AUS_Western			-0.132*	(0.071)			-0.129**	(0.057)
AUS_South			-0.027	(0.080)			-0.045	(0.056)
AUS_Tasmania			0.148	(0.108)			0.009	(0.062)
AUS_NorthTerritory			-0.102	(0.116)			-0.061	(0.077)
AUS_capitalTerritory			0.000	(0.088)			-0.065	(0.053)
Ratio of general to academics			-0.072	(0.076)			-0.029	(0.057)
Rate of Female students			2.073***	(0.533)			0.483	(0.448)
Log Likelihood	519.305		541.670		550.741		568.319	
sigma-squared	0.008		0.011		0.007		0.007	
gamma			0.486***				0.157**	
Likelihood ratio test of the one-sided error			44.730				35.156	
Mean efficiency			0.973				0.979	
Observations	495		495		495		495	

Key findings from the Inefficiency Effect Models in Table 6.4

In the translog models, the analysis of the inefficiency term reveals various determinants of inefficiency across universities. The coefficients on the explanatory factors exhibit different signs. A positive coefficient shows that an increase in the corresponding variable is associated with higher technical inefficiency (lower technical efficiency), while a negative sign suggests lowered technical inefficiency (higher technical efficiency).

Socio-Demographic Composition of EFTS Enrolments

International Students

The share of international enrolments consistently shows a positive and statistically significant coefficient across all models, showing that more international EFTS is related to lower technical efficiency. This suggests that international enrolments provide a critical revenue source for universities[113], but this revenue alone does not improve efficiency. Universities that rely heavily on international tuition income may face trade-offs between financial sustainability and efficient resource use, particularly if fluctuations in international enrolments create financial instability. This finding contrasts with Abbott and Doucouliagos (2009), who found that international students improved efficiency in their translog analysis of New Zealand and Australian universities.

Even among universities with high proportions of international students, efficiency gains are not guaranteed. Expanding international enrolments without a proportional increase in academic staff, facilities, and student support services can strain institutional resources, potentially leading to inefficiencies in teaching and research. In such cases, universities facing financial pressures may prioritise revenue generation over quality improvements, leading to larger class sizes, heavier staff workloads, and insufficient student support. Additionally, a diverse student population may introduce additional administrative and teaching complexities, such as language support, visa processing, and specialised student services, which could contribute to inefficiency.

While international student income has played a financially stabilising role by replacing lost government funding, not all institutions benefit from this revenue stream. Regional and outer

[113] Australasian universities increasingly rely on international students to generate revenue through higher tuition fees. During the study period, international students contributed, on average, 11% of university income in New Zealand and 17% in Australia. In some universities, such as Lincoln University, nearly one in three students was from overseas.

suburban universities, particularly in Australia, have faced growing financial pressures due to their limited ability to attract international students (Howard, 2021, p. 45). This financial disparity may also contribute to inefficiencies.

Female Students

In the unadjusted translog model, the proportion of female students is positively and significantly related to inefficiency, indicating that universities with more female students tend to exhibit lower technical efficiency. This suggests that inefficiency is observed with raw undergraduate completions rather than credit and income-weighted completions, indicating gender composition affects efficiency in ways unrelated to qualification value (e.g., credit weight) or post-graduation earnings (e.g., income weight). This finding aligns with Zoghbi et al. (2013), who suggest that some study areas more commonly chosen by female enrolments may affect efficiency. However, it contrasts with Laureti et al. (2014) and Barra et al. (2018), who found that a greater share of female students improve efficiency.

A possible explanation is disciplinary differences in enrolment patterns. Universities with large nursing and teacher training faculties tend to have a larger proportion of female enrolments, whereas those with focuses on Science, Technology, Engineering, and Mathematics (STEM) fields—which typically attract higher research funding and require greater resource investments—have a lower percentage of female students. Since education and nursing programmes have lower delivery costs than STEM fields, universities with higher female students might be expected to operate more efficiently in the unadjusted completions. However, the positive inefficiency effect observed in the unadjusted model suggests otherwise, indicating that factors beyond cost structure, such as student retention rates and teaching methods, may also affect efficiency.

While universities may not have direct control over broader societal factors influencing gender composition, they can influence enrolment patterns through programme design, outreach, and recruitment strategies; their impact on completions and research income may influence universities' efficiency. The observed positive relationship between the share of female students and inefficiency suggests that universities' efficiency may be influenced by universities' structural and disciplinary differences rather than gender composition alone.

Medical Schools

Universities with medical schools show a negative coefficient, but this effect is statistically insignificant across all translog models. This indicates that medical schools do not significantly influence university efficiency in this study. However, medical schools may still enhance university efficiency by increasing research output, commercial income and intellectual property income from medical research activities (University of Otago, 2018, p. 60).

Findings from international studies present mixed results. Letti et al. (2022) found that medical schools reduce inefficiency, likely due to scale or scope economies that enhance university operations. In contrast, Chapple et al. (2005) found that medical schools in UK universities exhibited higher technical inefficiency, possibly due to differences in healthcare markets. Similarly, Barra et al. (2018) found that medical schools were related to lower efficiency, likely due to different health product markets.

Staff composition

The general-to-academic staff ratio is negative across all translog models but not statistically insignificant, indicating no measurable effect on Australasian university efficiency. Previous studies highlight the importance of general staff in supporting academic functions. Abbott and Doucouliagos (2009) found that hiring more senior administrators enhanced university efficiency in Australia. Baltaru (2019) also found that universities with a moderately larger share of professional staff had higher degree completions. General staff are now more involved in direct academic support, including tutoring and teaching activities (Whitchurch, 2008; Schneijderberg & Merkator, 2013; Graham & Regan, 2016).

Regional Variations

The region dummy variables serve as proxies for the location effect, with New Zealand's North Island as the reference region. These account for differences across New Zealand regions and Australian state territories. Results from the translog model indicate notable regional variation in efficiency, particularly in Australia, where universities in certain states have higher efficiency.

Universities in Victoria, New South Wales, and the Western Australian States, where six Go8 universities are located (excluding the University of Adelaide and Queensland), exhibit higher efficiency. These universities typically enrol more students, deliver higher teaching outputs, and generate significant research income. Their urban locations may also provide better access to funding, industry collaboration, and highly skilled labour markets, which could further enhance efficiency. In contrast, regional and outer suburban universities may face challenges such as lower enrolments, higher operational costs, and fewer external funding opportunities.

In contrast, South Island universities in New Zealand (e.g., Lincoln University, the University of Canterbury, and the University of Otago) exhibit lower inefficiency than their North Island counterparts, but these effects are insignificant. This may be due to lower population density and fewer employment opportunities, which may affect student enrolment patterns and post-graduation earnings. Universities in regional areas often specialise in disciplines aligned with local industries (e.g., agriculture or environmental sciences, such as Lincoln University), which may receive lower research funding and income potential.

Economic opportunities and regional income effects may also influence efficiency, particularly for credit and income-weighted completions. Students often prefer to attend local universities and remain in their region after graduation. Universities in regions with fewer job opportunities and lower wages may see their graduates earning less, negatively impacting efficiency in models that adjust for post-graduation income.

Inefficiency measure (Gamma γ)

The gamma coefficients, which measure the proportion of total variation attributed to inefficiency rather than noise, are 0.486 and 0.157 in two translog models, respectively, and both are statistically significant. This indicates that inefficiency plays a role in explaining the variation in performance among universities. Values close to one indicate that inefficiency significantly impacts the production system, whereas values close to zero suggest that the variation is solely attributable to noise rather than inefficiency.

These results indicate that while inefficiency is an important factor in university performance, its impact appears more pronounced in completion rates than in credit and income-weighted completions. This is in line with expectations since post-graduation income is influenced by external factors beyond universities' control, which is likely to introduce more noise into the model, reducing the share of variation explained by inefficiency. In contrast, the first model focuses on undergraduate completions, in which universities have more direct influence. If different disciplines have varying income outcomes, this could introduce more unexplained variation into the adjusted model.

6.2.2 *Technical Efficiency Scores*

Table 6.5 presents the average technical efficiency scores for Australasian universities, using SFA with Cobb-Douglas and translog models. Appendix Chapter 6 Table A6.1 shows university technical efficiency score rankings. The results indicate that New Zealand universities and Australian university groups exhibit relatively high technical efficiency levels. However, New Zealand universities show higher efficiency scores than their Australian counterparts across all models.

Efficiency Comparisons between New Zealand and Australian Universities

When using unadjusted undergraduate completions, New Zealand universities achieve higher average efficiency scores than Australian universities. Specifically, New Zealand universities achieve average efficiency scores of 0.991 (Cobb-Douglas) and 0.983 (translog), compared to 0.977 and 0.970 for Australian universities. However, when teaching outputs are quality-adjusted, Australian universities improve their efficiency, with mean technical efficiencies of 0.971 and 0.978 in the Cobb-Douglas and translog models, respectively. Despite this improvement, New Zealand universities maintain a slight edge, with higher average scores of 0.977 and 0.983, respectively, in the quality-adjusted models relative to their unadjusted models.

Table 6.5
Average Technical Efficiency Scores for Australasian Universities, 2008-2018

University	Cobb-Douglas Model 2	Adjusted Cobb-Douglas Model 4	Translog Model 2	Adjusted Translog Model 4
Auckland	0.995	0.988	0.986	0.991
Waikato	0.991	0.977	0.979	0.978
Massey	0.985	0.966	0.975	0.973
VUW	0.992	0.983	0.986	0.987
Canterbury	0.995	0.986	0.989	0.993
Lincoln	0.989	0.963	0.984	0.976
Otago	0.996	0.987	0.988	0.994
AUT	0.983	0.964	0.977	0.972
New Zealand Mean	*0.991*	*0.977*	*0.983132*	*0.983126*
Go8	0.979	0.978	0.976	0.985
IRU	0.981	0.973	0.970	0.977
RUN	0.975	0.964	0.963	0.970
ATN	0.959	0.955	0.958	0.962
Non-aligned	0.980	0.975	0.974	0.985
AUS Mean	*0.977*	*0.971*	*0.970*	*0.978*

Note: 1. Australian mean refers to the geomeans of all individual Australian universities.
2. Efficiency scores in the case of a distance frontier range from zero and one, where a score of one denotes full technical efficiency.
3. The mean technical efficiency scores of each university are computed as the geometric mean of its annual scores from 2008 to 2018.
4. Illustrative efficiency frontier charts are not included here, as the analysis covers 45 universities across multiple model specifications. Plotting all frontiers and universities would produce highly dense figures, which would be difficult to interpret. Instead, efficiency results are summarised in the above table, which present average TE scores in a form that enables clear and direct comparison between New Zealand and Australian universities.

Factors Influencing Efficiency Differences

Several factors may explain these efficiency differences. New Zealand operates within a smaller, more research-focused system, with only eight public universities, most of which are comprehensive universities offering a broad range of programmes. Lincoln University is only a specialised land-based university. In contrast, the Australian university sector is more diverse, with a mix of large research-intensive universities (e.g., Go8) and smaller, regional and non-research-intensive universities (e.g., RUN). This variation contributes to greater efficiency differences within Australia.

Moreover, differences in funding structures contribute to efficiency disparities. New Zealand universities derived 44% of their revenue from government sources in 2022 (see Figure 1.1), including tuition funding and PBRF income, particularly international tuition fees contributing 9% of total revenue (New Zealand Tertiary Education Commission, 2022). In contrast, Australian universities heavily rely on international tuition fees, which account for 24% of total revenue (see Figure 1.2), while 54% came from government sources in 2022 (Australian Government Department of Education, 2022a). This greater dependence on international student fees introduces financial volatility, particularly during the periods of declining international enrolments, which may impact efficiency.

Technical Efficiency Scores for Specific University

At the institutional level, technical efficiency scores in the adjusted translog model increase for the University of Auckland, Otago, Canterbury and VUW compared to the unadjusted translog model. This variation suggests that institutional characteristics, research intensity, and quality-adjusted teaching output significantly affect efficiency outcomes. For instance, the University of Auckland and Otago produce more completions in high-credit and high-income disciplines (e.g., medicine and engineering) and attract substantial research funding, which may influence efficiency. The improvement in the University of Canterbury in the adjusted translog model may be related to post-earthquake recovery efforts.

In contrast, the University of Waikato, Massey University, Lincoln University and AUT experience declines in efficiency scores in the adjusted translog model, likely due to resource constraints, fluctuating student enrolments, lower research income and fewer weighted qualifications. For instance, Lincoln University’s reduced score in the adjusted translog model could be associated with its smaller operations (e.g., limited programme offerings) and specialisation in agricultural disciplines.

AUT's relatively high share of graduates with lower-credit and lower-income-weighted qualifications may reduce efficiency in the quality-adjusted translog model.

Australian universities improve their efficiency when using quality-adjusted teaching outputs, likely due to their stronger research intensity and higher enrolments in high-credit and high-income disciplines. Additionally, financial stability and sustainability, such as international student enrolments and external research income, enable Australian universities to invest in infrastructure, facilities, technologies, and student support systems (Curtin University Annual Report, 2011, p. 7; RMIT University Annual Report, 2013, p. 5; University of Technology Sydney Annual Report, 2018, p. 24).

Differences between MPI (Chapter 5) and SFA (Chapter 6)

Different results between the MPI and SFA are not contradictory because each method captures a distinct performance aspect. The apparent differences are not evidence of methodological unreliability, but reflect that different methods are used to answer different research questions. The text below discusses differences between MPI and SFA from both methodological perspectives and the different results observed for Australian and New Zealand universities.

Methodological differences

From a conceptual perspective, two broad frontier approaches are used in efficiency analysis: non-parametric (e.g., DEA, MPI) and parametric (e.g., SFA, SCFA). As a non-parametric method, MPI measures changes in total factor productivity (TFP) over time, capturing both technical and efficiency change relative to a reference period. It does not require price data, which makes it particularly suitable for analysing productivity in the state sector where market prices are absent.

MPI also decomposes TFP into efficiency change (movement towards or away from the best-practice frontier, further split into pure and scale efficiency change) and technical change (shifts in the frontier due to innovation or technological regress). This makes it particularly useful for tracking long-term productivity trends in public universities, which produce multiple outputs without clear market prices. It answers research questions such as: how has TFP in universities changed over time, and what factors drive these changes?

In contrast, SFA is a parametric method that estimates technical efficiency at a given time point relative to a best-practice frontier. It measures how well outputs are produced from given inputs. SFA addresses research questions such as: how technically efficient are universities in maximising the production of teaching and research outputs given a set of inputs, after accounting for external and institutional factors? The BC95 model used here accommodates panel data, accounts for time-varying efficiency and incorporates universality-specific inefficiency determinants, offering a richer picture of efficiency analysis.

When comparing advantages and disadvantages, the New Zealand Productivity Commission (2018b, Box 8.1) outlines key considerations. Non-parametric approaches like DEA or MPI treat all deviations from the frontiers as inefficiency. This makes them sensitive to heterogeneity and outliers, and less suited to contexts where demand is variable and unpredictable. Their main advantage is that they do not require a functional form or error structure specification, making them simpler to apply.

By contrast, parametric methods like SFA separate inefficiency from random error, reducing sensitivity to outliers and heterogeneity. They are better suited to heterogeneous samples and can directly incorporate exogenous influences (e.g., location or staffing structure) into the regression. However, they require the specification of a functional form, estimation of the production function parameters, and the use of random error terms, which can be demanding in smaller samples.

Differences also arise in variables and scope. MPI applies a multi-output framework, incorporating undergraduate, postgraduate completions, and research income as the dependent variable. It uses detailed inputs such as staff classifications (i.e., teaching, research, general) and EFTS enrolments, but does not explicitly control for inefficiency determinants.

In contrast, SFA uses only undergraduate completions as the dependent variable, producing a teaching-focused efficiency measure. It accounts for statistical noise and explicitly controls for labour, capital inputs and inefficiency determinants such as student demographics, faculty composition, regional location, and staffing structure. This framework highlights trade-offs between teaching and research outputs: universities that prioritise research may appear less efficient when efficiency is measured only by undergraduate completions.

Thus, MPI offers a straightforward way to track productivity change over time in a multi-output, non-market sector. SFA provides richer insights into institutional efficiency once price inputs and environmental factors are considered.

Application to New Zealand vs. Australia

The results show that MPI and SFA highlight different aspects of performance. MPI captures productivity changes over time. Between 2008 and 2018, New Zealand universities experienced an average annual TFP decline of 0.7%, driven by falling efficiency that outweighs modest technological progress. Australian universities exhibited an average annual TFP increase of 1.6%, due to stronger technological progress and slight efficiency gains.

SFA estimates technical efficiency at a given point in time relative to the best-practice frontier. Both New Zealand universities and Australian university groups exhibit relatively high technical efficiency levels. However, New Zealand universities score higher on average across all models. For instance, AUT records strong productivity growth under MPI but lower technical efficiency under SFA. This indicates that while its performance improved over time, it remains less efficient relative to the best-practice frontier.

One factor affecting comparability is how undergraduate completions are defined across the two countries. In New Zealand, completions include sub-degree qualifications (Levels 1—4 certificates), while in Australia they begin at diploma Level 5–6. This limits comparability and may bias the results in favour of New Zealand universities, particularly an issue for models using unadjusted undergraduate completions. However, it would underrepresent the universities to exclude sub-degree qualifications in New Zealand universities, as this would introduce an even greater issue/bias against New Zealand universities.

Differences also stem from sector composition. New Zealand universities are smaller-scale and relatively homogeneous. By contrast, the Australian university sector is more heterogeneous, combining large research-intensive institutions (e.g., Go8) with smaller, regional, and less research-focused universities (e.g., RUN). This heterogeneity increases within-country efficiency variation in Australia.

Funding structures further distinguish the two systems. In 2022 (details in Figures 1.1 and 1.2 for New Zealand and Australian revenue sources), New Zealand universities derived around 44% of their revenue from government sources compared with 54% in Australia. Australian universities also relied more heavily on international tuition fees (24% of total revenue, compared with 9% in New Zealand), which gave them greater financial capacity to invest in staff, facilities, and support services. However, greater reliance on international tuition revenue for Australian universities introduces volatility and may impact efficiency, particularly during declining international enrolments.

Institutional characteristics and research intensity also shaped performance. New Zealand universities such as the University of Auckland and Otago benefited from high completions in high-credit and high-income disciplines (e.g., medicine and engineering) and substantial research income, boosting their measured efficiency. The University of Canterbury's gains in adjusted models may reflect post-earthquake restructuring and recovery investments. In contrast, the University of Waikato, Massey University, Lincoln University, and AUT showed lower adjusted efficiency due to resource constraints, fluctuating enrolments, and weaker research income.

Finally, the role of quality-adjusted teaching output highlights further differences. Australian universities improved their efficiency rankings once outputs were quality-adjusted, reflecting their greater research intensity and higher completions in high-credit and high-income disciplines. Their stronger financial stability, supported by international enrolments and diversified research income, enhanced their ability to invest in infrastructure, technology, and student support, further improving efficiency.

University Technical Efficiency Scores Ranking

The efficiency scores in unadjusted Cobb-Doulas models are higher than those in quality-adjusted Cobb-Douglas models across all New Zealand and Australian universities. The unadjusted Cobb-Douglas models measure efficiency purely based on raw completions, ignoring variations in qualification quality, such as earnings potential and credit weighting. This adjustment may reduce efficiency scores in the adjusted Cobb-Douglas model for universities with more students in lower-credit or lower-income disciplines.

The results indicate that the choice of functional forms and the inclusion of quality-adjusted teaching output significantly affect the efficiency estimates, affecting the observed differences in university performance. While Johnes (2014a) identified a consistent set of high and poor-performing universities across different models, Barra et al. (2018) found that different methodologies did not yield a common ranking of university performance. In this chapter, some universities consistently emerge as high-performing (e.g., the University of Auckland, the Western Sydney University and the University of Newcastle) and low-performing (e.g., AUT, Federation University of Australia and the University of South Australia), regardless of the model specification.

However, compared with efficiency estimates from MPI analysis, there are many differences in university rankings and efficiency scores, indicating that performance gaps between Australasian universities may vary depending on the estimation method used. This highlights the importance of using multiple methodological methods when assessing university performance.

6.2.3 *Sensitivity Analysis of Alternative Variable Measurements on the Base Model*

Sensitivity analysis explores the robustness of the stochastic ODF model for Australasian universities under alternative variable measurements. Table 6.6 summarises the results, with further details provided in Appendix Chapter 6 (Tables A6.2—A6.7). These analyses compare the key determinants of technical inefficiency with the base model shown in Table 6.4. The selection of appropriate functional forms and model specifications are based on the hypothesis tests using log-likelihood ratios (see Table 6.2 for the decisions). This comparison shows how changes in input variables (e.g., labour), research output measures (e.g., citation-weighted research publications), and alternative data sources influence the estimated inefficiency determinants. The different specifications used, and the key findings are as follows:

0. **Base models (in Table 6.3)**

   They jointly estimate the stochastic ODF and the inefficiency effects using credit and income-weighted undergraduate and postgraduate completions. Results show that more international and female students are associated with lower technical efficiency.

1. **Research output variations** (Citation-weighted WoS research publications vs. base model research income, see Appendix Chapter 6 in Table A6.2—A6.3)

   In the citation-based translog models, the international student share remains positive and significant. Universities prioritising international enrolments for revenue generation may not enhance efficiency and research quality, particularly when research quality is measured using citation-weighted WoS-indexed publications. However, the presence of medical schools remains negative but significant, indicating that having a medical school leads to higher technical efficiency due to their generating high-impact research publications, attracting external funding and operating with resource-intensive programmes.

   However, a higher general-to-academic staff ratio is related to lower efficiency when citation-weighted research publications are used. This may reflect differences in research intensity across universities. Research-intensive universities, such as Go8 universities, have the lowest ratio (0.418) but produce the largest CNCI-weighted indexed publications (7,471). This suggests that research-intensive universities tend to operate with streamlined administrative structures but produce high-impact research. In contrast, universities with higher ratios may allocate more resources to administrative functions and less to research, which could reduce efficiency when quality-adjusted research publications are used. Despite having a higher ratio (1.319), the University of Auckland maintains strong research publications (3,842), indicating that its research strength may offset potential inefficiencies. These findings highlight the role of research intensity in affecting university efficiency.

2. **Data source variations** (New Zealand TEC data/Australian DoE data vs. base model using universities' annual reports, see Appendix Chapter 6 in Table A6.4—A6.5)

   The sensitivity analysis using alternative data sources indicates that most explanatory factors (except region dummies) remain statistically significant and retain the same signs as in the annual report-based models. However, the technical efficiency scores obtained from alternative data sources are lower than those derived from annual reports, possibly due to inconsistencies in reporting practices and data classification, particularly in New Zealand.

   Using the alternative data source, the general-to-academic staff ratio becomes positively and significantly related to efficiency. This finding implies that more general staff may improve efficiency by supporting university operations and allowing academic staff to concentrate more on teaching and research activities.

3. **Labour input variations** (disaggregated teaching, research and general FTE vs. base model using academic and general FTE; see Appendix Chapter 6 in Table A6.6—A6.7)

   The base model includes academic and general FTE and capital expenditure (as a proxy for non-labour expenditure). The alternative specification distinguishes teaching, research, and general staff and maintains the same capital expenditure measure. This alternative is to capture the distinct functions of staff (e.g., teaching and research) that may affect efficiency. Although the coefficients for teaching and research staff remain negative (as expected), they are not statistically significant. This may be due to the difficulty of separating teaching and research functions in practice, as academic roles often overlap in many universities.

   In this alternative specification, all explanatory variables remain significant and retain the same signs as in the annual report-based models. The coefficient for the general-to-academic staff ratio becomes larger (in absolute value) and more significant, highlighting the role of general staff in supporting both teaching and research activities. Separate teaching and research staff appear to make the distinct supportive role of general staff more apparent, leading to a stronger relationship with efficiency. However, the resulting technical efficiency scores are lower than those obtained from annual reports, consistent with earlier results using academic and general staff as labour inputs.

Table 6.6

Sensitivity Analysis for Determinants of Technical Inefficiency for Australasian Universities, 2008-2018

Model Specification		Medical school	% Overseas	Ratio of general to academics	% Female students	Mean Efficiency
0. Base Model	Translog	-0.035	2.877***	-0.072	2.073***	0.973
	Adjusted Translog	-0.049	1.117***	-0.029	0.483	0.979
1. Research outputs: Citation-weighted Research publications	Translog	-0.131**	2.813***	0.194***	1.539**	0.972
	Adjusted CD	-0.125***	1.094**	0.069	0.49	0.982
2. Data Source New Zealand TEC data/Australian DoE data	Translog	-0.148***	2.117***	-0.183***	1.995***	0.967
	Adjusted Translog	-0.156***	2.027***	-0.159**	1.669***	0.970
3. Labour inputs include teaching, research and general FTE (50:50)	Translog	-0.178***	2.462***	-0.228***	2.423***	0.965
	Adjusted Translog	-0.167***	2.293***	-0.194**	2.101***	0.968

Note: Significance levels: *p<0.1; **p<0.05; ***p<0.01

Overall, the sensitivity analysis reveals some quantitative differences, but the qualitative findings from the base model remain robust. The results consistently highlight the importance of faculty composition (e.g., medical schools), staff composition, and student demographics (e.g., international or female enrolments) in affecting university efficiency. Additionally, the findings highlight that selecting appropriate inputs (e.g., labour), outputs (e.g., research output), and data measures (alternative data sources) is crucial in university technical efficiency analysis, as changes in these variables can affect efficiency estimates.

A key implication of the sensitivity analysis is the different impacts of the general-to-academic staff ratio across model specifications. When research output is measured using citation-weighted WoS-indexed publications, a lower staff ratio is associated with higher efficiency, whereas this effect is the opposite in other models. This suggests that research-intensive universities (e.g., Go8), which tend to have lower ratios, produce a higher volume of high-impact research, reflecting their streamlined administrative structures and strong research performance. This highlights the importance of carefully specifying research output measures, as whether efficiency is assessed using income or publication quality can influence the results.

Staffing structures also play a crucial role in shaping institutional performance. This finding aligns with prior studies by Abbott and Doucouliagos (2009), which found that hiring more senior administrators improved efficiency in Australian universities. Baltaru (2019) similarly found that universities with a moderately higher proportion of professional staff had higher degree completions. Other studies show that general staff increasingly support academic activities, including tutoring and teaching activities (Whitchurch, 2008; Schneijderberg & Merkator, 2013; Graham & Regan, 2016).

6.3 Conclusion

This chapter applied SFA with ODF to measure and compare the technical efficiency of eight New Zealand and 37 Australian universities from 2008 to 2018. A novel feature of this analysis was considering the capital inputs for Australasian universities. The estimates used Cobb-Douglas and translog functional forms. Only Abbott and Doucouliagos (2009) have previously assessed New Zealand university efficiency using SFA. In addition to comparing New Zealand universities to their Australian counterparts, this study also considered a more recent period (2008 – 2018) than Abbott and Doucouliagos (1997-2003).

Several key findings emerge from our analysis. First, the ODF analysis indicates that postgraduate completions and research income are significantly and negatively related to undergraduate completions, while academic and general staff and capital expenses significantly and positively impact undergraduate completions. Quality adjustments to undergraduate and postgraduate completions result in minor changes to input and output coefficients.

Second, the inefficiency analysis highlights key factors affecting university efficiency. A higher proportion of international students is associated with lower efficiency. Although international enrolments provide a critical revenue source for universities, revenue from international students alone does not improve efficiency. Universities heavily reliant on international tuition income may face trade-offs between financial sustainability and resource allocation, particularly if fluctuations in international enrolments create financial instability.

Similarly, a higher share of female students relates to low efficiency, possibly reflecting universities' structural and disciplinary differences rather than gender composition alone. Universities with large nursing and teacher training faculties tend to have a higher proportion of female students, whereas those with STEM fields are lower. While universities may not have direct control over broader societal factors influencing gender composition, they can influence enrolment patterns through programme design, outreach, and recruitment strategies.

Moreover, regional location also significantly affects efficiency. For instance, Australian universities in metropolitan states such as Victoria, New South Wales, and Western Australia show higher efficiency, benefiting from their densely populated metropolitan areas, which provide greater access to funding, industry partnerships, and highly skilled labour markets, which could enhance efficiency. In contrast, universities on New Zealand's South Island (e.g., Lincoln University, the University of

Otago, and Canterbury) exhibit lower efficiency, likely due to lower population density and fewer employment opportunities.

New Zealand universities show higher efficiency scores than their Australian counterparts across all models. New Zealand operates within a smaller, more homogenous system of eight public universities. In contrast, Australia's university sector is more heterogeneous, combining large research-intensive institutions (e.g., Go8) with smaller, regional and non-research-intensive universities (e.g., RUN). Such heterogeneity contributes to greater efficiency differences within Australia. Moreover, differences in funding structures also matter. Australian universities rely more on international tuition revenue, which increases financial capacity but also introduces volatility, particularly when international enrolments decline.

This chapter (SFA) and Chapter 5 (MPI) differ because the two methods address different research questions. MPI is a non-parametric approach that tracks changes in TFP over time, decomposing these into efficiency and technical change. It is suited to public sector analysis, where price data are absent, and highlights long-term productivity trends. By contrast, SFA is a parametric method that estimates technical efficiency at a given time point relative to the best-practice frontier. It separates inefficiency from statistical noise and explicitly controls for inputs and institutional factors such as student composition, staffing structure, and regional effects.

The scope of variables also differs. MPI adopts a multi-output framework that includes undergraduate, postgraduate completions, and research income as the dependent variable. SFA focuses only on undergraduate completions as the dependent variable, producing a teaching-oriented efficiency measure. This highlights trade-offs between teaching and research: universities prioritising research tend to lower efficiency scores in a teaching-focused framework.

Additionally, differences in output definitions affect cross-country comparability. New Zealand universities include sub-degree qualifications (e.g., Levels 1-4 certificates) as undergraduate completion, while Australian universities begin at Level 5 (diploma). This may result in bias in favour of New Zealand, particularly in models using unadjusted completions. However, excluding sub-degree qualifications would understate teaching activity in New Zealand universities, potentially introducing an even greater issue/bias against New Zealand universities.

The sensitivity analysis confirms that key determinants of technical inefficiency in Australasian universities are robust across model specifications. A higher share of international students consistently reduces efficiency, while universities with medical schools improve efficiency. Although efficiency scores vary slightly when different data sources are used, the explanatory factors remain statistically significant and directionally consistent. Lower efficiency scores based on government data likely reflect inconsistencies in reporting standards and data classification, particularly in New Zealand.

Moreover, expanding the labour input specification (by disaggregating academic roles) does not significantly change the results. However, the stronger effect of the general-to-academic staff ratio highlights the importance of general staff in supporting teaching and research functions. However, when research output is adjusted for citation impact, the relationship reverses: a lower general-to-academic staff ratio indicates higher efficiency. This suggests that research-intensive universities like Go8 tend to operate with streamlined administrative structures but produce high-impact research. This highlights the importance of carefully specifying research output measures, as whether efficiency is assessed using income or publication quality can influence the results.

Chapter 7 Empirical Results: Stochastic Cost Frontier Analysis

This chapter assesses the cost efficiency of Australasian universities through a stochastic cost frontier (SCFA) analysis. It builds on the theoretical framework introduced in Chapter 2.4.2 and the data analysis outlined in Chapter 4.4, focusing on the relationship between costs, input prices, and outputs. The Battese and Coelli (1995) (BC95) model is applied to jointly estimate cost efficiency and identify the key environmental factors of inefficiency.

The SCFA uses total costs as the dependent variable, normalised by equivalent full-time student (EFTS) enrolments, to ensure comparability across universities of different sizes. Output measures include undergraduate and postgraduate completions and research income, also normalised by EFTS enrolments. Input variables include the labour price, calculated as total personnel costs divided by full-time equivalent (FTE) staff, and the capital price, proxied by non-labour expenses per EFTS.

Section 7.1 presents the empirical model specification, including the Cobb-Douglas (CD) and translog models. It also introduces the inefficiency determinants, including medical schools, the proportion of international or female students, regional variations, and the general-to-academic FTE staff ratio. Section 7.2 presents and discusses the main results, including cost frontier estimates, cost efficiency scores and sensitive analyses. This section also examines the impact of alternative model specifications, such as different capital price measures, alternative data sources, and different reach output measures, on cost efficiency results. These alternative specifications examine the robustness of the findings. Section 7.3 concludes the main findings. Appendix Chapter 7 provides supplementary and additional tables for robustness analyses.

7.1 Empirical Model Specification

Stochastic Cost Frontier Framework

The cost function describes the minimum cost to produce a certain output level, given the existing technologies and input prices. Universities that operate on this minimum-cost frontier are considered fully cost-efficient (CE). Those operating above the frontier are less efficient (see Figure 2.7), with cost efficiency measured by the minimum to actual costs ratio. Within the SCFA framework, CE is expressed as the ratio of the stochastic frontier cost to the actual cost (Kumbhakar & Lovell, 2003, p.138)

Cobb-Douglas and Translog Model Specifications

To examine CE among Australasian universities, this study estimates a cost function using two popular functional forms: the Cobb-Douglas (CD) and the Translog model. These models provide a structured approach to capturing the relationship between total costs, output volumes and input prices. The Cobb-Douglas and Translog specifications are presented in Equations (2.42) and (2.43) (Coelli et al., 2005, p. 266).

Cobb-Douglas Model

The empirical Cobb-Douglas model estimated in this study is expressed as:

$$\ln\left(\frac{C_{it}}{EFTS_{it}}\right) = \alpha + \sum_{m=1}^{3} \alpha_m \left(\frac{lny_{mit}}{EFTS_{it}}\right) + \sum_{k=1}^{2} \beta_k lnw_{kit} + \theta_1 t + \theta_2 t^2 + v_{it} + u_{it}$$
$$= \alpha_0 + \alpha_1 \ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right) + \alpha_2 \ln\left(\frac{y_{PG_{it}}}{EFTS_{it}}\right) + \alpha_3 \ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right) + \beta_1 lnw_{FTE_{it}} + \beta_2 lnw_{Cap_{it}} + \theta_1 t + \theta_2 t^2 + v_{it} + u_{it} \quad (7.1)$$

Translog Model

The empirical translog model estimated in this study is expressed as:

$$
\begin{aligned}
\ln\left(\frac{C_{it}}{EFTS_{it}}\right) = {} & \alpha + \sum_{m=1}^{3} \alpha_m ln\left(\frac{y_{mit}}{EFTS_{it}}\right) \\
& + \frac{1}{2}\sum_{m=1}^{3}\sum_{n=1}^{3} \alpha_{mn}\left[\ln\left(\frac{y_{mit}}{EFTS_{it}}\right) * \ln\left(\frac{y_{nit}}{EFTS_{it}}\right)\right] + \sum_{k=1}^{2} \beta_k lnw_{kit} \\
& + \frac{1}{2}\sum_{k=1}^{2}\sum_{l=1}^{2} \beta_{kl}(lnw_{kit} * lnw_{lit}) + \sum_{m=1}^{3}\sum_{k=1}^{2} \zeta_{mk} ln\left(\frac{y_{mit}}{EFTS_{it}}\right) * \ln w_{kit} + \theta_1 t \\
& + \theta_2 t^2 + v_{it} + u_{it} \\
& = \alpha_0 + \alpha_1 \ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right) + \alpha_2 \ln\left(\frac{y_{PG_{it}}}{EFTS_{it}}\right) + \alpha_3 \ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right) + 0.5\alpha_{11} \\
& * \left[\ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right)\right]^2 + 0.5\alpha_{22} * \left[\ln\left(\frac{y_{PG_{it}}}{EFTS_{it}}\right)\right]^2 + 0.5\alpha_{33} * \left[\ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right)\right]^2 + \alpha_{12} \\
& * \left[\ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right)\ln\left(\frac{y_{PG_{it}}}{EFTS_{it}}\right)\right] + \alpha_{13} * \left[\ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right)\ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right)\right] + \alpha_{23} \\
& * \left[\ln\left(\frac{y_{PG_{it}}}{EFTS_{it}}\right)\ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right)\right] + \beta_1 lnw_{FTE_{it}} + \beta_2 lnw_{Cap_{it}} + 0.5\beta_{11} * (lnw_{FTE_{it}})^2 \\
& + 0.5\beta_{22} * (lnw_{Cap_{it}})^2 + \beta_{12} * \left(lnw_{FTE_{it}} lnw_{Cap_{it}}\right) + \zeta_{11} \\
& * \left[lnw_{FTE_{it}} ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right)\right] + \zeta_{12} * \left[lnw_{FTE_{it}} ln\left(\frac{y_{PG_{it}}}{EFTS_{it}}\right)\right] + \zeta_{13} \\
& * \left[lnw_{FTE_{it}} ln\left(\frac{y_{RI}}{EFTS_{it}}\right)\right] + \zeta_{21} * \left[lnw_{Cap_{it}} ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right)\right] + \zeta_{22} \\
& * \left[lnw_{Cap_{it}} ln\left(\frac{y_{PG_{it}}}{EFTS_{it}}\right)\right] + \zeta_{23} * \left[lnw_{Cap_{it}} ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right)\right] + \theta_1 t + \theta_2 t^2 + v_{it} \\
& + u_{it}
\end{aligned} \tag{7.2}
$$

where:

- $C_{it}/EFTS_{it}$ represents total costs per EFTS at university i in year t;
- $y_{mit}/EFTS_{it}$ denotes teaching outputs (undergraduate and postgraduate qualification completions) per EFTS and the research output (research income) per EFTS;
- w_{it} represents input prices, including labour price[114] (measured as total personnel costs per FTE staff, following Stevens, 2005; McMillan & Chan, 2006; Kempkes & Pohl, 2008, 2010; Daghbashyan, 2011; Gralka, 2018b; Gralka et al., 2019), and capital price (proxied by non-labour expenditure per EFTS, following Worthington & Higgs, 2011);
- $\alpha, \beta, \zeta, \theta$ refer to unknown parameters to be estimated;
- t captures the time trend to account for technological change;

[114] Due to the unavailability of academic and general personnel cost data at Massey University, Victoria University of Wellington (VUW) and Lincoln University, it is impossible to separately estimate the effect of average academic staff costs and average general staff costs on cost efficiency.

- $\boldsymbol{v_{it}}$ denotes random errors, assumed to be independently and identically distributed as $\boldsymbol{N(0, \sigma_v^2)}$, and independent of $\boldsymbol{u_{it}}$;
- $\boldsymbol{u_{it}}$ represents cost inefficiency in the production of teaching and research at universities.

Partial Derivatives and Marginal Impact of Interaction Terms in the Translog Model

The translog cost function provides a flexible specification that captures nonlinear relationships and interactions among teaching outputs, research outputs, and input prices. The marginal impact of an output or input price on costs per EFTS is evaluated using the first derivatives of the cost function concerning that output or input price.

Partial Derivatives of <u>Outputs</u> in the Cost Function

The partial derivative of the cost function for an output in Equation (7.2) is:

$$\frac{\partial ln(C_{it}/EFTS_{it})}{\partial ln(\frac{y_{mit}}{EFTS_{it}})} = \alpha_m + \sum_{n}^{N} \alpha_{mn} ln\left(\frac{y_{nit}}{EFTS_{it}}\right) + \sum_{k}^{K} \zeta_{mk} \ln w_{kit} \tag{7.3}$$

This equation indicates that the marginal impact of each output (e.g., undergraduate completions per EFTS, postgraduate completions per EFTS, or research income per EFTS) on costs per EFTS varies depending on the direct impact of each output on costs per EFTS ($\boldsymbol{\alpha_m}$), the interaction terms between different outputs ($\boldsymbol{\alpha_{mn}}$: how changes in one output influence the costs per EFTS impact of another output), and the interactions with input prices ($\boldsymbol{w_{kit}}$).

Marginal Impact of Interaction Terms in the Translog Model

Positive and significant interaction terms indicate that expanding one output reduces the marginal impact of another, leading to increased costs per student (e.g., undergraduate completion and research income). Negative and significant interaction terms suggest that increasing one output increases the marginal effect of another, resulting in reduced costs per student (e.g., postgraduate completions and research income).

Partial Derivatives of <u>Input Prices</u> in the Cost Function

The partial derivatives of the cost function for input prices in Equation (7.2) are:

$$\frac{\partial \ln \left(C_{it}/EFTS_{it}\right)}{\partial lnw_{kit}} = \beta_k + \sum_{l}^{L} \beta_{kl}(lnw_{lit}) + \sum_{k}^{K} \zeta_{mk}\, ln\left(\frac{y_{mit}}{EFTS_{it}}\right) \tag{7.4}$$

The Equation shows that the marginal impact of each input price (e.g., labour or capital prices) on costs per EFTS, is determined by three factors: the direct effect of input price on costs per EFTS (β_k), the interaction term between input prices (β_{kl}: reflecting how changes in one input price affect the cost elasticity of another), and the interaction with outputs (ζ_{mk}: how the impact of input prices depends on the level of outputs produced).

As indicated above, input prices and outputs interact to influence costs per EFTS. Positive and significant interaction terms between labour prices and teaching output per EFTS suggest that higher teaching output increases the cost per EFTS impact of staff wages, indicating labour-intensive teaching activities may drive up costs per EFTS.

Normalisation of Cost and Output Variables

In cost efficiency analysis, total university costs are commonly used as the primary cost variable (Stevens, 2005; Kuo & Ho, 2008; Daghbashyan, 2011). Studies on German universities (Kempkes & Pohl, 2008, 2010; Agasisti & Haelermans, 2016; Gralka, 2018b; Agasisti & Gralka, 2019) have adopted normalisation approaches to account for institutional differences among higher education institutions. The choice of the normalisation method can significantly influence efficiency estimates.

For instance, Gralka (2018b) and Agasisti and Gralka (2019) applied graduate-based normalisation to control for substantial variations in non-completion rates across institutions (Johnes, 2014a). Additionally, Agasisti and Haelermans (2016) found that efficiency estimates could differ significantly depending on whether student enrolments or graduate numbers were used as output measures in translog models for Italian and Dutch universities. However, due to data limitations, graduate numbers were unavailable for Australasian universities in this study.

Therefore, to facilitate comparison across universities of different sizes, total expenses, qualification completions, and research income were normalised by EFTS enrolments. This approach accounts for differences in cost structure and allows for easier interpretation of the coefficients, particularly regarding the impact of input prices and outputs on costs per student.

Quality-Adjustment of Teaching Outputs

To account for variations in teaching quality, undergraduate and postgraduate completions were weighted based on qualification credits and income. This adjustment captures differences in programme intensity and resource demands as a proxy for the value of education delivered rather than only teaching output quantity.

Inefficiency Effects Model: Battese and Coelli (1995, BC95) Model

The inefficiency term, $\boldsymbol{u_{it}}$, represents non-negative random variables representing inefficiency in the production of teaching and research activities. Based on Battese and Coelli's (1995) panel data framework, $\boldsymbol{u_{it}}$ terms are assumed to be independently and identically distributed, following a truncated normal distribution: $\boldsymbol{N^{+}\left(\delta Z_{it}, \sigma_u^2\right)}$. That is, inefficiency $\boldsymbol{u_{it}}$ is modelled as a function of the $\boldsymbol{Z_{it}}$ variables, which are the same as those used in the distance function specification in Equation (6.4).

Therefore, the inefficiency terms, $\boldsymbol{u_{it}}$, are modelled as a function of institutional characteristics:

$$\begin{aligned} u_{it} = \delta_0 &+ \delta_1 Medical\ school_{it} + \delta_2 Share\ of\ Overseas_{it} + \delta_3 Region_i \\ &+ \delta_4 Ratio\ of\ General\ \ to\ Academic\ FTE\ staff_{it} \\ &+ \delta_5 Ratio\ of\ Female\ EFTS_{it}\ + \omega_{it} \end{aligned} \quad (6.4)$$

where:

- $\boldsymbol{Medical\ school_{it}}$ is a dummy variable that takes the value of 1 if a university has a medical school, and 0 otherwise, which accounts for cost structures associated with specialised programmes and research-intensive disciplines;
- $\boldsymbol{Share\ of\ Overseas_{it}}$ represents the proportion of international to total EFTS enrolments. While international students may introduce additional costs, they can also enhance cost efficiency by contributing higher tuition fees, diversifying revenue streams, and potentially attracting high-quality students;
- $\boldsymbol{Ratio\ of\ Female\ EFTS_{it}}$ represents the proportion of domestic female EFTS to total domestic EFTS, capturing potential socio-demographic effects on university cost efficiency;
- $\boldsymbol{Region_i}$ includes dummy variables for New Zealand regions and Australian state territories where universities are located (with universities located in New Zealand's North Island as the reference region) to control for geographic, institutional and local economic differences that may influence cost efficiency;
- $\boldsymbol{Ratio\ of\ General\ to\ Academic\ FTE\ staff_{it}}$ reflects variations in staffing composition, which may impact cost efficiency.

The BC95 model specification is widely used in university cost efficiency studies by Stevens (2005), McMillan and Chan (2006), Kuo and Ho (2008), Kempkes and Pohl (2008, 2010), Daghbashyan (2011), and Sav (2012, 2012d, 2012f, 2012g, 2012h, 2012j, 2016).

Estimation with FRONTIER Version 4.1

All unknown parameters in Equations (7.2) and (6.4) were jointly estimated using the Maximum Likelihood (ML) method, implemented through the FRONTIER 4.1 software package. In distance functions, efficiency scores range from zero to one, with a value of one indicating full technical efficiency. In contrast, in cost functions, efficiency scores lie between one and infinity (Coelli, 1996, p. 9), with a score of one indicating full cost efficiency.

Inefficiency measure (γ)

This model uses the variance ratio between $\boldsymbol{\sigma_u^2}$ and $\boldsymbol{\sigma_v^2 + \sigma_u^2}$ to assess the significance of inefficiency effects on university costs. Following Battese and Corra (1977), ($\boldsymbol{\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)}$) and varies in the interval $\boldsymbol{0 \leq \gamma \leq 1}$. A value of $\boldsymbol{\gamma = 0}$ indicates that all deviations from the cost frontier are entirely random noise. If $\boldsymbol{\gamma = 1}$, then deviations from the minimum attainable costs are entirely attributable to inefficiency.

7.2 Empirical Results and Discussion

7.2.1 *Results and Discussion*

Table 7.1 presents the cost function models and inefficiency determinants using SCFA. The dependent variable is the total cost, with outputs, input prices, and inefficiency determinants. Four model specifications were estimated to evaluate the appropriate functional form and inefficiency effects, while OLS estimations without inefficiency terms were removed for conciseness.

Thus, Inefficiency Effect Model 1, used in both the Cobb-Douglas and translog models, includes undergraduate and postgraduate completions per EFTS, research income per EFTS, labour price, capital price, and all inefficiency variables. Model 2, also estimated using Cobb-Douglas and translog models, replaces undergraduate and postgraduate completions per EFTS with their quality-adjusted completions and uses the same explanatory variables from Model 1.

Table 7.1
Cost Function Specifications and Determinants of Inefficiency

Cost, Outputs, Input prices, and Determinants of Inefficiency		Inefficiency Effect model	
		1	2
Cost	Total Expenditure/EFTS	√	√
Output	No. of Undergraduate Completions (UG)/EFTS	√	
	No. of Postgraduate Completions (PG)/EFTS	√	
	Research Income (RI)/EFTS	√	√
Adjusted Output	No. of Credit-and Income-weighted UG Completions/EFTS		√
	No. of Credit-and Income-weighted PG Completions/EFTS		√
Input Price	Labour: Total Personnel Costs per FTE staff	√	√
	Capital: Non-labour Expenditure/EFTS	√	√
Inefficiency effect model			
	Medical School	√	√
	Region/State Territories Dummies	√	√
	Share of Overseas Students	√	√
	Ratio of General to Academics	√	√
	Rate of Female Students	√	√

Following the approach of Battese and Broca (1997), log-likelihood ratio (LR) tests were used to determine the appropriate model specification and functional form, given the nested structure of the models. Table 7.2 shows the hypothesis test results, assessing the choice of model specification and the significance of inefficiency in Australasian universities.

The first hypothesis tests whether the Cobb-Douglas model adequately captures the cost structure by restricting all second-order interaction terms between outputs and input prices to zero ($\boldsymbol{H_0}: \boldsymbol{\alpha_{mn}} = \boldsymbol{0}, \boldsymbol{\beta_{kl}} = \boldsymbol{0}\ \boldsymbol{and}\ \boldsymbol{\zeta_{km}} = \boldsymbol{0}$). In both Model 1 (using unadjusted completions) and Model 2 (using quality-adjusted completions), the LR test results exceed the critical value at the 5% significance level. These findings support the use of the translog specifications, which capture more complex relationships between costs, outputs and input prices.

The second hypothesis examines whether inefficiency effects are present ($\boldsymbol{H_0}: \boldsymbol{\gamma} = \boldsymbol{0}$), implying that an OLS model without inefficiency terms would be appropriate. The LR test results strongly reject this hypothesis across both models. These confirm that inefficiency effects are statistically significant and thus should be included in the analysis.

Table 7.2
Hypothesis Tests

Null hypothesis ($\boldsymbol{H_0}$)	L($\boldsymbol{H_0}$)	L($\boldsymbol{H_1}$)	LR-test statistic	Critical value ($\boldsymbol{x^2_{0.95}}$)	Decision

Model 1: Costs and Outputs (Number of undergraduate and postgraduate completions and research income) are normalised by EFTS with labour price and capital price as inputs used						
(1) Cobb-Douglas	$\boldsymbol{H_0: \alpha_{mn} = 0, \beta_{kl} = 0\ and\ \zeta_{km} = 0}$	878.986	737.248	-283.477	24.996	Reject $\boldsymbol{H_0}$
(1) OLS estimation	$\boldsymbol{H_0: \gamma = 0}$	878.986	773.392	-211.189	20.410	Reject $\boldsymbol{H_0}$
Model 2: Costs and Output (Number of credit- and income-weighted undergraduate and postgraduate completions and research income) are normalised by EFTS with labour price and capital price as inputs used						
(1) Cobb-Douglas	$\boldsymbol{H_0: \alpha_{mn} = 0, \beta_{kl} = 0\ and\ \zeta_{km} = 0}$	886.236	714.426	-343.620	24.996	Reject $\boldsymbol{H_0}$
(2) OLS estimation	$\boldsymbol{H_0: \gamma = 0}$	886.236	772.446	-227.581	20.410	Reject $\boldsymbol{H_0}$

Note:

1. The LR-test statistic is given by -2[log likelihood ($\boldsymbol{H_0}$)-log likelihood ($\boldsymbol{H_1}$)], where $\boldsymbol{H_0}$ denotes the model with the explanatory variables related to the inefficiency effects in the Cobb-Douglas estimation and $\boldsymbol{H_1}$ denotes the model including the explanatory variables in the translog estimation. This statistic has asymptotically a chi-square distribution with degrees of freedom equal to 15 (Berndt, 1991; Kuo & Ho, 2008; Kempkes & Pohl, 2010). The log likelihood can be obtained from the Table.
2. The critical values for $\boldsymbol{\gamma = 0}$ are obtained from Table 1 of Kodde and Palm (1986) due to the mixed chi-square distribution with the degree of freedom are q-1 (Battese & Broca, 1997), here is equal to 12. $\boldsymbol{H_0}$ denotes the model without the explanatory variables related to the inefficiency effects (OLS) in the Cobb-Douglas or Translog estimation and $\boldsymbol{H_1}$ denotes the model including the explanatory variables in the Cobb-Douglas or Translog estimation.

Cost Function Estimation in Translog Models

Table 7.3 shows the estimated results of the inefficiency effect models, comparing Cobb-Douglas and Translog functional forms. Model 1 utilises unadjusted completions, while Model 2 uses quality-adjusted completions in both functional forms. Given the earlier hypothesis test results, the subsequent discussion focuses on the translog models, which provide greater flexibility in capturing the nonlinear relationships between costs per student, outputs per student, and input prices.

The partial derivative derived from Equation (7.3) for an output includes three components: (1) the direct effect of each output on costs per EFTS, (2) interactions among different outputs, and (3) interactions with input prices. Likewise, the partial derivatives in Equation (7.4) with respect to input prices capture (1) the direct impact of input price on costs per EFTS, (2) interactions between input prices, and (3) interactions with outputs.

According to Coelli et al. (2005, p. 23), a well-behaved cost function (as discussed in Section 2.4.2) is non-decreasing and linearly homogeneous in input prices (meaning that total costs increase proportionally when all input prices increase by the same proportion for a given level of output), non-decreasing in output, and concave in input prices. The estimated translog models presented in Table 7.3 satisfy these theoretical conditions. Specifically, the first partial derivatives for labour and capital prices and three output variables (undergraduate completions, postgraduate completions, and research income per EFTS) are consistently positive. This confirms that the estimated cost functions behave consistently with economic theory, with total costs increasing as universities produce more outputs or face higher input prices.

Undergraduate Completions per EFTS and Total Costs per EFTS

In the adjusted translog Model 2 (using quality-adjusted completions in the right panel of Table 7.3), the first partial derivative for undergraduate completions per EFTS is significantly positive (1.462). This suggests that universities with more undergraduate completions per EFTS tend to incur higher costs per student. Specifically, this derivative was calculated using Equation (7.3) by applying the estimated parameters and mean values of the significant variables involved in the interaction terms, as follows:

$$\frac{\partial \ln(C_{it}/EFTS_{it})}{\partial \ln\left(y_{UG_{it}}/EFTS_{it}\right)} = -1.717 + 0.344 * 2 * \ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right) + 0.096 * \ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right) + 0.104 * \ln\left(FTE\ price_{it}\right) + (-0.156) * \ln(Capital\ price_{it}) = 1.462 \tag{7.5}$$

As undergraduate completions increase, universities may be unable to maintain constant per-unit costs due to constraints on scaling their current operations. For instance, universities may face shortages of suitably qualified academic and administrative staff, particularly in high-demand disciplines. Expanding undergraduate completions could require hiring additional qualified staff, potentially making additional hiring costly. This also requires additional investments in teaching infrastructure and student support services, leading to increased costs per student.

This result is consistent with Stevens's (2005) and Daghbashyan's (2011) findings for science undergraduate students but contrasts their findings for art undergraduate students. It also aligns with Agasisti and Milano (2016) for bachelor's degree completions. Similarly, it supports findings from Kuo and Ho (2008), Manum (2011), Sav (2012, 2012d, 2012f, 2012h, 2012j, 2016), and Agasisti and Milano (2016), who found a positive relationship between undergraduates and costs.

Postgraduate Completions per EFTS and Total Costs per EFTS

The positive first partial derivative for postgraduate completions per EFTS (0.280[115] and 0.275[116] in the two translog models) indicates that universities with larger postgraduate education tend to experience higher costs per student, particularly in research-intensive disciplines, such as STEM fields, medicine and engineering. This is as expected given postgraduate and research-intensive disciplines require specialised resources and highly qualified academic staff. Postgraduate courses are typically delivered by senior academics and professors, who tend to earn higher salaries than those teaching undergraduate courses. This is especially relevant in thesis-based master's or PhD programmes, where more individual supervision, mentoring and research guidance increase personnel costs. Additionally, postgraduate students often require access to advanced laboratories and specialised equipment, which also contribute to higher costs per EFTS.

This result aligns with Daghbashyan (2011), Manum (2011) and Agasisti and Milano (2016), who found that PhD students were associated with higher costs. However, it contrasts with the findings of Kuo and Ho (2008).

Research Income per EFTS and Total Costs per EFTS

In the adjusted translog model, the first partial derivative for research income per EFTS (right panel in Table 7.3) is positively associated with total costs per student (0.214[117]). This reflects that universities generating greater research income incur higher costs per student. Research-intensive universities often employ senior academics, research fellows and highly qualified professors, who are paid higher salaries due to their research expertise and productivity.

Universities also engaged in industry collaborations, government-funded projects, and commercialisation activities may face high administrative and operational costs. Significant investments in research infrastructure, including laboratories, specialised equipment and research

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[115] This result is calculated from Equation (7.3) using the estimated coefficients from the unadjusted translog model (left panel in Table 7.3): $\frac{\partial ln(C_{it}/EFTS_{it})}{\partial ln(y_{PG_{it}}/EFTS_{it})} = -0.523 + 0.076 * \ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right) + 0.186 * \ln(FTE\ price_{it}) = 0.280.$ The value is calculated by inserting the mean values of the statistically significant variables into this equation.

[116] This value is calculated from Equation (7.3) using the estimated coefficients from the adjusted translog model (right panel in Table 7.3): $\frac{\partial ln(C_{it}/EFTS_{it})}{\partial ln(y_{PG_{it}}/EFTS_{it})} = -1.070 + 0.074 * 2 * \ln\left(\frac{y_{PG_{it}}}{EFTS_{it}}\right) + (-0.029) * \ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right) + 0.188 * \ln(FTE\ price_{it}) = 0.275.$

[117] This result is calculated from Equation (7.3) using the estimated coefficients from the adjusted translog model (right panel in Table 7.3): $\frac{\partial ln(C_{it}/EFTS_{it})}{\partial ln(y_{RI_{it}}/EFTS_{it})} = -0.490 + 0.066 * 2 * \ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right) + 0.096 * \ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right) + (-0.029) * \ln\left(\frac{y_{PG_{it}}}{EFTS_{it}}\right) + 0.067 * \ln(Capital\ price_{it}) = 0.214.$

centres, further increase capital and operational costs. Maintaining state-of-the-art facilities may attract external grants and top researchers but also increases costs per student.

This finding is consistent with Kempkes and Pohl (2010), who found that higher research income per student increased costs per student. However, this contrasts with Stevens (2005), Agasisti and Haelermans (2016) and Sav (2016), who suggested that research income reduced costs.

Labour Price and Total Costs per EFTS

The positive first partial derivative for labour price in the adjusted translog model (right panel in Table 7.3) indicates that higher average staff costs contribute to increase per-student costs (2.301[118]). This effect may be due to more experienced or highly qualified staff receiving higher salaries and additional research incentives, increasing overall labour costs and costs per student.

This result reflects differences in cost structures and workforce composition (e.g., the ratio of general to academic staff) between the two university systems. Over the study period, labour costs in Australian universities tend to be significantly higher than in New Zealand universities. The average FTE staff cost in Australia was NZD 161,887, nearly double New Zealand's (NZD 95,248, see Table 4.13). Additionally, New Zealand's annual average growth rate in total staff costs was 1.3%, compared to 4.01% in Australia. Similarly, personnel costs per FTE grew by only 0.27% per year in New Zealand, far below the 1.35% observed in Australia.

This result highlights the trade-off between staff quality and cost. While higher labour costs may improve research performance, enhance teaching and research quality, create a greater institutional reputation, and attract more qualified academic staff and international students, they also significantly increase university costs. This result aligns with Steven (2005), Kempkes and Pohl (2008), and Daghbashyan (2011), who found that higher average salaries were associated with increased university costs but contrasts with the findings of Kuo and Ho (2008), and Kempkes and Pohl (2010).

Capital Price and Total Costs per EFTS

[118] This value is calculated from Equation (7.3) using the estimated coefficients from the adjusted translog model (right panel in Table 7.3): $\frac{\partial ln(C_{it}/EFTS_{it})}{\partial ln(FTE\ price_{it})} = -2.588 + 0.420 * 2 * \ln(FTE\ price_{it}) + (-0.127) * \ln(Capital\ price_{it}) + 0.104 * \ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right) + 0.188 * \ln\left(\frac{y_{PG_{it}}}{EFTS_{it}}\right) = 2.301$.

The positive first partial derivative for capital price in both translog models (e.g., 0.477[119] and 0.481[120], respectively) indicates that higher capital prices contribute to increased costs per student. To maintain educational quality and research excellence, universities require investments in physical and technological infrastructure, including buildings, laboratories, classrooms, and digital learning environments. This leads to increased costs per student, particularly in research-intensive universities that require specialised equipment and advanced facilities.

Additionally, capital costs are usually fixed in the short run, indicating that universities with large infrastructure investments may not immediately receive cost efficiencies. Unlike labour costs, which could adjust with student enrolment levels, capital costs are relatively inflexible, leading to higher costs per student when enrolment numbers are lower. This result also aligns with the impact of depreciation and amortisation on university cost structures. Universities with older and more extensive infrastructure may face higher maintenance and depreciation expenses, further increasing costs per EFTS. This finding aligns with Sav (2011), who observed that increasing capital prices contributed to higher university costs.

Differences in institutional spending patterns, such as the general-to-academic staff ratio and capital expenditure, may have affected universities' cost structures. The capital price growth was modest, averaging 0.43% annually in Australia and 0.38% in New Zealand from 2008 to 2018. Although the difference is relatively small, it reflects a general upward trend across both countries. Some universities may have prioritised labour inputs (e.g., hiring more academic and support staff) over capital investments to manage costs efficiently. This highlights the trade-offs between capital and labour inputs in university cost structures and suggests that managing capital expenditure is important for improving cost efficiency.

Teaching and Research Interactions and Their Impact on Costs per EFTS

The interaction terms between teaching and research activities in universities are complex, as reflected by the cross-effects in the translog models. These terms account for the nonlinear effects and interdependencies between key cost drivers, reflecting how changes in one output influence the costs

[119] This result is calculated from Equation (7.3) using the estimated coefficients from the unadjusted translog model (left panel in Table 7.3): $\frac{\partial ln(C_{it}/EFTS_{it})}{\partial ln(Capital\ price_{it})} = 0.838 + (-0.194) * \ln(FTE\ price_{it}) + (-0.297) * \ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right) + 0.072 * \ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right) = 0.477$.

[120] This value is calculated from Equation (7.3) using the estimated coefficients from the adjusted translog model (right panel in Table 7.3): $\frac{\partial ln(C_{it}/EFTS_{it})}{\partial ln(Capital\ price_{it})} = 1.651 + (-0.127) * \ln(FTE\ price_{it}) + (-0.156) * \ln\left(\frac{y_{UG_{it}}}{EFTS_{it}}\right) + 0.067 * \ln\left(\frac{y_{RI_{it}}}{EFTS_{it}}\right) = 0.481$.

per student impact of another. In other words, the marginal impact of an output depends on its interactions with other outputs and input prices, as presented by squared and interaction terms.

There are trade-offs in teaching and research outputs. Positive and significant interaction terms (e.g., between completions per EFTS and research income per EFTS) indicate that expanding one output could reduce the marginal impact of another, leading to higher costs per student. Conversely, negative and significant interaction terms indicate that increasing one output strengthens the marginal effect of another, decreasing costs per student.

Undergraduate Completions per EFTS and Research Income per EFTS Impact on Costs per EFTS

The positive and significant coefficient for the interaction term between undergraduate completions per EFTS and research income per EFTS indicates that higher undergraduate teaching output may experience a decline in research income, leading to increased costs per EFTS. Academic staff with heavier undergraduate teaching loads may have less time and fewer resources for research activities. Consequently, universities that expand undergraduate completions at the expense of research outputs may need to recruit additional staff and reallocate resources to maintain their research performance, further increasing costs per student. The observed trade-off between teaching and research activities highlights the need for universities to manage academic workloads and funding allocations strategically.

This result aligns with Stevens (2005) for UK universities, where science undergraduate programmes were found to be time-consuming to teach, reducing the time for research. Similarly, Kuo and Ho (2008) observed that greater undergraduate teaching loads reduced research output for Taiwanese universities. Kempkes and Pohl (2010) for German universities also found a negative and significant relationship between degree completions per student and research grants per student, further supporting that increased undergraduate completions per student may come at the expense of research performance.

Postgraduate Completions per EFTS and Research Income per EFTS Impact on Costs per EFTS

The relationship between quality-adjusted postgraduate completions per student and research income per student is significantly negative. This suggests a cost-reducing effect per EFTS when postgraduate students are involved in teaching and research activities. Since postgraduate students often participate as teaching and research assistants, they may help reduce instructional workloads for academic staff while also contributing to research output. Their dual role may allow universities to improve cost efficiency by lowering costs per student while maintaining or enhancing research performance.

This result is consistent with Kuo and Ho (2008) and Sav (2011) but contrasts with Sav (2016). Earlier research has often overlooked how institutional decisions about student numbers and the quality of teaching and research shape cost structures.

Undergraduate Completions per EFTS and Postgraduate Completions per EFTS Impact on Costs per EFTS

In the unadjusted Translog model (left panel in Table 7.3), the relationship between undergraduate and postgraduate completions per EFTS is significantly positive, indicating that undergraduate and postgraduate teaching activities are substitutes. This implies there is a trade-off between undergraduate and postgraduate programmes for limited institutional resources, such as academic staff time, administrative support and infrastructure. Consequently, if universities aim to increase completion at both undergraduate and postgraduate levels, they require additional resources, which raises the costs per student. This finding contrasts with Stevens's (2005) and Kuo and Ho's (2008) studies, which did not identify similar competitive interactions between these two teaching outputs.

Labour Price and Postgraduate Completions per EFTS Impact on Costs per EFTS

The relationship between postgraduate completions per EFTS and the labour price is significantly positive in both translog models. This indicates that as postgraduate completions per EFTS increase, the marginal impact of average staff costs on total costs per EFTS also rises. One possible explanation is that postgraduate programmes are typically delivered by senior academics, professors, and highly specialised staff, all of whom receive higher salaries. Therefore, expanding postgraduate teaching activities may increase overall personnel costs and, consequently, costs per student. This result is consistent with Stevens (2005) and Kuo and Ho (2008), indicating that higher levels of academic expertise required for postgraduate education are associated with increased financial costs for universities.

Table 7.3

Stochastic Cost Frontier Specification: Cobb-Douglas and Translog Models

ln(Costs/EFTS)	Inefficiency effects model 1				Inefficiency effects model 2			
Coefficients	Cobb-Douglas (1)	se	Translog (1)	se	Cobb-Douglas (2)	se	Translog (2)	se
Constant	0.295**	(0.125)	1.774**	(0.809)	0.397*	(0.225)	11.685***	(2.178)
ln(UG/EFTS)	0.056***	(0.014)	0.423	(0.334)	0.036**	(0.016)	-1.717***	(0.529)
ln(PG/EFTS)	0.045***	(0.010)	-0.523**	(0.230)	0.041***	(0.011)	-1.070***	(0.304)
ln(RI/EFTS)	0.093***	(0.007)	-0.172	(0.146)	0.095***	(0.007)	-0.490**	(0.193)
ln(FTE Price)	0.287***	(0.022)	-0.388	(0.307)	0.198***	(0.032)	-2.588***	(0.570)
ln(Capital Price)	0.613***	(0.015)	0.838**	(0.326)	0.574***	(0.018)	1.651***	(0.445)
t	-0.001	(0.004)	0.003	(0.003)	0.001	(0.004)	0.003	(0.003)
t^2	0.0003	(0.000)	0.0003	(0.000)	0.0003	(0.000)	0.0003	(0.000)
$ln(UG/EFTS)^2$			0.020	(0.072)			0.344***	(0.111)
$ln(PG/EFTS)^2$			0.061	(0.041)			0.074*	(0.042)
$ln(RI/EFTS)^2$			0.062***	(0.018)			0.066***	(0.017)
ln(UG/EFTS)*ln(PG/EFTS)			0.076*	(0.039)			0.009	(0.047)
ln(UG/EFTS)*ln(RI/EFTS)			0.113***	(0.029)			0.096***	(0.033)
ln(PG/EFTS)*ln(RI/EFTS)			-0.020	(0.016)			-0.029*	(0.017)
$ln(FTE\ Price)^2$			0.311***	(0.071)			0.420***	(0.089)
$ln(Capital\ Price)^2$			-0.009	(0.087)			0.023	(0.087)
ln(FTE Price)*ln(Capital Price)			-0.194***	(0.049)			-0.127**	(0.050)
ln(FTE Price)*ln(UG/EFTS)			0.072	(0.052)			0.104*	(0.061)
ln(Capital Price)*ln(UG/EFTS)			-0.297***	(0.067)			-0.156**	(0.073)
ln(FTE Price)*ln(PG/EFTS)			0.186***	(0.041)			0.188***	(0.040)
ln(Capital Price)*ln(PG/EFTS)			-0.024	(0.039)			-0.010	(0.042)
ln(FTE Price)*ln(RI/EFTS)			0.034	(0.023)			0.007	(0.022)
ln(Capital Price)*ln(RI/EFTS)			0.072**	(0.035)			0.067**	(0.033)
Inefficiency effect:								
Constant	0.089*	(0.051)	0.164***	(0.039)	0.088	(0.073)	0.124***	(0.041)
Medical School	0.020**	(0.008)	0.019***	(0.006)	0.024**	(0.011)	0.017***	(0.006)
% Overseas students	-0.065	(0.070)	-0.234***	(0.051)	-0.086	(0.093)	-0.226***	(0.049)
NZ_South Island	0.071***	(0.015)	0.027**	(0.013)	0.085***	(0.018)	0.023*	(0.012)
AUS_NewSouthWales	-0.108***	(0.016)	-0.029*	(0.017)	-0.097***	(0.021)	-0.021	(0.018)
AUS_Victoria	-0.114***	(0.018)	-0.028	(0.019)	-0.110***	(0.026)	-0.020	(0.020)
AUS_Queensland	-0.063***	(0.014)	0.002	(0.015)	-0.067***	(0.019)	0.013	(0.018)
AUS_Western	-0.063***	(0.017)	0.001	(0.019)	-0.066***	(0.023)	0.010	(0.020)
AUS_South	-0.080***	(0.017)	-0.006	(0.020)	-0.094***	(0.022)	0.003	(0.020)
AUS_Tasmania	-0.136***	(0.021)	-0.065***	(0.020)	-0.161***	(0.027)	-0.044**	(0.022)
AUS_NorthTerritory	-0.233***	(0.038)	-0.243**	(0.115)	-0.132***	(0.050)	-0.233***	(0.058)
AUS_capitalTerritory	-0.032	(0.021)	-0.018	(0.019)	-0.012	(0.028)	-0.006	(0.021)
% General to academics	-0.088***	(0.009)	-0.021**	(0.010)	-0.143***	(0.015)	-0.014	(0.011)
% Female students	0.433***	(0.085)	0.165**	(0.064)	0.430***	(0.106)	0.222***	(0.061)
Log Likelihood	737.248		878.986		714.426		886.236	
sigma-squared	0.003		0.002		0.003		0.002	
gamma	0.018***		0.063		0.118***		0.057	
Likelihood ratio test of the one-sided error	223.933		211.189		181.069		227.581	
Mean efficiency	1.138		1.165		1.094		1.165	
Observations	495		495		495		495	

Note: Standard errors are in parenthesis. Significance level: *p<0.1; **p<0.05; ***p<0.01

Key Findings from Inefficiency Effect Models

In the SCFA, a positive coefficient indicates that a rise in inefficiency determinants leads to increased cost inefficiency (or reduced cost efficiency), ceteris paribus. This means universities operate further above the minimum cost frontier (Stevens, 2005, p. 364). A negative coefficient indicates lower cost inefficiency (or higher cost efficiency).

Medical Schools

Universities with medical schools are significantly linked to lower cost efficiency in both Translog models, as indicated by the positive coefficients for the medical school dummy variable. It captures the impact of medical education, which typically requires longer training periods and higher costs compared to other undergraduate programmes. This suggests that universities with medical schools tend to have higher infrastructure and research expenses, leading to increased operational costs and ultimately higher cost inefficiency.

Although universities with medical schools produce substantial research outputs, commercial income, and intellectual property income through medical research activities (University of Otago, 2018, p. 60), they also incur higher costs than those focusing on social sciences (Kempkes & Pohl, 2008). This is likely due to specialised equipment, clinical training requirements, and laboratory-intensive research, which require significant financial investment.

This result aligns with Groot et al. (1991), Kempkes and Pohl (2010) and Bolli and Farsi (2015), who argue that medical schools face a more expensive cost structure per EFTS, partly because educational and clinical resources[121] are difficult to separate.

Regional Variations

The results show that universities on New Zealand’s South Island have lower cost efficiency than those on the North Island. This may be attributed to smaller institutional size, more specialised focus (e.g., Lincoln University), and weaker agglomeration effects (e.g., the University of Otago) compared with universities in major metropolitan centres and proximity to high-tech firms/industries (e.g., the

[121] For instance, the medical and health sciences faculty at the University of Auckland provides the clinical campuses and sites where students undertake placements in urban, regional and rural hospital settings, like Auckland clinical campus offers medical teaching and training within the Auckland District Health Board. Similarly, The University of Otago, Christchurch Simulation Centre is developed as part of an Otago Medical School and is a field of education rapidly expanding within medical and other health professional programmes. And it has joined General Practice to become the Department of Primary Care and Clinical Simulation.

University of Auckland). Regional universities also face higher per-student costs, smaller student markets, and limited economies of scale. Their distance from urban hubs further restricts industry collaboration opportunities, research infrastructure access, and participation in national and international academic networks. These contextual disadvantages highlight regional universities' challenges, despite their important social and economic contributions.

By contrast, some Australian universities, particularly those in Tasmania, the Northern Territory, and New South Wales, exhibit higher cost efficiency than New Zealand's North Island universities. These universities benefit from favourable regional environments, such as economic spillovers [122] and institutional resources, such as research funding and student demand. Large universities in New South Wales (e.g., the University of Sydney and New South Wales) gain from scale advantages, substantial research resources, high-quality staff, and strong international reputations that attract both students and resources. Universities in Tasmania (e.g., University of Tasmania) and the Northern Territory (e.g., Charles Darwin University) have improved efficiency through international enrolments and partnerships with international colleges (e.g., UP Education[123]). Such an internationalisation strategy helps offset the financial pressures of smaller size and geographic remoteness by diversifying revenue sources and expanding student markets.

These results confirm that location matters for university efficiency. Contextual conditions such as remoteness, population density or local economic activity shape institutional performance. Therefore, policies should recognise both the higher costs and the distinctive contributions of regional universities, such as the University of Otago's medical school and Lincoln University's land-based specialised programmes, to ensure fairer assessment and more effective support.

Socio-Demographic Composition of EFTS Enrolments

Gender Composition

A higher percentage of female students is consistently associated with lower cost efficiency across the models. This result may be explained by programme mix, funding allocations, and delivery needs.

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[122] Universities in economically stronger states may benefit from collaborations with research-intensive companies and the existence of laboratories and research institutions in these rich states. While these relationships could enhance cost efficiency, Kempkes and Pohl (2010) suggest that these agglomeration areas may also increase costs due to higher wages and resource prices.

[123] Both universities have provided UP Education, which has provided preparatory education throughout Australia and New Zealand (e.g., Auckland, VUW and AUT provide this) for over 20 years (Charles Darwin University 2019 Annual Report, 2019).

Female enrolments are concentrated in disciplines such as education, management and commerce, and society and culture. These subjects generally have lower delivery costs but receive proportionally less government funding. As a result, the funding imbalance offsets potential cost advantages and increases financial pressure on universities. In contrast, Science, Technology, Engineering, and Maths (STEM) subjects are prioritised in New Zealand's funding system, while non-STEM disciplines remain relatively underfunded (Scott et al., 2015). The undervaluation of the humanities and social sciences within the university sector (Universities New Zealand, 2025) further widens these disparities, contributing to lower measured cost efficiency. Such imbalances risk compromising programme quality in underfunded fields, while overfunding in others may encourage inefficiency (Scott et al., 2015, p. 11).

Some female-dominated programmes, such as teacher education and nursing, also require intensive supervision, practicum placements, and small-class teaching, which increase delivery costs. In addition, female students include higher proportions of mature-age and part-time learners, some of whom balance study with caregiving responsibilities. This group may require more flexible delivery modes and greater institutional support, increasing administrative and service costs.

Although female and male students are charged the same tuition fees within disciplines, the distribution of students across fields may influence the universities' cost structures. Descriptive statistics show similar female enrolment shares across most universities, except Lincoln University, where the lower proportion of female students (32.3%) reflects its agriculture specialisation rather than efficiency-related gender differences. This aligns with Stevens (2005), who also found that higher proportions of female students decreased cost efficiency.

As noted in the sensitivity analysis (Section 7.2.3), this relationship varies with measurement methods and model specifications. The link between female enrolments and cost efficiency appears to be driven less by gender itself than by programme composition, funding imbalances, and delivery or support requirements.

International Students

The shares of overseas students are positively linked to cost efficiency in both Translog models. This indicates that universities with more international students are more cost-efficient, likely due to the financial benefits associated with international tuition fees. Revenue per international student is higher than per domestic student. Universities that attract international students often invest in high-cost programmes (e.g., MBA) and premium educational services, including high-quality accommodation and specific academic support. These investments, possibly supported by international tuition revenue, may enhance cost efficiency by allowing institutions to scale operations effectively.

The ability to attract international students is also closely linked to a university's global reputation (AUT 2018 Annual Report, 2018, p. 20). Universities with strong international reputations are more likely to attract research funding, industry partnerships, and external investments, which may improve cost efficiency. However, this finding contrasts with Daghbashyan (2011), who reported a negative impact of international students on cost efficiency in Swedish universities.

Staff composition

The general-to-academic staff ratio is significantly and positively related to cost efficiency in the unadjusted translog model. This indicates that differences in staff composition significantly affect universities' cost efficiency. A higher general-to-academic staff ratio appears to improve cost efficiency. This may occur because more administrative staff possibly reduce administrative burdens on academics, allowing them to concentrate more on their core activities (Abbott & Doucouliagos, 2009). This implies that universities with well-structured administrative workforces reduce inefficiencies and improve performance. These findings align with Abbott and Doucouliagos (2009) and Letti et al. (2022), who found similar significant relationships for universities in New Zealand/Australia and Brazil, respectively.

Variations in disciplinary focus, research expectations, and teaching loads may contribute to differences in staff composition[124]. Research-intensive universities may require more academic staff to sustain high-quality research outputs (e.g., Australian Go8 universities), while teaching-focused universities may benefit from more general staff to support efficient administrative functions. These results suggest that balancing academic and general staff is important for improving cost efficiency, ensuring academic staff can focus on teaching and research work while administrative staff manage support services efficiently.

Inefficiency measure (Gamma γ)

[124] Descriptive statistics indicate that New Zealand universities employ more general staff than academics, while Australian universities exhibit a higher proportion of academic staff. Over the period, the annual average growth rates for academic and general staff in New Zealand were 0.52% and 1.63%, respectively, and 1.86% and 4.16%, respectively, in Australia. For example, the University of Waikato experienced declines in average annual growth rates of general and academic staff. In contrast, Massey University and Lincoln University expanded their general staff but reduced academic staff. Similar patterns are observed in Victoria University and the University of Western Australia, which decreased academic staff with increasing general staff, while the Queensland University of Technology faced the reverse case.

The gamma values in translog models are statistically insignificant. Roughly 6% of the total variance in the composite error term can be attributed to inefficiency effects. Over 90% of deviations from the cost frontier arise from stochastic or unexplained sources. This suggests that random shocks, measurement errors, or other external factors contribute more to the observed variation in university costs than inefficiency.

7.2.2 *Cost Efficiency Scores*

Cost Efficiency Scores Comparison between New Zealand and Australian universities

The cost inefficiency scores in the SCFA range from one to infinity, where a score of one indicates full cost efficiency and values greater than one represent different degrees of inefficiency (Coelli, 1996, p.9). These estimates were obtained using FRONTIER 4.1. The average cost inefficiency scores derived from the SCFA estimations using both Cobb-Douglas and Translog models are shown in Table 7.4. The results show that none of the universities achieved full cost efficiency (universities operate above the minimum cost frontier), and substantial variation exists in inefficiency scores across universities.

On average, New Zealand universities exhibit higher cost inefficiency than Australian universities across all models. This suggests that Australian universities are more cost-efficient, possibly due to differences in income sources (e.g., greater international student revenue, research income, and external research contracts in absolute terms), average staff costs and university sizes.

Factors Influencing Efficiency Differences

A key factor contributing to efficiency differences is the composition of revenue streams, particularly income from international student fees and external research contracts. On average, Australian universities generate significantly higher revenue from international student fees. For instance, the University of Sydney receives approximately NZD 464.264 million annually from international student fees, accounting for 22% of its total income, compared to NZD 95.851 million (10% of total income) at the University of Auckland. Additionally, the significant and negative coefficients for the proportion of international students in both translog models indicate that more international students improve cost efficiency.

New Zealand universities rely more heavily on research contracts as a share of total income (14%) than Australian universities (e.g., Go8 universities: 5%). However, the total amount of research income is still lower in absolute terms. For example, the University of Auckland receives an average of NZD 133.207 million annually from research contracts, compared to NZD 111.457 million at the University of Sydney. Despite this, the University of Sydney's total income (NZD 2,031.898 million) is more than double that of the University of Auckland (NZD 959.812 million), making its income sources more diversified and reducing reliance on any single stream.

Furthermore, the significant and negative coefficient for research income per EFTS in the adjusted translog model (-0.49***) suggests that universities with higher research income per EFTS tend to operate at lower costs per student. One possible explanation is that research-intensive universities, particularly Go8 universities, are more efficient in integrating research activities with teaching, attracting external research funding and high-quality academic staff.

Differences in average staff costs may also explain the cost efficiency gap between New Zealand and Australian universities. Australian universities incur significantly higher personnel costs per FTE staff, approximately double those of New Zealand universities. For instance, the average FTE staff cost is NZD 95,248 in New Zealand, compared to NZD 161,887 in Australia (see Table 4.13). While higher wages may allow universities to attract higher-quality staff, improving research performance, international recognition, and increasing research grants and publications (Agasisti & Haelermans, 2016), they also increase total costs, requiring careful cost management to maintain efficiency.

University size also plays an important role. Australia had 37 public universities during the study period, many larger than New Zealand's eight universities. For example, Go8 universities enroll larger student populations, attract higher international enrolments, and receive substantial government and research funding. Their greater institutional size allows them to spread fixed costs across a larger student base, making them more cost-efficient.

In contrast, New Zealand universities are relatively smaller, with fewer students and less funding flexibility than Australia's demand-driven system and the Higher Education Loan Program (HELP) Scheme (see Section 1.4.2). Smaller institutional size and limited funding sources may constrain New Zealand universities' ability to achieve a similar cost-efficiency level.

Cost Efficiency Scores for Individual Universities

The average inefficiency scores for New Zealand universities are 1.230 and 1.214 in the unadjusted Cobb-Douglas and translog models, respectively, compared to 1.116 and 1.1536 for Australian universities under the same model. When adjusted completions are used (Model 2), the average inefficiency scores for New Zealand universities are 1.150 and 1.209 in Cobb-Douglas and translog models, respectively, compared to 1.080 and 1.1541 for Australian universities.

Among New Zealand universities, the University of Otago is the least cost-efficient university, with inefficiency scores ranging from 1.225 to 1.307, indicating relatively higher costs compared to the minimum cost frontier (see Figure 2.7). This may reflect its high research intensity, specialised medical programmes, and geographical disadvantages. The New Zealand South Island (dummy variable) significantly reduced cost efficiency, suggesting that more isolated regions face structural cost challenges. Similarly, the medical school (dummy variable) is significant and positive, indicating that universities operating medical education incur higher costs, lowering cost efficiency.

Conversely, Lincoln University shows relatively high-cost efficiency in both translog models. Its smaller enrolment size (EFTS), focused research income, and specialised agricultural orientation may explain this. As New Zealand’s only specialist land-based university, Lincoln University offers agriculture, environmental management, and related field programmes. This may attract targeted government funding, industry partnerships, and research grants aligned with primary industries. Additionally, its smaller scale may support more streamlined operations and efficient resource allocation, minimising the inefficiencies often seen in larger, more diversified universities. Its focused mission may also foster strong industry linkages and attract external funding, further contributing to its cost efficiency. While this finding may seem to contradict the broader pattern in which larger universities benefit from economies of scale, it highlights that specialisation and alignment with external funding opportunities can also drive efficiency in smaller institutions.

In Australia, Go8 universities (inefficiency scores between 1.114 and 1.161) exhibit slightly lower cost efficiency than the Australian university average (1.080-1.154). This could be due to their research-intensity profiles, largest student enrolments and completions, and substantial research infrastructure investment, which increase operating costs.

In contrast, ATN universities (inefficiency scores between 1.051 and 1.121) are the most cost-efficient group. Their focus on teaching-oriented programmes (e.g., its second-largest EFTS and completions), moderately high international rankings (e.g., QS and THE, see Table 1.4), and strong links to industry help maintain high-cost efficiency. Given the construct of the dependent variables (costs per student), this result aligns with expectations. ATN universities prioritise undergraduate completions, maintain close industry collaboration, and offer vocational pathways (e.g., internships), which may enable them to keep per-student costs lower. Moreover, ATN universities generate a significantly higher share of their revenue from overseas tuition fees, averaging around 23% of total income (data from the Australian Government Department of Education).

Differences between SFA (Chapter 6) and SCFA (Chapter 7)

New Zealand universities exhibited relatively strong technical efficiency in SFA (Chapter 6) but lower cost efficiency in SCFA (Chapter 7). These contrasting results reflect the different purposes of the two methods rather than methodological unreliability. Each method addresses a distinct research question and captures different aspects of performance.

One key difference lies in the conceptual focus of efficiency (or research questions). SFA measures *technical efficiency*, assessing how efficient universities are in maximising their teaching and research outputs given their labour and capital inputs, while accounting for institutional and environmental factors. By contrast, SCFA measures *cost efficiency*, evaluating how cost-efficient universities are in delivering these outputs once labour and capital prices are considered. Thus, a university may appear technically efficient under SFA but cost-inefficient under SCFA if it uses resources effectively but faces high input prices or allocates resources suboptimally. Both approaches apply the Battese and Coelli (1995) framework, which accounts for statistical noise and controls for inefficiency determinants such as staffing structure, faculty decomposition, location, and student mix. The key difference lies in the dependent variable: SFA focuses on outputs, while SCFA focuses on costs.

The methods also differ in their choice of variables. The SFA uses undergraduate completions as the dependent variable, providing a teaching-oriented efficiency measure. In contrast, the SCFA uses costs per EFTS, which captures both technical and allocative efficiency. The cost-based measure is normalised by EFTS to allow comparisons across institutions of different sizes and to control for differences in non-completion rates. Unlike SFA, which relies on physical measures of labour and capital inputs, SCFA directly incorporates labour and capital input prices into the analysis.

Another difference arises from the trade-off between teaching and research focus. The SFA highlights a trade-off in resource allocation for teaching and research activities. Universities that allocate more resources to research achieve substantial research income and postgraduate completions, which increases their technical efficiency. However, this often occurs at the expense of undergraduate completions. Consequently, some research-intensive universities, such as the University of Auckland and the University of Otago, perform well under SFA, but record lower cost efficiency under SCFA, reflecting the higher per-student costs of delivering research-intensive and medical programmes.

Programme structures further explain the contrasting results. New Zealand universities offer a larger share of shorter, sub-degree programmes (Levels 1–4 certificates) as undergraduate completions. These require fewer resources, increasing undergraduate outputs and boosting SFA technical efficiency scores. At the same time, these low-cost and less resource-intensive programmes contribute less to cost efficiency in the SCFA models, where cost structures do not fully capture such outputs.

In contrast, Australian universities start at Level 5 (diplomas) and above, offering longer and more resource-intensive programmes, where cost efficiency favours larger universities. A university may appear technically efficient (high SFA score) but cost-inefficient (low SCFA score) if its input mix is not cost-minimising. For example, high staff costs, an imbalanced allocation between academic and general staff, or reliance on expensive delivery modes may reduce SCFA scores even when outputs are high.

Regional economic and institutional conditions also play a role. In Australia, universities in research-intensive, high-demand regions such as New South Wales (e.g., the University of Sydney and the University of New South Wales) achieve both high technical and cost efficiency, supported by industry collaboration, strong student demand, and greater access to external funding. In New Zealand, the University of Otago records the lowest cost efficiency, reflecting its specialised medical programmes and geographical disadvantages associated with its South Island location. By contrast, Lincoln University shows relatively high-cost efficiency, likely due to agricultural specialisation, targeted funding, industry partnerships, and streamlined operations despite its small size. Specialisation and alignment with external funding opportunities can also drive efficiency in smaller institutions. These cases indicate how regional factors, institutional focus, and external funding opportunities can either constrain or enhance efficiency.

Institutional size and revenue composition further influence efficiency outcomes. Large Australian universities (e.g., Go8 and ATN) operate at a greater scale by spreading fixed costs over more students. Their greater revenue diversity, particularly from international tuition fees and external research income, creates greater financial flexibility to invest in staff, facilities, technology, and support services, which improves cost efficiency. In contrast, New Zealand universities are generally smaller, with fewer students and less funding flexibility. They rely more on government funding and research contracts, but at lower absolute levels, constraining their ability to achieve similar cost-efficiency gains.

Staff cost structures add another explanation. Australian universities face higher average staff costs, possibly offset by stronger research performance and greater funding capacity. In New Zealand, lower staff costs do not always translate into higher cost efficiency, as smaller scale and resource constraints limit their capacity to leverage these savings.

Therefore, the SFA and SCFA yield different results, not because the methods are unreliable, but because they answer different efficiency questions. SFA evaluates universities' ability to convert resources into outputs, while the SCFA assesses their ability to minimise costs given input prices and technologies. They are not contradictory perspectives and provide a more comprehensive understanding of university performance. They show that a university may be technically efficient but cost-inefficient due to factors such as input prices, programme mix, regional conditions or institutional scale.

Table 7.4

Average Cost Inefficiency Scores for Australasian Universities, 2008-2018

University	Cost efficiency estimates			
	Cobb-Douglas Model 1	Cobb-Douglas Model 2	Translog Model 1	Translog Model 2
Auckland	1.211	1.125	1.225	1.221
Waikato	1.185	1.094	1.193	1.194
Massey	1.235	1.152	1.2130	1.2129
VUW	1.207	1.119	1.204	1.201
Canterbury	1.240	1.149	1.228	1.220
Lincoln	1.223	1.174	1.179	1.159
Otago	1.307	1.225	1.266	1.259
AUT	1.234	1.166	1.206	1.203
New Zealand mean	*1.230*	*1.150*	*1.214*	*1.209*
Go8	1.137	1.114	1.161	1.154
IRU	1.124	1.087	1.157	1.160
RUN	1.108	1.062	1.162	1.168
ATN	1.083	1.051	1.121	1.117
Non-aligned	1.113	1.074	1.153	1.155
AUS mean	*1.116*	*1.080*	*1.1536*	*1.1541*

Note: 1. Australian mean refers to the geomeans of all individual Australian universities.
2. The average cost efficiency scores of individual universities are measured as the geometric mean of their annual cost efficiency scores from 2008 to 2018.
3. As the estimations use FRONTIER 4.1, efficiency scores from cost frontier range between one and infinity (Coelli, 1996, p. 9); hence, a score of one denotes that the university is fully cost-efficient.
4. Illustrative efficiency frontier charts are not included here, as the analysis covers 45 universities across multiple model specifications. Plotting all frontiers and universities would produce highly dense figures, which would be difficult to interpret. Instead, efficiency results are summarised in the above table, which present average CE scores in a form that enables clear and direct comparison between New Zealand and Australian universities.

University Cost Inefficiency Score Rankings

Appendix Chapter 7, Table A7.1 presents the university cost inefficiency rankings. These results reveal variations in cost efficiency across universities, reflecting differences in model specifications and output measures.

Differences across Model Specifications

Comparing results across the four different model specifications shows that universities exhibit lower cost efficiency (e.g., higher inefficiency scores) under the translog models compared to the Cobb-Douglas models. This finding suggests that the flexible structure of the translog models captures more complex cost relationships, including interactions between inputs and outputs that are not reflected in the more restrictive Cobb-Douglas specification. Therefore, translog models may offer a more detailed evaluation of cost efficiency, particularly in institutions with diverse staff and capital structures.

Impact of Adjusted Output Measures

The results also indicate that models using quality-adjusted teaching outputs tend to yield higher efficiency (e.g., lower inefficiency scores), particularly for New Zealand universities. This indicates that adjusting teaching outputs for student workload and income-weighting improves the measure of cost efficiency of New Zealand universities. However, an exception is observed in the Australian translog models, where efficiency estimates decrease when quality-adjusted outputs are used. This indicates differences in how universities allocate resources between teaching and research activities affect their cost structures differently across countries. One possible explanation is that Australian universities, particularly research-intensive institutions, may focus more heavily on postgraduate education and research activities. These activities require significant investments in high-quality staff, infrastructure, and specialised facilities, increasing costs per student.

University Rankings Across Model Variations

University inefficiency rankings vary depending on the model specification, highlighting the sensitivity of cost-efficiency results to the choice of functional form and quality-adjusted output measures. Certain universities consistently rank among the most cost-efficient institutions across all models. For instance, RMIT (ATN group), Charles Darwin University (IRU), and Federation University (RUN) tend to be the most efficient institutions, likely due to their strong emphasis on teaching-focused programmes and industry collaboration initiatives (e.g., internships). In contrast, the University of Otago exhibits the lowest cost-efficiency across all model specifications, possibly due to the combined impact of its medical school operations, research-intensive profile, and geographical constraints.

7.2.3 *Sensitivity Analysis of Alternative Variable Measurements on the Base Model*

Sensitivity analysis explores the robustness of the SCF model for Australasian universities under alternative variable measurements. Table 7.5 summarises the results, with further details provided in Appendix Chapter 7 (Tables A7.2—A7.5). This analysis compares the key determinants identified in the base model (Table 7.3) with results obtained from alternative variable measurements, including variations in capital price measures, alternative data sources and research output measures. The appropriate model specifications were selected based on log-likelihood ratio tests (see Table 7.2). The key findings are as follows:

0. **Base Models (Table 7.3)**

   The results confirm that universities with medical schools are significantly less cost-efficient. The general-to-academic staff ratio shows a significantly positive relationship with cost efficiency, indicating that a well-structured administrative workforce improves cost efficiency. A higher proportion of female students is linked to greater inefficiency, likely reflecting differences in programme funding and labour market returns. Universities with more international students are more cost-efficient, likely due to the financial benefits associated with international tuition fees.

1. **Alternative capital price measures** (Depreciation and amortisation per EFTS vs. Non-labour expenses per net assets vs. Base model non-labour expenditure per EFTS, see Appendix Chapter 7 in Table A7.2—A7.3)

   The first alternative capital price is depreciation and amortisation per EFTS (see Appendix Chapter 7, Tables A7.2). This measure captures the effect of costs associated with tangible assets (e.g., property, plant and equipment) and intangible assets (e.g., software) on university operations. Most explanatory variables remain significantly increased efficiency levels, consistent with the core analysis. For instance, universities with medical schools continue to show significantly reduced cost efficiency, highlighting the high operational costs associated with medical education, such as specialised infrastructure. The proportion of international students remains a key driver of improved cost efficiency. The effect of female students becomes significantly negative, suggesting a reversal in its impact, potentially due to differences in capital investment allocation across disciplines.

   The second alternative capital price measure is on-labour expenses per net asset[125]. The sensitivity analysis results are showed in Appendix Chapter 7, Tables A7.3. The capital price is statistically positive, indicating that more capital expenses lead to lower cost efficiency. This could be because

[125] Net assets are the total assets of tertiary education institutions minus their total liabilities, representing equity. This accumulated investment cost is influenced by movements in the level of government and other funding and the tertiary education institutions' operational and investment decisions and programmes over time (Controller and Auditor-General Report, 2017). In 2015, New Zealand tertiary education institutions held about NZD 9.7 billion in net assets, including NZD 9.5 billion on capital assets (Controller and Auditor-General Report, 2017).

Equity, which represents the community's interest in the university, is the difference between total assets and total liabilities. It consists of accumulated funds, other reserves, and revaluation reserves (related to the revaluation of the fair value of land, buildings and other assets) (University of Otago, 2022, p. 121).

capital prices are distorted when universities undertake significant capital investments or face major disruptions (e.g., the University of Canterbury following the Christchurch earthquake in 2011). Unlike the base analysis, the general-to-academic staff ratio becomes highly significant, indicating that universities with greater administrative support improve efficiency under this specification. The inefficiency scores overall improve, suggesting that the choice of capital price measures significantly affects cost efficiency estimates.

2. **Data source measures** (New Zealand TEC data/Australian DoE data vs. Base model Universities' annual reports, see Appendix Chapter 7 in Table A7.4)

This analysis examines whether using alternative data sources affects cost efficiency estimates. In the unadjusted translog model, only New Zealand's South Region remains significantly associated with higher inefficiency, while other explanatory variables become insignificant. However, in the adjusted translog model, most coefficients remain significant and consistent with the base model. The female student proportion is an exception and becomes statistically insignificant, suggesting that output adjustments reduce its effect on cost inefficiency. Moreover, the inefficiency scores obtained using alternative data sources are lower than those university annual reports (base model), highlighting that data reporting standards influence cost structure assessment.

3. **Research output measures** (Citation-weighted WoS-indexed publications vs. Base model research income, see Appendix Chapter 7, Table A7.5)

The results from using citation-weighted WoS-indexed publications provide notable differences in inefficiency effects. For instance, for the medical schools, the percentage of international students and the general-to-academic staff ratio are no longer significantly related to inefficiency. However, more female students tend to reduce cost efficiency significantly.

This highlights the sensitivity of cost efficiency estimates to the choice of research output measure. Since research income more directly reflects the financial contributions of research activities to university operations, it aligns more closely with cost and funding structures (e.g., research and contracts). It also has a statistically significant effect on key inefficiency variables. (e.g., medical schools, international and female students). In contrast, citation-weighted publications focus on research quality and scholarly impact rather than financial returns, which may not fully account for how research activities affect universities' costs per student. It also leads to different statistical significance for explanatory variables, with only the female student proportion remaining significant).

Table 7.5

Sensitivity Analysis for Determinants of Cost Inefficiency for Australasian Universities, 2008-2018

Model Specification		**Medical school**	**Overseas%**	**Ratio of general to academics**	**Female students%**	**Mean Efficiency**
0. Base Model	Translog	0.019***	-0.234***	-0.021**	0.165**	1.1654
	Adjusted Translog	0.017***	-0.226***	-0.014	0.222***	1.1650
1. Capital Price (Depreciation and Amortisation per EFTS)	Translog	0.034*	-0.521***	-0.023	-0.537**	1.097
	Adjusted Translog	0.030**	-0.471***	-0.006	-0.447***	1.236
Capital Price (Non-labour expenses per net assets)	Translog	0.003	-0.930***	-0.203***	-0.575***	1.055
	Adjusted Translog	0.006	-0.791***	-0.114*	-0.546***	1.067
2. Data Source: New Zealand TEC data/Australian DoE data	Translog	0.043	-0.117	-0.047	0.098	1.022
	Adjusted Translog	0.033**	-0.318***	-0.071***	0.073	1.036
3. Research outputs: Citation-weighted Research publications	Translog	-0.002	-0.034	0.021	0.342***	1.070
	Adjusted Translog	0.009	-0.077	-0.003	0.296***	1.241

Note: Significance levels: *p<0.1; **p<0.05; ***p<0.01

The sensitivity analysis confirms that specific inefficiency determinants, such as the medical schools and international student share, are robust across model specifications. However, other variables, including staff composition, the female student proportion, and research output measures, are more sensitive to the choices of models and data sources. These findings highlight the importance of carefully selecting inefficiency determinants, particularly in selecting research outputs and capital price measures, when assessing university cost efficiency analyses.

The results suggest that universities with substantial research income may appear more cost-efficient when using financial-based research measures. However, the publication-based research output may experience different cost structures affecting efficiency estimates. This distinction highlights that the research output measure should align with the study's objectives. Since this study focuses on cost efficiency rather than research productivity, research income remains the preferred research output measure, as it directly reflects the financial implications of research activities to university operations.

Similarly, the choice of capital price measure affects cost efficiency estimations. Non-labour expenditure per EFTS is preferred as it more accurately captures the capital cost structures associated with educational delivery relative to student numbers. This measure directly links capital spending to student enrolments, ensuring that efficiency estimates reflect costs per student and current cost structure rather than historical investment decisions.

Non-labour expenditure per net asset may be distorted by historical asset valuations, historical investments in land and infrastructure or location-specific factors (e.g., universities with large property holdings in high-value regions) or research-specific factors (e.g., universities with large research investments and specialised infrastructure, like a medical school). The depreciation and amortisation of physical and intangible assets per EFTS reflect historical capital investment decisions and follow accounting rules where different asset classes depreciate at different rates over time.

7.3 Conclusion

This chapter estimated cost efficiency performance using an SCFA model. It compared Cobb-Douglas and translog functional forms with quality-adjusted output variables, covering eight New Zealand and 37 Australian universities from 2008 to 2018. It is the first application of SCFA to analyse cost efficiency in New Zealand universities. It also provides new insight into their performance of inefficiency determinants across different model specifications and alternative variable measurements.

In the analysis, the translog model was preferred over the Cobb-Douglas specification due to its greater flexibility in capturing nonlinear relationships and interaction effects among costs per student, output per student and input prices. Results from the translog models show that increases in outputs (e.g., research income and completions) per student or higher labour and capital prices are associated with higher costs per student, as indicated by their positive first derivatives. These findings confirm the theoretical expectations for a well-behaved cost function, being nondecreasing in input prices and outputs (Coelli et al., 2005, p. 23). Additionally, translog models explicitly capture interactions and trade-offs between teaching and research activities.

Universities with medical schools consistently exhibited lower cost efficiency across all models. This implies that universities with medical schools tend to have higher infrastructure and research expenses, leading to increased operational costs. Universities with a higher share of international students consistently tend to be more cost-efficient, likely due to the financial benefits of international tuition fees, particularly in Australian universities.

Significant regional variations in cost efficiency were observed. South Island universities in New Zealand perform less efficiently than those in the North Island. This may be attributed to smaller scale, specialised focus (e.g., Lincoln University), weaker agglomeration effects, geographic isolation and high delivery costs of specialised programmes such as Otago’s medical school. In Australia, universities in Tasmania, the Northern Territory, and New South Wales achieve higher cost efficiency, supported by favourable regional conditions and internationalisation strategies. These findings highlight that location and context shape university performance, with regional universities facing higher costs despite their important contributions.

Variations in staff composition also affect cost efficiency, with a well-structured general-to-academic staff ratio improving administrative support and cost efficiency. More administrative staff possibly reduce administrative burdens on academics, allowing them to concentrate more on their core activities (Abbott & Doucouliagos, 2009). However, more female students tend to be less cost-efficient, reflecting differences in programme choices, funding imbalances, and delivery needs rather than gender itself. Female enrolments are concentrated in underfunded non-STEM disciplines and programmes such as teacher education and nursing, requiring intensive supervision and support. In addition, large shares of mature-age and part-time female students increase demand for flexible delivery and student services, raising costs.

The estimated inefficiency score indicates that no university operated at full cost efficiency. This suggests that all universities have room for cost improvements, with different degrees of inefficiency across universities. Australian universities are more cost-efficient than New Zealand universities, potentially due to differences in revenue sources (e.g., international student fees, research income, and external research contracts), average staff costs and institutional size. Australian universities are more cost-efficient than New Zealand universities, suggesting that Australian universities operate closer to the cost frontier. ATN universities are the most cost-efficient group. New Zealand universities exhibit higher cost inefficiency, with the University of Otago being the least cost-efficient New Zealand university and Lincoln University the most cost-efficient.

Quality-adjusted teaching outputs tend to yield higher efficiency (e.g., lower inefficiency scores), particularly for New Zealand universities. This suggests that efficiency estimates improve when student workload and income-weighting adjustments are used. However, in Australian universities, efficiency decreases when quality-adjusted outputs are used, likely due to high research investments and different resource allocations.

University rankings differ across model specifications, reflecting the sensitivity of cost-efficiency estimates to the choices of functional form and quality-adjusted output measures. RMIT (ATN group), Charles Darwin University (IRU), and Federation University (RUN) consistently rank among the most efficient institutions, likely due to their teaching focus and industry collaborations (e.g., internships). In contrast, the University of Otago remains the lowest cost-efficient, possibly due to its medical school operations, research-intensive nature, and geographical constraints contributing to lower cost efficiency.

New Zealand universities show relatively strong technical efficiency in the SFA analysis (Chapter 6) but lower cost efficiency in the SCFA analysis (Chapter 7). These differences reflect the distinct purpose of the two methods, which address different efficiency questions. SFA evaluates how well universities convert labour and capital inputs into outputs, while SCFA assesses how efficiently they minimise costs given input prices and technologies. A university may therefore appear technically efficient but cost-inefficient if it uses resources effectively but faces high input prices or costly programme structures.

Several factors explain these contrasting results. The two methods use different variables: SFA focuses on outputs, while SCFA focuses on costs. Programme structures also differ, with New Zealand universities including short sub-degree qualifications that boost SFA efficiency scores but contribute less to cost efficiency. In contrast, Australian universities concentrate on longer, more resource-intensive degrees. Regional and institutional factors also affect outcomes: for example, universities in New South Wales benefit from strong demand, funding, and industry links, while the University of Otago experiences low-cost efficiency due to high-cost medical programmes and its South Island location.

Moreover, larger Australian universities gain further advantages from economies of scale and more diverse revenue sources, particularly from international tuition and research income, which enhance cost efficiency. Higher average staff costs are also better offset in Australia by stronger research performance and greater funding capacity.

Thus, the SFA and SCFA results are not contradictory. The SFA highlights universities' ability to convert resources into outputs, while the SCFA reveals how cost structures, institutional scale, and funding influence efficiency. These approaches show that universities may perform well in one dimension but less well in another, highlighting the value of using multiple methods to gain a more comprehensive understanding of performance.

The sensitivity analysis confirms that specific inefficiency determinants (e.g., medical schools and international student share) remain robust across specifications, but other variables (e.g., staff composition, the proportion of female students, and research output measures) are sensitive to how variables are measured (e.g., when research output is measured using research income or citation-weighted WoS-indexed publications). These findings highlight the need to carefully select inefficiency determinants, particularly regarding research outputs and capital prices, as they may significantly affect cost efficiency estimates.

Chapter 8 Conclusions

8.1 Introduction

This chapter concludes the thesis by summarising the main findings and contributions. It also discusses policy implications, research limitations, and suggestions for future research. Before turning to the results, this section introduces the key concepts of university productivity and efficiency, outlines the methods used in this study, and provides a brief chapter structure.

In higher education, productivity refers to the ratio of outputs to inputs. Outputs include teaching and research outputs. Inputs consist of labour and capital inputs. When multiple inputs and outputs are involved, the total factor productivity (TFP) method is employed to aggregate them into a single index. This reflects the overall productivity of a university by accounting for all inputs used and outputs produced.

Efficiency compares the observed performance of a university to the best possible performance achieved by similar institutions using the same production technology. Technical efficiency measures whether a university produces the maximum possible output from a given set of inputs. Allocative efficiency assesses whether universities choose the optimal input mix to minimise costs. Economic efficiency combines both technical and allocative efficiency to reflect overall productivity performance. Cost efficiency assesses how well universities manage their costs relative to input prices and output levels.

This thesis investigates the productivity and efficiency of eight New Zealand universities from 2008 to 2018. It also includes 37 Australian universities to allow cross-country comparisons and improve the robustness of the models, given the small size of the New Zealand university sector. Four empirical methods are used to assess university performance: partial labour productivity, the Malmquist Productivity Index (MPI), Stochastic Frontier Analysis (SFA), and Stochastic Cost Frontier Analysis (SCFA). Each method captures a different aspect of university performance.

Partial productivity measurement focuses on labour productivity, using simple ratios of teaching or research outputs per respective staff. For instance, completions per teaching full-time equivalent staff (FTE), research income per research FTE staff, and research publications per research FTEs. They examined changes in partial labour productivity in teaching and research separately, accounting only for a single input. Additionally, quality adjustments are applied to outputs to improve accuracy. Completions are weighted by credit and income to reflect the student workload and economic value of different qualifications. Research outputs are adjusted using citation-weighted indexed publications to capture scholarly impact. These quality-adjusted measures provide a more accurate basis for comparing university performance.

Since universities use multi-inputs to produce multiple outputs, TFP is also examined. One widely adopted method in higher education is the MPI, which assesses changes in TFP over time. Inputs examined in this thesis included teaching, research and general staff FTEs, capital expenditure, and undergraduate and postgraduate equivalent full-time students (EFTS). Outputs include quality-adjusted undergraduate and postgraduate completions and research income. The MPI decomposes productivity changes into two components: technical change (shifts in the frontier due to innovation or technological regress) and efficiency change (moving closer to the existing production frontier). Efficiency change is further decomposed into pure efficiency change (producing more outputs without increasing inputs) and scale efficiency change (operating closer to technically optimal productive scale). An MPI score above one indicates productivity improvement, while below one indicates a decline.

SFA estimates technical efficiency by measuring how closely universities operate to a best-practice production frontier. SCFA evaluates cost efficiency by comparing actual costs to a minimum-cost frontier. In this thesis, SFA and SCFA are used to assess the performance of New Zealand and Australian universities. Both methods include inefficiency determinants using the Battese and Coelli (1995, i.e., BC95) specification. These variables are not direct inputs or outputs but are external to university control and influence efficiency outcomes. They include the presence of a medical school, the proportion of international and female EFTS enrolments, the ratio of general to academic FTE staff, and regional location. These determinants capture institutional, demographic and geographic factors that affect universities' performance.

The rest of this chapter is structured as follows. Section 8.2 summarises the key empirical results of each method. Section 8.3 discusses the main contributions of the study. Section 8.4 outlines the policy implications of the findings. Section 8.5 presents the limitations and recommendations for future research.

8.2 **Summary of Key Findings**

8.2.1 ***Partial Labour Productivity and Malmquist Productivity Index Analysis***

This thesis examines teaching and research labour productivity (TLP and RLP) in New Zealand and Australian universities from 2008 to 2018. New Zealand universities exhibit lower TLP levels than Australian universities across all measures, indicating a gap between the two countries. Australian universities achieve the highest TLP levels in all measures due to financial stability and strategic partnerships with international universities. In research, all New Zealand universities steadily improve over time, but their RLP levels remain lower than Australian universities. Australian universities, particularly the Group of Eight (Go8), show consistently high and stable RLP levels, indicating their research-intensive focus on postgraduate education and research outputs.

New Zealand universities exhibit higher annual average growth rates (AAGRs) for all TLP measures, driven by increased master and doctoral completions with higher credit or/and income weights. New Zealand universities outperform Australian universities in AAGRs for research income per research FTE staff. Australian universities achieve larger productivity based on Web of Science (WoS) publications.

To estimate productivity, academic FTEs are divided into teaching and research roles. Two allocation assumptions are tested: a 50:50 split (equal weight to teaching and research) and a 40:60 split (greater emphasis on research). The 40:60 staff allocation serves as a robustness check against the base 50:50 assumption. Results show that New Zealand universities have similar AAGRs in TLP under both allocations. For RLP, changing staff allocation assumptions have a small impact when using WoS-based measures. Table 8.1 shows the summary of key results in partial labour productivity.

Table 8.1
Summary of Key Results in Partial Labour Productivity

Analysis of Partial Labour Productivity	Description
Methodology	Productivity = Output/Input
Teaching Labour Productivity (TLP)	
TLP1= Completions/Teaching FTE	All New Zealand universities show lower teaching productivity levels than their Australian counterparts
TLP2= Credit weighted completions /Teaching FTE	New Zealand and Australian universities generally exhibit similar levels of productivity
TLP3= Credit & income weighted completions /Teaching FTE	Australian universities consistently show higher productivity levels than New Zealand universities
Research Labour Productivity (RLP)	
RLP1 = Research income/Research FTE	New Zealand universities indicate more stable and consistent increases, while Australian universities, except for Go8, exhibit declines and considerable fluctuations
RLP2 = WoS indexed articles and reviews/Research FTE	All New Zealand universities show considerable increased productivity and Australian universities, particularly Go8, consistently show the highest productivity levels.

RLP3 = CNCI-weighted WoS indexed articles & reviews/Research FTE	All New Zealand universities show steady increases and Australian universities, especially Go8, had the highest productivity levels
Labour Productivity Average Annual Growth Rates (AAGR)	All teaching productivity measures, and research income per research FTE staff in New Zealand are larger than those in Australian counterparts. Conversely, AAGRs for research productivity measures based on WoS publications are, on average, higher for Australian universities than New Zealand universities
Sensitivity Analysis	
Teaching: Research: 40:60 assumption	New Zealand's AAGRs in TLP are similar to those under a 50:50 allocation, AAGRs in RLP perform exceptionally well across all research measures. Australian AAGRs in TLP is smaller than those based on a 50:50 allocation, suggesting a trade-off between teaching and research outputs under research-focused allocation. A 40:60 allocation increases the proportion of research FTE staff, which theoretically increase the denominator and lead to a decrease in RLP, the actual results show an increase in Australian RLP measures
Limitation	This comparison highlights that a 50:50 allocation supports consistent growth across TLP and RLP. In contrast, a research-oriented allocation (40:60) appears advantageous for enhancing research outputs, such as research income. The absolute levels of RLP decrease under the 40:60 staff allocation due to the larger denominator caused by an increased proportion of research FTEs. Interpreting the AAGR also requires caution. A high AAGR does not always equal a high output volume. While partial labour productivity provides a list of input and (adjusted) output indicators, it cannot represent the functional relationship between the various inputs and outputs used for and produced by university operations.

Partial labour productivity offers useful input-output indicators but does not capture the full relationship between multiple inputs and outputs. To address this, MPI is used to analyse productivity trends in New Zealand and Australian universities from 2008 to 2018. The MPI is appropriate for evaluating multi-input, multi-output production technology and does not require assumptions about cost minimisation or profit maximisation. Table 8.2 shows the summary of key results in MPI analysis.

Table 8.2
Summary of Key Results in Malmquist Productivity Index

Analysis of MPI	Description
Methodology	Caves, Christensen and Diewert (1982a, 1982b)
Model Specification	MPI decomposes TFP changes into Technical Change and Efficiency Change (further decomposes into Pure Efficiency Change and Scale Efficiency Change)
	Cumulative TFP change for each year between 2008 and 2018, the base year 2008 is normalised to a value of 1. The cumulative TFP change in 2009 is

	calculated by multiplying the base value in 2008 by the change in TFP or TFP growth for 2008/09
Brief Description of Key Results	
Malmquist TFP index	
TFP change	On average, New Zealand universities experience a slight decline in TFP (0.993), indicating a decrease in productivity of 0.7% per year. Conversely, Australian universities achieve an average productivity change of 1.6% per year
New Zealand TFP change decomposition	New Zealand's technical change shows a modest improvement of 0.6% annually, outweighed by a decline in efficiency (-1.4%). Their pure efficiency change declines slightly (average 0.992 per year), similarly scale efficiency change decreases (averaged 0.995 per year)
Australian TFP change decomposition	Australian universities experience greater technical change than their New Zealand counterparts, with an average rise of 1.3% per year, and efficiency change at an average of 0.3 % per year. Pure Efficiency change was 1.001 and scale efficiency change is 1.002
Cumulative TFP changes	
New Zealand Cumulative TFP change	These results confirm the Malmquist TFP analysis, showing that productivity changes in New Zealand are caused by strong technological improvements, offset by efficiency declines
	In New Zealand, cumulative TFP decreases by 7.0% on average, primarily driven by an 12.7% decrease in efficiency, which outweighs a 7.3% improvement in technology. This substantial decline in efficiency is mainly due to reductions in pure efficiency of 8.0% and scale efficiency of 5.1%
Australian Cumulative TFP change	Australian universities experience a 17.1% increase in cumulative TFP, mainly due to a significant 14.0% improvement in technology, and a 2.8% gain in efficiency. The efficiency improvement consists of a 0.5% increase in pure efficiency and a 2.2% enhancement in scale efficiency
Cumulative TFP Trend	New Zealand and Australian universities display contrasting productivity trends. New Zealand universities experience fluctuating TFP, while Australian universities consistently grow in cumulative TFP
New Zealand Cumulative TFP change decomposition	The decomposition of cumulative TFP change shows the different drivers of productivity in the two countries. New Zealand universities primarily rely on technological improvements, but persistent efficiency declines largely offset these technological gains
Australian Cumulative TFP change decomposition	Australian universities achieve balanced cumulative productivity change, driven by continuous technological advancements and moderate efficiency improvements, resulting in better overall productivity
Cumulative TFP changes for Individual New Zealand Universities	
AUT	It exhibits the fastest increase in cumulative TFP (by 38.5%) among New Zealand universities, driven by an 73.1% increase in research income from a low base
The University of Auckland	It experiences fluctuating cumulative TFP growth over time, due to its largest and top-ranked university and fluctuations of completions, research income and staff

The University of Waikato	Its cumulative TFP mainly benefits from a 14% improvement in technical change, due to its international collaborations, offshore programme delivery, and a decrease in teaching staff
Massey University	Its TFP trends show notable fluctuations, due to fluctuations of completions, research income and increased staff, and specialisation in primary sector-based subjects, such as agriculture and horticulture
Victoria University of Wellington	It achieves the second-highest cumulative growth in TFP, due to increased postgraduate completions and research income
The University of Canterbury	After a spike in 2009, driven by increased postgraduate completions and research income, it experiences a gradual decrease in productivity over time, particularly after the 2011 Canterbury earthquake
Lincoln University	It exhibits substantial fluctuations in cumulative TFP over time, with the lowest levels between 2009 and 2015, due to a decrease in short undergraduate programmes and heavily reliance on international students and its specialisation in agricultural-focused disciplines
The University of Otago	It experiences a steady decline in TFP, particularly after 2010, due to reductions in undergraduate completions and enrolments, reflecting inefficiencies in resource utilisation and difficulties in maintaining outputs relative to inputs, and substantial increases in labour and capital inputs
Sensitivity Analysis	
	This analysis produces some quantitative differences, the qualitative results observed in the base model are robust, highlighting the importance of selecting appropriate input, output and data measures in productivity analysis
Variations in labour input allocations	Changes in labour input allocations have minimal impact on TFP changes, indicating stable productivity trends
Variations in capital costs	Specific capital categories improve TFP for New Zealand universities but reduce it for Australian universities, due to the technical regress
Variations in citation-weighted publications	Using citation-weighted research publications reduces TFP for most universities, with Australian universities showing declines in all components and New Zealand universities experiencing efficiency improvements.
Alternative data sources	New Zealand universities show slightly declined TFP, due to technological regress, while Australian universities show modest gains due to technological progress
Limitation	In interpreting the results, it is critical to distinguish between productivity and productivity growth. A university may appear more or less productive or efficient relative to the other universities in the sample (44 universities), depending on its ability to generate outputs given its inputs. However, productivity growth represents the proportional change in productivity over time relative to a base period.

The MPI results show a clear contrast between New Zealand and Australian universities. On average, New Zealand universities experience a 0.7% annual decline in TFP change due to a 1.4% decrease in efficiency change that offset a modest 0.6% gain in technology. Both pure and scale efficiency change decline slightly. In contrast, Australian universities achieve 1.6% annual TFP growth due to greater technological progress and modest efficiency improvements.

Cumulative TFP results confirm the Malmquist TFP findings. New Zealand universities experience a 7.0% decline in cumulative TFP over the period, largely due to a 12.7% fall in efficiency that offset a 7.3% technology gain. In contrast, Australian universities experience a 17.1% increase in cumulative TFP, driven by a 14.0% improvement in technology and a 2.8% efficiency gain. These findings highlight the diverging productivity trends. New Zealand universities show fluctuating productivity, while Australian universities demonstrate steady productivity growth.

Smaller and newer universities (e.g., AUT) often exhibit the highest productivity improvements as they typically start from a lower base, with more room for improvement than larger and older ones. Differences in productivity change across universities may also reflect institutional specialisation. For example, the University of Auckland and Otago have medical schools, which may influence research income and quality-adjusted completions in clinical disciplines. Similarly, Massey and Lincoln University specialise in primary sector areas, such as agriculture, which may affect the composition and funding of research activities. Universities with a higher proportion of international students, such as Lincoln University, may also benefit from increased tuition income, which can affect revenue-based output measures.

The sensitivity analysis tests how changes in TFP and its components respond to alternative input and output measures, allowing assessment of the robustness of the results. Using the credit- and income-weighted completions help capture the social and economic value of teaching outputs. Variations in capital cost measures significantly affect TFP changes, highlighting the importance of capital measurement in shaping productivity outcomes. New Zealand universities exhibit efficiency-driven improvements but face technical regress, that is, while they move closer to the frontier, the frontier itself shifts unfavourably over time. When research outputs use citation-weighted publications, all universities (except the University of Canterbury) exhibit decreased changes in TFP and technical change relative to the preferred case. Using alternative data sources also impacts TFP change, primarily through the technical change component.

8.2.2 *Technical Efficiency Analysis*

This thesis uses SFA to measure and compare technical efficiency for 8 New Zealand and 37 Australian universities from 2008 to 2018. The results indicate that higher postgraduate completions and research income are significantly and negatively related to undergraduate completions, while academic, general staff and capital expenses significantly and positively impact undergraduate outputs. This suggests a potential trade-off between different university outputs, particularly between research and postgraduate focus versus undergraduate teaching performance.

The SFA applies the BC95 inefficiency specification with both Cobb-Douglas and translog functional forms, with the translog preferred for its flexibility in capturing non-linearities and interaction effects. The results show that student demographics and regional differences influence technical efficiency. A higher proportion of international students is significantly associated with lower efficiency, suggesting added resource pressures. Similarly, more female students reduce efficiency, particularly in unadjusted completion models. This may reflect structural and disciplinary factors rather than gender effects alone. Regional effects are evident: Australian universities in Victoria, New South Wales, and Western Australia achieve higher efficiency, due to larger scale and greater access to funding and infrastructure. South Island universities in New Zealand show higher but statistically insignificant efficiency.

The sensitivity analysis confirms the robustness of key inefficiency factors across different model specifications. Variations in labour input definitions (e.g., academic versus teaching and research staff), research output measures (e.g., research income versus citation-weighted publications), and data sources all influence efficiency estimates. For example, when citation-weighted publications are used as the research output, a lower general-to-academic staff ratio is associated with higher efficiency. In contrast, in other models, this relationship is reversed. This suggests that the impact of staffing structures on efficiency depends on how outputs are measured, highlighting the need for careful model specification when assessing university performance.

Table 8.3
Summary of Key Results in Stochastic Frontier Analysis

Analysis of SFA	Description
Methodology	Stochastic Frontier Analysis (SFA) using the Battese & Coelli (1995) inefficiency model
Model Specification	Cobb-Douglas and (preferred) Translog functional forms
Brief Description of Key Results	
Impact of Labour input (e.g., academic and general staff)	Significantly Negative: increasing staff numbers reduce technical efficiency
Impact of Outputs (e.g., postgraduate completions and research income)	Significantly Positive: increased outputs improve technical efficiency, indicating a trade-off situation
Interaction term: Academic staff*General staff	Complementarity (significantly positive relationship): they jointly enhance undergraduate completions
Interaction term: Staff inputs*Capital input	Substitution (significantly negative relationship): universities may offset increasing labour costs by rising capital investments in teaching delivery
Time Trend Impact	Capturing the effects of technological change improvements over time (e.g., technological progress)

Scale Elasticities	Universities operate under decreasing return to scale, means that a proportional increase in all inputs results in a less than proportional increase in overall output. This indicates potential inefficiencies in scaling up university operations
International Student Ratio	Significantly positive: A higher percentage of overseas students relates to higher technical inefficiency. Universities face trade-offs between financial sustainability and resource allocation, particularly if fluctuations in international enrolments create financial instability
Female Student Ratio	Significantly positive: Universities with more female students tend to exhibit lower technical efficiency, possibly due to disciplinary differences in enrolment patterns
Medical Schools	Insignificantly negative: indicating that a medical school has no impact on university efficiency
General-to-Academic Staff Ratio	Insignificantly negative: suggesting that staff composition has no measurable impact on university efficiency
Regional Variations	Universities on New Zealand's South Island (e.g., Lincoln, Canterbury, and Otago) exhibit insignificantly lower efficiency than their North Island counterparts. Universities in Victoria, New South Wales, and the Western Australian States tend to be more efficient, due to their more students, teaching and research outputs, and in densely populated metropolitan areas
Discussion	
Why are NZ universities more technically efficient than Australian universities?	New Zealand's smaller, research-focused system contrasts Australia's more heterogeneous sector, which includes large research-intensive and smaller regional universities. Cross-country differences in output definitions also matter: New Zealand counts sub-degree qualifications (Levels 1—4) as undergraduate completions, while Australia counts from Levels 5 (diplomas). This definitional gap can result in bias in favour of New Zealand
Why do these results differ from Chapter 5 MPI findings (NZ universities have lower TFP change than Australian universities)?	The methods measure different aspects of performance. MPI tracks changes in TFP over time using multiple outputs as dependent variables, highlighting long-term productivity trends. SFA measures technical efficiency at a point in time, using undergraduate completions as the sole dependent variable and explicitly controlling for inputs and institutional factors
Sensitivity Analysis	Sensitivity analysis reveals some quantitative differences, but the qualitative findings from the base model remain robust. The results consistently highlight the importance of faculty composition (e.g., medical schools), staff composition, and student demographics (e.g., international or female enrolments) in affecting university efficiency

8.2.3 *Cost Efficiency Analysis*

The SCFA also uses the BC95 model with both Cobb-Douglas and translog functional forms, and the translog model is preferred. No university achieves full cost efficiency. On average, Australian universities (particularly the ATN group) are generally more cost-efficient than New Zealand universities. This difference reflects income structures, with Australian universities benefiting from higher international student revenue, greater research income, and larger external research contracts in absolute terms. Differences in average staff costs and institutional size may also contribute.

Several determinants influence cost efficiency. Universities with medical schools and more female students show lower cost efficiency. In contrast, higher international student shares and a greater general-to-academic staff ratio are associated with better efficiency. Regional effects also matter. South Island universities in New Zealand are less cost-efficient due to small size, specialisation, and location disadvantages. In Australia, universities in Tasmania, the Northern Territory, and New South Wales are more efficient, benefiting from favourable environments, large student enrolments, high-quality staff, strong research capacity, and high international reputations.

Interaction effects highlight further cost dynamics. More postgraduate completions help reduce per-student costs by supporting research activity. Additionally, expanding undergraduate and postgraduate teaching outputs simultaneously increases costs per student, suggesting these functions act as substitutes in resource use rather than complements.

The sensitivity analysis shows that some determinants, such as medical schools and international students, consistently affect cost efficiency. In contrast, other factors, like female student proportions, staff composition, and research output measures, depend on variable definitions. Results also vary with alternative capital price measures, with non-labour expenditure per EFTS providing the most reliable estimates. Research income is preferred as a research output measure because it reflects financial impacts, while publication-based measures capture research quality but not costs. Efficiency scores also differ across data sources, highlighting that the data reporting standards affect cost structure assessment. Table 8.4 summarises key results for the SCFA.

Table 8.4
Summary of Key Results in Stochastic Cost Frontier Analysis

Analysis of SCFA	Description
Methodology	Stochastic Cost Frontier analysis (SCFA) using the Battese & Coelli (1995) inefficiency model
Model Specification	Cobb-Douglas and (preferred) Translog functional forms
Brief Description of Key Results	No university achieves full cost efficiency; Australian universities are generally more cost-efficient than New Zealand universities. Medical schools, regional locations, student demographics (international proportion and female student proportion), and staff composition significantly affect cost efficiency.
Impact of UG completions per EFTS	Positive First Partial Derivative: Larger UG completions per EFTS tend to have higher costs per EFTS, due to shortages of qualified academic staff with high-demand disciplines and investments additional teaching infrastructure

Impact of PG completions per EFTS	Positive First Partial Derivative: Larger PG completions per EFTS tend to have higher costs per EFTS, particularly in research-intensive disciplines, requiring specialised resources and highly qualified academic staff and high related personnel costs
Impact of Research Income per EFTS	Positive First Partial Derivative: Research-intensive universities operate at high per-EFTS costs, due to high personnel costs for paid highly qualified staff and high administrative and operational costs and research infrastructure investments
Impact of Labour Price	Positive First Partial Derivative: Higher average staff costs contribute to higher per-student costs, reflecting differences in cost structures and workforce composition, and the trade-off between staff quality and cost
Impact of Capital Price	Positive First Partial Derivative: Higher capital prices contribute to increased costs per student, as universities investing more in infrastructure, equipment, and facilities face higher costs per student
Interaction term: UG completions*Research income	Positive relationship: Higher UG teaching output is linked to reduced research output, leading to increased costs per EFTS, due to time-consuming to teach and administrative duties limiting research time for academic staff
Interaction term: PG completions*Research income	Negative relationship: PG students are involved in teaching and research activities which reduce costs per EFTS by reducing academic staff workload and supporting research output
Interaction term: UG completions*PG completions	Positive relationship: UG and PG teaching activities are substitute, indicating a trade-off for limited institutional resources, thereby increasing both will require additional resources, leading to increase per-student costs
Interaction term: Labour price*PG completions	Positive relationship: Higher PG completions and staff salaries increase costs per student due to senior academics or professors with higher salaries teaching most PG programmes
Medical Schools	The presence of a medical school reduces cost efficiency due to higher infrastructure and research costs
International Student Ratio	A higher proportion of international students improves cost efficiency due to higher revenue per international student and strong global reputations
Female Student Ratio	A higher proportion of female students reduces cost efficiency, due to their concentration in disciplines with lower government funding (e.g., education, humanities, social science); higher delivery needs for teaching education and nurse disciplines (e.g., practicum, small class supervision); increased demand for flexible study modes and support services
Regional Variations	NZ South Island universities exhibit lower cost efficiency, due to smaller institutional size, specialisation (e.g., Lincoln University) and weaker agglomeration effects (e.g., the University of Otago); Australian universities in Tasmania, Northern Territory, and NSW are more cost-efficient, due to scale advantages (NSW) and internationalisation strategies (partnerships and international enrolments)
General-to-Academic Staff Ratio	A higher general-to-academic staff ratio improves cost efficiency by reducing administrative burdens on academic staff
Discussion	

Why are NZ universities less cost-efficient than Australian universities?	This may be due to differences in income sources (e.g., international student revenue, research income, and external research contracts), average staff costs and university size
Why do NZ universities show higher technical efficiency (SFA) but lower cost efficiency (SCFA)?	Differences in measurement approach to address different efficiency questions, the construction of the dependent variable (outputs vs. costs), programme structures (shorter sub-degree programmes in NZ vs. longer degrees in Australia), regional and institutional factors, and economies of scale and revenue composition. Together, the methods are not contradictory, showing that universities may perform well in one dimension but less well in another
Sensitivity Analysis	Sensitivity analysis confirms the robustness of key inefficiency determinants such as medical schools and international student share. However, factors like staff composition, female-student ratios, and research output measures vary depending on alternative variable measurements. This highlights the importance of inefficiency determinants in university cost-efficiency analyses, particularly in selecting research outputs and capital prices.

8.2.4 *Efficiency Scores Analysis*

Over the study period, TFP in New Zealand universities decreases by an annual average of 0.7% due to a 1.4% decline in efficiency and a 0.6% annual gain in technological change. Technological progress is the main contributor to TFP growth. This contrasts with Margaritis and Smart (2011), who finds that the early 2000s TFP growth in New Zealand universities is mainly due to efficiency improvements, particularly scale efficiency.

On the other hand, Australian universities experience stronger performance, with an average annual TFP increase of 1.6%, driven by a 1.3% gain in technological change and a modest 0.3% rise in efficiency. These results align with earlier findings by Carrington et al. (2005), Worthington and Lee (2008), and Margaritis and Smart (2011). Table 8.5 indicates the geometric mean changes in MPI and its components.

Table 8.5
Geometric Mean Changes in Malmquist Productivity Index and Its Components, 2008-2018

University Group	TFP	Technical	Efficiency	Pure efficiency	Scale efficiency
New Zealand	0.993	1.006	0.986	0.992	0.995
Australia	1.016	1.013	1.003	1.001	1.002

Table 8.6 reports average technical efficiency and cost inefficiency scores. Results show that translog models yield lower cost efficiency than Cobb-Douglas models. This suggests that the translog models offer a more flexible and comprehensive assessment, particularly for institutions with diverse staff and

capital structures. Moreover, adjusting teaching outputs for credit and income weights improves cost efficiency for New Zealand universities. In contrast, Australian universities show slightly lower cost efficiency when using these quality-adjusted outputs, possibly due to different resource allocations.

Although university rankings vary across model specifications and output measures, some universities consistently emerge as the most cost-efficient across all models, including RMIT (ATN), Charles Darwin University (IRU), and Federation University (RUN). Their stronger performance likely reflects teaching-focused programmes and close industry collaborations, such as vocational pathways and internships.

Table 8.6

Average Technical Efficiency and Cost Inefficiency Scores, 2008-2018

University Group	Efficiency Type	Cobb-Douglas Model	Adjusted Cobb-Douglas Model	Translog Model	Adjusted Translog Model
New Zealand	TE	0.991	0.977	0.983132	0.983126
AUS	TE	0.977	0.971	0.97	0.978
New Zealand	CE	1.23	1.15	1.214	1.209
AUS	CE	1.116	1.08	1.1536	1.1541

Note: Technical efficiency scores in a distance frontier range between zero and one, with a value of one indicating that the university is fully technically efficient. Cost efficiency scores in cost function take a value between one and infinity, a score of one denotes that the university is fully cost-efficient.

8.2.5 *Understanding Methodological Differences: MPI, SFA and SCFA*

The results from MPI (Chapter 5), SFA (Chapter 6), and SCFA (Chapter 7) differ not because the methods are unreliable, but because each addresses a different productivity or efficiency question and captures a distinct aspect of performance. Thus, they provide different perspectives on university productivity and efficiency.

MPI shows that New Zealand universities experienced an average annual TFP decline of 0.7%, driven by large declining efficiency, while Australian universities recorded average annual growth of 1.6%, mainly due to stronger technological progress. SFA indicates that New Zealand universities achieved higher technical efficiency, reflecting their smaller and research-focused system compared with Australia's heterogeneous sector. SCFA results differ again, showing that Australian universities are generally more cost-efficient, supported by economies of scale, greater revenue diversity, and stronger financial capacity to invest in staff and infrastructure.

A key distinction lies in methodological focus. MPI is a non-parametric method that measures changes in TFP over time without requiring price data. It decomposes TFP change into efficiency change (further divided into pure and scale efficiency change) and technical change. It addresses questions such as how productivity has evolved and what factors drive these changes. This makes it suitable for analysing state-sector productivity where market prices are absent. However, it is sensitive to measurement error and sample heterogeneity since all deviations from the frontier are treated as inefficiency.

In contrast, SFA is a parametric method that measures technical efficiency at a given time relative to a best-practice frontier. It assesses how efficient universities are in maximising their teaching and research outputs given their labour and capital inputs. It separates inefficiency from statistical noise and explicitly controls for institutional and environmental factors. SCFA extends this framework by assessing cost efficiency, evaluating how cost-efficient universities are in delivering outputs and considering labour and capital prices. Thus, a university may appear technically efficient under SFA but cost-inefficient under SCFA if it uses resources effectively but faces high input prices or resources suboptimally.

Differences also emerge in the choice of variables and scope. MPI applies a multi-output framework, incorporating undergraduate and postgraduate completions and research income as dependent variables, with detailed staff classifications (e.g., teaching, research and general FTEs) and undergraduate and postgraduate EFTS enrolments as inputs. However, it does not explicitly control for inefficiency determinants.

SFA uses only undergraduate completions as the dependent variable, producing a teaching-oriented efficiency measure while controlling for labour (e.g., academic and general FTEs), capital, postgraduate completions, research income, and inefficiency factors such as demographics, location, and staffing structure. SCFA instead uses costs per EFTS as the dependent variable, capturing both technical and allocative efficiency. This cost-based measure incorporates labour and capital input prices, undergraduate and postgraduate completions, research income, and inefficiency factors. These variable differences highlight important trade-offs. SFA shows that universities prioritising research may appear less technically efficient when efficiency is measured only by undergraduate completions. For example, research-intensive universities, such as the University of Auckland and Otago, achieve substantial research income and postgraduate completions, boosting their technical efficiency, but often at the expense of undergraduate completions. Under SCFA, the higher per-student costs for research-intensive and medical programmes reduce cost efficiency.

Contextual and institutional factors further influence results. Programme structures differ across countries: in New Zealand, undergraduate completions include sub-degree qualifications (Levels 1-4 certificates); in Australia, they begin at Level 5 (diplomas). This boosts SFA efficiency scores for New Zealand universities but would understate their teaching activity if excluded.

Institutional size and financial structures also matter. Large Australian universities (e.g., Go8 and ATN) benefit from larger scale and greater revenue diversity, particularly from international tuition and external research income. This provides greater financial flexibility to invest in staff, facilities, technology, and support services, which improves cost efficiency. The Australian university sector is also more heterogeneous, combining large research-intensive institutions (e.g., Go8) with smaller, regional, and less research-focused universities (e.g., RUN), increasing efficiency variation within the country. In contrast, New Zealand universities are smaller, more research-focused, and more dependent on government funding and research contracts, limiting their financial flexibility.

Regional conditions further reinforce these differences. In Australia, universities in New South Wales (e.g., the University of Sydney and New South Wales) benefit from industry collaboration, strong student demand, and substantial external funding. In New Zealand, the University of Otago records low-cost efficiency due to its South Island location and the high costs of delivering specialised medical programmes. However, Lincoln University achieves relatively high-cost efficiency despite its small size, supported by agricultural specialisation, targeted funding, and industry partnerships.

Staff costs provide another contrast. New Zealand universities face lower average staff costs, but smaller scale and resource constraints mean these savings do not always improve cost efficiency. In contrast, Australian universities face higher average staff costs, which are possibly offset by stronger research performance and greater funding capacity.

Overall, MPI captures long-term productivity trends in a non-market, multi-output context. SFA measures technical efficiency in converting inputs into outputs, while accounting for heterogeneity and statistical noise. SCFA evaluates cost efficiency by considering output levels, input prices and technologies. These methods are not contradictory but reflect different purposes and address productivity or efficiency questions. They show that New Zealand universities may appear more technically efficient but less cost-efficient, due to factors such as input prices, programme mix, regional conditions or institutional scale. In contrast, Australian universities benefit from economies of scale, revenue diversification, and stronger resource capacity. Therefore, using multiple methods provides a more comprehensive understanding of university performance across different dimensions of productivity and efficiency.

8.2.6 *Challenges and Lessons from Comparative Studies*

Beyond methodological differences, challenges arise from contextual contrasts between New Zealand and Australia that shape measured efficiency outcomes. A key challenge is programme structure. In New Zealand, undergraduate completions include sub-degree qualifications (Levels 1-4 certificates); in Australia, they begin at diploma Level 5. This affects comparability: excluding sub-degree qualifications understates New Zealand's teaching activity, but including them risks overstating efficiency relative to Australia.

A second challenge is heterogeneity in institutional scale, composition and revenue structures. New Zealand has a small, homogenous system of only eight public universities that rely heavily on government funding and research contracts, limiting financial flexibility. Australia's sector is larger and more diverse, combining major research-intensive universities with smaller regional and teaching-focused ones. Australian universities also benefit from more diversified revenue, particularly from international tuition and external research income, which strengthens financial capacity but introduces volatility. Such differences shape efficiency results and highlight the importance of interpreting them within their specific context.

Third, regional and institutional settings also complicate comparisons. Locations affect efficiency through access to students, industry and external resources. Universities in large urban regions such as New South Wales gain efficiency advantages from strong student demand, industry collaboration, and extensive funding opportunities. In contrast, institutions in smaller or more remote regions, such as the University of Otago and Lincoln University, face higher costs due to medical programmes, agricultural specialisation, and geographic isolation. These cases show how local conditions influence both technical and cost efficiency, highlighting the need to interpret results within national and regional contexts rather than treating all universities as directly comparable.

Finally, data and measurement issues present another challenge. While both countries collect detailed financial and performance data, differences in reporting standards, research output measures, and capital input or price proxies can influence results. The sensitivity analysis confirms that efficiency estimates vary when alternative data sources or output measures are used. These challenges highlight the need for caution in drawing policy conclusions from cross-country studies and suggest the importance of developing possibly harmonised measures to improve comparability.

Overall, efficiency measures are not only shaped by methodology but also by local conditions. Lessons from cross-country studies need to recognise definitional, structural, and contextual differences rather than treating results as directly comparable. Accounting for these factors help avoid overstating findings or misattributing them to methodological unreliability. Using multiple methods and quality-adjusted measures can also mitigate these challenges and provide more meaningful insights into university performance.

8.3 Contributions of the Study

This thesis makes several contributions to the literature on productivity and efficiency in the New Zealand university sector. It applies three methods, MPI, SFA and SCFA, to assess how efficiently universities use their resources. It is the first to apply SCFA to New Zealand universities. By including data from 37 Australian public universities, this study allows cross-country comparisons and addresses the challenge posed by the small size of New Zealand's university sector. A common frontier is used for both countries, based on the assumption that their university systems are sufficiently similar in nature that a common technological frontier can reasonably be applied to both.

Unlike most prior studies that rely on a single method, this thesis applies both MPI and SFA methods to a consistently constructed dataset covering New Zealand and Australian universities. This enables cross-method validation and robustness checks, highlighting the distinct insights each method offers. This study also compares functional forms (Cobb-Douglas versus translog) within the SFA framework, offering insights into how functional form assumptions affect efficiency estimates.

The thesis examines how efficiently universities use both labour and capital, providing a more comprehensive assessment than previous studies. It also contributes by incorporating quality-adjusted outputs across all three empirical methods, such as credit-and-income-weighted completions and citation-weighted indexed publications. These adjustments better reflect teaching effort and research impact, offering more meaningful university performance measures.

Another key contribution is the inclusion of environmental (inefficiency) factors, estimated using the BC95 model. Variables such as the presence of a medical school, regional location, student composition (e.g., share of international and female students), and staff structure are considered. These variables help explain performance variation and identify drivers of under- or over-performance.

Finally, the thesis conducts sensitivity analyses using alternative input and output measures and data sources. This highlights the importance of model specification and data construction in frontier efficiency analysis, particularly in cross-country or small-sample contexts.

The study presents efficiency scores clearly and consistently, with attention to interpreting differences across institutions and systems. It provides methodological and empirical insights and can inform policy and future research on improving university performance in small countries like New Zealand.

8.4 **Policy Implications**

The analysis shows important differences in the productivity and efficiency of New Zealand and Australian universities, with implications for funding policy, institutional and investment strategies, and system-wide reform. New Zealand universities are generally less cost-efficient than their Australian counterparts, reflecting differences in scale, revenue diversification, and distinct institutional contexts. Policy responses should therefore focus on improving efficiency while recognising the distinctive contributions of different types of universities.

8.4.1 ***Reforming Funding Models for Flexibility and Responsiveness***

The Productivity Commission has criticised tertiary funding for relying on "learning hours" as the basis for EFTS, which incentivises course inflation rather than quality improvement (NZPC, 2018a, p.50). It also noted that the system is often unresponsive to student needs (NZPC, 2017, p.3; NZPC, 2018a, p.24), offering little support for credit transfer or course changes, which undermines flexibility and efficiency (NZPC, 2017, p. 5; NZPC, 2018a, p.21). These concerns align with this study's findings that current performance measures can distort efficiency estimates.

Therefore, funding systems should be redesigned to support student mobility, recognise credit transfers, and reward responsiveness, ensuring that efficiency incentives reflect actual educational value. Funding models should also reflect enrolment shifts and actual programme delivery costs, enabling more efficient and equitable resource allocation. Reforms should balance efficiency with quality and institutional diversity, avoiding one-size-fits-all models that risk widening disparities across universities, particularly regional and specialised institutions.

8.4.2 ***Funding System Reform: Cancellation of the 2026 PBRF Quality Evaluation***

The recent cancellation of the 2026 PBRF Quality Evaluation and establishment the University Advisory Group provide a timely opportunity for systemic reform. A balanced funding framework is needed, combining performance-based incentives with recognition of contextual challenges such as programme mix, regional conditions, and institutional scale. Strengthening system-level coordination through shared services, would help reduce operational duplication and costs, improve scale efficiency, and enhance international competitiveness.

Research funding should be broadened, especially in the humanities and social sciences, where current support is limited. Expanding postgraduate training funding through scholarships and grants at the master's level for coursework programmes would strengthen research capacity and provide a clear career pathway for emerging academics (Tertiary Education Union, 2024).

8.4.3 *Collaboration and Investment Strategies*

Collaboration and strategic investment are essential to improving efficiency and sustaining the international competitiveness of New Zealand universities. Cross-institutional collaboration may reduce duplication and generate economies of scale. Shared services or forming strategic university groupings, similar to Australia's Go8 or ATN, could help reduce operational costs while strengthening their collective international standing. Greater collaborative and technology-enabled programme delivery would also reduce excessive competition between universities and improve adaptability. New Zealand universities could adopt similar strategies, pursuing shared services, joint programme delivery, or formal university groupings to achieve economies of scale and reduce duplication.

Industry collaboration or partnership can further enhance outcomes. Curtin's practical and work-integrated programmes and RMIT's applied research partnerships show how embedding vocational and work experience components into courses improves graduate employability and aligns education with labour market needs (Curtin University Annual Report, 2011, p.8; RMIT Annual Report, 2013, p.17). Similarly, UTS combines traditional and emerging disciplines with internships, international exchanges, and small and medium enterprise (SME) partnerships to prepare students for a changing labour market and drive innovation in the broader economy (UTS Annual Report, 2018, p.9-12). These models suggest New Zealand universities strengthen their links with industry, government, and community by integrating industry and international opportunities into teaching and research. Embedding work-integrated learning and external partnerships into funding and performance frameworks would ensure graduates are adaptable, globally competitive, and better aligned with economic and social impact goals.

International partnerships also enhance resilience and visibility. Curtin's offshore campuses (Curtin University Annual Report, 2011, p.18) and UTS's global partnerships show how strategic alliances can internationalise research through joint journal publications, attract postgraduate students via dual/joint PhD programmes, and diversify income streams (UTS Annual Report, 2018, p.17). Building stronger academic and research partnerships beyond student recruitment would help New Zealand universities reduce financial risk and strengthen their contribution to national and international knowledge networks.

Moreover, the University of Waikato provides a domestic example. It was the first New Zealand university approved by China's Ministry of Education to deliver complete degree programmes in China (University of Waikato, n.d.1). Its joint institute with Chinese Zhejiang University City College, alongside other offshore programmes in Asia (University of Waikato, n.d.2), shows how international partnerships can extend reach, generate revenue, and strengthen academic exchange.

Capital investment and infrastructure renewal remain priorities. Australian universities such as Curtin University and the University of Technology Sydney (UTS) have used strong financial positions to invest in digital platforms, research laboratories, and postgraduate training facilities that foster innovation and productivity. In contrast, underinvestment in New Zealand universities constrains the adaptation of new technologies and limits long-term TFP growth. Targeted government support for research infrastructure and digital teaching resources could help address this gap and enhance efficiency in the sector.

Overall, cross-institutional collaboration, industry collaboration, international partnerships, capital investment and infrastructure renewal represent complementary strategies for New Zealand universities. Pursued jointly, these approaches can improve efficiency, enhance student outcomes, and strengthen long-term global competitiveness.

8.4.4 *Managing Trade-offs between Teaching and Research*

The analysis highlights a trade-off between teaching and research. Research-intensive universities perform strongly in research but may sacrifice teaching, particularly in undergraduate completions under SFA analysis. To address this, universities should adopt systematic internal assessments measuring both teaching and research performance. Research evaluation should consider financial income and academic impact, such as citation-weighted outputs. Teaching assessment is better measured through credit- and income-adjusted completions. Therefore, institutions should focus on their comparative advantages, adopt differentiated strategies, and avoid one-size-fits-all approaches to performance management. The funding framework also needs to balance support for teaching quality with incentives for high-quality research.

Productivity estimates are susceptible to how staff time is allocated between teaching and research. Gemmell, Nolan and Scobie (2017a) and the New Zealand Productivity Commission (2018b, p. 34) show that productivity growth estimates vary substantially depending on how academic staff time and expenditures are weighted. Teaching-heavy allocations produce lower productivity growth, even after quality adjustments. This highlights the importance of designing performance and funding frameworks that recognise universities' dual roles in teaching and research, rather than privileging one at the expense of the other.

Research-intensive universities (e.g., University of Auckland, Otago, and Australia's Go8) often face higher costs but contribute strongly to postgraduate completions and research income. Curtin University shows how targeted resources and support for postgraduate and research students through scholarships, recruitment, and structured programmes, can strengthen research performance while linking to internationalisation strategies (Curtin University Annual Report, 2011, p.18). UTS's research strategy demonstrates expanding staff research involvement, recruiting established researchers, and investing in research infrastructure and equipment to increase scale, quality and research impact (UTS Annual Report, 2018, p.12). New Zealand should adopt similar strategies by expanding funding and targeted support for postgraduate and research students (e.g., targeted scholarships and international recruitment) to enhance research capacity, attract international students, maintain international competitiveness and balance teaching and research priorities.

UTS also shows the value of modular, flexible, and digitally supported postgraduate programmes, aligned with a lifetime of learning strategy (UTS Annual Report, 2018, p.8-9). New Zealand could adopt a similar approach, using a hybrid learning on campus and online, redesigning the postgraduate curriculum to be more modular and flexible, ensuring it meets diverse professional and personal needs while reinforcing research capacity and international competitiveness.

Investment in staff remains central. UTS has embedded human-centred design in its research support systems, digital literacy, facilities, and collaboration tools for staff and research students (UTS Annual Report, 2018, pp.8-9, 20). The University of Waikato also highlights that investment in world-class staff and facilities is critical to sustaining efficiency and international competitiveness (University of Waikato Annual Report, 2012, p.5). At the national level, such investment strengthens human capital by producing highly-skilled graduates trained to apply knowledge and solve economic problems.

Overall, managing the teaching-research trade-off requires balanced funding, robust performance assessment, and sustained investment in staff, postgraduate training and research infrastructure. These policies would allow New Zealand universities to maintain excellence in teaching and research, while contributing to long-term productivity and economic growth.

8.4.5 ***Innovation: Digital Infrastructure and Productivity***

The decline in TFP among New Zealand universities is driven mainly by falling efficiency, despite modest technological progress. Reversing this trend requires better resource utilisation and targeted investment in research infrastructure and digital technologies to support innovation in teaching and research. Strategic resource reallocation, reducing duplication in programme delivery, and adopting collaborative or digital teaching models would help balance financial sustainability with effective resource use.

Future learning and workforce development further highlight the importance of digital investment. UTS emphasises hybrid on-campus and online delivery, lifelong learning, and digital literacy as part of its strategy for the future of work (UTS Annual Report, 2018, p.20). In contrast, New Zealand universities have underinvested in these areas, limiting their ability to adapt to technological change. Thus, universities should promote digital and data literacy, flexible delivery models, and reskilling pathways to prepare students for a changing labour market. Such approaches would improve efficiency and enhance social impact, particularly for female mature-age students in teaching education and nursing programmes.

The New Zealand Productivity Commission highlights innovation and technology as the main long-term drivers of state-sector productivity, but restrictive funding arrangements and weak incentives often discourage experimentation (NZPC, 2018a, pp. 14, 22). Aligning funding models with productivity and quality outcomes, rather than volume-based measures, would better support innovation and efficiency gains. The Government also has a vital role in promoting the adoption of new technologies in the state sector (NZPC, 2018a, p.10). Sustained investment in digital infrastructure and supportive funding frameworks are critical to revitalising productivity growth in New Zealand universities.

Overall, reversing the decline in TFP requires better use of resources, investment in digital infrastructure, and funding frameworks that reward quality outcomes. Universities should adopt flexible and technology-enabled models, while government support is essential to promote innovation. These steps would improve efficiency, prepare students for future work, and support long-term productivity growth.

8.4.6 ***Strengthen Financial Sustainability and Diversification***

International student tuition and research contracts are important income sources, but heavy reliance on them introduces volatility. Fluctuations in international enrolments expose institutions to financial instability, particularly in the context of limited government funding and growing global competition. Thus, future funding frameworks should incorporate more resilient and flexible mechanisms to balance financial sustainability with effective resource allocation.

To reduce financial risk, universities should diversify income streams by expanding industry partnerships, securing external research funding, and adopting shared services or joint programme delivery. Streamlined visa processes, stronger international marketing, and enhanced student support services can also help stabilise enrolments. Institutions should consider reallocating resources strategically, reducing duplication in programme delivery, and adopting collaborative or digital teaching models.

Examples from New Zealand and abroad highlight practical strategies for diversification. The University of Waikato has expanded and tailored postgraduate offerings, such as a 180-point Master's in education, management and creative arts, while strengthening global visibility through offshore partnerships. These initiatives enhance competitiveness in international markets while meeting national needs (University of Waikato Annual Report, 2012, p.6). The University of Canterbury's partnership with Navitas (an Australian-based education provider) to establish UC International College shows how collaborations with international providers can broaden student markets and improve resilience (University of Canterbury Annual Report, 2012, p.5).

UTS provides another example. With more than half its international students coming from China, UTS has sought to reduce reliance on single markets by targeting Southeast Asia, South Asia and the Middle East. New marketing and recruitment strategies, including direct-entry pathways for high school graduates in their home country and expanded international pathway partners, have increased enrolments from various countries (UTS Annual Report, 2018, p.10). Such diversification reduces financial risk while maintaining global reach.

While internationalisation remains vital, universities and governments should strengthen alternative income sources, such as industry collaboration, alumni engagement, and philanthropic funding. The University of Waikato highlighted the importance of global rankings and international partnerships in attracting talent and strengthening teaching and research outcomes (University of Waikato Annual Report, 2012, p.5). These cases suggest that when combined with quality teaching and research support, internationalisation strategies can enhance both competitiveness and efficiency.

Financial surpluses and capital investment further support resilience. Universities like Waikato, Curtin, RMIT, and UTS highlight stable margins and ongoing investment in infrastructure, research facilities, and digital upgrades as critical to maintaining performance and resilience in uncertain environments. New Zealand universities need targeted capital investment and diversification strategies to remain competitive.

Overall, diversification strategies through international partnerships, expanded postgraduate markets, industry collaboration, alumni and philanthropic engagement, and targeted capital investment would reduce financial risk and strengthen the sustainability of New Zealand universities in an uncertain global environment.

8.4.7 *Ensure Equity and Sustainability in Funding for Regional Differences*

The analysis confirms that location and context significantly shape university efficiency. Regional universities face disadvantages such as remoteness, small scale, and higher delivery costs. These factors reduce measured efficiency, even though such universities make distinctive contributions to national priorities. For instance, the University of Otago's medical school and Lincoln University's land-based programmes are essential for health and agricultural research but incur high operating costs. Standard productivity indicators risk underestimating their true performance by not accounting for these contextual factors (NZPC, 2018b, p. 46).

Funding and performance frameworks should avoid applying uniform benchmarks across all universities. Differentiated approaches are needed to incorporate environmental variables such as remoteness and regional economic conditions, providing targeted support for high-cost teaching and research missions. This would ensure that universities with specialised roles, such as the University of Otago and Lincoln University, can continue contributing to national education and research priorities without compromising financial sustainability.

The University of Canterbury's experience further shows these challenges. After the Canterbury earthquakes, the university faced high operating costs and enrolment pressures but contributed significantly to regional recovery through earthquake-related research and rebuilding efforts (University of Canterbury Annual Report, 2012, pp.4-8). While government support was essential, the university also undertook its own cost-saving measures, such as staff reductions and more efficient use of space (University of Canterbury Annual Report, 2012, p.4). This example highlights the need for funding models that recognise regional conditions and specialised missions, rather than applying one-size-fits-all benchmarks, to ensure regional universities can continue contributing to national education and research priorities.

Overall, policies should recognise both the higher costs and the distinctive contributions of regional universities. Differentiated funding and evaluation frameworks would provide fairer assessments, effective support, strengthen resilience, and ensure that regional institutions continue to meet critical national education and research priorities.

8.4.8 *Ensure Equity and Sustainability in Funding for Discipline Differences*

Funding imbalance across disciplines undermine both equity and sustainability. Cost efficiency was negatively associated with higher proportions of female students, reflecting structural issues in programme mix and funding rather than gender itself. Female enrolments are concentrated in underfunded non-STEM disciplines, such as arts and social sciences, and in high-cost programmes like nursing and teacher education, requiring intensive supervision and service supports.

Therefore, funding models should address discipline-based funding imbalances by aligning resources more closely with actual delivery costs. This means providing stronger support for both underfunded non-STEM fields, which play a vital role in social and economic outcomes, and for high-cost professional programmes such as nursing and teacher education, which are critical for national workforce needs. Recognising these structural realities would ensure greater equity across disciplines, reduce inefficiencies caused by funding gaps, and sustain programme quality in fields critical to New Zealand's society and economy.

8.4.9 *Incentivise Quality Outcomes in Teaching and Research*

Productivity measures in education should account for quality. The New Zealand Productivity Commission emphasises that productivity estimates are highly sensitive to how quality is defined, and that quality-adjusted indicators should be part of the performance framework (NZPC, 2018b, p. 45). Comparisons between universities must also consider differences in operating environments, such as regional conditions, institutional size, programme structure and student composition, and output quality (NZPC, 2018b, p. 46). Incorporating these considerations into funding and evaluation frameworks would provide fairer and more meaningful insights into university performance while ensuring incentives align with national goals.

This thesis applies quality-adjusted outputs, such as credit- and income-weighted completions and citation-weighted publications, to better capture teaching effort and research impact. The findings suggest that funding models should reward universities delivering high-quality teaching and impactful research, rather than focusing on raw student numbers or publication counts. This approach also reflects university strategies that prioritise quality. For example, the University of Waikato notes that international rankings depend on attracting world-class staff and providing world-class facilities, which require sustained investment in academic leadership and high-performance culture (University of Waikato, 2012, p. 5).

8.4.10 *Improve Data Quality and Consistency*

High-quality and comparable data are critical for reliable efficiency analysis and evidence-based decision making. Efficiency results vary depending on how inputs and outputs are defined, underlining the need for robust and consistent reporting standards. Investment in transparent reporting systems, benchmarking tools, and sector-wide monitoring would improve performance evaluation and provide stronger evidence for both government policy and institutional decisions. Harmonised approaches across New Zealand and Australia could enhance cross-country benchmarking and policy learning.

The sensitivity analysis in the SCFA confirms the importance of precise data definitions. Efficiency scores vary when different capital price and output measures are used. Non-labour expenditure per EFTS provides the most reliable capital proxy, while research income better reflects the financial impacts of research activity. Publication-based measures capture research quality but not costs. Some determinants, such as medical schools and international students, consistently affect cost efficiency, while female students and staff composition are sensitive to variable definitions. These findings highlight the need to match input and output measures with the aims of cost efficiency analysis.

In summary, the key policy recommendations resulting from the analysis in this thesis are:

1. Reform university funding models to increase flexibility and responsiveness, support student mobility, recognise credit transfers, and align efficiency incentives with educational value.
2. Redesign performance-based funding following the cancellation of the 2026 PBRF Quality Evaluation, balancing incentives with recognition of contextual challenges, broadening research support, and expanding postgraduate scholarships and grants.
3. Improve cost efficiency through cross-institutional collaboration, shared services, industry partnerships, international alliances, and targeted capital investment in research infrastructure and digital teaching resources.
4. Manage teaching–research trade-offs by adopting differentiated strategies, balanced funding frameworks, and systematic teaching and research performance assessments, alongside greater investment in postgraduate training and staff development.
5. Support innovation and long-term productivity growth through digital infrastructure investment, hybrid delivery models, lifelong learning pathways, and funding frameworks that reward quality outcomes rather than volume.

6. Strengthen financial sustainability by diversifying income sources, reducing reliance on international tuition, expanding international partnerships, industry collaboration, alumni and philanthropic engagement, targeted capital investment, and pursuing international market diversification.
7. Ensure equity in funding for regional universities by adopting differentiated frameworks that recognise higher costs, remoteness, and distinctive contributions to national priorities.
8. Address discipline-based funding imbalances by aligning resources with actual delivery costs, strengthening support for underfunded non-STEM fields and high-cost professional programmes such as nursing and teacher education.
9. Incentivise quality outcomes in teaching and research by embedding quality-adjusted outputs, such as credit- and income-weighted completions and citation-weighted publications, into funding and performance frameworks.
10. Improve data quality and consistency through transparent reporting standards, benchmarking tools, and harmonised monitoring systems across New Zealand and Australia for more accurate and reliable evaluation.

Overall, the significance of this study extends beyond the university sector itself. University productivity and efficiency are central to institutional sustainability and education quality, but they also have wider implications for national economic and social outcomes. An efficient university system develops a highly skilled workforce, drives research and innovation, and strengthens the international competitiveness of New Zealand and Australia in the global knowledge economy. Therefore, these findings provide valuable evidence to guide government, university leaders, and stakeholders in aligning resource allocation and strategic choices with long-term growth and social well-being.

Improving the productivity and efficiency of universities is not only about institutional performance but also about the wider economy. Efficient use of labour and capital in universities strengthens teaching and research outputs, expanding human capital, fostering innovation, and supporting long-term economic growth. Human capital enhances economic growth by improving the quality of labour through education (NZPC, 2018a, p. 9).

Improving productivity and efficiency requires both consistency of purpose and adaptability. Universities should pursue ambitious strategies with careful execution, while remaining flexible to shifts in national and global economic conditions, government policy, student needs, and academic priorities (RMIT annual report, 2013, p. 5).

8.5 Limitations and Recommendations for Future Research

Limitations

While this thesis uses modern methods to provide novel insights into the productivity and efficiency of Australasian public universities, several limitations warrant acknowledgement. These constraints highlight opportunities for refinement in future research to contextualize the interpretative boundaries of the current findings.

First, the analysis of New Zealand universities was restricted to eight universities, an inherent reflecting the country's small university sector. Although including Australian universities expanded the dataset, cross-country comparisons may be affected by unobserved heterogeneity stemming from differences in funding models, institutional structures, and national policies.

A second limitation is that the study period (2008-2018) excludes recent disruptions, such as the COVID-19 pandemic. Changes such as the shift to online learning, fluctuating enrolments, and new budgetary pressures may have significantly altered university operations. One major impact was the sharp decline in international student numbers, which affected revenue streams and explored the financial vulnerability of universities reliant on international tuition. Consequently, the findings may not fully reflect current productivity and efficiency challenges facing the sector.

Third, some differences in variable definitions between countries may affect comparability. For instance, New Zealand includes sub-degree qualifications (Levels 1 to 4) in undergraduate completions, while Australia does not. This discrepancy particularly affects models using unadjusted teaching outputs. In addition, while this study applied quality adjustments (e.g., credit and income-weighted completions, citation-weighted publications), such proxies do not fully capture the complexity of output quality. For instance, the citation measure includes only journal articles and reviews, omitting books, chapters, and conference papers.

Future Research Directions

The findings and limitations of this study highlight several promising directions for future research to deepen understanding of productivity and efficiency in higher education institutions. Future research could build on this work by incorporating more recent data and alternative quality indicators. For instance, expanding the dataset to include more recent years would help capture the impact of major disruptions, such as the COVID-19 pandemic, on university productivity and efficiency.

Second, future work should explore more comprehensive quality indicators. While this study used quality-adjusted teaching and research outputs, other indicators—such as student satisfaction, retention, attrition, and qualification completion rates—would provide a richer picture. However, in New Zealand, these measures are often only available at the sector level, with limited data for individual universities.

Third, there is a pressing need for more consistent, detailed, and institution-level data collection in New Zealand. Key indicators such as qualification completion, attrition, and progression rates are currently only published at the national tertiary sector level. Improved human resource and financial reporting—aligned with the level of detail available for Australian universities—would enhance institutional-level analysis.

Finally, future research should explore indicators that capture teacher quality and long-term educational outcomes (Witte & López-Torres, 2017). These might include student satisfaction surveys and graduate destination data (e.g., the percentage of graduates entering employment or further study). While some of these indicators are available in university annual reports, they lack national consistency and coverage.

References

Abbott, M., & Doucouliagos, C. (2003). The efficiency of Australian universities: a data envelopment analysis. *Economics of Education review, 22*(1), 89-97. https://doi.org/10.1016/S0272-7757(01)00068-1

Abbott, M., & Doucouliagos, H. (2004). Research output of Australian universities. Education Economics, 12(3), 251-265. https://doi.org/10.1080/0964529042000258608

Abbott, M., & Doucouliagos, C. (2009). Competition and efficiency: overseas students and technical efficiency in Australian and New Zealand universities. *Education Economics, 17*(1), 31-57. https://doi.org/10.1080/09645290701773433

Afriat, S. N. (1972). Efficiency estimation of production functions. *International economic review*, 568-598.

Agasisti, T. (2011). Performances and spending efficiency in higher education: a European comparison through non-parametric approaches. *Education Economics, 19*(2), 199-224. https://doi.org/10.1080/09645290903094174

Agasisti, T. (2016). Cost structure, productivity and efficiency of the Italian public higher education industry 2001–2011. *International Review of Applied Economics, 30*(1), 48-68. https://doi.org/10.1080/02692171.2015.1070130

Agasisti, T., & Dal Bianco, A. (2009). Measuring efficiency of higher education institutions. *International Journal of Management and Decision Making, 10*(5-6), 443-465. https://doi.org/10.1504/IJMDM.2009.026687

Agasisti, T. & A. Dal Bianco (2009a). Reforming the university sector: effects on teaching efficiency—evidence from Italy. *Higher education* 57(4): 477-498. https://doi.org/10.1007/s10734-008-9157-x

Agasisti, T., & Johnes, G. (2010). Heterogeneity and the evaluation of efficiency: the case of Italian universities. *Applied Economics, 42*(11), 1365-1375. https://doi.org/10.1080/00036840701721463

Agasisti, T., & Johnes, G. (2015). Efficiency, costs, rankings and heterogeneity: the case of US higher education. *Studies in Higher Education, 40*(1), 60-82. https://doi.org/10.1080/03075079.2013.818644

Agasisti, T. (2016). Cost structure, productivity and efficiency of the Italian public higher education industry 2001–2011. *International Review of Applied Economics, 30*(1), 48-68. https://doi.org/10.1080/02692171.2015.1070130

Agasisti, T., Barra, C., & Zotti, R. (2016). Evaluating the efficiency of Italian public universities (2008–2011) in presence of (unobserved) heterogeneity. *Socio-Economic Planning Sciences, 55*, 47-58. https://doi.org/10.1016/j.seps.2016.06.002

Agasisti, T., & Haelermans, C. (2016). Comparing Efficiency of Public Universities among European Countries: Different Incentives Lead to Different Performances. *Higher Education Quarterly, 70*(1), 81-104. https://doi.org/10.1111/hequ.12066

Agasisti, T., & Pohl, C. (2012). Comparing German and Italian public universities: Convergence or divergence in the higher education landscape? *Managerial and decision economics*, *33*(2), 71-85. https://doi.org/10.1002/mde.1561

Agasisti, T. & J. Wolszczak-Derlacz (2016). Exploring efficiency differentials between Italian and Polish universities, 2001–11. *Science and Public Policy* 43(1): 128-142. https://doi.org/10.1093/scipol/scv026

Agasisti, T., & Belfield, C. (2017). Efficiency in the community college sector: stochastic frontier analysis. *Tertiary Education and Management*, *23*(3), 237-259. https://doi.org/10.1080/13583883.2016.1238956

Agasisti, T., & Gralka, S. (2019). The transient and persistent efficiency of Italian and German universities: A stochastic frontier analysis. *Applied Economics*, *51*(46), 5012-5030. https://doi.org/10.1080/00036846.2019.1606409

Ahn, T., Arnold, V., Charnes, A., & Cooper, W. W. (1989). DEA and ratio efficiency analyses for public institutions of higher learning in Texas. *Research in Governmental and Nonprofit Accounting*, *5*(2), 165-185.

Ahn, T., & Seiford, L. M. (1993). Sensitivity of DEA to models and variable sets in a hypothesis test setting: The efficiency of university operations. *Creative and innovative approaches to the science of management*, *6*, 191-208.

Aigner, D. J., & Chu, S.-f. (1968). On estimating the industry production function. The American economic review, 58(4), 826-839.

Aigner, D., Lovell, C. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, *6*(1), 21-37.

Anderson, T. R., Daim, T. U., & Lavoie, F. F. (2007). Measuring the efficiency of university technology transfer. *Technovation*, *27*(5), 306-318. https://doi.org/https://doi.org/10.1016/j.technovation.2006.10.003

Andersson, C. & K. Sund (2022). Technical Efficiency and Productivity of Higher Education Institutions in the Nordic Countries. *International Journal of Public Administration,* 45(2): 107-120. https://doi.org/10.1080/01900692.2020.1868508

Australian Government Australian Research Council. (2015). *State of Australian University Research 2015-2016. Vol 1 ERA National Report. Introduction. Field of Research (FoR) Codes.* Retrieved Feb Mar 1, 2025, from https://www.arc.gov.au/sites/default/files/minisite/static/4551/ERA2015/intro-4_fields-of-research-codes.html

Australian Government Australian Research Council. (2023). *National Competitive Grants Program.* Retrieved Feb 28, 2025, from https://www.arc.gov.au/sites/default/files/202306/National%20Competitive%20Grants%20Program.pdf

Australian Government Australian Research Council. (2023a). *Australia's Economic Accelerator (AEA).* Retrieved Feb Mar 1, 2025, from https://www.researchgrants.gov.au/grant-opportunities/australias-economic-accelerator-aea

Australian Government Australian Research Council. (2023b). About the ARC's Research Grants Services. Retrieved Feb Mar 1, 2025, from https://www.researchgrants.gov.au/index.php/about-us

Australian Government Australian Research Council. (2025). *About the ARC.* Retrieved Mar 1, 2025, from https://www.arc.gov.au/about-arc

Australian Government Australian Research Council. (2025a). *Excellence in Research for Australia.* Retrieved Mar 1, 2025, from https://www.arc.gov.au/evaluating-research/excellence-research-australia

Australian Government Australian Research Council. (2025b). *Engagement and Impact Assessment.* Retrieved Mar 1, 2025, from https://www.arc.gov.au/evaluating-research/ei-assessment

Australian Government Australia's Economic Accelerator (2025). *About Australia's Economic Accelerator.* Retrieved Feb Mar 1, 2025, from https://www.aea.gov.au/about-australias-economic-accelerator

Australian Government Business. (2025). *Funding for short-term, industry-led research collabourations.* Retrieved Feb Mar 1, 2025, from https://business.gov.au/Grants-and-Programs/Cooperative-Research-Centres-Projects-CRCP-Grants

Australian Government Department of Education. (2022). Higher Education Loan Program (HELP). Announcemens. End 10% HECS-HELP Upfront Discount. Retrieved Feb 24, 2025, from https://www.education.gov.au/higher-education-loan-program/announcements/end-10-percent-hecs-help-upfront-discount

Australian Government Department of Education. (2022a). Finance 2022: Financial Reports of Higher Education Providers. Retrieved Feb 24, 2025, from https://www.education.gov.au/higher-education-publications/resources/2022-higher-education-providers-finance-tables

Australian Government Department of Education. (2024b). *Research Block Grants*. Retrieved Feb 28, 2024, from https://www.education.gov.au/research-block-grants

Australian Government Department of Education. (n.d.c). *Staff Data*. Retrieved Mar 26, 2023, from https://www.education.gov.au/higher-education-statistics/staff-data

Australian Government Department of Education. (2025). Retrieved Mar 1, 2025, from: https://www.education.gov.au/australias-economic-accelerator

Australian Government Medical Research Future Fund. (2024). *Medical Research Future Fund.* Retrieved Mar 1, 2025, from https://www.health.gov.au/our-work/mrff

Australian Government National Health and Medical Research Council. (n.d.). *Overview*. Retrieved Mar 1, 2025, from https://www.nhmrc.gov.au/funding/new-grant-program/overview

Australian Technology Network of Universities. (n.d.). *Shaping the future of higher education.* Retrieve Dec 3, 2024, from https://www.atn.edu.au/

Australian Qualifications Framework. (2013). *The Australian Qualifications Framework (Second Edition)*. Retrieved from https://www.aqf.edu.au/framework/australian-qualifications-framework

Avilés-Sacoto, S. V., Cook, W. D., Güemes-Castorena, D., & Zhu, J. (2020). Measuring efficiency in DEA in the presence of common inputs. *Journal of the Operational Research Society*, *71*(11), 1710-1722. https://doi.org/10.1080/01605682.2019.1630329

Avilés-Sacoto, S. V., Avilés-Sacoto, E. C., Cook, W. D., & Güemes-Castorena, D. (2022). Modelling efficiency in the presence of shared inputs within groups of DMUs. *Journal of the Operational Research Society*, *73*(9), 1961-1977. https://doi.org/10.1080/01605682.2021.1963196

Avkiran, N. K. (2001). Investigating technical and scale efficiencies of Australian universities through data envelopment analysis. *Socio-Economic Planning Sciences*, *35*(1), 57-80. https://doi.org/10.1016/S0038-0121(00)00010-0

Bachan, R. (2017). Grade inflation in UK higher education. *Studies in Higher Education*, *42*(8), 1580-1600. https://doi.org/10.1080/03075079.2015.1019450

Baltaru, R.-D. (2019). Do non-academic professionals enhance universities' performance? Reputation vs. organisation. *Studies in Higher Education*, *44*(7), 1183-1196. https://doi.org/10.1080/03075079.2017.1421156

Barra, C., & Zotti, R. (2016). Measuring Efficiency in Higher Education: An Empirical Study Using a Bootstrapped Data Envelopment Analysis. *International Advances in Economic Research*, *22*(1), 11-33. doi:10.1007/s11294-015-9558-4

Barra, C., Lagravinese, R., & Zotti, R. (2018). Does econometric methodology matter to rank universities? An analysis of Italian higher education system. *Socio-Economic Planning Sciences*, *62*, 104-120. https://doi.org/10.1016/j.seps.2017.09.002

Battese, G. E. & S. S. Broca (1997). Functional forms of stochastic frontier production functions and models for technical inefficiency effects: a comparative study for wheat farmers in Pakistan. *Journal of Productivity Analysis*, *8*, 395-414.

Battese, G. E., & Corra, G. S. (1977). Estimation of a production frontier model: with application to the pastoral zone of Eastern Australia. Australian journal of agricultural economics, 21(3), 169-179.

Battese, G. E., & Coelli, T. J. (1988). Prediction of firm-level technical efficiencies with a generalised frontier production function and panel data. *Journal of Econometrics, 38*(3), 387-399.

Battese, G. E., & Coelli, T. J. (1992). Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India. Journal of Productivity Analysis, 3(1), 153-169.

Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, *20*(2), 325-332.

Belotti, F., Daidone, S., Ilardi, G., & Atella, V. (2013). Stochastic frontier analysis using Stata. The Stata Journal, 13(4), 719-758. https://doi.org/10.1177/1536867X1301300404

Bentley, P. J., Goedegebuure, L. C. & Meek, V. L. (2014). Australian Academics, Teaching and Research: History, Vexed Issues and Potential Changes. Shin, JC (Ed.). Arimoto, A (Ed.). William, KC (Ed.). Ulrich, T (Ed.). *Teaching and Research in Contemporary Higher Education*, (1), pp.357-377. Springer.

Berndt, E. (1991). *The Practice of Econometrics. Classic and Contemporary*, Addison-Wesley Publishing Company, Reading, MA, pp. 465–7.

Bessent, A. M., & Bessent, E. W. (1980). Determining the comparative efficiency of schools through data envelopment analysis. *Educational Administration Quarterly*, *16*(2), 57-75.

Bessent, A., Bessent, W., Kennington, J., & Reagan, B. (1982). An application of mathematical programming to assess productivity in the Houston independent school district. *Management science*, *28*(12), 1355-1367.

Bezat, A. (2009). Comparison of the deterministic and stochastic approaches for estimating technical efficiency on the example of non-parametric DEA and parametric SFA methods. *Metody ilościowe w badaniach ekonomicznych*, *10*(1), 20-29.

Bolli, T., & Farsi, M. (2015). The dynamics of productivity in Swiss universities. *Journal of Productivity Analysis, 44,* 21-38. https://doi.org/10.1007/s11123-015-0450-2

Bolli, T., Olivares, M., Bonaccorsi, A., Daraio, C., Aracil, A. G., & Lepori, B. (2016). The differential effects of competitive funding on the production frontier and the efficiency of universities. *Economics of Education Review*, *52*, 91-104. https://doi.org/10.1016/j.econedurev.2016.01.007

Bonaccorsi, A., Daraio, C., & Simar, L. (2006). Advanced indicators of productivity of universities: An application of robust nonparametric methods to Italian data. *Scientometrics, 66*(2), 389-410. https://doi.org/10.1007/s11192-006-0028-x

Carrington, R., Coelli, T., & Rao, D. P. (2005). The performance of Australian universities: Conceptual issues and preliminary results. *Economic Papers: A journal of applied economics and policy, 24*(2), 145-163. https://doi.org/10.1111/j.1759-3441.2005.tb01001.x

Castano, M. C. N., & Cabanda, E. C. (2007). Performance evaluation of the efficiency of Philippine Private Higher Educational Institutions: application of frontier approaches. *International Transactions in operational research, 14*(5), 431-444. https://doi.org/10.1111/j.1475-3995.2007.00599.x

Casu, B., Girardone, C., & Molyneux, P. (2004). Productivity change in European banking: A comparison of parametric and non-parametric approaches. *Journal of Banking & Finance, 28*(10), 2521-2540. https://doi.org/10.1016/j.jbankfin.2003.10.014

Catalyst Fund. (2023). *Catalyst Fund.* Retrieved Nov 11, 2024 from https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities/investment-funds/catalyst-fund

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982a). Multilateral comparisons of output, input, and productivity using superlative index numbers. *The economic journal*, *92(365)*, 73-86.

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982b). The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica: Journal of the Econometric Society*, 1393-1414.

Chapple, W., Lockett, A., Siegel, D., & Wright, M. (2005). Assessing the relative performance of UK university technology transfer offices: parametric and non-parametric evidence. *Research Policy*, *34*(3), 369-384. https://doi.org/10.1016/j.respol.2005.01.007

Charles Darwin University. (2019). Charles Darwin University 2019 Annual Report. Retrieved Feb 20, 2025 from https://www.cdu.edu.au/media-communications/annual-reports

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European journal of operational research*, *2*(6), 429-444.

Charnes, A., Cooper, W. W., & Rhodes, E. (1981). Evaluating program and managerial efficiency: an application of data envelopment analysis to program follow through. *Management science*, *27*(6), 668-697.

Coelli, T. J. (1992). A computer program for frontier production function estimation: Frontier version 2.0. *Economics letters*, *39*(1), 29-32.

Coelli, T. J. (1996). *A guide to FRONTIER version 4.1: a computer program for stochastic frontier production and cost function estimation*: CEPA Working papers.

Coelli, T., & Perelman, S. (2000). Technical efficiency of European railways: a distance function approach. *Applied Economics, 32(15)*, 1967-1976.

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). An introduction to efficiency and productivity analysis. springer science & business media.

Compagnucci, L., & Spigarelli, F. (2020). The Third Mission of the university: A systematic literature review on potentials and constraints. *Technological Forecasting and Social Change*, *161*, 120284. https://doi.org/10.1016/j.techfore.2020.120284

Controller and Auditor-General report. (2017). Investing in tertiary education assets. Retrieved Mar 6, 2025, from https://oag.parliament.nz/2017/tei-assets/part4.htm

Conway, M. (2012). Using causal layered analysis to explore the relationship between academics and administrators in universities. *Journal of Futures Studies*, *17*(2), 37-58.

Cornwell, C., Schmidt, P., & Sickles, R. C. (1990). Production frontiers with cross-sectional and time-series variation in efficiency levels. *Journal of Econometrics, 46(1-2)*, 185-200.

Cuesta, R. A., & Orea, L. (2002). Mergers and technical efficiency in Spanish savings banks: A stochastic distance function approach. *Journal of Banking & Finance*, *26(12)*, 2231-2247. https://doi.org/10.1016/S0378-4266(01)00184-4

Cuesta, R. A., & Zofío, J. L. (2005). Hyperbolic Efficiency and Parametric Distance Functions: With Application to Spanish Savings Banks. *Journal of Productivity Analysis*, *24(1)*, 31-48. https://doi.org/10.1007/s11123-005-3039-3

Cuesta, R. A., Lovell, C. A. K., & Zofío, J. L. (2009). Environmental efficiency measurement with translog distance functions: A parametric approach. *Ecological Economics*, *68(8-9)*, 2232-2242. https://doi.org/10.1016/j.ecolecon.2009.02.001

Cullen, D., & Ergas, H. (2014). *Efficiency and Productivity in the Australian Health Care System*. Australian Centre for Economic Research on Health. Research report series. Number 14.

Retrieved Nov 22, 2022 from https://www.researchgate.net/publication/321025556_Efficiency_and_Productivity_in_the_Australian_Health_Care_System

Ćulum, B. (2015). Academics and service to the community: an international (European) perspective. *The relevance of academic work in comparative perspective*, 139-162. https://doi.org/10.1007/978-3-319-11767-6_9

Curi, C., Daraio, C., & Llerena, P. (2012). University technology transfer: how (in)efficient are French universities? *Cambridge Journal of Economics*, *36(*3), 629-654. https://doi.org/10.1093/cje/bes020

Curtin University Annual Report. (2011). *Curtin University Annual Report 2011*. Retrieved from: https://www.curtin.edu.au/about/governance/annual-reports/

Daghbashyan, Z. (2011). The economic efficiency of Swedish higher education institutions: CESIS, KTH Royal Institute of Technology.

Duan, S. X. (2019). Measuring university efficiency: An application of data envelopment analysis and strategic group analysis to Australian universities. *Benchmarking: an international journal.* https://doi.org/10.1108/BIJ-10-2017-0274

D'Elia, V., & Ferro, G. (2021). Efficiency in public higher education: A stochastic frontier analysis considering heterogeneity. Revista de Análisis Económico–Economic Analysis Review, 36(2), 21-51.

Edvardsen, D. F., Førsund, F. R., & Kittelsen, S. A. (2017). Productivity development of Norwegian institutions of higher education 2004–2013. *Journal of the Operational Research Society, 68*(4), 399-415. https://doi.org/10.1057/s41274-017-0183-x

Employment New Zealand. (2024). *Dismissal*. Retrieved Nov 24, 2024, from https://www.employment.govt.nz/ending-employment/dismissal#scroll-to-7

Endeavour Fund. (2024). Endeavour Fund. Retrieved Nov 11, 2024, from https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities/investment-funds/endeavour-fund

Erkoc, T. E. (2015). Assessing the research performance in higher education with stochastic distance function approach. *International Journal of Education Economics and Development*, *6*(4), 366-380. https://doi.org/10.1504/IJEED.2015.075797

Färe, R. (1988). *Fundamentals of production theory* (Vol. 22): Springer.

Färe, R., Grifell-Tatjé, E., Grosskopf, S., & Knox Lovell, C. A. (1997). Biased technical change and the Malmquist productivity index. *Scandinavian Journal of Economics*, *99(1)*, 119-127.

Färe, R., Grosskopf, S., & Norris, M. (1997). Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries: Reply. The American Economic Review, 87(5), 1040–1044.

Färe, R., Grosskopf, S., Norris, M., & Zhang, Z. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *The American economic review*, 66-83.

Färe, R. and S. Grosskopf, (2000), Reference Guide to OnFront, Economic Measurement and Quality Corporation, Lund, Sweden

Färe, R., & Primont, D. (1995). *Multi-output production and duality: theory and applications*. Boston: Kluwer Academic Publishers.

Farsi, M., Filippini, M., & Greene, W. (2006). Application of panel data models in benchmarking analysis of the electricity distribution sector. *Annals of Public and Cooperative Economics, 77*(3), 271-290. https://doi.org/10.1111/j.1467-8292.2006.00306.x

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society: Series A (General), 120(3)*, 253-281.

Ferguson, H. (2022). University research funding: A quick guide. *Social Policy*, 1-6. Research Paper Series, 2021-22. Canberra: Parliament of Australia.

Fernando, B. I. S. and E. C. Cabanda (2007). Measuring efficiency and productive performance of colleges at the university of Santo Tomas: a nonparametric approach. *International Transactions in Operational Research 14*(3): 217-229. https://doi.org/10.1111/j.1475-3995.2007.00582.x

Ferro, G., & D'Elia, V. (2020). Higher Education Efficiency Frontier Analysis: A Review of Variables to Consider. *Journal on Efficiency and Responsibility in Education and Science, 13*(3), 140-153.

Fisher, R. A. (1922). On the mathematical foundations of theoretical statistics. *Philosophical transactions of the Royal Society of London. Series A, containing papers of a mathematical or physical character, 222*(594-604), 309-368.

Flegg, A.-T., Allen, D. O., Field, K., & Thurlow, T. (2004). Measuring the efficiency of British universities: a multi-period data envelopment analysis. *Education Economics, 12*(3), 231-249.

Fried, H. O., Lovell, C. K., Schmidt, S. S., & Schmidt, S. S. (Eds.). (2008). *The measurement of productive efficiency and productivity growth*: Oxford University Press.

Fu, T. t., Huang, C. J., & Tien, F. F. (2008). University cost structure in Taiwan. *Contemporary Economic Policy, 26*(4), 651-662. https://doi.org/10.1111/j.1465-7287.2008.00104.x

Gemmell, N., Nolan, P., & Scobie, G. M. (2017). *Estimating quality-adjusted productivity in tertiary education: Methods and evidence for New Zealand*: Chair in Public Finance, Victoria Business School.

Gemmell, N., Nolan, P., & Scobie, G. (2018). Quality Adjusting Education Sector Productivity. *Policy Quarterly, 14*(3). https://doi.org/10.26686/pq.v14i3.5102

Geuna, A., Piolatto, M., (2016). Research assessment in the UK and Italy: costly and difficult, but probably worth it (at least for a while), Research Policy, 45 (1), 260-271. https://doi.org/10.1016/j.respol.2015.09.004

Glass, J. C., McKillop, D. G., & Hyndman, N. S. (1995). The achievement of scale efficiency in UK universities: a multiple-input multiple-output analysis. *Education Economics, 3*(3), 249-263. https://doi.org/10.1080/09645299500000023

Glass, J. C., McKillop, D. G., & O'Rourke, G. (1997). Productivity growth in UK accountancy departments 1989–96. *Financial Accountability & Management*, *13*(4), 313-330. https://doi.org/10.1111/1468-0408.00041

Glass, J. C., McKillop, D. G., & O'Rourke, G. (1998). A cost indirect evaluation of productivity change in UK universities. *Journal of Productivity Analysis*, *10*(2), 153-175. https://doi.org/10.1023/A:1018607223276

Glass, J., McKillop, D., & O'Rourke, G. (2002). Evaluating the productive performance of UK universities as cost-constrained revenue maximizers: an empirical analysis. *Applied Economics*, *34*(9), 1097-1108. https://doi.org/10.1080/00036840110088119

Glass, J. C., McCallion, G., McKillop, D. G., Rasaratnam, S., & Stringer, K. S. (2006). Implications of variant efficiency measures for policy evaluations in UK higher education. *Socio-Economic Planning Sciences*, *40*(2), 119-142. https://doi.org/10.1016/j.seps.2004.10.004

Gralka, S. (2018). Persistent inefficiency in the higher education sector: evidence from Germany. *Education Economics*, *26*(4), 373-392. https://doi.org/10.1080/09645292.2017.1420754

Gralka, S. (2018a). Stochastic frontier analysis in higher education: A systematic review.

Gralka, S., Wohlrabe, K., & Bornmann, L. (2019). How to measure research efficiency in higher education? Research grants vs. publication output. *Journal of Higher Education Policy and Management*, *41*(3), 322-341. https://doi.org/10.1080/1360080X.2019.1588492

Graham, C., & Regan, J. A. (2016). Exploring the contribution of professional staff to student outcomes: A comparative study of Australian and UK case studies. *Journal of Higher Education Policy and Management*, *38*(6), 595-609. https://doi.org/10.1080/1360080X.2016.1211935

Gray, S. (2015). Culture clash or ties that bind? What Australian academics think of professional staff. *Journal of Higher Education Policy and Management*, *37*(5), 545-557. https://doi.org/10.1080/1360080X.2015.1079397

Greene, W. H. (1980a). Maximum likelihood estimation of econometric frontier functions. *Journal of Econometrics*, *13*(1), 27-56.

Greene, W. H. (1980b). On the estimation of a flexible frontier production model. *Journal of Econometrics*, *13*(1), 101-115.

Greene, W. H. (2003). Simulated likelihood estimation of the normal-gamma stochastic frontier function. *Journal of Productivity Analysis*, *19*(2), 179-190. https://doi.org/10.1023/A:1022853416499

Greene, W. (2005a). Reconsidering heterogeneity in panel data estimators of the stochastic frontier model. *Journal of Econometrics*, *126*(2), 269-303. https://doi.org/10.1016/j.jeconom.2004.05.003

Greene, W. (2005b). Fixed and random effects in stochastic frontier models. *Journal of Productivity Analysis*, *23*(1), 7-32. https://doi.org/10.1007/s11123-004-8545-1

Grifell-Tatjé, E., & Lovell, C. K. (1995). A note on the Malmquist productivity index. *Economics letters*, *47*(2), 169-175.

Groot, H., McMahon, W. W., & Volkwein, J. F. (1991). The Cost Structure of American Research Universities. *The Review of economics and statistics*, *73*(3), 424-431.

Grosskopf, S., Hayes, K., & Hirschberg, J. (1995). Fiscal stress and the production of public safety: a distance function approach. *Journal of public Economics*, *57*(2), 277-296.

Harris, R. I. (1993). Measuring efficiency in New Zealand manufacturing in 1986/7 using a frontier production function approach. *New Zealand Economic Papers*, *27*(1), 57-79.

Health Research Council. (2024). *Health Research Council.* Retrieved Nov 11, 2024, from https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities/funding-agencies/health-research-council

Health Research Council of New Zealand. (2017). *Health Research Council of New Zealand. Briefing for the incoming Minister of Health*. Retrieve Nov 11, 2024, from https://www.beehive.govt.nz/sites/default/files/2017-12/Health%20Research%20Council.pdf

Horne, J., & Hu, B. (2008). Estimation of cost efficiency of Australian universities. *Mathematics and computers in simulation*, *78*(2-3), 266-275. https://doi.org/10.1016/j.matcom.2008.01.018

Howard, J. H. (2021). *Rethinking Australian higher education*. Canberra: Howard Partners.

Huang, T. H., Lin, Y. C., Huang, K. J., & Liao, Y. W. (2022). Comparing cost efficiency between financial and non-financial holding banks and insurers in Taiwan under the framework of copula methods and metafrontier. *Asia-Pacific Financial Markets*, *29*(4), 735-766. https://doi.org/10.1007/s10690-022-09373-9

Investopedia. (2021a). Longitudinal data: definition and uses in finance and economics. Retrieve Oct 12, 2024, from https://www.investopedia.com/terms/l/longitudinaldata.asp

Investopedia. (2023). Understanding capital as a factor of production. Retrieve Nov 21, 2024, from https://www.investopedia.com/ask/answers/051115/what-capital-relation-factors-production.asp

Izadi, H., Johnes, G., Oskrochi, R., & Crouchley, R. (2002). Stochastic frontier estimation of a CES cost function: The case of higher education in Britain. *Economics of Education review*, *21*(1), 63-71. https://doi.org/10.1016/S0272-7757(00)00044-3

Johnes, G., & Johnes, J. (1993). Measuring the research performance of UK economics departments: an application of data envelopment analysis. *Oxford Economic Papers*, 332-347.

Johnes, J. (1996). Performance assessment in higher education in Britain. *European Journal of Operational Research*, *89(1),* 18-33.

Johnes, G. (1997). Costs and industrial structure in contemporary British higher education. *The Economic Journal*, *107*(442), 727-737.

Johnes, J. (2006). Data envelopment analysis and its application to the measurement of efficiency in higher education. *Economics of Education Review*, *25*(3), 273-288. https://doi.org/10.1016/j.econedurev.2005.02.005

Johnes, J. (2006a). Efficiency and productivity change in the English higher education sector from 1996/07 to 2002/03. Working Paper 2006/017 Lancaster: Lancaster University Management School.

Johnes, G., & Salas-Velasco, M. (2007). The determinants of costs and efficiencies where producers are heterogeneous: the case of Spanish universities. *Economics Bulletin, 4*(15), 1-9.

Johnes, J. (2008). Efficiency and productivity change in the English higher education sector from 1996/97 to 2004/5. *The Manchester School, 76*(6), 653-674. https://doi.org/10.1111/j.1467-9957.2008.01087.x

Johnes, G., Camanho, A. S., & Portela, M. S. (2008). Assessing efficiency of Portuguese universities through parametric and non-parametric methods. *Portuguese Journal of Management Studies, 13*(1), 39-66.

Johnes, G., Johnes, J., & Thanassoulis, E. (2008). An analysis of costs in institutions of higher education in England. *Studies in Higher Education, 33*(5), 527-549. https://doi.org/10.1080/03075070802372901

Johnes, G., & Johnes, J. (2009). Higher education institutions' costs and efficiency: Taking the decomposition a further step. *Economics of Education review, 28*(1), 107-113. https://doi.org/10.1016/j.econedurev.2008.02.001

Johnes, J. (2010). Efficiency and Input-and Output-Substitutability in English Higher Education 1996/97 to 2007/08: A Parametric Distance Function Approach. *Available at SSRN 1615512*.

Johnes, G., & Schwarzenberger, A. (2011). Differences in cost structure and the evaluation of efficiency: the case of German universities. *Education Economics, 19*(5), 487-499. https://doi.org/10.1080/09645291003726442

Johnes, J. (2014a). Efficiency and Mergers in English Higher Education 1996/97 to 2008/9: Parametric and Non-parametric Estimation of the Multi-input Multi-output Distance Function. *The Manchester School, 82*(4), 465-487. https://doi.org/10.1111/manc.12030

Johnes, J. (2014b). Efficiency and input substitutability in English higher education 1996/97 to 2008/09. In *INFORMS* conference, San Francisco.

Johnes, J. (2015). Operational research in education. *European Journal of Operational Research, 243*(3), 683-696. https://doi.org/10.1016/j.ejor.2014.10.043

Johnes, G., & Johnes, J. (2016). Costs, efficiency, and economies of scale and scope in the English higher education sector. *Oxford Review of Economic Policy, 32*(4), 596-614. https://doi.org/10.1093/oxrep/grw023

Johnes, J. (2022). Applications of Production Economics in Education. In S. C. Ray, R. G. Chambers, & S. C. Kumbhakar (Eds.), *Handbook of production economics* (pp. 1193-1239). Springer Nature Singapore.

Johnson, A. L., & Ruggiero, J. (2014). Nonparametric measurement of productivity and efficiency in education. *Annals of Operations Research, 221*(1), 197-210. https://doi.org/10.1007/s10479-011-0880-9

Jondrow, J., Lovell, C. K., Materov, I. S., & Schmidt, P. (1982). On the estimation of technical inefficiency in the stochastic frontier production function model. *Journal of Econometrics, 19*(2-3), 233-238.

Kalb, A. (2010). Public sector efficiency: applications to local governments in Germany: Springer Science & Business Media.

Kempkes, G., & Pohl, C. (2008). Do Institutions Matter for University Cost Efficiency? Evidence from Germany. *CESifo Economic Studies, 54*(2), 177-203. https://doi.org/10.1093/cesifo/ifn009

Kempkes, G., & Pohl, C. (2010). The efficiency of German universities–some evidence from nonparametric and parametric methods. *Applied Economics, 42*(16), 2063-2079. https://doi.org/10.1080/00036840701765361

Klitkou, A., & Gulbrandsen, M. (2010). The relationship between academic patenting and scientific publishing in Norway. *Scientometrics, 82*(1), 93-108. https://doi.org/10.1007/s11192-009-0050-x

Knight, P. T., & Trowler, P. R. (2001). Departmental leadership in higher education. Buckingham, UK: SRHE.

Kodde, D. A., & Palm, F. C. (1986). Wald criteria for jointly testing equality and inequality restrictions. *Econometrica: Journal of the Econometric Society*, 1243-1248.

Koshal, R. K., & Koshal, M. (1999). Economies of scale and scope in higher education: a case of comprehensive universities. *Economics of Education review*, *18*(2), 269-277.

Kuo, J.-S., & Ho, Y.-C. (2008). The cost efficiency impact of the university operation fund on public universities in Taiwan. *Economics of Education review*, *27*(5), 603-612. https://doi.org/10.1016/j.econedurev.2007.06.003

Kumbhakar, S. C. (1990). Production frontiers, panel data, and time-varying technical inefficiency. *Journal of Econometrics*, 46(1-2), 201-211. ABDC-A star.

Kumbhakar, S. C., & Lovell, C. K. (2003). Stochastic frontier analysis. Cambridge University Press.

Kwiek, M. (2008). Academic Entrepreneurship vs. changing governance and institutional management structures at European Universities. *Policy Futures in Education*, *6(*6), 757–770. https://doi.org/10.2304/pfie.2008.6.6.757

Laureti, T., Secondi, L., & Biggeri, L. (2014). Measuring the efficiency of teaching activities in Italian universities: An information theoretic approach. *Economics of Education Review*, *42*, 147-164. https://doi.org/10.1016/j.econedurev.2014.07.001

Lee, K. R., Leem, B., Lee, C. W., & Lee, C. (2011). Malmquist productivity index using DEA frontier in Stata. The *Stata Journal*, 2(2), 1-9.

Lee, Y. H., & Schmidt, P. (1993). A production frontier model with flexible temporal variation in technical efficiency. The measurement of productive efficiency: Techniques and applications, 237, 255.

Lenton, P. (2008). The cost structure of higher education in further education colleges in England. *Economics of Education Review*, *27*(4), 471-482. https://doi.org/https://doi.org/10.1016/j.econedurev.2007.05.003

Letti, A. G., Bittencourt, M. V. L., & Vila, L. E. (2022). Stochastic vs. deterministic frontier distance output function: Evidence from Brazilian higher education institutions. *Journal of Productivity Analysis*, 1-20. https://doi.org/10.1007/s11123-022-00636-1

Lincoln University. (2011). *Lincoln University Annual Report 2011*. Retrieve Oct 16, 2024, from https://livingheritage.lincoln.ac.nz/nodes/view/247

Liu, Q., Patton, D., & Kenney, M. (2018). Do university mergers create academic synergy? Evidence from China and the Nordic Countries. *Research Policy*, *47(1)*, 98-107. https://doi.org/10.1016/j.respol.2017.10.001

London School of Economics Business Review. (2016). *The more universities in a country, the faster is economic growth.* Retrieved from *https://blogs.lse.ac.uk/businessreview/2016/03/23/the-more-universities-in-a-country-the-faster-its-economic-growth/*

Lu, Y.-H., & Chen, K.-H. (2013). Appraising the cost efficiency of higher technological and vocational education institutions in Taiwan using the metafrontier cost-function model. *Research in higher education*, *54*, 627-663. https://doi.org/10.1007/s11162-013-9292-9

Mamun, S. A. K. (2011). Are public universities of Bangladesh cost efficient? An empirical evidence. *South Asia Economic Journal*, *12*(2), 221-237. https://doi.org/10.1177/139156141101200202

Margaritis, D., & Smart, W. (2011). *Productivity change in Australasian universities 1997–2005: A Malmquist analysis.* Paper presented at the Annual Conference of the New Zealand Association of Economics.

Massey University. (n.d.). *Distance and online study at Massey*. Retrieved Nov 10, 2022, from https://www.massey.ac.nz/study/distance-and-online-study-at-massey/

McMillan, M. L., & Datta, D. (1998). The relative efficiencies of Canadian universities: a DEA perspective. *Canadian Public Policy/Analyse de Politiques*, 485-511.

McMillan, M. L., & Chan, W. H. (2006). University efficiency: A comparison and consolidation of results from stochastic and non-stochastic methods. *Education Economics*, *14*(1), 1-30. https://doi.org/10.1080/09645290500481857

Meeusen, W., & van Den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International economic review*, 435-444.

Melbourne Institute (2015). *Household, Income and Labour Dynamics in Australia Survey (HILDA): Selected Findings from Waves 1 to 12. Melbourne, Australia.* Retrieved from *https://melbourneinstitute.unimelb.edu.au/__data/assets/pdf_file/0006/2155506/hilda-statreport-2015.pdf*

Mensah, Y. M., & Werner, R. (2003). Cost efficiency and financial flexibility in institutions of higher education. *Journal of Accounting and Public Policy*, *22*(4), 293-323. https://doi.org/10.1016/S0278-4254(03)00036-X

Ministry of Business, Innovation & Employment. (2024). Funding information and opportunities. Retrieved Nov 11, 2024, from https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities

Ministry of Education (2016). *Life after Study. Income Statistics*. Wellington: Ministry of Education. Retrieved from http://www.educationcounts.govt.nz/statistics/tertiaryeducation/life_after_study

Ministry of Education (2021). *Beyond study. Income and Earnings*. Wellington: Ministry of Education. Retrieved from https://www.educationcounts.govt.nz/statistics/life_after_study

Ministry of Education. (2022). Tertiary statistics, Tertiary Participation, provider-based enrolments, Ministry of Education, 2021 data. Wellington: Ministry of Education. 2022 data (Updated June 2022). Retrieved from: https://www.educationcounts.govt.nz/statistics/tertiary-participation

Ministry of Education. (2022a). *Tertiary Research.* Retrieve from: https://www.educationcounts.govt.nz/statistics/research

Ministry of Education. (n.d.a). *Tertiary Research*. Retrieved from https://www.educationcounts.govt.nz/statistics/research

Ministry of Education. (n.d.b). *Beyond study*. Retrieved from https://www.educationcounts.govt.nz/statistics/beyond-study

Minviel, J. J. and T. Sipiläinen (2021). A dynamic stochastic frontier approach with persistent and transient inefficiency and unobserved heterogeneity. *Agricultural Economics* (United Kingdom), *52(4)*, 575-589-589. https://doi.org/10.1111/agec.12636

Miranda, R., Gramani, M. C., & Andrade, E. (2012). Technical efficiency of business administration courses: a simultaneous analysis using DEA and SFA. *International Transactions in operational research, 19*(6), 847-862. https://doi.org/10.1111/j.1475-3995.2012.00857.x

Moore, K. (2020). *Investigating higher education productivity and its measurement in Australia* University of Melbourne]. Moore, K. (2020). Investigating higher education productivity and its measurement in Australia (Doctoral dissertation, University of Melbourne).

Moore, K. (2021). *Measuring Productivity in Education and Not-for-profits: With Tools and Examples in R*. Springer Nature.

Moradi-Motlagh, A., C. Jubb and K. Houghton (2016). Productivity analysis of Australian universities. *Pacific Accounting Review. https://doi.org/10.1108/PAR-02-2016-0027*

Nemoto, J., & Furumatsu, N. (2014). Scale and scope economies of Japanese private universities revisited with an input distance function approach. *Journal of Productivity Analysis*, *41*(2), 213-226. https://doi.org/10.1007/s11123-013-0378-3

New Zealand Institute of Economic Research. (2020). *Regional activity of universities: New Zealand universities' economic footprint, draft report*.

New Zealand Productivity Commission. (2016). *History of tertiary educaiton reforms in New Zealand.* Wellington: New Zealand Productivity Commission. Retrieved June 24, 2018, from https://www.productivity.govt.nz/assets/Documents/65759a16ed/History-of-tertiary-education-reforms.pdf

New Zealand Productivity Commission. (2017). *New models of tertiary education*. Retrieved Sep 2, 2025, from www.productivity.govt.nz/sites/default/files/New%20models%20of%20tertiary%20education%20FINAL.pdf

New Zealand Productivity Commission. (2018a). *Improving state sector productivity*. Final report of the measuring and improving state sector productivity inquiry, vol. 1. Wellington: New Zealand Productivity Commission

New Zealand Productivity Commission. (2018b). *Measuring state sector productivity*. Final report of the measuring and improving state sector productivity inquiry, vol. 2. Wellington: New Zealand Productivity Commission.

New Zealand Tertiary Education Commission. (2006). *Performance-Based Research Fund Evaluating Research Excellence-The 2006 Assessment.* Retrieved from https://www.tec.govt.nz/assets/Reports/3f01ba2eba/PBRF-2006-quality-evaluation.pdf

New Zealand Tertiary Education Commission. (2019). *Improving Research Quality: The results of the PBRF 2018 Quality Evaluation*. Retrieved from: https://tec.govt.nz/assets/Publications-and-others/PBRF-2018/fd3f65348a/Improving-Research-Quality-The-results-of-the-PBRF-2018-Quality-Evaluation-12-09-2019.pdf

New Zealand Tertiary Education Commission. (2022). *Performance-Based Research Fund (PBRF) User Manual version 5.0: March 2022.* Retrieve Nov 9, 2024, from https://www.tec.govt.nz/assets/Publications-and-others/PBRF-Publications/PBRF-User-Manual-updated-February-2022.pdf

New Zealand Tertiary Education Commission. (2022). Performance-Based Research Fund. Retrieved from https://www.tec.govt.nz/funding/funding-and-performance/funding/fund-finder/performance-based-research-fund/

New Zealand Tertiary Education Commission. (2024a). *University Advisory Group established and PBRF Quality Evaluation 2026 cancelled.* Retrieve Nov 13, 2024, from https://www.tec.govt.nz/news-and-consultations/university-advisory-group-established-and-pbrf-quality-evaluation-2026-cancelled

New Zealand Tertiary Education Commission. (2024b). *Performance-Based Research Fund*. Retrieve Nov 15, 2024, from https://www.tec.govt.nz/funding/funding-and-performance/funding/fund-finder/pbrf

New Zealand Tertiary Education Commission. (2025). *Starting study in 2025?* Retrieve April 11, 2025, from https://www.feesfree.govt.nz/final-year/

New Zealand Qualifications Framework. (NZQF). (2016). *The New Zealand Qualifications Framework*. Retrieved from https://www.nzqa.govt.nz/assets/Studying-in-NZ/New-Zealand-Qualification-Framework/requirements-nzqf.pdf

Office of the Auditor-General. (2017). *Investing in tertiary education assets*. Wellington: Author.

OECD. (2010). Performance-Based funding for public research in tertiary education institutions, workshop proceedings. OECD: Paris.

OECD (2013), *Education at a Glance 2013: OECD Indicators*, OECD Publishing, Paris, https://doi.org/10.1787/eag-2013-en.

OECD. (2022, n.d.) *Unemployment rate*. Retrieved from https://data.oecd.org/unemp/unemployment-rate.htm

OECD. (2022). *Education at a Glance 2022: OECD Indicators. Chapter C. Financial resources invested in education, Table 1.2*. OECD. Retrieved Oct 10, 2023, from Indicator C1. How much is spent per student on educational institutions? | Education at a Glance 2022 : OECD Indicators | OECD iLibrary (oecd-ilibrary.org)

O'Donnell, C. J., & Coelli, T. J. (2005). A Bayesian approach to imposing curvature on distance functions. Journal of Econometrics, 126(2), 493-523. https://doi.org/10.1016/j.jeconom.2004.05.011

Olivares, M., & Wetzel, H. (2014). Competing in the higher education market: empirical evidence for economies of scale and scope in German higher education institutions. *CESifo Economic Studies*, *60*(4), 653-680. https://doi.org/10.1093/cesifo/ifu001

Open Universities Australia. (2025). *How do tertiary education fees work in Australia?* Retrieved Feb 24, 2025, from https://www.open.edu.au/advice/insights/tertiary-education-fees-in-australia

Pace, D., K. M. Blumreich, and H. B. Merkle. 2006. Increasing Collabouration between Student and Academic Affairs: Application of the Intergroup Dialogue Model. *NASPA Journal 43*(2), 301–315.

Parteka, A., & Wolszczak-Derlacz, J. (2013). Dynamics of productivity in higher education: Cross-European evidence based on bootstrapped Malmquist indices. *Journal of Productivity Analysis*, *40*(1), 67-82. https://doi.org/10.1007/s11123-012-0320-0

Paul, C. J. M., & Nehring, R. (2005). Product diversification, production systems, and economic performance in US agricultural production. *Journal of Econometrics*, *126*(2), 525-548. https://doi.org/10.1016/j.jeconom.2004.05.012

Pitt, M. M., & Lee, L.-F. (1981). The measurement and sources of technical inefficiency in the Indonesian weaving industry. *Journal of development economics*, *9*(1), 43-64.

QS TOP UNIVERSITIES. (2024). *QS World University Rankings 2024: Oceania*. Retrieved Sep 12, 2024, from https://www.qschina.cn/en/university-rankings/world-university-rankings/2024

Ray, S. C., & Desli, E. (1997). Productivity growth, technical progress, and efficiency change in industrialized countries: comment. *The American economic review, 87(5),* 1033-1039.

Research Assessment Exercise 2008. (2017). Submissions. Introduction to the RAE2008 submissions. Retrieved May 15, 2023. From https://webarchive.nationalarchives.gov.uk/ukgwa/20170914112138/http://www.rae.ac.uk/submissions/intro.aspx

Research Excellence Framework 2021. (2022). Guide to the REF results. Retrieved May 15, 2023, from https://ref.ac.uk/guidance-on-results/guidance-on-ref-2021-results/

Richmond, J. (1974). Estimating the efficiency of production. *International economic review*, 515-521.

RMIT University Annual Report. (2013). *RMIT University Annual Report 2013.* Retrieved Oct 17, 2024, from https://www.rmit.edu.au/about/governance-management/annual-reports

Robst, J. (2001). Cost efficiency in public higher education institutions. *The Journal of higher education, 72*(6), 730-750. https://doi.org/10.1080/00221546.2001.11777123

Royal Society of New Zealand. (2024). *Royal Society of New Zealand.* Retrieved Nov 9, 2024, from https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities/funding-agencies/royal-society-of-new-zealand

Salleh, M. I. (2012). *An empirical analysis of efficiency and productivity changes in Malaysian public higher education institutions*.

Santiago, P., Tremblay, K., Basri, E., & Arnal, E. (2008). *Tertiary education for the knowledge society (Vol. 1).* OECD Paris. http://bdigital.ula.ve/storage/pdf/cendes/v26n71/res.pdf

Sav, G. T. (2011). Cost Efficiencies and Rankings of Flagship Universities. *American Journal of Economics and Business Administration, 3*(4), 596.

Sav, G. T. (2012). Stochastic cost frontier and inefficiency estimates of public and private universities: does government matter? *International Advances in Economic Research, 18*(2), 187-198.

Sav, G. T. (2012a). Efficiency estimates and rankings employing data envelopment and stochastic frontier analyses: evaluating the management of US Public colleges. *Information Management and Business Review, 4*(8), 444.

Sav, G. T. (2012b). Frontier and envelopment evaluations of university graduation efficiencies and productivities: elements for performance-based funding. *Problems and Perspectives in Management, 4*(4), 71-79.

Sav, G. T. (2012c). Cost inefficiencies and rankings of Ivy Universities: Stochastic panel estimates. *International Journal of Economics and Finance, 4*(3), 3.

Sav, G. T. (2012d). Stochastic cost inefficiency estimates and rankings of public and private research and doctoral granting universities. *Journal of Knowledge Management, Economics, and Information Technology, 2*(3).

Sav, G. T. (2012e). Managing operating efficiencies of publicly owned universities: American university stochastic frontier estimates using panel data. *Advances in Management and Applied Economics, 2*(1), 1.

Sav, G. T. (2012f). Minority serving college and university cost efficiencies. *Journal of Social Sciences, 8*(1), 54.

Sav, G. T. (2012g). For-profit college entry and cost efficiency: Stochastic frontier estimates vs two-year public and non-profit colleges. *International Business Research, 5*(3), 26.

Sav, G. T. (2012h). Is the production of religious knowledge efficient? Managing faith related postsecondary institutions. *Journal of Knowledge Management, Economics, and Information Technology, 2*(1).

Sav, G. T. (2012i). Female Faculty, Tenure, and Student Graduation Success: Efficiency Implications for University Funding. *International Journal of Business Management & Economic Research*, *3*(6).

Sav, G. T. (2012j). Historically black college and university operating cost efficiencies: stochastic cost estimates and comparisons to predominately white institutions. *International Journal of Education Economics and Development*, *3*(3), 252-263.

Sav, G. T. (2012k). Does Faculty Tenure Improve Student Graduation Rates? *Journal of Business Management and Applied Economics*, *1*(5).

Sav, G. T. (2013). Private philanthropy in financing public universities: Fundraising stochastic frontier and efficiency evaluations. *International Research Journal of Finance and Economics*, *103*.

Sav, G. T. (2016). Declining state funding and efficiency effects on public higher education: Government really does matter. *International Advances in Economic Research 22:* 397-408.

Schmidt, P., & Sickles, R. C. (1984). Production frontiers and panel data. *Journal of Business & Economic Statistics*, *2*(4), 367-374.

Schneijderberg, C., & N. Merkator. (2013). The New Higher Education Professionals. In *Academic Profession in Europe: New Tasks and New Challenges*, edited by B. M. Kehm, and U. Teichler, 53–87. London: Springer.

Schreyer, P. & Koechlin, F. (2002). *Purchasing power parities – Measurement and uses*, Paris. Retrieved from: http://www.oecd.org/std/prices-ppp/2078177.pdf

Scott, C., Dickson, M., & Smart, W. (2015). *A comparison of delivery costs and tertiary education funding by field of study: Results and methodology.* Retrieved April 3, 2025, from https://www.educationcounts.govt.nz/__data/assets/pdf_file/0020/164054/A-Comparison-of-Delivery-Costs-and-Tertiary-Education-by-Field-of-Study.pdf

Scott (2020). Education and earnings, a New Zealand update. New Zealand Ministry of Education report, Retrieved from https://www.educationcounts.govt.nz/__data/assets/pdf_file/0006/198987/Education-and-Earnings-a-New-Zealand-update.pdf

Shephard, R. (1970). *Theory of Cost and Production Functions*. Princeton, New Jersey: Princeton University Press.

Simar, L., & Wilson, P. W. (1999). Estimating and bootstrapping Malmquist indices. *European journal of operational research*, *115*(3), 459-471.

Simar, L., & Wilson, P. W. (2007). Estimation and inference in two-stage, semi-parametric models of production processes. *Journal of Econometrics, 136*(1), 31-64. https://doi.org/10.1016/j.jeconom.2005.07.009

Smart, W. (2005). *An analysis of funding allocations for staff and research degree completions in the Performance-Based Research Fund.* Retrieved Nov 12, 2024, from https://www.educationcounts.govt.nz/__data/assets/pdf_file/0017/7307/an-analysis-of-funding-allocations-for-staff-and-r.pdf

Smart, W. (2009). *The measurement of the performance of New Zealand tertiary education institutions and the demand for their services.* (Doctor of Philosophy). Auckland University of Technology, Retrieved from https://openrepository.aut.ac.nz/bitstream/handle/10292/761/SmartW.pdf?sequence=4&isAllowed=y

Smart, W. (2009a). The impact of the performance-based research fund on the research productivity of New Zealand universities. *Social Policy Journal of New Zealand, 34*(1), 136-151.

Smart, W. & Engler R. (2013). *In Pursuit of Excellence: Analysing the results of New Zealand's PBRF Quality Evaluations (pdf).* Ministry of Education, Retrieved from: https://www.educationcounts.govt.nz/__data/assets/pdf_file/0013/122431/In-Pursuit-of-Excellence-Analysing-the-Results-of-NZ-PBRF-Quality-Evaluations.pdf

Smart, W. (2019a). *Government funding for research-led teaching and research performance: an analysis of PBRF and research top-ups funding allocations*. Ministry of Education, Retrieved from: https://www.educationcounts.govt.nz/__data/assets/pdf_file/0008/195893/Research-funding-report-2019-final.pdf

Stevens, P. A. (2004). Accounting for Background Variables in Stochastic Frontiers Analysis: National Institute of Economic and Social Research.

Stevens, P. A. (2005). A stochastic frontier analysis of English and Welsh universities. *Education Economics, 13*(4), 355-374. https://doi.org/10.1080/09645290500251581

Stevenson, R. E. (1980). Likelihood functions for generalised stochastic frontier estimation. *Journal of Econometrics*, *13*(1), 57-66.

Studylink for Providers. (n.d.) Glossary. Student Achievement Component (SAC) funding. Retrieve Oct 16, 2024, from https://www.providers.studylink.govt.nz/about/glossary/sac-funding.html#:~:text=SAC%20funding%20is%20the%20Government's,TEO)%20receives%20through%20Investment%20Plans.

Sutherland, K. A. (2018). Cultivating connectedness and generosity in universities: A view of early career academic experiences in Aotearoa, New Zealand.

Szekeres, J. (2006). General staff experiences in the corporate university. *Journal of Higher Education Policy and Management*, *28(2)*, 133–145. https://doi.org/10.1080/13600800600750962

Szekeres, J. (2011). Professional staff carve out a new space. *Journal of Higher Education Policy and Management*, *33(6)*, 679–691. https://doi.org/10.1080/1360080X.2011.621193

Tertiary Education Union. (2024). *Bye bye PBRF*. Retrieved Sep 4, 2025, from Bye bye PBRF | Tertiary Education Union – Te Hautū Kahurangi o Aotearoa

Times Higher Education. (2024a). World University Rankings 2024. New Zealand. Retrieved Sep 18, 2024, from https://www.timeshighereducation.com/world-university-rankings/2024/world-ranking#!/length/25/locations/NZL/sort_by/rank/sort_order/asc/cols/stats

Times Higher Education. (2024b). World University Rankings 2024. Australia. Retrieved Sep 18, 2024, from https://www.timeshighereducation.com/world-university-rankings/2024/world-ranking#!/length/25/locations/AUS/sort_by/rank/sort_order/asc/cols/stats

Thursby, J. G., & Kemp, S. (2002). Growth and productive efficiency of university intellectual property licensing. *Research Policy, 31*(1), 109-124. https://doi.org/10.1016/S0048-7333(00)00160-8

Titus, M. A., & Eagan, K. (2016). Examining production efficiency in higher education: The utility of stochastic frontier analysis. *Higher education: Handbook of theory and research*, 441-512.

Titus, M. A., Vamosiu, A., & McClure, K. R. (2017). Are public master's institutions cost efficient? A stochastic frontier and spatial analysis. *Research in higher education*, *58*, 469-496. https://doi.org/10.1007/s11162-016-9434-y

Tran, C.-D. T. T. (2021). Cost efficiency–one size fits all? A university-level analysis of economies of scale and scope in Vietnamese higher education. *Asia Pacific Journal of Education*, *41*(2), 336-355. https://doi.org/10.1080/02188791.2020.1735996

Tyagi, P., Yadav, S. P., & Singh, S. (2009). Relative performance of academic departments using DEA with sensitivity analysis. *Evaluation and Program Planning*, *32*(2), 168-177. https://doi.org/10.1016/j.evalprogplan.2008.10.002

Universities Australia. (n.d.). *The Demand Driven System*. Retrieved Feb 23, 2025, from https://universitiesaustralia.edu.au/policy-submissions/diversity-equity/the-demand-driven-system/

Universities Australia. (n.d.a). *How universities are funded.* Retrieved Feb 23, 2025, from https://universitiesaustralia.edu.au/policy-submissions/teaching-learning-funding/how-universities-are-funded/

University Grants Committee. (2013). *Research Assessment Exercise 2014. Guidance Notes (Janauary 2013).* Retrieve Feb 23, 2025, from https://www.ugc.edu.hk/doc/eng/ugc/rae/gn_201301.pdf

University Grants Committee. (2017). *Framework for RAE 2020*. Retrieve May 15, 2023, from https://www.ugc.edu.hk/doc/eng/ugc/rae/2020/framework.pdf

University of Auckland. (2018). *Annual report 2018*. Retrieved Sep 5, 2023, from https://cdn.auckland.ac.nz/assets/auckland/about-us/the-university/official-publications/annual-report/annual-report-2018.pdf

University of Auckland. (2019). *Annual report 2019*. Retrieved Mar 10, 2023, from https://cdn.auckland.ac.nz/assets/auckland/about-us/the-university/official-publications/annual-report/annual-report-2019-web.pdf.

University of Canterbury. (2012). *Annual report 2012*. Retrieved Dec 23, 2024, from https://www.canterbury.ac.nz/content/dam/uoc-main-site/documents/pdfs/reports/Annual-Report-2012-UC.pdf

Universities New Zealand. (2023). *From the Chair: the time is right for a review into higher education funding*. Retrieved Oct 10, 2023, from https://www.universitiesnz.ac.nz/latest-news-and-publications/chair-time-right-review-higher-education-funding%C2%A0

Universities New Zealand. (2024). *New Zealand universities shine in latest international rankings.* Retrieved Nov 12, 2024, from https://www.universitiesnz.ac.nz/latest-news-and-publications/new-zealand-universities-shine-latest-international-rankings

Universities New Zealand. (2025). *Briefing to the Incoming Minister for Universities.* Retrieved April 2, 2025, from https://www.universitiesnz.ac.nz/sites/default/files/uni-nz/Briefing%20for%20the%20Incoming%20Minister%20of%20Universities%20January%202025.pdf

Universities New Zealand. (n.d). Growing New Zealand's economy. Retrieved Oct 10, 2023, from https://www.universitiesnz.ac.nz/sector-research/growing-new-zealand-economy

Universities New Zealand. (n.d.1). *University of Auckland.* Retrieved Nov 1, 2022, from https://www.universitiesnz.ac.nz/universities/university-auckland

Universities New Zealand. (n.d.2). *University research*. Retrieved Nov 13, 2022, from https://www.universitiesnz.ac.nz/about-university-sector/university-research

Universities New Zealand. (n.d.3). *University of Otago.* Retrieved Nov 1, 2022, from https://www.universitiesnz.ac.nz/universities/university-otago

Universities New Zealand. (n.d.4). *Victoria University of Wellington*. Retrieved May 13, 2023, from https://www.universitiesnz.ac.nz/universities/te-herenga-waka%E2%80%94victoria-university-wellington

Universities New Zealand. (n.d.5). *AUT*. Retrieved May 13, 2023, from https://www.universitiesnz.ac.nz/universities/aut

Universities New Zealand. (n.d. 6). *About the university sector.* Retrieved Feb 26, 2024, from https://www.universitiesnz.ac.nz/about-university-sector

Universities New Zealand. (n.d.7). *University of Canterbury*. Retrieved Sep 3, 2024, from https://www.universitiesnz.ac.nz/universities/university-canterbury

Universities New Zealand. (n.d.8). *Lincoln University*. Retrieved May 11, 2024, from https://www.universitiesnz.ac.nz/universities/lincoln-university

University of Otago. (2018). *University of Otago Annual Report 2018*. Retrieved Sep 3, 2023, from https://www.otago.ac.nz/about/official-documents/otago710847.pdf

University of Otago. (2022). *University of Otago Annual Report 2022.* Retrieved Mar 6, 2025, from https://www.otago.ac.nz/__data/assets/pdf_file/0015/320118/download-the-university-of-otago-annual-report-2022-0244376.pdf

University of the Sunshine Coast Australia. (2024). *Research Output Reporting. Information on UniSC reportable publication schemes. Field of Research (FoR) Codes.* Retrieved Dec 23, 2024, from https://libguides.usc.edu.au/HERDC-ERA/FoR-codes

University of Technology Sydney. (2018). *UTS Annual Report 2018.* Retrieved Sep 2, 2025, from https://utsd8.prod.acquia-sites.com/sites/default/files/2019-06/gsu-aboututs-utsannualreport-2018-vol1_0.pdf

University of Waikato. (n.d.). *Academic workloads guidelines. Resource document.* Retrieved Mar 20, 2024, from https://www.waikato.ac.nz/official-info/index/docs/academicworkloadsguidelines.

University of Waikato. (n.d.1). *Zhejiang University City College (ZUCC) Partnership*. Retrieved Oct 20th, 2022, from https://www.waikato.ac.nz/international/partnerships/zhejiang-university-city-college

University of Waikato. (n.d.2). *Offshore programmes*. Retrieved Oct 20th, 2022, from https://www.waikato.ac.nz/international/partnerships/offshore-programmes

Veles, N., Graham, C., & Ovaska, C. (2023). University professional staff roles, identities, and spaces of interaction: systematic review of literature published in 2000–2020. *Policy Reviews in Higher Education*, *7*(2), 127-168. https://doi.org/10.1080/23322969.2023.2193826

Wang, C.-N., Tibo, H., Nguyen, V. T., & Duong, D. H. (2020). Effects of the Performance-Based Research Fund and Other Factors on the Efficiency of New Zealand Universities: A Malmquist Productivity Approach. *Sustainability*, *12*(15). https://doi.org/10.3390/su12155939

Wang, H.-J., & Schmidt, P. (2002). One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels. *Journal of Productivity Analysis*, *18*, 129-144. https://doi.org/10.1023/A:1016565719882

Whitchurch, C. (2008). Shifting Identities and Blurring Boundaries: The Emergence of Third Space Professionals in UK Higher Education. *Higher Education Quarterly 62*, 377–96. https://doi.org/10.1111/j.1468-2273.2008.00387.x

Wikipedia. (2024). *University of Auckland.* Retrieved Dec 8, 2024, from https://en.wikipedia.org/wiki/University_of_Auckland

Wikipedia. (2025). *Course credit*. Retrieved April 2, 2025, from Course credit - Wikipedia

Winston, C. (1957). Discussion on Mr. Farrell's paper. *Journal of the Royal Statistical Society, 120*(3), 282-284.

Witte, K. D., & López-Torres, L. (2017). Efficiency in education: a review of literature and a way forward. *Journal of the Operational Research Society*, *68*(4), 339-363. https://doi.org/10.1057/jors.2015.92

Worthington, A. C. (2001). An empirical survey of frontier efficiency measurement techniques in education. *Education Economics, 9*(3), 245-268. https://doi.org/10.1080/09645290110086126

Worthington, A. C., & Higgs, H. (2008). An empirical note on factor price elasticities and substitution in Australian higher education. *Available at SSRN 1313527*.

Worthington, A. C., & Lee, B. L. (2008). Efficiency, technology and productivity change in Australian universities, 1998–2003. *Economics of Education review*, *27*(3), 285-298. https://doi.org/10.1016/j.econedurev.2006.09.012

Worthington, A. C., & Higgs, H. (2011). Economies of scale and scope in Australian higher education. *Higher education*, *61*(4), 387-414. https://doi.org/10.1007/s10734-010-9337-3

Yaisawarng, S., & Ng, Y. C. (2014). The impact of higher education reform on research performance of Chinese universities. *China Economic Review*, *31*, 94-105. https://doi.org/10.1016/j.chieco.2014.08.006

York, J. (2010). *The Devil is in the Details: demonstrating the impact of measurement choices on inputs to government sector productivity.* Paper presented at the 51st conference of the New Zealand Association of Economists, Auckland.

Zhang, L., Bao, W., & Sun, L. (2016). Resources and research production in higher education: A longitudinal analysis of Chinese universities, 2000–2010. *Research in higher education*, *57*, 869-891. https://doi.org/10.1007/s11162-016-9410-6

Zhang, L.-C., Syu, J.-J., & Worthington, A. (2014). Scope economies in Australian distance education.

Zoghbi, A. C., Rocha, F., & Mattos, E. (2013). Education production efficiency: Evidence from Brazilian universities. Economic Modelling, 31, 94-103. https://doi.org/10.1016/j.econmod.2012.11.018

Appendix Chapter 3

Table A3.1

Summary of Findings from Previous Studies: Application of Malmquist Productivity Index

Studies	Countries	Data & Years	Method	Input/Price	Output	Main Findings
Margaritis and Smart (2011)	New Zealand & Australia	36 AUS & 8 NZ universities for 1997-2005	DEA-Malmquist index	(1) Academic FTE (2) General FTE (3) Non-labour operating expenditure (4) EFTS	(1) Number of indexed articles and reviews listed on the WoS lagged by one year and (2) Undergraduate completions (3) Postgraduate completions	The main driver of productivity growth in Australian universities was improved technology, while New Zealand universities were efficient. The introduction of the PBRF stimulated productivity improvement.
Wang, Tibo, Nguyen and Duong (2020)	New Zealand	8 NZ universities for 2013-2018	Malmquist index	(1) Academic staff (2) Non-academic staff (3) Total enrolment	(1) Degree graduates (2) Postgraduate graduates (3) Total graduates (4) Operating revenue	The MPI increased by an annual average of 0.6%, with only five universities achieving a productivity score 1. The universities have made little progress in efficiency and technological change.
Flegg, Allen, Field and Thurlow (2004)	Britain	45 British universities in the period 1980/81–1992/93.	DEA and Malmquist index	(1) Academic staff (2) UG EFTS (3) PG EFTS (4) aggregate departmental expenditure	(1) Research and consultancy income (2) UG completions, adjusted for the proportion of first-class honours completion to UG students (3) PG completions	TFP increased by 51.5%, mainly driven by frontier technology, which improved by 39.1%. Financial and managerial reforms introduced in the 1980s contributed significantly to these improvements.
Carrington, Coelli and Rao (2005)	Australia	35 Australian universities from 1996 to 2000	DEA and Malmquist index	(1) Operating costs	(1) Science EFTS (2) Non-science EFTS (3) Research higher degree EFTS (4) non-research higher degree EFTS (5)	Australian university's productivity growth averaged 1.8% per year, due to an average annual technical change of 2.1%, an average annual technical efficiency declines of

					Completions (6) weighted publications (7) research income	0.7%, and an average annual scale efficiency improvement of 0.4%. Data quality and differences could affect the university's performance.
Johnes (2006a)	England	113 English HEIs from 1996/97 to 2002/03	DEA and Malmquist index	(1) Academic FTE (2) Depreciation costs and interest payable (3) First degree and other UG EFTS (4) PG EFTS	(1) First-degree and other UG qualifications awarded (2) PG qualifications awarded (3) Research income	HEIs experienced an average annual productivity growth of 1.5%, driven by a 2.3% increase in technology, though offset by a 0.8% decline in technical efficiency.
Castano and Cabanda (2007)	Philippine	30 Philippine Private HEIs for 1999-2003	DEA and Malmquist index and SFA	(1) Faculty FTE (2) Property, Plant and Equipment (3) operating expenses	(1) EFTS (2) Graduates (3) Total revenue	Higher technological progress boosted the productivity growth of the majority of institutions.
Worthington and Lee (2008)	Australia	35 Austrian universities for 1998-2003	Malmquist index	(1) Academic FTE (2) Non-academic FTE (3) Non-labour input expenditures (4) UG EFTS (5) PG EFTS	(1) UG completions (2) PG completions (3) PhD completions (4) National competitive grants (5) Industry grants (6) Weighted publications points	Annual productivity growth averaged 3.3%, driven by technological progress. Research productivity grew faster than teaching productivity, with research gains from efficiency improvements and teaching productivity boosted by technology and capital investments.
Johnes (2008)	England	112 English HEIs from 1996/97 to 2004/05	DEA and Malmquist index	(1) Academic FTE (2) Administrative and service expenditure (3) Centralised academic services expenditure (4) First degree and other UG EFTS (5) PG EFTS	(1) First-degree and other UG qualifications awarded (2) PG qualifications awarded (3) Research income	HEIs experienced an average annual productivity growth of 1%, driven by a 6% increase in technology, offset by a 5% decline in technical efficiency. Rapid changes in the higher education sector positively affect production technology, but these are achieved at the cost of lower technical efficiency.

Agasisti and Bianco (2009)	Italy	74 Italian universities from 1998/99 to 2003/04	DEA and Malmquist index	(1) Total number of enrolments with a score higher than 9/10 in secondary school (2) Total number of places available in teaching rooms, libraries and laboratories (3) Total students (4) Academic FTE	(1) Total number of graduates (2) Total number of graduates in four- or five-year courses	Although teaching reforms initially led to worse performance in the first year, productivity improved more rapidly in subsequent years. While the results indicate performance improvements, better analysis of unobservable factors (e.g., quality) and longer observation periods will stabilise these preliminary results.
Agasisti and Johnes (2009)	England and Italy	127 English institutions and 57 public Italian universities in 2002-2005	DEA and Malmquist index	(1) Total students (2) Total incomes (3) PhD students (4) Academic staff (5) Public direct funds	(1) Bachelor graduates (2) Master graduates (3) External research	Institutions in both countries typically performed the intra-country analysis with an average efficiency score above 0.8. English institutions were more efficient than those in Italy. Technical efficiency improved at Italian universities, while technology improved at English universities.
Kempkes and Pohl (2010)	Germany	72 German public universities in 1998-2003	DEA-Malmquist index and SFA	(1) Technical FTE (2) Research FTE (3) Current expenditure (total expenditure minus wage spending)	(1) Graduates (2) Research grants	German universities' faculty composition (e.g., engineering or/and medical) proves to be an essential element in the efficiency of higher education. Universities in East Germany outperformed West Germany in terms of TFP change. But West German universities continued to rank at the top of relative efficiency results based on their mean efficiency scores.
Agasisti and Pohl (2012)	Germany and Italy	69 German and 53 Italian public universities in 2001-2007	DEA and Malmquist index	(1) Enrolled students (2) Academic staff (3) Expenditures including professors’ salaries	(1) Degrees awarded (2) External research grants and contracts	Compared university efficiency in Germany and Italy using within-country and cross-country analyses. The TFP change was 1.57 overall, with Italy at 1.7 and

						Germany at 1.5. Most TFP growth was driven by substantial technical change, with only a minor contribution from efficiency change.
Parteka and Wolszczak-Derlacz (2013)	universities in EU and Non-EU country (across-country)	266 public HEIs in 7 EU (9 Austria, 15 Finland, 67 Germany, 54 Italy, 31 Poland and 79 UK), and non-EU (11 Switzerland) in 2001-2005	Bootstrapped DEA and Malmquist index	(1) Registered students (2) Academic FTE (3) Total revenues	(1) WoS Publications (2) Graduates	Productivity at HEIs increased by an average of 4% annually, with notable differences across countries. German, Italian and Swiss HEIs performed better regarding productivity change than those in other countries examined.
Sav (2012b)	US	198 private and 216 public universities in 2005-2009	DEA-Malmquist index and SFA	(1) UG enrolment (2) % of students enrolled on government funded low-income grants (3) total graduates (4) total no. of faculty employed (5) average faculty salary (6) Research revenue per faculty member (7) % of faculty that are tenured (8) % of faculty that are employed in non-tenure track positions (9) Expenditures on student support services per UG students (10) Expenditure on academic support per faculty member	UG graduation rate	Overall productivity erosion for private and public universities, partially due to declines in managerial efficiencies and technological changes. Total productivity regress is not substantially different in two sectors and all universities are moving toward productivity gain territory despite the underlying burdens imposed by the financial crisis.

Yaisawarng and Ng (2014)	China	423 Chinese universities in 2007-2009	Meta-frontier and Malmquist indexes	(1) Research staff (2) non-staff related research expenditure (3) the prior year's university rank	(1) Published books (2) International articles (3) Domestic articles (4) Research grants	Meta-frontier analysis revealed that Project 211 universities, on average, outperformed the non-Project 211 group due to managerial inefficiency. Malmquist index analysis showed that Project 211 universities experienced more productivity regress than non-Project 211 universities.
Bolli and Farsi (2015)	Swiss	103 university departments distributed over 12 Swiss universities in 1995-2012	Malmquist index	(1) Professors (2) Lectures (3) Assistants (4) Admins and technical staff (5) Department's non-labour expenditure	(1) Enrolments (2) Research grants (3) other external funds	There has been a negative trend in the Malmquist index since 2002, with an average decline of 1% per year. But this decline is more or less offset by universities' constant expansion and the resulting economies of scale. Productivity changes varied across scientific fields, reflecting potential gains from scale economies.
Barra and Zotti (2016)	Italy	ONE Italian public university (University of Salerno) classified 1) the Humanity and Social Science sector (18 departments and 6 faculties) 2) Science and Technology sector (10	Bootstrapped DEA and Malmquist index	(1) Aggregate equivalent personnel = 1*professors + 0.8*associate professors + 0.6*researchers + 0.4*assistant professors +0.2*non-academic staff (2) Expenses for research	Model 1: (1) Aggregate number of publications = 1*articles in international journals + 0.75*articular in national journals + 0.5*articles in international books + 0.25*articles in national books. Model 2: (2) funds for research. Model 3: (3) Research productivity index (4) Capacity of attracting resources index (5)	The Science and Technology sector demonstrates higher efficiency in the quality of research, while the Humanity and Social Science sector performs better in teaching. Efficiency estimates are affected by output specifications, including quality proxies, such as research indexes and student-questionnaire-based teaching alternative indexes, reducing performance and its differentials for both teaching and research activities.

		departments and 3 faculties) in 2005-2009			research productivity per cost of the academic staff index	
Agasisti and Wolszczak-Derlacz (2016)	Polish and Italy	54 Italian and 30 Polish state universities in 2001-11	DEA and Malmquist index	(1) Expenditure (2) Academic staff	(1) WoS Publications (2) Graduates (3) PhD degrees awarded	A significant heterogeneity in efficiency scores within each country exceeds the difference in average efficiency scores between them. Efficiency is affected by the structure of a university's revenues and academic staff: competitive vs. non-competitive resources, and the professor numbers. Changes in pure efficiency were similar between the two countries; the efficiency frontier improved more in Italy than in Poland.
Moradi-Motlagh, Jubb and Houghton (2016)	Australia	37 Austrian universities from 2007 to 2013	Bootstrapped DEA and Malmquist index	(1) Total expenses	(1) EFTS (2) Total weighted Publications	An average productivity growth of 15.7% (2.6% annually) ranged from -4.3% to 51.3%. Technological progress primarily drove this growth, with individual university efficiency improvements being negligible.
Edvardsen, Førsund and Kittelsen (2017)	Norwegian	49 Norwegian HEIs in 2004-2013	Malmquist index	(1) Faculty employees (2) Administration and other employees	(1) Cost weighed study points for courses of a lower degree (2) Cost weighed study points for courses of a higher degree (3) Publication points (4) Doctorates	Most institutions experienced positive productivity growth over the total period. The impact on productivity varied significantly when compared with growth in labour input.

Andersson and Sund (2022)	Nordic (across-country)	68 Nordic HEIs (27 Sweden, 8 Denmark, 16 Norway, 13 Finland, 3 Iceland, 1 Faroe Islands) between 2011 and 2016	Bootstrapped DEA and Malmquist index	(1) Teaching and/or research FTEs (2) other FTEs (3) UG and graduate EFTS (adjusted for differences in prerequisites) (4) Doctoral EFTS (5) Office space in square meters	(1) Number of ECTS-credits (European Credit Transfer and Accumulation System) (adjusted for cost differences based on the varying educational mix between HEIs) (2) Number of PhD degrees (3) Publications (4) Highly cited publications	A positive yearly average productivity development of 0.4% for all included HEIs was found from 2011 to 2016. Swedish HEIs had slightly below-average growth at 0.3%. Danish and Finnish HEIs showed the highest productivity improvement, averaging around 2% per year.

Table A3.2
Literature Summary from Previous Studies: Application of Stochastic Frontier Analyses (incl. Production/Distance/Cost Functions)

Studies	**Countries**	**Efficiency Type**	**Function Type**	**Functional Form**	**Data & Years**	**Methodology**	**Variables**	**Variables used to Inefficiency Effect Model Battese and Coelli (1995)**
Chapple, Lockett, Siegel, and Wright (2005)	UK	Technical Efficiency	Production Function	Cobb-Douglas and Translog	50 U.K. universities in 2001	DEA and SFA	Outputs: (1) Number of licences or (2) License income (£). Inputs: (1) Invention disclosures or total research income (2) Number of technology transfer offices (TTO) staff (3) External legal IP expenditure	(1) Dummy for presence of a medical school (2) Age of TTO (3) Regional GDP (4) Regional R&D intensity
Castano and Cabanda (2007)	Philippine	Technical Efficiency	Production Function	Translog	30 Philippine Private Higher Educational Institutions for 1999-2003	DEA and Malmquist index and SFA	Outputs: (1) EFTS (2) Graduates (3) Total revenue Inputs: (1) Faculty FTE (2) Capital cost: the value of Property, Plant and Equipment (3) operating expenses	(1) Number of operating years of the institutions (2) Institution's ownership structure (3) Autonomous status dummy
Abbott and Doucouliagos (2009)	New Zealand and Australia	Technical Efficiency	Output Distance Function	Cobb-Douglas and Translog	36 Australian public universities in 1995-2002 and cross-sections data of 7 New Zealand universities (exclude AUT) in 1997-2003	SFA	Outputs: (1) A weighted index of research outputs (books (0.4), book chapter (0.2); journal articles (0.3); other (0.1)). Inputs: (1) PG EFTS (2) UG EFTS (3) Academic FTE staff (4) Non-academic FTE staff (5) Time trend.	(1) The proportion of overseas students (2) Dawkins universities dummy (3) The ratio of general to academic staff (4) The proportion of senior administrators (5) The proportion of senior academic staff (6) The number of undergraduate program offerings (7) Time trend

Sav (2012i)	U.S.	Technical Efficiency	Production Function	Cobb-Douglas	199 U.S. public universities in 2005-09	SFA	Outputs: (1) Graduation rates. Inputs: (1) Aptitude: Student admission test score (2) Retention: Student fail to fall semester return enrolment (3) Grants: student financial aid from low-income government provided grants (4) UG enrolments (5) UG female enrolments (6) Student service expenditures per UG student (7) Master enrolment (8) % of total expenditure devoted to research (9) Faculty employment (10) Faculty academic salary (11) Time trend	(1) Female % of tenured faculty (2) Female % of tenure track faculty (3) female % of non-tenure track faculty (4) female % of administrative faculty (5) Time trend
Sav (2012k)	U.S.	Technical Efficiency	Production Function	Cobb-Douglas	318 U.S. public universities in 2005-09	SFA	Outputs: (1) Graduation rates. Inputs: (1) Aptitude: Student admission test score (2) Retention: Student fail to fall semester return enrolment (3) Grants: student financial aid from low-income government provided grants (4) UG enrolments (5) FTE graduate enrolment (6) Expenditure per student-on-student service (7) University provided grants and	(1) % of tenured faculty (2) % of tenure track faculty (3) % of non-tenure track faculty (4) Average faculty salary

							scholarships per student (8) % of total expenditure devoted to research (9) total university faculty (10) Time trend	
Sav (2013)	U.S	Technical Efficiency	Production Function	Cobb-Douglas	353 U.S. public universities in 2006-09	SFA	Outputs: (1) Private Gifts revenue. Inputs: (1) UG university enrolment (2) Graduate student enrolled (3) Research grants (4) % of total funding from state and local governments (5) Endowment fund $ (6) Capital costs: Art collection and equipment $ (7) Faculty FTE employed (8) Professional staff (9) Executives employed (10) Time trend	(1) Medical school dummy (2) Hospital dummy (3) both medical and hospital dummy (4) Carnegie classified as research-doctoral (5) no. of executive employed (6) Time trend
Zoghbi, Rocha and Mattos (2013)	Brazil	Technical Efficiency	Production Function	Linear and Cobb-Douglas	164 Brazilian universities, including 88 private HEI, and 76 public HEI in 2007	SFA	Outputs: (1) The difference between the scores of last-year and first-year students in ENADE 2007 (Exam National Examination of Performance Evaluation of Student--ENADE). Inputs: (1) Number of professors per enrolled students (2) Capital cost: Number of computers per enrolled student (3) Complete teaching plan of the HEI (%) (4) Dropout rates (5) North Region (6) Northeast	(1) Average income of the state where the university is located (2) average years of schooling in the state where the university is located (3) Student working 20h or more (%) (4) Non-white students (%) (5) Mothers with higher education (%) (6) students' average age (7) Female students (%)

							Region (7) South Region (8) Midwest Region	
Laureti, Secondi and Biggeri (2014)	Italy	Technical Efficiency	Production Function	Translog	9 subjects of study in 59 Italian State universities from 2003/04 to 2006/07	SFA	Output: (1) no. of graduates. Inputs: (1) Teaching FTE staff (2) UG enrolments (freshmen) (3) Capital cost: no. of seats in lecture halls (4) Capital cost: no. of seats in the computer laboratories (5) Capital cost: no. of books and scientific journals in libraries. (6) Time trend.	(1) % of female freshmen (2) % of best freshmen (with the best results of secondary school leaving examination, e.g., a final mark greater or equal 90/100 (3) % of freshmen with lyceum diplomas (4) % of freshmen aged over 22 (5) % of freshmen from areas other than the university region (6) average final degree mark that ranges from a minimum of 66 to a maximum of 110 (7) GDP per capita (8) no. of students enrolled (9) time trend
Bolli and Farsi (2015)	Swiss	Technical Efficiency	Input Distance Function	Translog	103 university departments over 12 Swiss universities in 1995-2012	SFA	Output: (1) Number of professors. Inputs: (1) Enrolments (2) Swiss National Science Foundation (SNSF) External Research grants (3) Other external funds (4) Lectures (5) Assistants (6) Admins and technical staff (7) Capital cost:	(1) International openness: Share of foreign students (2) Bologna penetration: Share of Bologna degrees

							Department's Non-labour expenditure	
Bolli, et al. (2016)	European countries	Technical Efficiency	Output Distance Function	Translog	263 universities across 8 European countries (Across-country)	SFA	Outputs: (1) Number of ISI publications. Inputs: (1) Enrolled students (2) Professors and assistant professors (3) Other research staff (4) Technical and administrative staff (5) – (13) year dummies 1995-2003 (14) Budget share of international public funds (15) Budget share of international public funds squared (16) Budget share of private funds (17) Budget share of private funds squared (18) Budget share of tuition fees (19) Budget share of tuition fees squared	(1) Yearly country average of budget share of international public funds (2) Yearly country average of budget share of international public funds squared (3) Yearly country average of budget share of private funds (4) Yearly country average of budget share of private funds squared (5) Yearly country average of budget share of tuition fees (6) Yearly country average of budget share of tuition fees squared
Agasisti, Barra and Zotti (2016)	Italy	Technical Efficiency	Output Distance Function	Cobb-Douglas and Translog	53 Italian public universities from 2008-2011	SFA	Output: (1) Number of graduates weighted by their degree classification. Inputs: (1) Research grants (2) Weighted number of the academic and non-academic staff (3) Total number of students weighted by the % of enrolments with a score higher than 9/10 in secondary school	(1) Market share (the ratio between the number of enrolments at university i and the total number of enrolments in the universities located in the same region) (2) Market share squared (3) Added value per capita (equivalent to GDP per capita) (4) undergraduates students fees per student

Barra, Lagravinese and Zotti (2018)	Italy	Technical Efficiency	Output Distance Function	Cobb-Douglas and Translog	53 Italian public universities from 2008-2011	SFA and DEA	Output: (1) Number of graduates weighted by their degree classification. Inputs: (1) Research grants (2) Number of academic staff (3) The % of enrolments with a score higher than 9/10 in secondary school (4) The % of enrolments who attended a lyceum (a non-vocational secondary school) (5) Total number of students	(1) Medical school (2) Fees per student (3) Market share (the ratio between the number of enrolments at university i and the total number of enrolments in the universities located in the same region) (4) Market share squared (5) the year of foundation of university (6) number of females among students (7') Financial Development 1--aggregate private credits/GDP) (7'') Financial Development 2--aggregate private deposits/GDP)
Letti, Bittencourt and Vila (2022)	Brazil	Technical Efficiency	Output Distance Function	Translog	56 Brazilian federal universities in 2010-2016	SFA and DEA	Output: (1) UG degrees. Inputs: (1) PG degrees (2) Quality index of PG programmes (3) No. of professors engaged in third mission activities (4) No. of registered patents (5) Current costs (with 35% of university hospital expenditures, excl. expenditures on pensions, judicial sentences, not active staff) (6) FTE professors (7) Total FTE (excl. professors and	(8) – (11) input variables (12) % of student's degrees by enrolled students (13) Index of student's participation (14) % of EFTS by FTE professors (15) % of EFTS by FTE employees (16) Index related to professor qualifications (17) % of FTE employees by FTE professors

							contract employees) (8) A fixed-HEI dummy variable with the existence of university hospital (9) Year variables (10) A fixed-HEI dummy variable relative to the year of federalization of the HEI (11) Region dummy variable	
Stevens (2005)	England and Welsh	Cost Efficiency	Cost Function	Translog	80 English and Welsh universities over four years (1995/96-1998/99)	SCFA	Cost: Total expenditure. Outputs: (1) Science UG students (2) Arts UG students (3) PG students (4) Research Income. Inputs: (1) Labour Input price: Average staff costs (2) Average A-level score (3) Proportion of first and upper-second class	(1) Proportion of staff aged > 50 years (2) Proportion of female staff (3) Proportion of non-white staff (4) Proportion of professors (5) Proportion of senior lecturers (6) Proportion of RAE (research) active staff (7) Proportion of students aged > 25 years (8) Proportion of female students (9) Proportion of non-white students (10) Proportion of students from lower classes (11) Proportion of students from other EU (12) Proportion of non-EU students (13) Proportion of arts students

McMillan and Chan (2006)	Canada	Cost Efficiency	Cost Function	Translog	45 Canadian universities in 1992-93	SCFA and DEA	Cost: Total operating expenditure and sponsor research expenditure. Outputs: (1) Science UG EFTS enrolments (2) Other UG EFTS (3) Master's EFTS (4) Doctorates EFTS (5) Total sponsored research expenditure Input: (1) Labour Input price: Average salary and benefit for faculty (2) Number of active SSHRC & CC grants as % of eligible faculty (3) Number of active MRC & NSERC grants as % of eligible faculty (4) Proportion of faculty eligible for MRC and/or NSERC (5) Dummy variable for no PhD programmes	(1) Total student enrolment in universities within 200km (2) UG EFTS enrolment per UG degree awarded (3) Part-time student enrolment divided by total student enrolment (4) Proportion of 3rd and 4th year classes with less than 26 students (5) Herfindahl index for specialisation among programmes (6) % change in total enrolment 1990/91 to 1992/93 (7) % change in total revenue 1989/90 to 1992/93 (8) Total EFTS enrolment
Kuo and Ho (2008)	Taiwan	Cost Efficiency	Cost Function	Translog	34 public Taiwan universities over 1992-2000	SCFA	Cost: Total current expenditure. Outputs: (1) UG enrolments (2) Graduate enrolments (3) Research expenditure. Input: (1) Labour Input price: Faculty salaries (2) Year time trend (3) Dummy for master's program (4) Dummy for doctorate program (5) Dummy for research activity (6) Diversity of	(1) Total enrolment (2) Year trend (3) Dummy for adopting University operation fund (UFO)

							academic field (7) Engineering and science orientation	
Kempkes and Pohl (2008)	Germany	Cost Efficiency	Cost Function	Translog	67 German public universities for the years 1998-2003	SCFA	Cost: Total costs minus third-party funds (research income) per student. Outputs:(1) Third-party funds per student (2) Number of graduates per student. Inputs: (1) Labour Input price: Average staff costs (2) Faculty composition: % of Medicine staff to total staff (3) % of science staff to total staff (4) %of Engineering staff to total staff (5) % of social staff to total staff	(1) "Bestlaw" Dummy variable: a university is located in a state with liberal state university regulation (2) "Worstlaw" Dummy variable: a university is located in a state with restrictive state university regulation (3) "East" location Dummy variable: a university is located in the Eastern states (4) "Applied" sciences degree graduates: the share of graduates who have been awarded degrees of the "university of applied sciences" status (5) "Cohort": the share of population aged 18-35 at the state level
Kempkes and Pohl (2010)	Germany	Cost Efficiency	Cost Function	Translog	72 public German universities in 1998-2003	SCFA and Malmquist Index	Cost: Total costs minus third-party funds (research income) per student. Outputs: (1) Research grants per student (2) Final degrees completed per student. Inputs: (1) Labour Input price: Wage spending per university	(1) Time trend (2) Regional GDP per capita

							employee (2) Medical faculty dummy variable (3) Engineering faculty dummy variable (4) Time trend	
Daghbashyan (2011)	Swedish	Cost Efficiency	Cost Function	Cobb-Douglas	30 Swedish universities from 2001-2005	SCFA	Cost: Total costs. Outputs: (1) Research expenditure (2) Medicine UG EFTS (3) Technical science UG EFTS (4) Humanity UG EFTS (5) PhD students Inputs: (1) Labour Input price: Average annual staff salary (2) % of graduates employed after 1-2 years of graduation (3) No. of applicants per place in HEI (admission) (4) Dummy for HEI with the right to graduate PhD students (5) % of professors in teaching and research personnel (6) % of foreign students.	(1) No. of students per teacher (2) UG EFTS (3) % of government funding (4) % of professors in teaching and research personnel (5) % of teaching and research personnel aged above 50 (6) % of foreign students (7) % of external research income (8) % of students age below 25 (9) No. of applicants per place in HEI (admission)
Mamun (2011)	Bangladesh	Cost Efficiency	Cost Function	Quadratic Translog	14 public Bangladesh in 2002-2007	SCFA	Cost: Total costs. Outputs: (1) UG EFTS (2) PG EFTS (3) Research expenditure. Inputs: (1) Labour Input price: average faculty salary (2) Teaching staff (3) the non-teaching staff (4) No. of teachers having a PhD degree (5) No. of professors and associate professors.	(1) % of total amount of yearly grant (2) total years of operation of a university (age)

Sav (2012)	U.S.	Cost Efficiency	Cost Function	Cobb-Douglas	257 public vs. 297 private non-profit universities in 2005-09	SCFA	Cost: Total costs. Outputs: (1) UG EFTS (2) PG EFTS (3) Research grants. Inputs: (1) Labour Input price: $ average 9-month contract faculty salary (2) $ average 12-month contract faculty salary.	(1) % of minority student enrolment (2) % of non-tenure track faculty (3) % of faculty with tenure (4) % of revenue from government
Sav (2012d)	U.S.	Cost Efficiency	Cost Function	Cobb-Douglas	142 public vs. 77 private non-profit universities in 2005-09	SCFA	Cost: Total costs. Outputs: (1) UG EFTS (2) PG EFTS (3) Research grants. Inputs: (1) Labour Input price: $ average faculty salary (2) Capital input price: $ the year ending value of all university equipment and art and library collection (3) Medical school dummy (4) a time trend.	(1) Student to faculty ratio (%) (2) Student retention rate (%) (3) Tenured faculty (%) (4) non-tenure track faculty (%)
Sav (2012f)	U.S.	Cost Efficiency	Cost Function	Cobb-Douglas	56 public vs. 72 private non-profit universities in 2005-09	SCFA	Cost: Total costs. Outputs: (1) UG EFTS (2) PG EFTS (3) Research grants. Inputs: (1) Labour Input price: $ average 9-month contract faculty salary (2) $ average 12-month contract faculty salary. (3) Capital input price: $ the year ending value of buildings	(1) % of minority student enrolment (2) % of students on low-income Government grants (3) % of full-time student retention measured as students returning fall term (4) Debt: % liabilities to assets (5) Control dummy: 1 institutional control is private non-profit, 0 otherwise

Sav (2012g)	U.S.	Cost Efficiency	Cost Function	Translog	872 public colleges vs. 58 private non-profit colleges vs. 207 private for-profit colleges in 2005-09	SCFA	Cost: Total costs. Outputs: (1) Annual production of teaching credit hours generated from enrolments (2) Research grants. Inputs: (1) Labour Input price: $ average 9-month contract faculty salary (2) $ average 12-month contract faculty salary	(1) % of students on low-income Government grants (2) % graduate rate (3) No. of 9-month contract faculty staff (4) No. of 12-month contract faculty staff (5) Time dummy: 2006/07 (6) Time dummy: 2007/08 (7) Time dummy: 2008/09
Sav (2012h)	U.S.	Cost Efficiency	Cost Function	Cobb-Douglas	222 faiths based postsecondary institutions in 2005-09	SCFA	Cost: Total costs. Outputs: (1) UG EFTS (2) PG EFTS. Inputs: (1) Labour Input price: $ average faculty salary (2) Capital input price: $ the year ending value of buildings (3) Dummy=1 if only graduate education is produced (4) Dummy=1 if both undergraduate and graduate education are produced	(1) % of enrolled students receiving government grants (2) % of university revenues received from private giving (3) Institution debt: % of liabilities to assets
Sav (2012j)	U.S.	Cost Efficiency	Cost Function	Cobb-Douglas	26 public historically black universities and 136 predominately white universities in 2005-09	SCFA	Cost: Total costs. Outputs: (1) UG EFTS (2) PG EFTS (3) Research grants. Inputs: (1) Labour Input price: $ average faculty salary	(1) Student retention rate: % of fall enrolled students that re-enrolled the following fall term (2) % of FTE faculty that have received tenure (3) % of total university revenue that is appropriated through state government funds (4) time trend

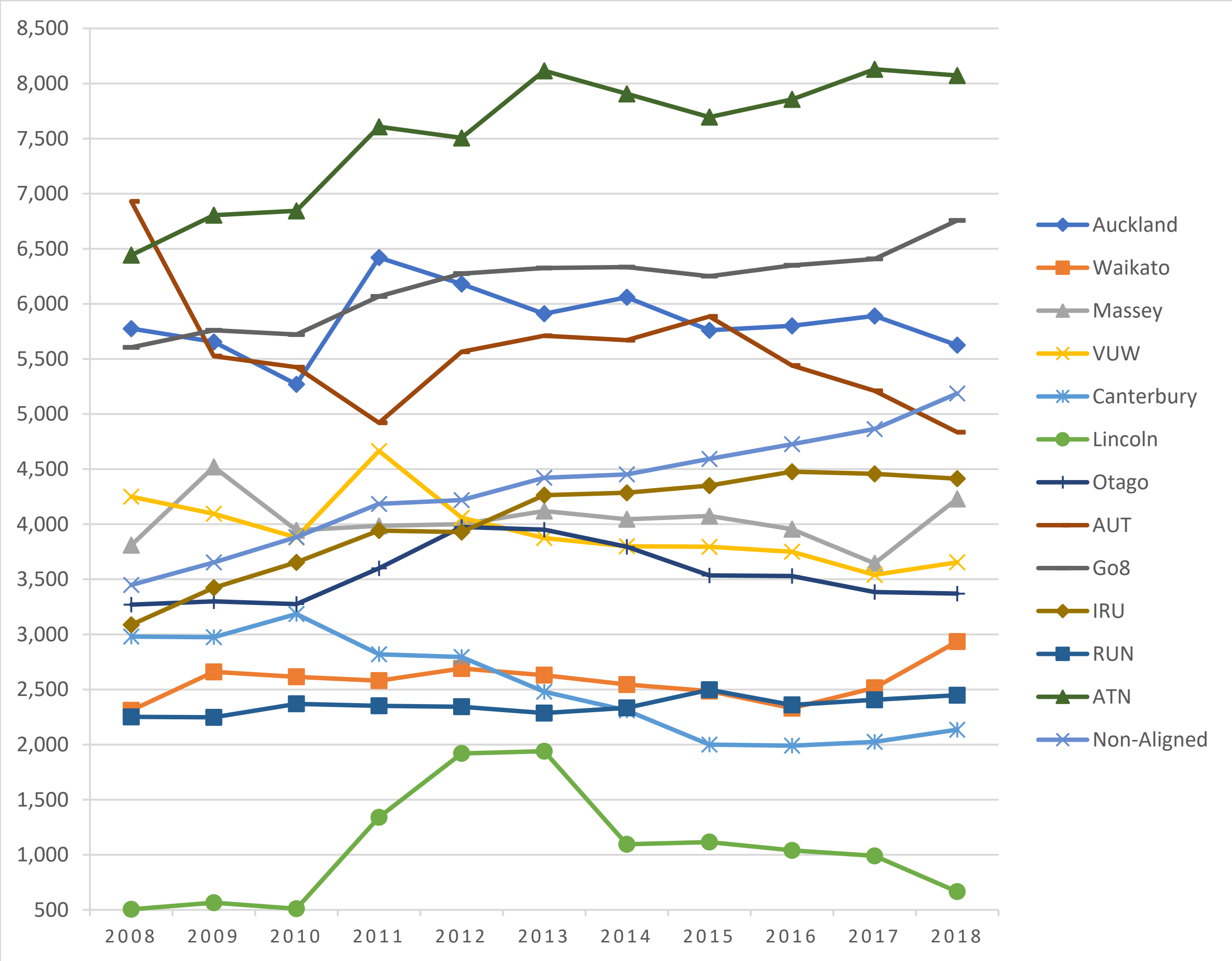
Sav (2016)	U.S.	Cost Efficiency	Cost Function	Translog	378 U.S. institutions from 2004-2013	SCFA	Cost: Total operating costs. Outputs: (1) UG education production of credit hours (2) PG education production of credit hours (3) UG degree graduation rate (4) Research grants. Inputs: (1) % of non-tenure track staff to total faculty employed staff (2) Ratio of non-faculty employees to tenure-track and tenured faculty (3) Capital costs: Total of university capital and other assets	(1) % of state funding to total revenue (2) % of private giving to total revenue (3) Pell Grants per UG enrolment
Agasisti and Haelermans (2016)	Dutch and Italy	Cost Efficiency	Cost Function	Translog	13 Dutch and 58 Italian public universities from 2005/06-2008/09	SCFA	Cost: Expenditure. Group 1: (1) Bachelor EFTS enrolments (2) Master EFTS (3) PhD EFTS (4) Number of staff (5) Research grants (6) Time dummy (2006 dummy, 2007 dummy and 2008 dummy) (7) Country dummy (Italy =1) Group 2: (1) Research grants (2) Bachelor graduates (2) Master graduates (3) PhD graduates (4)— (7)	Time-invariant Efficiency SFA model; Time-varying decay SFA model (Battese and Coelli (1992) model)

Johnes (2014a)	England	Technical Efficiency	Output Distance Function	Translog	108 to 113 English HEIs from 1996/97 to 2008/09	SFA and DEA	Outputs: (1) No. of UG first degree qualifications adjusted for quality (2) Research income (3) No. of PG degree qualifications. Inputs: (1) PG EFTS (2) UG EFTS weighted by average entry (A level) points (3) FTE academics plus 0.5 times the number of part-time academics (4) Expenditure on administration and central services (5) Capital Input: Expenditure on library, computing, and other learning resources	Time-invariant SFA Random Effects model; Time-invariant SFA model; and Time-varying decay SFA model (Battese and Coelli (1992) model)
Johnes (2014b)	England	Technical Efficiency	Output Distance Function	Translog	108 to 113 English HEIs from 1996/97 to 2008/09	SFA and DEA	Outputs: (1) Number of UG first degree qualifications (Model 1-no quality); Number of UG first degree qualifications adjusted for quality (Model 2-quality). (2) No. of PG qualifications (3) Research income. Inputs: (1) PG EFTS (2) UG EFTS (Model 1) (2) UG EFTS weighted by average entry (A level) points (Model 2) (3) FTE academics plus 0.5 times the number of part-time academics (4) Expenditure on administration and central	Time-invariant SFA Random Effects model; Time-invariant SFA model; and Time-varying decay SFA model (Battese and Coelli (1992) model)

							services (5) Capital Input: Expenditure on library, computing, and other learning resources	
Erkoc (2015)	Turkey	Technical Efficiency	Output Distance Function	Translog	123 Turkish HEIs between 2009 and 2013	SFA	Outputs: (1) Citation scores. Inputs: (1) No. of professors (2) No. of associate professors (3) No. of assistant professors	Time-invariant SFA Random Effects model; Time-invariant SFA model; and Time-varying decay SFA model (Battese and Coelli (1992) model)
Zhang, Bao and Sun (2016)	China	Technical Efficiency	Production Function	Cobb-Douglas	72 institutions in 2000-10	DEA and SFA	Outputs: (1) Publications. Inputs: (1) No. of research faculty (who teach and conduct research) (2) Lectures and instructors (who teach only) (3) No. of graduate students (4) No. of undergraduate students (5) research equipment (no.) (6) Research expenditures (1M CNY) (7) Instructional expenditures (1M CNY)	Time-invariant SFA model, Time-varying decay SFA model (Battese and Coelli (1992) model)

Appendix Chapter 4

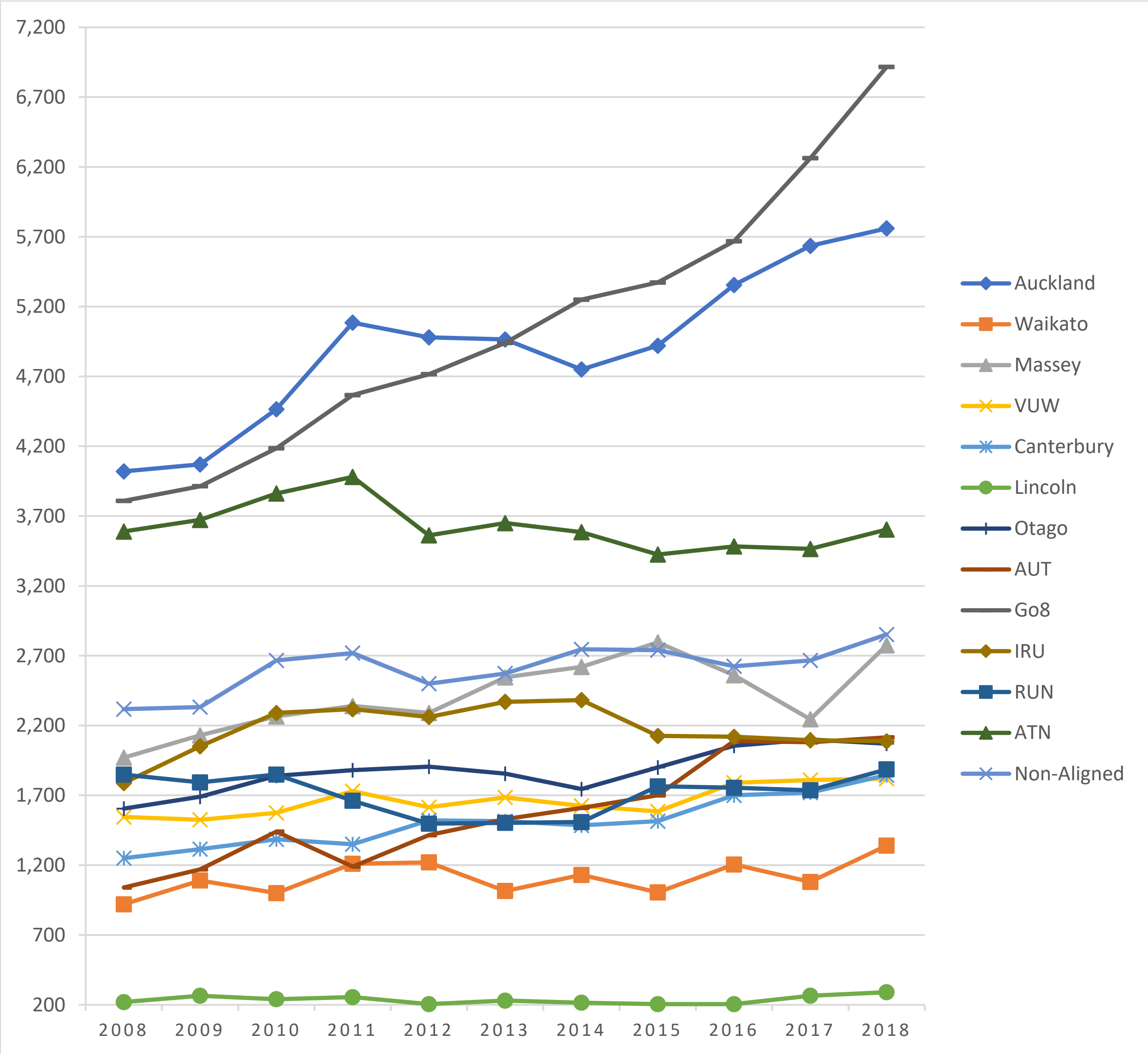
Figure A4.1:
New Zealand vs. Australian Universities: Undergraduate Completions, 2008-2018



Source: New Zealand Ministry of Education, and Australian Government DoE.
Note: The numbers for Australian groupings are the averages for the universities within the groupings.

Figure A4.2

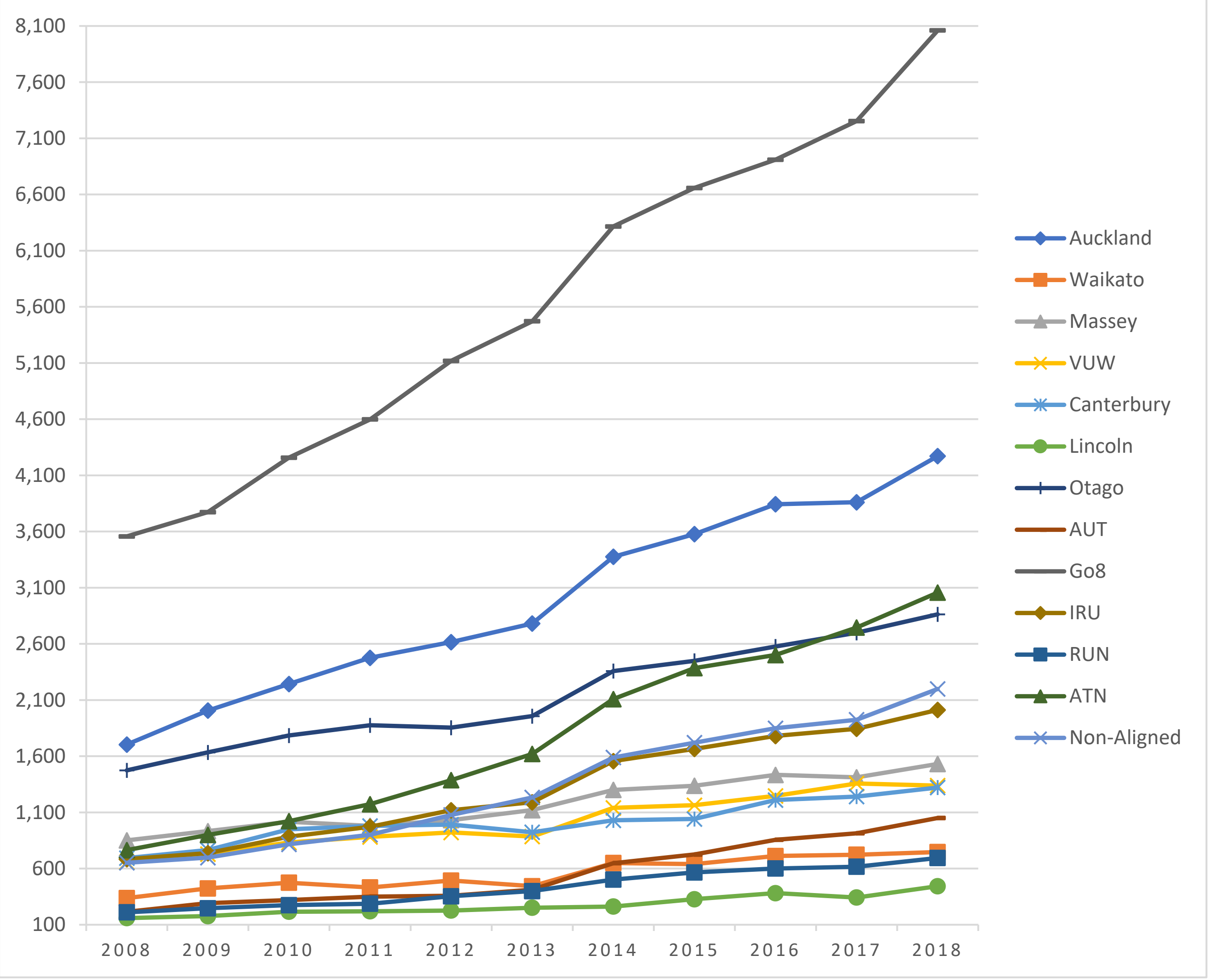
New Zealand vs. Australian Universities: Postgraduate Completions, 2008-2018



Source: New Zealand Ministry of Education, and Australian Government DoE.
Note: The numbers for Australian groupings are the averages for the universities within the groupings.

Figure A4.3

New Zealand vs. Australian Universities: Number of WoS indexed articles and reviews, 2008-2018



Source: Web of Science (WoS).

Note: The numbers for Australian groupings are the averages for the universities within the groupings.

Appendix Chapter 5

Table A5.1

Geometric Mean Changes in TFP, Technical, Efficiency, Pure Efficiency and Scale Efficiency of Australasian universities, 2008/09 to 2017/18

University	TFP Δ	Efficiency Δ	Technical Δ	Pure efficiency Δ	Scale efficiency Δ
Auckland	0.997	1.000	0.998	1.003	0.997
Waikato	0.984	0.971	1.013	0.974	0.997
Massey	0.982	0.981	1.001	0.985	0.996
VUW	1.008	1.003	1.005	1.003	1.000
Canterbury	0.991	0.996	0.995	0.994	1.002
Lincoln	0.972	0.968	1.003	1.000	0.968
Otago	0.976	0.972	1.004	0.974	0.998
AUT	1.033	1.000	1.033	1.000	1.000
Sydney	1.007	1.010	0.997	1.005	1.005
NSW	1.003	0.994	1.008	1.000	0.994
Monash	1.011	1.000	1.011	1.000	1.000
Melbourne	0.975	1.000	0.975	1.000	1.000
Queensland	1.010	0.997	1.013	1.000	0.997
UWA	1.019	0.988	1.031	1.000	0.988
Adelaide	1.018	0.997	1.021	1.000	0.997
ANU	0.985	1.000	0.985	1.000	1.000
WSU	1.045	1.018	1.026	1.015	1.003
La Trobe	1.003	0.988	1.015	0.989	0.999
Griffith	1.025	1.013	1.011	1.016	0.998
JCU	0.977	0.959	1.019	0.961	0.997
Murdoch	0.974	0.960	1.015	0.961	0.999
Flinders	1.012	1.000	1.012	1.000	1.000
CDU	1.044	1.000	1.044	1.000	1.000
CSU	0.982	1.000	0.982	1.000	1.000
SCU	1.007	1.013	0.994	1.000	1.013
UNE	1.040	1.024	1.015	1.000	1.024
Federation	1.052	1.023	1.029	1.002	1.021
CQU	1.055	1.025	1.029	1.013	1.011
USQ	1.052	1.010	1.041	1.000	1.010
USC	1.048	1.025	1.022	1.013	1.013
UTS	1.028	1.008	1.020	1.007	1.001
RMIT	1.000	1.000	1.000	1.000	1.000
Curtin	1.011	0.999	1.012	1.000	0.999
USA	1.027	1.003	1.024	1.002	1.001
Macquarie	1.037	1.016	1.021	1.016	1.000
Newcastle	1.014	1.003	1.011	1.006	0.997
Wollongong	1.024	1.005	1.019	1.000	1.005
Deakin	1.018	1.005	1.013	1.004	1.001
Swinburne	1.024	1.011	1.013	1.008	1.003
Victoria	1.015	1.000	1.015	1.000	1.000
QUT	1.011	1.004	1.007	1.003	1.002
ECU	1.025	1.011	1.015	1.004	1.007
Tasmania	0.990	0.985	1.005	0.998	0.987
Canberra	1.039	1.010	1.029	1.000	1.010
Catholic	0.993	1.000	0.993	1.000	1.000
Mean	*1.012*	*1.000*	*1.012*	*0.999*	*1.001*

Note: 1. All means are geometric means.

2. The first year in each column indicates the base year, and the indices show change from one year to the next.
3. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.

Table A5.2

Geometric Mean Changes in TFP of Australasian universities, 2008/09 to 2017/18

University	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	*Mean*
Auckland	1.038	0.970	0.885	1.030	1.039	0.995	1.005	1.028	0.990	1.004	*0.997*
Waikato	0.942	1.106	0.833	1.001	1.136	0.975	1.066	0.904	1.100	0.835	*0.984*
Massey	0.895	1.167	0.932	1.050	0.856	0.937	1.010	1.110	1.090	0.833	*0.982*
VUW	1.087	0.919	0.927	1.043	1.062	1.023	1.026	0.965	1.038	1.005	*1.008*
Canterbury	1.088	0.898	0.920	0.944	0.949	1.036	1.089	0.962	1.047	0.999	*0.991*
Lincoln	0.891	0.950	0.854	1.000	0.921	1.039	1.171	1.038	0.924	0.967	*0.972*
Otago	0.996	0.989	0.978	0.887	0.939	1.043	0.977	0.958	0.984	1.018	*0.976*
AUT	1.375	1.037	1.059	0.855	1.028	0.995	1.046	0.967	1.008	1.028	*1.033*
Sydney	0.965	0.993	0.979	1.040	0.988	1.024	1.046	1.047	0.941	1.055	*1.007*
NSW	0.958	0.945	1.018	1.028	1.022	1.045	1.074	1.040	0.964	0.943	*1.003*
Monash	1.021	1.093	0.980	0.964	1.064	1.007	1.011	1.020	0.989	0.969	*1.011*
Melbourne	0.989	1.019	0.886	0.930	1.004	0.966	0.999	0.994	1.019	0.953	*0.975*
Queensland	1.060	1.045	0.923	1.050	1.008	0.941	1.039	1.028	1.009	1.008	*1.010*
UWA	0.990	0.986	1.050	0.981	1.029	1.002	1.020	1.048	1.072	1.016	*1.019*
Adelaide	1.029	0.984	0.998	1.052	0.945	1.118	1.031	1.029	0.990	1.016	*1.018*
ANU	0.891	0.864	1.027	0.991	1.071	0.973	1.073	1.122	0.930	0.943	*0.985*
WSU	0.975	1.008	1.059	1.066	0.955	1.056	1.143	1.113	0.985	1.102	*1.045*
La Trobe	0.849	0.931	1.009	1.152	1.018	1.073	1.000	0.991	1.072	0.965	*1.003*
Griffith	1.050	0.983	0.979	1.001	1.036	1.024	1.102	0.987	1.036	1.057	*1.025*
JCU	0.763	1.087	0.818	1.127	1.025	0.904	1.076	1.002	1.012	1.023	*0.977*
Murdoch	0.916	0.687	1.055	1.133	0.817	1.013	0.985	0.998	1.065	1.185	*0.974*
Flinders	1.058	0.942	1.005	1.022	1.005	0.980	1.115	0.928	1.080	0.996	*1.012*
CDU	1.009	1.001	1.010	1.008	1.197	1.141	1.086	0.983	0.967	1.062	*1.044*
CSU	0.990	1.027	1.007	1.220	0.906	0.892	0.906	0.948	1.029	0.933	*0.982*
SCU	0.948	0.851	1.173	0.899	1.085	1.030	1.189	0.934	1.014	0.999	*1.007*
UNE	1.060	1.059	1.037	1.153	0.953	1.008	1.038	1.058	1.007	1.035	*1.040*
Federation	1.027	0.826	1.197	1.312	1.327	1.565	0.456	1.105	0.974	1.230	*1.052*
CQU	1.178	0.939	1.117	1.235	1.143	0.826	0.966	1.168	1.019	1.030	*1.055*
USQ	0.924	1.125	1.106	0.948	1.034	1.087	1.066	1.034	1.167	1.052	*1.052*
USC	1.063	0.968	0.914	0.955	1.130	1.026	1.081	1.238	1.200	0.959	*1.048*
UTS	1.022	0.992	1.027	1.098	0.979	1.002	1.085	1.051	1.066	0.967	*1.028*
RMIT	0.973	0.975	0.965	1.004	0.904	1.099	1.073	1.011	1.001	1.004	*1.000*
Curtin	1.015	1.059	0.856	1.170	1.012	0.990	0.973	1.001	1.018	1.041	*1.011*
USA	0.964	1.014	0.980	1.128	0.924	1.097	1.051	1.026	1.025	1.073	*1.027*
Macquarie	1.121	0.870	1.032	1.230	0.978	0.962	0.985	1.230	1.044	0.982	*1.037*
Newcastle	1.078	1.056	0.949	0.996	0.967	1.045	0.937	1.039	0.976	1.109	*1.014*
Wollongong	1.023	0.898	1.082	1.151	1.015	1.002	1.097	0.990	1.014	0.988	*1.024*
Deakin	0.986	0.986	0.992	1.027	1.073	0.896	1.185	1.041	1.159	0.880	*1.018*
Swinburne	0.956	0.929	0.981	1.084	1.007	1.271	0.954	1.059	0.997	1.038	*1.024*
Victoria	1.005	0.994	0.905	1.166	1.184	1.101	0.949	0.822	1.141	0.951	*1.015*
QUT	1.031	1.017	0.991	1.038	1.021	1.030	0.941	1.025	0.999	1.024	*1.011*
ECU	1.014	1.041	0.992	1.040	1.045	0.936	1.053	1.151	0.923	1.077	*1.025*
Tasmania	1.001	0.933	1.110	0.961	1.076	1.066	0.974	0.964	0.961	0.881	*0.990*
Canberra	1.161	0.910	0.989	1.042	1.077	1.061	1.018	0.989	1.032	1.133	*1.039*
Catholic	0.962	1.102	0.986	1.079	0.880	1.098	0.968	0.983	1.128	0.797	*0.993*
Mean	*1.003*	*0.978*	*0.987*	*1.047*	*1.014*	*1.026*	*1.017*	*1.022*	*1.025*	*1.000*	1.012

Note:
1. All means are geometric means.
2. The first year in each column indicates the base year, and the indices show change from one year to the next.
3. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.

Table A5.3

Geometric Mean Change in Efficiency of Australasian universities, 2008/09 to 2017/18

University	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	*Mean*
Auckland	1.057	1.052	0.824	1.033	0.996	0.962	0.945	1.042	1.021	1.095	*1.000*
Waikato	0.935	1.085	0.828	0.955	1.170	0.953	1.016	0.922	1.062	0.840	*0.971*
Massey	0.899	1.191	0.894	1.026	0.871	0.966	0.956	1.182	1.027	0.864	*0.981*
VUW	1.059	0.898	0.942	0.996	1.084	1.003	0.995	0.950	1.035	1.088	*1.003*
Canterbury	1.100	0.889	0.944	0.912	0.977	1.054	1.111	0.980	0.989	1.031	*0.996*
Lincoln	0.847	0.964	0.889	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*0.968*
Otago	0.953	0.981	1.014	0.831	0.984	0.992	0.961	0.980	1.000	1.044	*0.972*
AUT	1.000	1.157	0.995	0.869	1.042	0.959	1.066	0.938	1.000	1.000	*1.000*
Sydney	0.990	1.042	0.964	1.025	0.971	1.012	1.016	1.046	0.930	1.113	*1.010*
NSW	0.963	1.023	0.959	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*0.994*
Monash	1.000	1.094	1.026	0.916	1.065	0.945	0.967	1.000	1.000	1.000	*1.000*
Melbourne	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
Queensland	1.042	1.097	0.940	1.006	0.941	0.959	1.000	1.000	1.000	1.000	*0.997*
UWA	0.931	1.019	1.031	0.908	1.000	1.000	1.000	1.000	1.000	1.000	*0.988*
Adelaide	1.012	1.017	1.005	1.001	0.940	1.000	1.000	1.000	1.000	1.000	*0.997*
ANU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
WSU	1.000	1.000	1.004	0.996	1.000	1.012	1.088	1.172	0.874	1.060	*1.018*
La Trobe	0.856	0.936	1.000	1.076	1.020	1.046	0.965	0.937	1.109	0.963	*0.988*
Griffith	1.073	0.956	0.989	0.957	1.056	1.017	1.065	0.966	1.006	1.058	*1.013*
JCU	0.763	1.082	0.834	1.056	0.997	0.863	1.023	0.990	1.045	0.992	*0.959*
Murdoch	0.861	0.771	1.056	1.100	0.861	1.000	1.000	1.000	1.000	1.000	*0.960*
Flinders	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
CDU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
CSU	1.000	1.000	1.000	1.139	0.937	0.937	1.000	1.000	1.000	1.000	*1.000*
SCU	0.993	1.000	1.000	1.000	1.000	1.000	1.133	1.066	0.855	1.112	*1.013*
UNE	1.063	1.038	0.985	1.100	0.930	0.967	1.008	1.076	0.986	1.102	*1.024*
Federation	1.000	1.000	1.000	1.000	1.194	1.575	0.532	1.079	0.932	1.246	*1.023*
CQU	1.000	1.000	1.000	1.000	1.019	0.982	1.000	1.114	1.005	1.140	*1.025*
USQ	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.003	1.105	*1.010*
USC	1.071	1.007	0.927	1.000	1.025	0.976	1.031	1.251	1.165	0.855	*1.025*
UTS	1.003	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.024	1.058	*1.008*
RMIT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
Curtin	0.990	1.067	0.938	1.088	1.033	0.944	0.942	1.000	1.028	0.972	*0.999*
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.014	1.020	0.992	*1.003*
Macquarie	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.038	1.047	1.082	*1.016*
Newcastle	1.083	1.007	0.999	0.920	0.974	1.008	0.970	1.000	1.000	1.076	*1.003*
Wollongong	1.000	1.000	1.000	1.000	1.000	1.000	1.004	1.022	1.005	1.017	*1.005*
Deakin	0.978	0.974	1.033	0.985	1.053	0.870	1.124	1.075	1.090	0.899	*1.005*
Swinburne	1.000	1.000	1.000	1.000	1.000	1.055	0.948	1.016	1.013	1.081	*1.011*
Victoria	1.000	1.000	1.000	1.000	1.057	1.026	0.923	1.000	1.000	1.000	*1.000*
QUT	1.035	1.002	1.046	0.957	1.046	1.013	0.945	0.960	1.020	1.024	*1.004*
ECU	1.026	0.995	0.980	1.003	1.050	0.949	1.000	1.120	0.893	1.113	*1.011*
Tasmania	0.908	0.951	1.097	0.912	1.014	0.993	0.993	1.000	1.000	1.000	*0.985*
Canberra	1.165	0.869	0.988	1.000	1.000	1.012	1.013	0.975	1.000	1.103	*1.010*
Catholic	1.000	1.000	1.000	1.016	0.984	1.000	1.002	1.083	0.922	1.000	*1.000*
Mean	*0.990*	*1.001*	*0.979*	*0.994*	*1.005*	*0.998*	*0.990*	*1.020*	*1.001*	*1.022*	1.000

Note:
1. All means are geometric means.
2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.
3. The first year in each column indicates the base year, and the indexes show changes from one year to the next year.

Table A5.4

Geometric Mean Change in Technical of Australasian Universities, 2008/09 to 2017/18

University	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	*Mean*
Auckland	0.982	0.922	1.074	0.996	1.044	1.034	1.064	0.987	0.970	0.917	*0.998*
Waikato	1.008	1.020	1.006	1.049	0.971	1.023	1.050	0.980	1.036	0.993	*1.013*
Massey	0.995	0.980	1.043	1.023	0.983	0.970	1.056	0.939	1.061	0.964	*1.001*
VUW	1.027	1.023	0.985	1.047	0.980	1.020	1.032	1.016	1.003	0.923	*1.005*
Canterbury	0.990	1.010	0.975	1.036	0.971	0.983	0.980	0.982	1.059	0.969	*0.995*
Lincoln	1.052	0.986	0.961	1.000	0.921	1.039	1.171	1.038	0.924	0.967	*1.003*
Otago	1.045	1.007	0.964	1.067	0.954	1.052	1.016	0.977	0.984	0.976	*1.004*
AUT	1.375	0.896	1.065	0.984	0.986	1.038	0.981	1.031	1.008	1.028	*1.033*
Sydney	0.975	0.953	1.015	1.014	1.017	1.011	1.030	1.001	1.012	0.948	*0.997*
NSW	0.995	0.924	1.062	1.028	1.022	1.045	1.074	1.040	0.964	0.943	*1.008*
Monash	1.021	0.999	0.955	1.053	1.000	1.066	1.045	1.020	0.989	0.969	*1.011*
Melbourne	0.989	1.019	0.886	0.930	1.004	0.966	0.999	0.994	1.019	0.953	*0.975*
Queensland	1.017	0.953	0.982	1.044	1.072	0.981	1.039	1.028	1.009	1.008	*1.013*
UWA	1.063	0.967	1.019	1.081	1.029	1.002	1.020	1.048	1.072	1.016	*1.031*
Adelaide	1.017	0.967	0.993	1.050	1.005	1.118	1.031	1.029	0.990	1.016	*1.021*
ANU	0.891	0.864	1.027	0.991	1.071	0.973	1.073	1.122	0.930	0.943	*0.985*
WSU	0.975	1.008	1.055	1.071	0.955	1.044	1.050	0.950	1.127	1.039	*1.026*
La Trobe	0.992	0.996	1.009	1.071	0.997	1.026	1.036	1.057	0.967	1.002	*1.015*
Griffith	0.978	1.028	0.989	1.046	0.981	1.007	1.035	1.021	1.030	0.999	*1.011*
JCU	1.000	1.004	0.980	1.067	1.028	1.047	1.052	1.011	0.968	1.031	*1.019*
Murdoch	1.064	0.891	0.999	1.030	0.949	1.013	0.985	0.998	1.065	1.185	*1.015*
Flinders	1.058	0.942	1.005	1.022	1.005	0.980	1.115	0.928	1.080	0.996	*1.012*
CDU	1.009	1.001	1.010	1.008	1.197	1.141	1.086	0.983	0.967	1.062	*1.044*
CSU	0.990	1.027	1.007	1.071	0.967	0.952	0.906	0.948	1.029	0.933	*0.982*
SCU	0.955	0.851	1.173	0.899	1.085	1.030	1.050	0.877	1.186	0.898	*0.994*
UNE	0.997	1.020	1.052	1.048	1.024	1.043	1.029	0.983	1.022	0.939	*1.015*
Federation	1.027	0.826	1.197	1.312	1.112	0.994	0.856	1.024	1.045	0.987	*1.029*
CQU	1.178	0.939	1.117	1.235	1.122	0.841	0.966	1.048	1.014	0.903	*1.029*
USQ	0.924	1.125	1.106	0.948	1.034	1.087	1.066	1.034	1.163	0.952	*1.041*
USC	0.993	0.961	0.986	0.955	1.103	1.051	1.048	0.990	1.030	1.122	*1.022*
UTS	1.019	0.995	1.027	1.098	0.979	1.002	1.085	1.051	1.042	0.914	*1.020*
RMIT	0.973	0.975	0.965	1.004	0.904	1.099	1.073	1.011	1.001	1.004	*1.000*
Curtin	1.026	0.993	0.913	1.076	0.979	1.049	1.033	1.001	0.990	1.071	*1.012*
USA	0.964	1.014	0.980	1.128	0.924	1.097	1.051	1.012	1.005	1.082	*1.024*
Macquarie	1.121	0.870	1.032	1.230	0.978	0.962	0.985	1.185	0.997	0.908	*1.021*
Newcastle	0.996	1.048	0.949	1.082	0.993	1.037	0.966	1.039	0.976	1.031	*1.011*
Wollongong	1.023	0.898	1.082	1.151	1.015	1.002	1.092	0.968	1.009	0.972	*1.019*
Deakin	1.008	1.011	0.960	1.042	1.019	1.030	1.055	0.968	1.063	0.979	*1.013*
Swinburne	0.956	0.929	0.981	1.084	1.007	1.204	1.006	1.042	0.984	0.961	*1.013*
Victoria	1.005	0.994	0.905	1.166	1.121	1.074	1.029	0.822	1.141	0.951	*1.015*
QUT	0.995	1.015	0.948	1.084	0.976	1.016	0.995	1.068	0.979	1.000	*1.007*
ECU	0.988	1.047	1.013	1.037	0.995	0.986	1.053	1.028	1.033	0.968	*1.015*
Tasmania	1.102	0.981	1.013	1.053	1.061	1.073	0.981	0.964	0.961	0.881	*1.005*
Canberra	0.997	1.048	1.001	1.042	1.077	1.049	1.005	1.014	1.032	1.027	*1.029*
Catholic	0.962	1.102	0.986	1.063	0.894	1.098	0.966	0.908	1.224	0.797	*0.993*
Mean	*1.014*	*0.976*	*1.008*	*1.053*	*1.010*	*1.028*	*1.028*	*1.002*	*1.024*	*0.978*	1.012

Note:

1. All means are geometric means.
2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.
3. The first year in each column indicates the base year, and the indexes show changes from one year to the next year.

Table A5.5

Geometric Mean Change in Pure Efficiency of Australasian Universities, 2008/09 to 2017/18

University	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	Mean
Auckland	1.144	0.963	0.903	1.000	1.062	0.949	0.993	1.010	0.990	1.038	1.003
Waikato	0.925	1.060	0.831	1.005	1.031	0.968	1.079	0.941	0.985	0.944	0.974
Massey	0.934	1.147	0.927	1.022	0.859	0.979	0.962	1.182	1.021	0.869	0.985
VUW	1.058	0.898	0.927	1.013	1.083	1.003	0.987	0.954	1.036	1.089	1.003
Canterbury	1.074	0.913	0.858	0.945	0.926	1.066	1.085	0.951	1.076	1.081	0.994
Lincoln	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Otago	0.968	1.020	1.017	0.826	0.935	1.036	0.967	0.988	1.000	1.000	0.974
AUT	1.000	1.156	0.956	0.905	1.000	1.000	1.046	0.956	1.000	1.000	1.000
Sydney	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.011	0.990	1.048	1.005
NSW	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Monash	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Melbourne	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Queensland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
UWA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Adelaide	1.000	1.016	0.984	1.020	0.980	1.000	1.000	1.000	1.000	1.000	1.000
ANU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
WSU	1.000	1.000	1.000	1.000	1.000	1.000	1.006	1.073	1.022	1.057	1.015
La Trobe	0.872	0.936	1.000	1.066	1.013	1.054	0.972	0.937	1.108	0.955	0.989
Griffith	1.051	0.953	1.032	0.967	1.009	0.991	1.074	0.981	1.009	1.098	1.016
JCU	0.763	1.105	0.834	1.060	0.990	0.873	1.019	0.992	1.043	0.991	0.961
Murdoch	0.866	0.776	1.013	1.143	0.864	1.000	1.000	1.000	1.000	1.000	0.961
Flinders	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
CDU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
CSU	1.000	1.000	1.000	1.118	0.948	0.944	1.000	1.000	1.000	1.000	1.000
SCU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
UNE	1.033	1.069	0.903	1.117	0.899	1.041	0.993	1.067	0.903	1.000	1.000
Federation	1.000	1.000	1.000	1.000	1.000	1.596	0.627	1.000	1.000	1.022	1.002
CQU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.036	1.019	1.079	1.013
USQ	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.084	1.046	1.013
UTS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.006	1.066	1.007
RMIT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Curtin	1.000	1.000	1.000	1.037	1.017	0.948	1.000	1.000	1.000	1.000	1.000
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.005	1.006	1.008	1.002
Macquarie	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.035	1.038	1.094	1.016
Newcastle	1.030	1.081	1.010	0.917	0.958	1.023	0.977	1.000	1.000	1.073	1.006
Wollongong	1.000	1.000	1.000	1.000	1.000	1.000	1.004	0.996	1.031	0.970	1.000
Deakin	0.995	0.974	1.032	0.975	1.062	0.849	1.111	1.002	1.140	0.931	1.004
Swinburne	1.000	1.000	1.000	1.000	1.000	1.024	0.977	1.000	1.000	1.084	1.008
Victoria	1.000	1.000	1.000	1.000	1.043	1.000	0.959	1.000	1.000	1.000	1.000
QUT	1.004	1.015	1.043	0.975	0.993	1.021	0.951	1.000	1.000	1.026	1.003
ECU	1.006	1.005	0.990	1.000	1.042	0.960	1.000	1.055	0.948	1.043	1.004
Tasmania	0.981	1.000	1.053	0.950	1.011	0.994	0.995	1.000	1.000	1.000	0.998
Canberra	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Catholic	1.000	1.000	1.000	1.004	0.996	1.000	1.000	1.085	0.922	1.000	1.000
Mean	*0.992*	*1.000*	*0.984*	*1.000*	*0.993*	*1.003*	*0.993*	*1.005*	*1.008*	*1.013*	*0.999*

Note:
1. All means are geometric means.
2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.
3. The first year in each column indicates the base year, and the indexes show changes from one year to the next year.

Table A5.6

Geometric Mean Change in Scale Efficiency of Australasian Universities, 2008/09 to 2017/18

University	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	*Mean*
Auckland	0.924	1.092	0.913	1.033	0.937	1.015	0.952	1.032	1.031	1.055	*0.997*
Waikato	1.011	1.024	0.996	0.950	1.135	0.985	0.942	0.980	1.078	0.890	*0.997*
Massey	0.963	1.038	0.965	1.003	1.014	0.986	0.994	1.000	1.005	0.995	*0.996*
VUW	1.000	1.000	1.016	0.984	1.001	0.999	1.008	0.996	0.999	0.999	*1.000*
Canterbury	1.024	0.974	1.099	0.965	1.055	0.989	1.024	1.030	0.919	0.954	*1.002*
Lincoln	0.847	0.964	0.889	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*0.968*
Otago	0.984	0.962	0.997	1.005	1.052	0.957	0.994	0.992	1.000	1.044	*0.998*
AUT	1.000	1.001	1.041	0.960	1.042	0.959	1.019	0.981	1.000	1.000	*1.000*
Sydney	0.990	1.042	0.964	1.025	0.971	1.012	1.016	1.035	0.939	1.062	*1.005*
NSW	0.963	1.023	0.959	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*0.994*
Monash	1.000	1.094	1.026	0.916	1.065	0.945	0.967	1.000	1.000	1.000	*1.000*
Melbourne	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
Queensland	1.042	1.097	0.940	1.006	0.941	0.959	1.000	1.000	1.000	1.000	*0.997*
UWA	0.931	1.019	1.031	0.908	1.000	1.000	1.000	1.000	1.000	1.000	*0.988*
Adelaide	1.012	1.001	1.021	0.982	0.959	1.000	1.000	1.000	1.000	1.000	*0.997*
ANU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
WSU	1.000	1.000	1.004	0.996	1.000	1.012	1.081	1.092	0.855	1.003	*1.003*
La Trobe	0.982	1.000	1.000	1.009	1.007	0.993	0.994	1.000	1.001	1.008	*0.999*
Griffith	1.021	1.003	0.958	0.990	1.046	1.027	0.991	0.985	0.997	0.963	*0.998*
JCU	0.999	0.979	1.000	0.996	1.007	0.989	1.003	0.998	1.002	1.001	*0.997*
Murdoch	0.994	0.995	1.041	0.963	0.997	1.000	1.000	1.000	1.000	1.000	*0.999*
Flinders	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
CDU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
CSU	1.000	1.000	1.000	1.019	0.988	0.993	1.000	1.000	1.000	1.000	*1.000*
SCU	0.993	1.000	1.000	1.000	1.000	1.000	1.133	1.066	0.855	1.112	*1.013*
UNE	1.029	0.971	1.091	0.985	1.034	0.929	1.016	1.009	1.091	1.102	*1.024*
Federation	1.000	1.000	1.000	1.000	1.194	0.987	0.849	1.079	0.932	1.219	*1.021*
CQU	1.000	1.000	1.000	1.000	1.019	0.982	1.000	1.075	0.986	1.057	*1.011*
USQ	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.003	1.105	*1.010*
USC	1.071	1.007	0.927	1.000	1.025	0.976	1.031	1.251	1.074	0.818	*1.013*
UTS	1.003	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.018	0.993	*1.001*
RMIT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
Curtin	0.990	1.067	0.938	1.049	1.016	0.996	0.942	1.000	1.028	0.972	*0.999*
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.008	1.014	0.984	*1.001*
Macquarie	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.003	1.009	0.988	*1.000*
Newcastle	1.052	0.932	0.989	1.004	1.017	0.985	0.993	1.000	1.000	1.003	*0.997*
Wollongong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.026	0.975	1.048	*1.005*
Deakin	0.983	1.001	1.001	1.010	0.992	1.025	1.011	1.073	0.956	0.966	*1.001*
Swinburne	1.000	1.000	1.000	1.000	1.000	1.031	0.970	1.016	1.013	0.997	*1.003*
Victoria	1.000	1.000	1.000	1.000	1.013	1.026	0.962	1.000	1.000	1.000	*1.000*
QUT	1.031	0.988	1.003	0.981	1.053	0.992	0.994	0.960	1.020	0.998	*1.002*
ECU	1.020	0.990	0.990	1.003	1.008	0.989	1.000	1.061	0.942	1.068	*1.007*
Tasmania	0.925	0.951	1.042	0.960	1.003	0.999	0.999	1.000	1.000	1.000	*0.987*
Canberra	1.165	0.869	0.988	1.000	1.000	1.012	1.013	0.975	1.000	1.103	*1.010*
Catholic	1.000	1.000	1.000	1.011	0.989	1.000	1.002	0.998	1.000	1.000	*1.000*
Mean	*0.998*	*1.001*	*0.995*	*0.993*	*1.012*	*0.994*	*0.997*	*1.015*	*0.993*	*1.010*	1.001

Note: 1. All means are geometric means.

2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.
3. The first year in each column indicates the base year, and the indexes show changes from one year to the next year.

Table A5.7

Geometric Mean Changes in TFP, Technical, Efficiency, Pure Efficiency and Scale Efficiency of Australasian Universities, 2008/09 to 2017/18, for 40:60 FTEs

University	TFP Δ	Efficiency Δ	Technical Δ	Pure efficiency Δ	Scale efficiency Δ
Auckland	0.998	1.000	0.998	1.002	0.998
Waikato	0.984	0.971	1.013	0.974	0.997
Massey	0.982	0.981	1.001	0.985	0.996
VUW	1.008	1.003	1.005	1.003	1.000
Canterbury	0.992	0.996	0.995	0.994	1.002
Lincoln	0.971	0.968	1.003	1.000	0.968
Otago	0.976	0.972	1.004	0.974	0.998
AUT	1.033	1.000	1.033	1.000	1.000
Sydney	1.007	1.010	0.997	1.005	1.005
NSW	1.004	0.994	1.009	1.000	0.994
Monash	1.010	1.000	1.010	1.000	1.000
Melbourne	0.976	1.000	0.976	1.000	1.000
Queensland	1.011	0.997	1.014	1.000	0.997
UWA	1.019	0.988	1.031	1.000	0.988
Adelaide	1.018	0.997	1.021	1.000	0.997
ANU	0.986	1.000	0.986	1.000	1.000
WSU	1.045	1.018	1.027	1.015	1.002
La Trobe	1.004	0.987	1.017	0.988	0.999
Griffith	1.025	1.013	1.011	1.016	0.998
JCU	0.978	0.958	1.021	0.960	0.998
Murdoch	0.973	0.960	1.014	0.962	0.999
Flinders	1.012	1.000	1.012	1.000	1.000
CDU	1.045	1.000	1.045	0.999	1.001
CSU	0.981	1.000	0.981	1.000	1.000
SCU	1.006	1.014	0.992	1.000	1.014
UNE	1.038	1.020	1.018	1.000	1.020
Federation	1.056	1.024	1.031	1.004	1.020
CQU	1.058	1.024	1.033	1.012	1.012
USQ	1.050	1.009	1.040	1.000	1.009
USC	1.047	1.024	1.023	1.011	1.013
UTS	1.028	1.007	1.021	1.007	1.000
RMIT	1.000	1.000	1.000	1.000	1.000
Curtin	1.011	0.999	1.012	1.000	0.999
USA	1.026	1.003	1.023	1.002	1.001
Macquarie	1.037	1.016	1.021	1.015	1.000
Newcastle	1.014	1.000	1.013	1.003	0.997
Wollongong	1.022	1.003	1.019	1.000	1.003
Deakin	1.018	1.005	1.013	1.004	1.001
Swinburne	1.024	1.011	1.013	1.008	1.003
Victoria	1.013	1.000	1.013	1.000	1.000
QUT	1.011	1.003	1.008	1.003	1.001
ECU	1.026	1.011	1.015	1.005	1.006
Tasmania	0.990	0.985	1.005	0.998	0.987
Canberra	1.039	1.010	1.029	1.000	1.010
Catholic	0.993	1.000	0.993	1.000	1.000
Mean	*1.012*	*1.000*	*1.012*	*0.999*	*1.001*

Note: 1. All means are geometric means.
2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.

3. The first year in each column indicates the base year, and the indexes show changes from one year to the next year.

Table A5.8

Geometric Mean Changes in TFP, Technical, Efficiency, Pure Efficiency and Scale Efficiency of Australasian universities, 2008/09 to 2017/18, for TEC capital costs

University	TFP Δ	Efficiency Δ	Technical Δ	Pure efficiency Δ	Scale efficiency Δ
Auckland	0.996	0.996	1.000	1.007	0.989
Waikato	0.986	0.978	1.009	0.976	1.001
Massey	0.974	0.986	0.987	0.986	1.001
VUW	1.007	1.002	1.005	1.002	1.000
Canterbury	0.994	1.001	0.993	0.996	1.005
Lincoln	0.981	0.981	0.999	1.000	0.981
Otago	0.975	0.970	1.005	0.970	1.000
AUT	1.037	1.016	1.021	1.016	1.000
Sydney	1.009	1.010	0.999	1.005	1.005
NSW	1.006	0.994	1.013	1.000	0.994
Monash	1.005	1.000	1.005	1.000	1.000
Melbourne	0.965	1.000	0.965	1.000	1.000
Queensland	1.018	1.000	1.018	1.000	1.000
UWA	1.009	1.000	1.009	1.000	1.000
Adelaide	1.017	0.998	1.019	1.000	0.998
ANU	0.976	1.000	0.976	1.000	1.000
WSU	1.044	1.018	1.025	1.015	1.003
La Trobe	1.006	0.990	1.016	0.989	1.001
Griffith	1.026	1.014	1.012	1.016	0.998
JCU	0.969	0.953	1.017	0.954	0.999
Murdoch	0.975	0.964	1.011	0.964	1.000
Flinders	1.015	1.011	1.003	1.009	1.003
CDU	1.038	1.000	1.038	1.000	1.000
CSU	0.975	1.000	0.975	1.000	1.000
SCU	1.008	1.010	0.998	1.000	1.010
UNE	1.042	1.027	1.015	1.000	1.027
Federation	1.045	1.020	1.025	1.002	1.018
CQU	1.061	1.027	1.034	1.022	1.005
USQ	1.060	1.023	1.037	1.015	1.008
USC	1.047	1.025	1.022	1.011	1.014
UTS	1.029	1.008	1.020	1.008	1.000
RMIT	0.993	1.000	0.993	1.000	1.000
Curtin	1.018	1.000	1.018	1.000	1.000
USA	1.024	1.003	1.021	1.002	1.001
Macquarie	1.034	1.014	1.020	1.012	1.002
Newcastle	1.010	1.003	1.007	1.006	0.997
Wollongong	1.016	1.000	1.016	1.000	1.000
Deakin	1.013	1.006	1.006	1.007	0.999
Swinburne	1.023	1.011	1.012	1.008	1.003
Victoria	0.999	1.000	0.999	1.000	1.000
QUT	1.011	1.005	1.006	1.003	1.003
ECU	1.007	1.000	1.007	1.000	1.000
Tasmania	0.991	0.999	0.992	1.000	0.999
Canberra	1.044	1.009	1.034	1.000	1.009
Catholic	0.992	1.000	0.992	1.000	1.000
Mean	*1.010*	*1.001*	*1.009*	*1.000*	*1.002*

Note:1. All means are geometric means.

2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.

3. The first year in each column indicates the base year, and the indexes show changes from one year to the next year.

Table A5.9

Geometric Mean Changes in TFP, Technical, Efficiency, Pure Efficiency and Scale Efficiency of Australasian universities, 2008/09 to 2017/18, TEC Depreciation and Amortisation

University	TFP Δ	Efficiency Δ	Technical Δ	Pure efficiency Δ	Scale efficiency Δ
Auckland	0.996	0.996	1.000	1.004	0.992
Waikato	0.987	0.975	1.013	0.974	1.001
Massey	0.973	0.982	0.991	0.982	1.000
VUW	1.007	1.002	1.005	1.002	1.000
Canterbury	0.993	0.998	0.995	0.994	1.004
Lincoln	0.970	0.967	1.003	1.000	0.967
Otago	0.975	0.970	1.005	0.970	1.000
AUT	1.038	1.016	1.021	1.016	1.000
Sydney	1.023	1.011	1.012	1.005	1.006
NSW	1.007	0.994	1.013	1.000	0.994
Monash	1.011	1.000	1.011	1.000	1.000
Melbourne	0.970	1.000	0.970	1.000	1.000
Queensland	1.012	0.994	1.017	1.000	0.994
UWA	1.017	0.998	1.019	1.000	0.998
Adelaide	1.035	1.000	1.035	1.000	1.000
ANU	0.993	1.000	0.993	1.000	1.000
WSU	1.044	1.018	1.025	1.015	1.003
La Trobe	1.002	0.985	1.017	0.983	1.001
Griffith	1.035	1.012	1.022	1.016	0.997
JCU	0.970	0.950	1.021	0.950	1.000
Murdoch	0.989	0.970	1.020	0.972	0.997
Flinders	1.027	1.011	1.015	1.009	1.003
CDU	1.034	1.000	1.034	1.000	1.000
CSU	0.977	1.000	0.977	1.000	1.000
SCU	1.017	1.011	1.006	1.000	1.011
UNE	1.039	1.022	1.017	1.000	1.022
Federation	1.050	1.018	1.031	1.000	1.018
CQU	1.051	1.024	1.027	1.015	1.009
USQ	1.061	1.026	1.035	1.017	1.008
USC	1.030	1.013	1.017	1.000	1.013
UTS	1.027	1.008	1.019	1.008	1.000
RMIT	1.001	1.000	1.001	1.000	1.000
Curtin	1.032	1.000	1.032	1.000	1.000
USA	1.019	1.003	1.017	1.002	1.001
Macquarie	1.040	1.016	1.023	1.016	1.000
Newcastle	1.017	1.003	1.014	1.006	0.997
Wollongong	1.027	1.000	1.027	1.000	1.000
Deakin	1.013	1.004	1.009	1.002	1.002
Swinburne	1.027	1.003	1.024	1.000	1.003
Victoria	1.006	1.000	1.006	1.000	1.000
QUT	1.011	1.004	1.006	1.003	1.002
ECU	1.012	1.000	1.012	1.000	1.000
Tasmania	0.994	1.000	0.994	1.000	1.000
Canberra	1.042	1.006	1.036	1.000	1.006
Catholic	0.986	1.000	0.986	1.000	1.000
Mean	*1.013*	*1.000*	*1.013*	*0.999*	*1.001*

Note:

1. All means are geometric means.
2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.
3. The first year in each column indicates the base year, and the indexes show changes from one year to the next year.

Table A5.10

Geometric Mean Changes in TFP, Technical, Efficiency, Pure Efficiency and Scale Efficiency of Australasian universities, 2008/09 to 2017/18, Adjusted Teaching capital Costs

University	TFP Δ	Efficiency Δ	Technical Δ	Pure efficiency Δ	Scale efficiency Δ
Auckland	1.001	0.996	1.006	1.004	0.992
Waikato	0.984	0.973	1.011	0.972	1.001
Massey	0.973	0.982	0.991	0.982	1.000
VUW	1.008	1.002	1.006	1.002	1.000
Canterbury	0.996	0.998	0.998	0.994	1.004
Lincoln	0.969	0.967	1.002	1.000	0.967
Otago	0.975	0.970	1.005	0.970	1.000
AUT	1.040	1.016	1.024	1.016	1.000
Sydney	1.021	1.011	1.010	1.005	1.005
NSW	1.012	0.995	1.017	1.000	0.995
Monash	1.012	1.000	1.012	1.000	1.000
Melbourne	0.978	1.000	0.978	1.000	1.000
Queensland	1.010	0.993	1.017	1.000	0.993
UWA	1.020	0.988	1.032	1.000	0.988
Adelaide	1.019	0.996	1.023	1.000	0.996
ANU	0.992	1.000	0.992	1.000	1.000
WSU	1.043	1.018	1.025	1.015	1.003
La Trobe	0.996	0.984	1.013	0.983	1.001
Griffith	1.019	1.012	1.007	1.016	0.997
JCU	0.965	0.948	1.017	0.949	0.999
Murdoch	0.970	0.959	1.012	0.961	0.998
Flinders	1.027	1.008	1.019	1.005	1.003
CDU	1.048	1.000	1.048	1.000	1.000
CSU	0.980	1.000	0.980	1.000	1.000
SCU	1.017	1.000	1.017	1.000	1.000
UNE	1.032	1.014	1.018	1.000	1.014
Federation	1.049	1.020	1.028	1.002	1.018
CQU	1.077	1.027	1.049	1.022	1.005
USQ	1.039	1.028	1.011	1.021	1.007
USC	1.040	1.023	1.017	1.010	1.013
UTS	1.028	1.008	1.019	1.008	1.000
RMIT	0.999	1.000	0.999	1.000	1.000
Curtin	1.024	1.000	1.024	1.000	1.000
USA	1.024	1.003	1.021	1.002	1.001
Macquarie	1.037	1.016	1.020	1.016	1.000
Newcastle	1.012	1.003	1.009	1.006	0.997
Wollongong	1.016	1.000	1.016	1.000	1.000
Deakin	1.009	0.999	1.010	0.992	1.007
Swinburne	1.032	1.004	1.028	1.002	1.002
Victoria	0.997	1.000	0.997	1.000	1.000
QUT	1.011	1.003	1.008	1.000	1.003
ECU	1.024	1.019	1.004	1.012	1.007
Tasmania	0.990	1.000	0.990	1.000	1.000
Canberra	1.034	1.006	1.028	1.000	1.006
Catholic	1.028	1.000	1.028	1.000	1.000
Mean	*1.013*	*1.000*	*1.013*	*0.999*	*1.000*

Note:
1. All means are geometric means.
2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.
3. The first year in each column indicates the base year, and the indexes show changes from one year to the next year.

Table A5.11

Geometric Mean Changes in TFP, Technical, Efficiency, Pure Efficiency and Scale Efficiency of Australasian universities, 2008/09 to 2017/18, Citation-weighted WoS-Indexed Articles and Reviews

University	TFP Δ	Efficiency Δ	Technical Δ	Pure efficiency Δ	Scale efficiency Δ
Auckland	0.973	0.998	0.975	0.998	1.000
Waikato	0.973	0.975	0.999	0.978	0.996
Massey	0.973	0.984	0.989	0.987	0.996
VUW	0.997	1.014	0.983	1.013	1.000
Canterbury	0.992	1.020	0.972	1.018	1.002
Lincoln	0.948	0.971	0.976	1.000	0.971
Otago	0.958	0.990	0.967	0.991	0.999
AUT	1.027	1.000	1.027	1.000	1.000
Sydney	0.942	1.000	0.942	1.000	1.000
NSW	0.971	0.994	0.977	0.996	0.998
Monash	0.962	1.000	0.962	1.000	1.000
Melbourne	0.954	1.000	0.954	1.000	1.000
Queensland	0.960	1.000	0.960	1.000	1.000
UWA	0.948	1.000	0.948	1.000	1.000
Adelaide	0.963	1.000	0.963	1.000	1.000
ANU	0.969	1.000	0.969	1.000	1.000
WSU	0.975	1.008	0.967	1.008	1.000
La Trobe	0.986	0.989	0.997	0.989	0.999
Griffith	0.969	1.001	0.968	1.000	1.001
JCU	0.955	0.997	0.958	1.005	0.992
Murdoch	0.951	0.968	0.983	0.974	0.994
Flinders	0.964	1.000	0.964	1.000	1.000
CDU	0.924	0.997	0.927	1.000	0.997
CSU	0.981	1.000	0.981	1.000	1.000
SCU	0.963	1.005	0.959	1.000	1.005
UNE	1.008	1.019	0.990	1.000	1.019
Federation	1.033	1.025	1.007	1.002	1.023
CQU	1.048	1.027	1.020	1.015	1.012
USQ	1.042	1.010	1.032	1.000	1.010
USC	1.000	1.022	0.979	1.000	1.022
UTS	1.003	1.000	1.003	1.000	1.000
RMIT	0.979	1.000	0.979	1.000	1.000
Curtin	0.948	1.000	0.948	1.000	1.000
USA	1.001	1.004	0.997	1.003	1.001
Macquarie	1.004	1.004	1.000	1.004	1.000
Newcastle	0.985	1.004	0.982	1.002	1.002
Wollongong	0.989	1.000	0.989	1.000	1.000
Deakin	0.964	0.997	0.967	0.993	1.004
Swinburne	0.965	0.999	0.966	1.004	0.995
Victoria	0.985	0.996	0.989	0.999	0.997
QUT	0.997	1.005	0.991	1.001	1.004
ECU	1.008	1.004	1.004	1.000	1.004
Tasmania	0.952	0.989	0.963	0.990	0.999
Canberra	1.007	1.004	1.003	1.000	1.004
Catholic	0.967	1.000	0.967	1.000	1.000
Mean	*0.979*	*1.000*	*0.978*	*0.999*	*1.001*

Note:
1. All means are geometric means.
2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.
3. The first year in each column indicates the base year, and the indexes show changes from one year to the next year.

Table A5.12

Geometric Mean Changes in TFP, Technical, Efficiency, Pure Efficiency and Scale Efficiency of Australasian universities, 2008/09 to 2017/18, Source from University Annual Reports

University	TFP Δ	Efficiency Δ	Technical Δ	Pure efficiency Δ	Scale efficiency Δ
Auckland	0.987	0.982	1.005	0.983	1.000
Waikato	0.981	0.971	1.011	0.973	0.997
Massey	0.978	0.981	0.997	0.983	0.998
VUW	1.012	1.007	1.005	1.006	1.001
Canterbury	0.978	0.995	0.983	0.992	1.003
Lincoln	0.969	0.972	0.997	1.000	0.972
Otago	0.996	0.987	1.010	0.999	0.988
AUT	1.033	1.000	1.033	1.000	1.000
Sydney	1.014	1.011	1.003	1.000	1.011
NSW	1.013	1.005	1.008	1.000	1.005
Monash	1.016	1.009	1.007	1.000	1.009
Melbourne	0.981	1.000	0.981	1.000	1.000
Queensland	1.024	0.997	1.027	1.000	0.997
UWA	1.016	0.987	1.029	1.000	0.987
Adelaide	1.019	0.996	1.023	1.000	0.996
ANU	0.982	1.000	0.982	1.000	1.000
WSU	1.036	1.017	1.018	1.015	1.002
La Trobe	0.992	0.984	1.008	0.984	1.000
Griffith	1.025	1.013	1.012	1.016	0.997
JCU	0.974	0.960	1.014	0.961	0.999
Murdoch	0.971	0.957	1.014	0.957	1.000
Flinders	1.010	1.000	1.010	1.000	1.000
CDU	1.048	1.000	1.048	1.000	1.000
CSU	0.984	1.000	0.984	1.000	1.000
SCU	1.022	1.026	0.996	1.000	1.026
UNE	1.036	1.018	1.018	1.011	1.007
Federation	1.071	1.031	1.038	1.020	1.011
CQU	1.057	1.027	1.029	1.024	1.003
USQ	1.049	1.011	1.038	1.002	1.008
USC	1.048	1.025	1.022	1.021	1.004
UTS	1.023	1.006	1.017	1.005	1.001
RMIT	1.005	1.000	1.005	1.000	1.000
Curtin	1.011	1.000	1.011	1.000	1.000
USA	1.023	1.001	1.022	1.001	1.000
Macquarie	1.036	1.012	1.024	1.011	1.001
Newcastle	1.016	1.007	1.009	1.010	0.997
Wollongong	1.028	1.009	1.019	1.004	1.005
Deakin	1.018	1.004	1.014	1.004	1.000
Swinburne	1.025	1.004	1.021	1.003	1.001
Victoria	1.006	1.000	1.006	1.000	1.000
QUT	0.996	0.996	1.001	1.000	0.996
ECU	1.024	1.009	1.015	1.007	1.002
Tasmania	0.988	0.990	0.999	1.000	0.990
Canberra	1.033	1.007	1.026	1.000	1.007
Catholic	1.020	1.000	1.020	1.000	1.000
Mean	*1.012*	*1.000*	*1.012*	*1.000*	*1.000*

Note:

1. All means are geometric means.
2. A value of 1.012 for an index represents that productivity had increased by 1.2%. A value of 0.999 would indicate that productivity had decreased by 0.1%.
3. The first year in each column indicates the base year, and the indexes show changes from one year to the next year

Appendix Chapter 6

Table A6.1

University Technical Efficiency Score Rankings

University	Cobb-Doulas Model 1	University	Cobb-Doulas Model 2	University	Translog Model 1	University	Translog Model 2
Otago	0.996	WSU	0.992	WSU	0.990	WSU	0.996
WSU	0.996	UNE	0.990	canterbury	0.989	UNE	0.996
canterbury	0.995	Newcastle	0.990	Newcastle	0.989	Newcastle	0.995
UNE	0.995	UWA	0.989	UNE	0.988	Deakin	0.995
Auckland	0.995	Auckland	0.988	Otago	0.988	UWA	0.994
Newcastle	0.994	Otago	0.987	UWA	0.988	Otago	0.994
UWA	0.994	canterbury	0.986	QUT	0.987	canterbury	0.993
VUW	0.992	NSW	0.985	Auckland	0.986	La Trobe	0.993
Waikato	0.991	Deakin	0.985	VUW	0.986	Melbourne	0.992
Deakin	0.990	Adelaide	0.984	Deakin	0.985	CSU	0.991
Victoria	0.990	VUW	0.983	Lincoln	0.984	Auckland	0.991
CSU	0.990	CSU	0.982	CSU	0.984	Catholic	0.990
ECU	0.989	Sydney	0.982	NSW	0.984	Victoria	0.990
Lincoln	0.989	Victoria	0.981	USC	0.983	NSW	0.990
Adelaide	0.989	Griffith	0.980	UTS	0.982	Sydney	0.989
USC	0.988	Flinders	0.980	USQ	0.982	QUT	0.989
NSW	0.988	UTS	0.980	Griffith	0.981	ECU	0.989
USQ	0.987	QUT	0.978	Queensland	0.980	Flinders	0.988
Griffith	0.987	ECU	0.978	Sydney	0.980	USC	0.988
Canberra	0.986	Melbourne	0.978	Victoria	0.980	SCU	0.988
Flinders	0.986	Waikato	0.977	Waikato	0.979	VUW	0.987
Massey	0.985	USC	0.977	La Trobe	0.979	UTS	0.987
SCU	0.984	Queensland	0.977	Melbourne	0.979	Monash	0.987
UTS	0.984	USQ	0.976	Adelaide	0.979	Griffith	0.985
La Trobe	0.984	SCU	0.976	Swinburne	0.978	Swinburne	0.985
AUT	0.983	La Trobe	0.976	AUT	0.977	Queensland	0.983
Sydney	0.983	Canberra	0.975	ECU	0.977	Adelaide	0.982
QUT	0.981	Wollongong	0.974	SCU	0.976	Canberra	0.981
Catholic	0.981	Catholic	0.972	Catholic	0.975	Waikato	0.978
Melbourne	0.978	CDU	0.972	CDU	0.975	USQ	0.978
Queensland	0.977	Monash	0.969	Flinders	0.975	CDU	0.977
CDU	0.976	Swinburne	0.969	Massey	0.975	Lincoln	0.976
Murdoch	0.970	Massey	0.966	Canberra	0.974	Wollongong	0.975
Wollongong	0.970	Macquarie	0.966	Macquarie	0.969	Macquarie	0.975
Swinburne	0.969	AUT	0.964	Monash	0.966	Massey	0.973
Monash	0.969	Lincoln	0.963	Wollongong	0.964	AUT	0.972
Macquarie	0.967	JCU	0.962	RMIT	0.961	Tasmania	0.967
JCU	0.967	ANU	0.961	JCU	0.954	ANU	0.967
ANU	0.959	RMIT	0.953	Curtin	0.952	RMIT	0.966
Tasmania	0.959	Tasmania	0.953	ANU	0.949	JCU	0.957
Curtin	0.956	Murdoch	0.951	CQU	0.945	Curtin	0.953
RMIT	0.952	Curtin	0.949	USA	0.939	Murdoch	0.945
CQU	0.950	CQU	0.940	Tasmania	0.937	USA	0.942
USA	0.945	USA	0.940	Murdoch	0.933	Federation	0.938
Federation	0.933	Federation	0.910	Federation	0.889	CQU	0.914

Table A6.2

Stochastic Output Distance Specification: Cobb-Douglas Models

Results:	Maximum likelihood estimates of the stochastic frontier and inefficiency analysis							
Dependent variable	Number of undergraduate completions				Number of adjusted undergraduate completions			
Model	1		2		3		4	
Stochastic Frontier		se		se		se		se
Constant	0.354***	(0.020)	0.376***	(0.019)	0.321***	(0.020)	0.333***	(0.020)
PG completions (PG)	0.272***	(0.019)	0.305***	(0.020)	0.227***	(0.021)	0.255***	(0.022)
CNCI-weighted Indexed publications (adjPub)	0.428***	(0.021)	0.410***	(0.020)	0.379***	(0.021)	0.361***	(0.022)
Academic FTE (Aca FTE)	-0.280***	(0.040)	-0.290***	(0.039)	-0.316***	(0.038)	-0.320***	(0.036)
General FTE (Gen FTE)	-0.276***	(0.036)	-0.276***	(0.035)	-0.280***	(0.035)	-0.287***	(0.032)
Capital expenses (Cap exp)	-0.196***	(0.035)	-0.169***	(0.033)	-0.176***	(0.034)	-0.159***	(0.035)
t	-0.374***	(0.028)	-0.380***	(0.027)	-0.334***	(0.028)	-0.335***	(0.026)
t^2	0.054***	(0.010)	0.059***	(0.010)	0.046***	(0.010)	0.049***	(0.009)
Inefficiency effect:								
Constant			-1.513***	(0.457)			-0.586*	(0.326)
Medical School			-0.103**	(0.043)			-0.125***	(0.037)
Share of Overseas students			2.333***	(0.692)			1.094**	(0.516)
NZ_South Island			0.074	(0.076)			0.017	(0.062)
AUS_NewSouthWales			-0.009	(0.057)			-0.050	(0.051)
AUS_Victoria			-0.165**	(0.082)			-0.109**	(0.054)
AUS_Queensland			-0.120**	(0.053)			-0.058	(0.046)
AUS_Western			-0.067	(0.064)			-0.051	(0.056)
AUS_South			0.153**	(0.060)			0.064	(0.054)
AUS_Tasmania			0.385***	(0.082)			0.221***	(0.073)
AUS_NorthTerritory			0.010	(0.074)			0.050	(0.053)
AUS_capitalTerritory			0.049	(0.081)			0.018	(0.051)
Ratio of general to academics			0.162***	(0.042)			0.069	(0.053)
Rate of Female students			1.372**	(0.562)			0.490	(0.483)
Log Likelihood	554.155		570.683		573.142		587.500	
sigma-squared	0.006		0.011		0.006		0.007	
gamma			0.514***				0.277***	
Likelihood ratio test of the one-sided error			33.057				28.716	
Mean efficiency			0.978				0.982	
Observations	495		495		495		495	

Note: 1. All data are from universities annual reports. 2. Capital costs use non-labour expenditure as a proxy for capital costs. 3. All inputs and outputs are mean-scaled. 4. Research output is CNCI-weighted WoS indexed publications, which refer to the number of articles and reviews indexed on the WoS. 5. Standard errors are in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A6.3

Stochastic Output Distance Specification: Translog Models

Results:	Maximum likelihood estimates of the stochastic frontier and inefficiency analysis							
Dependent variable	Number of undergraduate completions				Number of adjusted undergraduate completions			
Model	1		2		3		4	
Stochastic Frontier		se		se		se		se
Constant	0.360***	(0.024)	0.375***	(0.023)	0.330***	(0.025)	0.349***	(0.025)
Postgraduate completions (PG)	0.285***	(0.020)	0.321***	(0.020)	0.238***	(0.022)	0.271***	(0.021)
CNCI-weighted Indexed publications (adjPub)	0.421***	(0.021)	0.396***	(0.021)	0.379***	(0.021)	0.361***	(0.022)
Academic FTE (Aca FTE)	-0.276***	(0.042)	-0.308***	(0.0420	-0.307***	(0.040)	-0.330***	(0.040)
General FTE (Gen FTE)	-0.263***	(0.038)	-0.264***	(0.038)	-0.274***	(0.037)	-0.270***	(0.036)
Capital expenses (Cap exp)	-0.198***	(0.037)	-0.158***	(0.036)	-0.169***	(0.036)	-0.145***	(0.035)
t	-0.385***	(0.034)	-0.381***	(0.032)	-0.344***	(0.034)	-0.354***	(0.035)
$\boldsymbol{t^2}$	0.060***	(0.013)	0.062***	(0.013)	0.049***	(0.013)	0.055***	(0.013)
$\boldsymbol{PG^2}$	-0.045	(0.140)	0.300**	(0.136)	-0.190	(0.174)	0.143	(0.160)
$\boldsymbol{adjPub^2}$	-0.177**	(0.073)	-0.156**	(0.074)	-0.119	(0.077)	-0.124	(0.082)
PG * adjPub	0.047	(0.072	-0.128*	(0.073)	0.085	(0.085)	-0.062	(0.087)
$\boldsymbol{Aca\ FTE^2}$	0.495	(0.557)	0.342	(0.586)	0.277	(0.535)	0.044	(0.572)
$\boldsymbol{Gen\ FTE^2}$	0.432	(0.350)	0.791**	(0.339)	0.365	(0.334)	0.530*	(0.303)
$\boldsymbol{Cap\ exp^2}$	0.147	(0.346)	0.102	(0.319)	0.119	(0.331)	0.153	(0.321)
Aca FTE * Gen FTE	0.580*	(0.325)	0.887***	(0.327)	0.450	(0.304)	0.647**	(0.301)
Aca FTE * Cap exp	-1.149***	(0.377)	-0.879**	(0.365)	-1.038***	(0.357)	-1.015***	(0.386)
Gen FTE* Cap exp	-0.669*	(0.354)	-0.957***	(0.349)	-0.419	(0.348)	-0.688**	(0.334)
Aca FTE *PG	0.132	(0.211)	0.420*	(0.214)	-0.261	(0.234)	-0.001	(0.208)
Gen FTE *PG	0.400**	(0.194)	0.249	(0.189)	0.388*	(0.200)	0.294	(0.197)
Cap exp *PG	-0.598***	(0.153)	-0.287*	(0.154)	-0.539***	(0.166)	-0.377**	(0.171)
Aca FTE *adjPub	0.312**	(0.159)	0.210	(0.160)	0.263*	(0.150)	0.274*	(0.155)
Gen FTE * adjPub	0.021	(0.155)	0.062	(0.152)	-0.081	(0.153)	-0.013	(0.158)
Cap exp * adjPub	0.281**	(0.128)	0.202	(0.131)	0.282**	(0.131)	0.210	(0.136)
Inefficiency effect:								
Constant			-1.776***	(0.486)			-0.763***	(0.243)
Medical School			-0.131**	(0.060)			-0.084***	(0.026)
Share of Overseas students			2.813***	(0.718)			1.546***	(0.378)
NZ_South Island			-0.151	(0.194)			-0.022	(0.066)
AUS_NewSouthWales			0.008	(0.090)			-0.059	(0.040)
AUS_Victoria			-0.214*	(0.124)			-0.186***	(0.045)
AUS_Queensland			-0.096	(0.097)			-0.100**	(0.044)
AUS_Western			-0.114	(0.116)			-0.131***	(0.042)
AUS_South			0.148	(0.100)			0.000	(0.044)
AUS_Tasmania			0.466***	(0.147)			0.140***	(0.049)
AUS_NorthTerritory			0.093	(0.133)			-0.002	(0.044)
AUS_capitalTerritory			0.086	(0.099)			0.010	(0.034)
Ratio of general to academics			0.194***	(0.066)			0.024	(0.048)
Rate of Female students			1.539**	(0.604)			0.783***	(0.290)
Log Likelihood	568.358		588.225		587.092		601.396	
sigma-squared	0.006		0.014		0.006		0.007	
gamma			0.660***				0.278***	
Likelihood ratio test of the one-sided error			39.735				28.607	
Mean efficiency			0.972				0.982	
Observations	495		495		495		495	

Table A6.4

Stochastic Output Distance Specification: Cobb-Douglas Models

Results:	Maximum likelihood estimates of the stochastic frontier and inefficiency analysis							
Dependent variable	Number of undergraduate completions				Number of adjusted undergraduate completions			
Model	1		2		3		4	
Stochastic Frontier		se		se		se		se
Constant	0.041**	(0.018)	0.085***	(0.020)	0.040**	(0.017)	0.087***	(0.018)
PG completions (PG)	0.245***	(0.022)	0.289***	(0.022)	0.174***	(0.024)	0.218***	(0.024)
Research income (RI)	0.271***	(0.017)	0.267***	(0.018)	0.228***	(0.017)	0.221***	(0.018)
Academic FTE (Aca FTE)	-0.041	(0.056)	-0.032	(0.054)	-0.096*	(0.053)	-0.091*	(0.052)
General FTE (Gen FTE)	-0.384***	(0.059)	-0.400***	(0.056)	-0.394***	(0.056)	-0.401***	(0.055)
Capital expenses (Cap exp)	-0.119***	(0.043)	-0.086**	(0.042)	-0.110***	(0.041)	-0.081**	(0.040)
t	-0.087***	(0.029)	-0.1167***	(0.028)	-0.077***	(0.027)	-0.111***	(0.027)
t^2	0.034***	(0.011)	0.043***	(0.011)	0.028***	(0.010)	0.038***	(0.010)
Inefficiency effect:								
Constant			-1.007***	(0.285)			-0.835***	(0.290)
Medical School			-0.099***	(0.032)			-0.099***	(0.035)
Share of Overseas students			1.889***	(0.447)			1.714***	(0.475)
NZ_South Island			0.020	(0.071)			0.047	(0.067)
AUS_NewSouthWales			-0.132**	(0.064)			-0.146***	(0.056)
AUS_Victoria			-0.091	(0.059)			-0.148***	(0.051)
AUS_Queensland			-0.022	(0.052)			-0.063	(0.044)
AUS_Western			-0.130*	(0.068)			-0.144**	(0.062)
AUS_South			-0.074	(0.069)			-0.108*	(0.063)
AUS_Tasmania			0.069	(0.069)			0.041	(0.059)
AUS_NorthTerritory			-0.143*	(0.085)			-0.110	(0.068)
AUS_capitalTerritory			-0.005	(0.068)			-0.058	(0.057)
Ratio of general to academics			-0.207***	(0.072)			-0.177**	(0.071)
Rate of Female students			1.618***	(0.493)			1.357***	(0.492)
Log Likelihood	503.669		524.034		530.069		548.670	
sigma-squared	0.008		0.009		0.007		0.008	
gamma			0.330***				0.303***	
Likelihood ratio test of the one-sided error			40.731				37.201	
Mean efficiency			0.973				0.975	
Observations	495		495		495		495	

Note: 1. New Zealand data are from Tertiary Education Commission (TEC). Australian data are from Australian Government Department of Education (DoE). 2. Capital costs use non-labour expenditure as a proxy for capital costs. 3. All inputs and outputs are mean-scaled.4. Standard errors are in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01. 5. Model 1 is an OLS estimation and output is number of undergraduate and postgraduate completions, and research income with academic, general FTE and capital costs as inputs used. Model 2 adds the variable used in the inefficiency model. Model 3 uses the adjusted UG and PG completions. Model 4 adds the inefficiency explanatory variables.

Table A6.5

Stochastic Output Distance Specification: Translog Models

Results:	Maximum likelihood estimates of the stochastic frontier and inefficiency analysis							
Dependent variable	Number of undergraduate completions				Number of adjusted undergraduate completions			
Model	1		2		3		4	
Stochastic Frontier		se		se		se		se
Constant	0.034	(0.021)	0.077***	(0.022)	0.034*	(0.020)	0.077***	(0.020)
PG completions (PG)	0.248***	(0.023)	0.285***	(0.023)	0.168***	(0.024)	0.215***	(0.024)
Research income (RI)	0.283***	(0.017)	0.280***	(0.017)	0.244***	(0.017)	0.236***	(0.017)
Academic FTE (Aca FTE)	-0.063	(0.055)	-0.035	(0.053)	-0.117**	(0.052)	-0.102**	(0.051)
General FTE (Gen FTE)	-0.345***	(0.059)	-0.373***	(0.056)	-0.369***	(0.056)	-0.397***	(0.054)
Capital expenses (Cap exp)	-0.129***	(0.042)	-0.091**	(0.042)	-0.112***	(0.040)	-0.066	(0.041)
t	-0.082**	(0.032)	-0.101***	(0.033)	-0.072**	(0.030)	-0.091***	(0.030)
t^2	0.033***	(0.012)	0.037***	(0.013)	0.027**	(0.012)	0.030**	(0.012)
PG^2	-0.115	(0.139)	-0.101	(0.136)	-0.298*	(0.167)	-0.244	(0.162)
RI^2	0.010	(0.076)	0.075	(0.078)	0.021	(0.077)	0.113	(0.082)
PG * RI	0.067	(0.083)	0.076	(0.080)	-0.013	(0.092)	0.052	(0.094)
$Aca\ FTE^2$	0.409	(0.833)	0.890	(0.880)	-0.386	(0.773)	0.054	(0.868)
$Gen\ FTE^2$	1.393	(0.988)	1.191	(0.849)	0.782	(0.905)	0.569	(0.849)
$Cap\ exp^2$	1.238***	(0.446)	1.250**	(0.506)	1.277***	(0.432)	1.167**	(0.454)
Aca FTE * Gen FTE	-0.047	(0.659)	0.733	(0.620)	0.153	(0.587)	0.894	(0.581)
Aca FTE * Cap exp	-0.735	(0.518)	-1.202**	(0.553)	-0.375	(0.490)	-0.755	(0.506)
Gen FTE* Cap exp	-0.979*	(0.538)	-1.081**	(0.506)	-0.833	(0.507)	-0.902*	(0.484)
Aca FTE * PG	-0.611**	(0.272)	-0.635**	(0.263)	-1.030***	(0.355)	-0.881**	(0.345)
Gen FTE * PG	1.021***	(0.262)	1.039***	(0.272)	0.851***	(0.314)	0.685**	(0.303)
Cap exp * PG	-0.753***	(0.178)	-0.748***	(0.183)	-0.445**	(0.183)	-0.396**	(0.177)
Aca FTE * RI	0.486**	(0.239)	0.659***	(0.233)	0.645***	(0.235)	0.888***	(0.240)
Gen FTE * RI	-0.424*	(0.237)	-0.528***	(0.229)	-0.575**	(0.240)	-0.635***	(0.232)
Cap exp * RI	0.477***	(0.162)	0.343**	(0.162)	0.468***	(0.160)	0.304*	(0.167)
Inefficiency effect:								
Constant			-1.292***	(0.378)			-1.126***	(0.359)
Medical School			-0.148***	(0.042)			-0.156***	(0.043)
Share of Overseas students			2.117***	(0.527)			2.027***	(0.545)
NZ_South Island			0.121**	(0.073)			0.074	(0.071)
AUS_NewSouthWales			-0.157**	(0.077)			-0.096*	(0.057)
AUS_Victoria			-0.036	(0.060)			-0.101*	(0.053)
AUS_Queensland			0.055	(0.056)			0.036	(0.043)
AUS_Western			-0.104	(0.066)			-0.120**	(0.056)
AUS_South			-0.067	(0.070)			-0.071	(0.060)
AUS_Tasmania			0.160**	(0.079)			0.127*	(0.071)
AUS_NorthTerritory			-0.073	(0.077)			-0.046	(0.066)
AUS_capitalTerritory			0.095	(0.065)			0.049	(0.052)
Ratio of general to academics			-0.183***	(0.065)			-0.159**	(0.071)
Rate of Female students			1.995***	(0.597)			1.669***	(0.565)
Log Likelihood	528.016		551.306		555.446		577.588	
sigma-squared	0.007		0.010		0.007		0.009	
gamma			0.485***				0.435***	
Likelihood ratio test of the one-sided error			46.580				44.284	
Mean efficiency			0.967				0.970	
Observations	495		495		495		495	

Table A6.6

Stochastic Output Distance Specification: Cobb-Douglas Models

Results:	Maximum likelihood estimates of the stochastic frontier and inefficiency analysis							
Dependent variable	Number of undergraduate completions				Number of adjusted undergraduate completions			
Model	1		2		3		4	
Stochastic Frontier		se		se		se		se
Constant	0.040**	(0.018)	0.085***	(0.019)	0.039**	(0.017)	0.086***	(0.019)
PG completions (PG)	0.247***	(0.022)	0.290***	(0.022)	0.178***	(0.024)	0.225***	(0.025)
Research income (RI)	0.271***	(0.017)	0.270***	(0.018)	0.227***	(0.017)	0.221***	(0.018)
Teaching FTE (Teach FTE)	-0.050	(0.043)	-0.028	(0.041)	-0.059	(0.041)	-0.055	(0.041)
Research FTE (Res FTE)	-0.003	(0.039)	-0.003	(0.037)	-0.036	(0.037)	-0.027	(0.036)
General FTE (Gen FTE)	-0.371***	(0.061)	-0.392***	(0.058)	-0.388***	(0.058)	-0.402***	(0.057)
Capital expenses (Cap exp)	-0.125***	(0.043)	-0.092**	(0.042)	-0.117***	(0.041)	-0.087**	(0.041)
t	-0.086***	(0.029)	-0.117***	(0.028)	-0.077***	(0.027)	-0.110***	(0.027)
t^2	0.035***	(0.011)	0.044***	(0.011)	0.029***	(0.011)	0.038***	(0.010)
Inefficiency effect:								
Constant			-1.048***	(0.301)			-0.869***	(0.296)
Medical School			-0.106***	(0.034)			-0.098***	(0.034)
Share of Overseas students			1.939***	(0.472)			1.756***	(0.484)
NZ_South Island			0.030	(0.075)			0.060	(0.064)
AUS_NewSouthWales			-0.134**	(0.067)			-0.147***	(0.056)
AUS_Victoria			-0.089	(0.060)			-0.149***	(0.052)
AUS_Queensland			-0.024	(0.054)			-0.061	(0.043)
AUS_Western			-0.136*	(0.072)			-0.147**	(0.061)
AUS_South			-0.084	(0.070)			-0.103	(0.062)
AUS_Tasmania			0.075	(0.070)			0.044	(0.058)
AUS_NorthTerritory			-0.156*	(0.090)			-0.112	(0.068)
AUS_capitalTerritory			-0.015	(0.071)			-0.063	(0.059)
Ratio of general to academics			-0.213***	(0.076)			-0.174**	(0.069)
Rate of Female students			1.694***	(0.515)			1.401***	(0.496)
Log Likelihood	504.072		524.275		529.895		548.206	
sigma-squared	0.008		0.009		0.007		0.008	
gamma			0.344***				0.308***	
Likelihood ratio test of the one-sided error			40.406				36.622	
Mean efficiency			0.973				0.974	
Observations	495		495		495		495	

Note: 1. New Zealand data are from Tertiary Education Commission. Australian data are from Australian Government Department of Education. 2. Capital costs use non-labour expenditure as a proxy for capital costs. 3. All inputs and outputs are mean-scaled. 4. New Zealand Teaching FTE = 0.5*TEC Academic/Tutorial Staff FTE; AUS Teaching FTE=Teaching-only+0.5*(teaching and research). 5. New Zealand TEC Research FTE = 0.5*(TEC Academic / Tutorial Staff FTE) + research-only FTE; AUS Research FTE=Research-ONLY+0.5*(teaching and research).

Table A6.7

Stochastic Output Distance Specification: Translog Models

Results:	Maximum likelihood estimates of the stochastic frontier and inefficiency analysis							
Dependent variable	Number of undergraduate completions				Number of adjusted undergraduate completions			
Model	1		2		3		4	
Stochastic Frontier		se		se		se		se
Constant	0.046**	(0.021)	0.090***	(0.022)	0.043**	(0.020)	0.084***	(0.021)
PG completions (PG)	0.251***	(0.023)	0.290***	(0.023)	0.173***	(0.024)	0.220***	(0.025)
Research income (RI)	0.275***	(0.018)	0.273***	(0.018)	0.239***	(0.018)	0.233***	(0.018)
Teaching FTE (Teach FTE)	-0.079*	(0.044)	-0.041	(0.044)	-0.073*	(0.042)	-0.053	(0.041)
Research FTE (Res FTE)	-0.007	(0.039)	-0.002	(0.039)	-0.047	(0.038)	-0.043	(0.037)
General FTE (Gen FTE)	-0.307***	(0.063)	-0.350***	(0.062)	-0.349***	(0.060)	-0.381***	(0.059)
Capital expenses (Cap exp)	-0.145***	(0.043)	-0.103**	(0.043)	-0.123***	(0.041)	-0.084**	(0.041)
t	-0.105***	(0.034)	-0.121***	(0.034)	-0.088***	(0.032)	-0.100***	(0.031)
$\boldsymbol{t^2}$	0.043***	(0.013)	0.045***	(0.013)	0.034***	(0.012)	0.034***	(0.012)
$\boldsymbol{PG^2}$	-0.200	(0.144)	-0.179	(0.141)	-0.404**	(0.173)	-0.318*	(0.163)
$\boldsymbol{RI^2}$	0.039	(0.082)	0.087	(0.083)	0.056	(0.083)	0.099	(0.091)
PG * RI	0.094	(0.085)	0.112	(0.088)	-0.021	(0.094)	0.060	(0.098)
$\boldsymbol{Teach\ FTE^2}$	-0.552	(0.489)	-0.400	(0.562)	-0.382	(0.456)	-0.348	(0.463)
$\boldsymbol{Res\ FTE^2}$	1.087**	(0.521)	0.984*	(0.512)	0.347	(0.502)	0.613	(0.477)
$\boldsymbol{Gen\ FTE^2}$	0.354	(1.157)	-0.317	(0.926)	0.310	(1.058)	-0.603	(0.883)
$\boldsymbol{Cap\ exp^2}$	0.968**	(0.443)	0.964**	(0.477)	1.066**	(0.430)	0.924**	(0.447)
Teach FTE* Res FTE	0.051	(0.312)	-0.129	(0.315)	-0.054	(0.290)	-0.281	(0.286)
Teach FTE * Gen FTE	0.823	(0.650)	1.801**	(0.699)	0.441	(0.599)	1.632***	(0.583)
Teach FTE * Cap exp	-0.209	(0.404)	-0.641	(0.399)	-0.101	(0.388)	-0.546	(0.378)
Res FTE * Gen FTE	-0.030	(0.476)	0.083	(0.499)	0.103	(0.434)	0.067	(0.449)
Res FTE * Cap exp	-0.837**	(0.387)	-0.707*	(0.416)	-0.515	(0.374)	-0.381	(0.407)
Gen FTE * Cap exp	-0.898	(0.578)	-0.854	(0.570)	-0.715	(0.548)	-0.658	(0.492)
Teach FTE * PG	0.002	(0.232)	0.030	(0.236)	-0.151	(0.244)	-0.091	(0.246)
Res FTE* PG	-0.502***	(0.190)	-0.468**	(0.183)	-0.845***	(0.239)	-0.613***	(0.233)
Gen FTE * PG	0.996***	(0.296)	0.867***	(0.281)	0.905***	(0.349)	0.532	(0.338)
Cap exp *PG	-0.840***	(0.188)	-0.779***	(0.195)	-0.556***	(0.193)	-0.436**	(0.201)
Teach FTE * RI	0.297*	(0.158)	0.381**	(0.157)	0.338**	(0.156)	0.426***	(0.156)
Res FTE * RI	0.248	(0.155)	0.217	(0.150)	0.276*	(0.156)	0.326**	(0.151)
Gen FTE * RI	-0.419*	(0.253)	-0.472*	(0.248)	-0.548**	(0.255)	-0.585**	(0.251)
Cap exp * RI	0.449***	(0.170)	0.340*	(0.178)	0.464***	(0.167)	0.333**	(0.171)
Inefficiency effect:								
Constant			-1.555***	(0.393)			-1.382***	(0.387)
Medical School			-0.178***	(0.047)			-0.167***	(0.046)
Share of Overseas students			2.462***	(0.573)			2.293***	(0.595)
NZ_South Island			0.179**	(0.075)			0.146**	(0.070)
AUS_NewSouthWales			-0.127*	(0.069)			-0.078	(0.051)
AUS_Victoria			-0.023	(0.057)			-0.068	(0.047)
AUS_Queensland			0.067	(0.052)			0.053	(0.036)
AUS_Western			-0.114*	(0.067)			-0.104**	(0.051)
AUS_South			-0.095	(0.074)			-0.072	(0.054)
AUS_Tasmania			0.185**	(0.081)			0.139**	(0.066)
AUS_NorthTerritory			-0.089	(0.075)			-0.027	(0.055)
AUS_capitalTerritory			0.142**	(0.065)			0.109**	(0.054)
Ratio of general to academics			-0.228***	(0.072)			-0.194**	(0.076)
Rate of Female students			2.423***	(0.627)			2.101***	(0.601)
Log Likelihood	533.387		557.499		558.469		579.457	
sigma-squared	0.007		0.011		0.007		0.009	
gamma			0.538***				0.479***	
Likelihood ratio test of the one-sided error			48.224				41.975	
Mean efficiency			0.965				0.968	
Observations	495		495		495		495	

Appendix Chapter 7

Table A7.1
University Cost Inefficiency Score Rankings

University	Cobb-Doulas Model 1	University	Cobb-Doulas Model 2	University	Translog Model 1	University	Translog Model 2
RMIT	1.003	Federation	1.004	CDU	1.003	CDU	1.003
Federation	1.003	RMIT	1.004	RMIT	1.052	RMIT	1.044
CDU	1.020	Victoria	1.008	Federation	1.054	Federation	1.052
Victoria	1.021	Swinburne	1.008	Swinburne	1.088	Swinburne	1.082
Swinburne	1.021	CQU	1.021	Victoria	1.101	Victoria	1.103
Monash	1.070	Monash	1.038	Wollongong	1.113	Wollongong	1.105
UTS	1.072	Murdoch	1.038	Monash	1.115	Monash	1.108
CQU	1.072	UTS	1.042	Macquarie	1.123	Macquarie	1.120
Wollongong	1.078	USQ	1.046	UTS	1.128	UTS	1.124
Macquarie	1.081	Macquarie	1.047	CQU	1.128	Murdoch	1.128
Murdoch	1.088	Wollongong	1.048	Murdoch	1.128	Curtin	1.130
La Trobe	1.094	La Trobe	1.050	Curtin	1.134	NSW	1.131
NSW	1.100	Curtin	1.060	Tasmania	1.138	CQU	1.132
USQ	1.108	Tasmania	1.061	NSW	1.141	Melbourne	1.133
Curtin	1.109	SCU	1.065	Melbourne	1.142	ANU	1.148
Melbourne	1.109	CSU	1.066	Canberra	1.148	Tasmania	1.151
CSU	1.109	CDU	1.067	ANU	1.152	Canberra	1.155
SCU	1.113	JCU	1.079	La Trobe	1.155	Sydney	1.156
Tasmania	1.118	ECU	1.084	SCU	1.160	Lincoln	1.159
Adelaide	1.131	Adelaide	1.089	Sydney	1.161	La Trobe	1.162
Newcastle	1.132	Melbourne	1.089	CSU	1.166	Adelaide	1.164
Sydney	1.132	NSW	1.091	JCU	1.172	SCU	1.166
WSU	1.140	Canberra	1.091	Adelaide	1.172	CSU	1.173
Deakin	1.141	WSU	1.094	USA	1.175	USA	1.174
Canberra	1.144	Waikato	1.094	Lincoln	1.179	JCU	1.176
JCU	1.146	Newcastle	1.097	USQ	1.179	USQ	1.185
ECU	1.154	Deakin	1.099	Deakin	1.186	Deakin	1.187
USA	1.154	USA	1.100	Newcastle	1.189	Newcastle	1.188
Griffith	1.166	USC	1.103	ECU	1.190	Waikato	1.194
USC	1.171	Griffith	1.106	Waikato	1.193	Queensland	1.196
UWA	1.172	Sydney	1.118	Queensland	1.199	ECU	1.198
Waikato	1.185	VUW	1.119	VUW	1.204	VUW	1.201
Catholic	1.186	Auckland	1.125	Catholic	1.204	UWA	1.203
QUT	1.186	QUT	1.137	AUT	1.206	AUT	1.203
Queensland	1.188	UNE	1.137	WSU	1.206	WSU	1.209
UNE	1.189	UWA	1.145	UWA	1.209	QUT	1.213
ANU	1.199	Catholic	1.147	Griffith	1.209	Massey	1.213
VUW	1.207	canterbury	1.149	QUT	1.210	Griffith	1.214
Auckland	1.211	Massey	1.152	Massey	1.213	Catholic	1.218
Lincoln	1.223	Queensland	1.155	USC	1.220	canterbury	1.220
Flinders	1.229	AUT	1.166	Auckland	1.225	Auckland	1.221
AUT	1.234	Lincoln	1.174	canterbury	1.228	USC	1.230
Massey	1.235	Flinders	1.177	UNE	1.238	Flinders	1.242
canterbury	1.240	ANU	1.201	Flinders	1.240	UNE	1.248
Otago	1.307	Otago	1.225	Otago	1.266	Otago	1.259

Note: 1. Due to use FRONTIER 4.1, the efficiency scores in cost function take a value between one and infinity (Coelli, 1996, p. 9); hence, a score of one denotes that the university is fully cost-efficient.
2. Australian mean refers to the geomeans of all individual Australian universities.

3. The mean cost efficiency scores of individual universities are calculated as the geometric mean of their annual cost efficiency scores from 2008 to 2018.

Table A7.2

Stochastic Cost frontier Specification: Cobb-Douglas vs. Translog Models

ln(Costs/EFTS)	Inefficiency effects model 1				ln(Costs/EFTS)	Inefficiency effects model 2		
Coefficients	Cobb-Douglas	se	Translog	se	Cobb-Douglas	se	Translog	se
Constant	1.958***	0.091	4.753**	2.101	1.939***	0.126	14.348***	2.812
ln(UG compl/EFTS)	-0.098***	0.021	1.186**	0.491	-0.099***	0.023	-1.285	0.792
ln(PG compl/EFTS)	0.083***	0.015	0.372	0.370	0.084***	0.017	-2.061***	0.468
ln(Research income/EFTS)	0.146***	0.009	0.217	0.153	0.149***	0.009	-0.168	0.230
ln(FTE Price)	0.183***	0.018	-0.365	0.775	0.217***	0.018	-2.488***	0.728
ln(Capital Price)	0.144***	0.015	-0.053	0.346	0.131***	0.017	1.309**	0.556
t	-0.001	0.006	0.001	0.005	-0.003	0.007	0.003	0.004
$\boldsymbol{t^2}$	0.001*	0.001	0.001**	0.000	0.001*	0.001	0.001*	0.000
$\boldsymbol{ln(UG\ /EFTS)^2}$			0.193*	0.115			0.516***	0.166
$\boldsymbol{ln(PG/EFTS)^2}$			0.174**	0.069			0.232***	0.061
$\boldsymbol{ln(RI/EFTS)^2}$			0.208***	0.016			0.199***	0.017
ln(UG/EFTS)*ln(PG/EFTS)			0.076	0.067			0.056	0.070
ln(UG/EFTS)*ln(RI/EFTS)			0.125***	0.034			0.234***	0.042
ln(PG/EFTS)*ln(RI/EFTS)			-0.087***	0.020			-0.096***	0.020
$\boldsymbol{ln(FTE\ Price)^2}$			0.076	0.160			0.615***	0.127
$\boldsymbol{ln(Capital\ Price)^2}$			-0.009	0.073			-0.031	0.070
ln(FTE Price)*ln(Capital Price)			0.072	0.068			-0.118*	0.068
ln(FTE Price)*ln(UG/EFTS)			-0.161*	0.091			-0.258***	0.087
ln(Capital Price)*ln(UG/EFTS)			-0.195***	0.075			-0.241***	0.084
ln(FTE Price)*ln(PG/EFTS)			0.048	0.066			0.255***	0.064
ln(Capital Price)*ln(PG/EFTS)			0.187***	0.048			0.161***	0.047
ln(FTE Price)*ln(RI/EFTS)			-0.057*	0.031			-0.125***	0.030
ln(Capital Price)*ln(RI/EFTS)			-0.029	0.025			-0.002	0.026
Inefficiency effect:					Inefficiency effect:			
Constant	1.131***	0.184	-0.190	0.204	1.060***	0.104	0.135	0.171
Medical School	0.301***	0.028	0.034*	0.019	0.295***	0.030	0.030**	0.012
Share of Overseas students	-1.177***	0.229	-0.521***	0.196	-1.179***	0.165	-0.471***	0.090
NZ_South Island	0.548***	0.074	0.580***	0.124	0.472***	0.061	0.177	0.145
AUS_NewSouthWales	-0.055	0.057	0.611***	0.153	-0.055**	0.027	0.387***	0.145
AUS_Victoria	0.136***	0.041	0.666***	0.146	0.129***	0.029	0.435***	0.145
AUS_Queensland	0.136**	0.054	0.673***	0.143	0.134***	0.036	0.425***	0.145
AUS_Western	0.197***	0.061	0.653***	0.155	0.175***	0.035	0.430***	0.147
AUS_South	0.013	0.057	0.567***	0.170	0.006	0.040	0.359**	0.147
AUS_Tasmania	0.033	0.062	0.540***	0.189	0.030	0.056	0.364**	0.149
AUS_NorthTerritory	0.728***	0.062	0.535***	0.156	0.667***	0.068	0.538***	0.160
AUS_capitalTerritory	0.322***	0.058	0.662***	0.146	0.336***	0.043	0.426***	0.146
Ratio of general to academics	-0.476***	0.039	-0.023	0.039	-0.422***	0.040	-0.006	0.019
Rate of Female students	-1.898***	0.288	-0.537**	0.238	-1.740***	0.153	-0.447***	0.109
Log Likelihood	536.498		622.161		530.994		642.072	
sigma-squared	0.012		0.007		0.011		0.005	
gamma	0.626***		0.740***		0.550***		0.697***	
Likelihood ratio test of the one-sided error	310.750		89.055		298.243		130.654	
Mean efficiency	1.119		1.097		1.1157		1.236	
Observations	495		495		495		495	

Note: 1. Source: Universities annual reports. 2. Capital prices use depreciation and amortisation per EFTS as a proxy for capital price. 3. Standard errors are in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A7.3

Stochastic Cost frontier Specification: Cobb-Douglas vs. Translog Models

ln(Costs/EFTS)	Inefficiency effects model 1				Inefficiency effects model 2			
Coefficients	Cobb-Douglas	se	Translog	se	Cobb-Douglas	se	Translog	se
Constant	2.521***	0.093	9.956***	1.032	2.357***	0.130	21.402***	4.942
ln(UG compl/EFTS)	-0.084***	0.022	0.717	0.539	-0.111***	0.023	-4.215***	1.179
ln(PG compl/EFTS)	0.111***	0.015	0.146	0.365	0.111***	0.014	-2.111***	0.616
ln(Research income/EFTS)	0.190***	0.009	0.331**	0.152	0.185***	0.009	0.623***	0.201
ln(FTE Price)	0.104***	0.017	-2.100***	0.409	0.143***	0.017	-2.427***	0.872
ln(Capital Price)	0.072***	0.017	2.114***	0.415	0.067***	0.017	1.794***	0.569
t	0.002	0.007	0.003	0.005	0.003	0.007	0.004	0.005
$\boldsymbol{t^2}$	0.001**	0.001	0.002***	0.000	0.001*	0.001	0.001***	0.000
$\boldsymbol{ln(UG\ /EFTS)^2}$			0.413***	0.115			0.877***	0.199
$\boldsymbol{ln(PG/EFTS)^2}$			0.183***	0.063			0.180***	0.068
$\boldsymbol{ln(RI/EFTS)^2}$			0.200***	0.012			0.202***	0.015
ln(UG/EFTS)*ln(PG/EFTS)			0.312***	0.071			0.214***	0.076
ln(UG/EFTS)*ln(RI/EFTS)			-0.002	0.030			0.019	0.037
ln(PG/EFTS)*ln(RI/EFTS)			-0.012	0.020			-0.012	0.020
$\boldsymbol{ln(FTE\ Price)^2}$			0.516***	0.110			0.354***	0.126
$\boldsymbol{ln(Capital\ Price)^2}$			0.420***	0.079			0.435***	0.073
ln(FTE Price)*ln(Capital Price)			-0.266***	0.077			-0.325***	0.069
ln(FTE Price)*ln(UG/EFTS)			0.155*	0.090			0.003	0.101
ln(Capital Price)*ln(UG/EFTS)			0.135	0.089			0.135	0.085
ln(FTE Price)*ln(PG/EFTS)			0.176**	0.072			0.161**	0.072
ln(Capital Price)*ln(PG/EFTS)			-0.026	0.056			-0.018	0.052
ln(FTE Price)*ln(RI/EFTS)			-0.072**	0.031			-0.141***	0.024
ln(Capital Price)*ln(RI/EFTS)			0.023	0.022			0.003	0.022
Inefficiency effect:					Inefficiency effect:			
Constant	1.468***	0.208	0.552***	0.121	1.355***	0.216	0.502***	0.089
Medical School	0.305***	0.036	0.003	0.016	0.356***	0.029	0.006	0.025
Share of Overseas students	-1.659***	0.257	-0.930***	0.155	-1.637***	0.272	-0.791***	0.138
NZ_South Island	0.452***	0.139	0.202***	0.064	0.539***	0.089	0.078	0.066
AUS_NewSouthWales	-0.105	0.135	0.096	0.071	-0.068	0.063	0.065	0.046
AUS_Victoria	0.069	0.139	0.155**	0.072	0.140***	0.052	0.121**	0.050
AUS_Queensland	0.055	0.135	0.119*	0.069	0.120**	0.056	0.093**	0.039
AUS_Western	0.073	0.142	0.126*	0.073	0.148**	0.070	0.090**	0.043
AUS_South	-0.112	0.139	-0.144	0.100	-0.059	0.067	-0.011	0.057
AUS_Tasmania	-0.179	0.159	-0.222**	0.094	-0.106	0.085	-0.144	0.215
AUS_NorthTerritory	0.710***	0.154	0.007	0.110	0.842***	0.069	0.164**	0.068
AUS_capitalTerritory	0.303**	0.137	0.196***	0.069	0.367***	0.066	0.139***	0.048
Ratio of general to academics	-0.454***	0.041	-0.203***	0.035	-0.491***	0.059	-0.114*	0.062
Rate of Female students	-2.223***	0.264	-0.575***	0.179	-2.211***	0.338	-0.546***	0.151
Log Likelihood	507.598		588.156		505.530		599.568	
sigma-squared	0.013		0.006		0.015		0.005	
gamma	0.574***		0.161**		0.640***		0.042	
Likelihood ratio test of the one-sided error	366.392		147.276		345.392		145.440	
Mean efficiency	1.129		1.055		1.126		1.067	
Observations	495		495		495		495	

Note: 1. Source: Universities annual reports. 2. Capital prices use non-labour expenses per net assets as a proxy for capital price. 3. Standard errors are in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A7.4

Stochastic Cost Frontier Specification: Cobb-Douglas vs. Translog Models

ln(Costs/EFTS)	Inefficiency effects model 1				Inefficiency effects model 2			
Coefficients	Cobb-Douglas	se	Translog	se	Cobb-Douglas	se	Translog	se
Constant	1.660***	0.070	-0.976	0.959	1.599***	0.099	7.914***	1.146
ln(UG compl/EFTS)	-0.010	0.013	-0.399	0.744	-0.020	0.015	-0.513	0.461
ln(PG compl/EFTS)	0.030***	0.009	-1.163	0.903	0.021**	0.009	-0.739**	0.289
ln(Research income/EFTS)	0.089***	0.006	0.184	0.815	0.087***	0.006	-0.025	0.211
ln(FTE Price)	0.067***	0.012	0.685	0.649	0.073***	0.013	-1.321**	0.577
ln(Capital Price)	0.464***	0.017	-0.074	0.699	0.466***	0.016	-0.175	0.557
t	0.007*	0.004	0.012***	0.005	0.007*	0.004	0.007***	0.003
t^2	0.000	0.000	0.000	0.000	0.000	0.000	0.0001	0.000
$\boldsymbol{ln(UG\ /EFTS)^2}$			-0.123	0.288			0.172	0.105
$\boldsymbol{ln(PG/EFTS)^2}$			0.012	0.187			0.014	0.037
$\boldsymbol{ln(RI/EFTS)^2}$			0.080	0.093			0.049**	0.020
ln(UG/EFTS)*ln(PG/EFTS)			-0.002	0.176			-0.023	0.043
ln(UG/EFTS)*ln(RI/EFTS)			0.108	0.256			0.094***	0.034
ln(PG/EFTS)*ln(RI/EFTS)			-0.014	0.032			-0.059***	0.016
$\boldsymbol{ln(FTE\ Price)^2}$			0.028	0.221			0.210**	0.092
$\boldsymbol{ln(Capital\ Price)^2}$			0.119	0.747			-0.093	0.088
ln(FTE Price)*ln(Capital Price)			-0.017	0.248			0.102*	0.053
ln(FTE Price)*ln(UG/EFTS)			0.086	0.204			-0.027	0.057
ln(Capital Price)*ln(UG/EFTS)			-0.172	0.533			-0.061	0.089
ln(FTE Price)*ln(PG/EFTS)			0.239	0.242			0.124**	0.048
ln(Capital Price)*ln(PG/EFTS)			0.019	0.159			0.131***	0.042
ln(FTE Price)*ln(RI/EFTS)			-0.029	0.188			-0.080***	0.026
ln(Capital Price)*ln(RI/EFTS)			0.047	0.262			0.111***	0.036
Inefficiency effect:					Inefficiency effect:			
Constant	0.473***	0.115	0.006	0.481	0.456***	0.113	0.064	0.057
Medical School	0.165***	0.017	0.043	0.032	0.167***	0.017	0.033**	0.015
Share of Overseas students	-0.586***	0.136	-0.117	0.468	-0.553***	0.135	-0.318***	0.068
NZ_South Island	0.251***	0.056	0.062*	0.033	0.235***	0.052	0.127***	0.020
AUS_NewSouthWales	-0.034	0.060	-0.003	0.030	-0.046	0.057	0.019	0.023
AUS_Victoria	0.033	0.061	-0.048	0.030	0.018	0.058	0.039	0.032
AUS_Queensland	0.038	0.060	0.018	0.027	0.025	0.057	0.062***	0.021
AUS_Western	0.092	0.059	0.015	0.042	0.081	0.058	0.073***	0.021
AUS_South	0.016	0.060	0.004	0.029	0.009	0.056	0.056***	0.021
AUS_Tasmania	-0.061	0.069	-0.040	0.026	-0.068	0.058	-0.054*	0.032
AUS_NorthTerritory	0.335***	0.070	-0.115	0.263	0.317***	0.068	-0.079	0.055
AUS_capitalTerritory	0.200***	0.061	0.009	0.047	0.189***	0.059	0.090***	0.022
Ratio of general to academics	-0.207***	0.026	-0.047	0.033	-0.206***	0.025	-0.071***	0.014
Rate of Female students	-0.705***	0.182	0.098	0.720	-0.659***	0.183	0.073	0.089
Log Likelihood	765.701		846.656		763.550		898.416	
sigma-squared	0.004		0.003		0.004		0.002	
gamma	0.444***		0.101***		0.448***		0.130**	
Likelihood ratio test of the one-sided error	261.086		70.557		258.292		181.630	
Mean efficiency	1.064		1.022		1.064		1.036	
Observations	495		495		495		495	

Note: 1. Source: New Zealand TEC; Australian Government DoE. 2. Capital prices use non-labour expenses per EFTS as a proxy for capital price. 3. Standard errors are in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A7.5

Stochastic Cost Frontier Specification: Cobb-Douglas vs. Translog Models

ln(Costs/EFTS)	Inefficiency effects model 1				Inefficiency effects model 2			
Coefficients	Cobb-Douglas	se	Translog	se	Cobb-Douglas	se	Translog	se
Constant	0.455***	0.112	6.347***	1.384	0.156	0.181	12.604***	4.300
ln(UG compl/EFTS)	0.046***	0.004	0.186	0.390	0.016	0.018	-1.703***	0.596
ln(PG compl/EFTS)	0.040***	0.006	-0.383	0.313	0.0444***	0.011	-0.496	0.353
ln(Research income/EFTS)	0.097***	0.010	0.762***	0.171	0.092***	0.011	0.576***	0.211
ln(FTE Price)	0.335***	0.017	-1.858***	0.435	0.321***	0.024	-2.845***	0.671
ln(Capital Price)	0.652***	0.012	1.105***	0.347	0.645***	0.017	1.227***	0.414
t	-0.016***	0.004	-0.014***	0.004	-0.014***	0.004	-0.012***	0.003
$\boldsymbol{t^2}$	0.0003	0.000	0.0000	0.000	0.0003	0.000	0.0000	0.000
$\boldsymbol{ln(UG\ /EFTS)^2}$			0.102	0.076			0.413***	0.121
$\boldsymbol{ln(PG/EFTS)^2}$			0.044	0.046			0.056	0.044
$\boldsymbol{ln(RI/EFTS)^2}$			0.071***	0.016			0.064***	0.014
ln(UG/EFTS)*ln(PG/EFTS)			0.033	0.044			-0.054	0.051
ln(UG/EFTS)*ln(RI/EFTS)			-0.024	0.024			-0.007	0.028
ln(PG/EFTS)*ln(RI/EFTS)			0.027	0.018			0.040**	0.017
$\boldsymbol{ln(FTE\ Price)^2}$			0.547***	0.088			0.567***	0.094
$\boldsymbol{ln(Capital\ Price)^2}$			0.134**	0.057			0.158***	0.057
ln(FTE Price)*ln(Capital Price)			-0.211***	0.053			-0.208***	0.056
ln(FTE Price)*ln(UG/EFTS)			0.034	0.059			-0.006	0.068
ln(Capital Price)*ln(UG/EFTS)			-0.067	0.055			0.072	0.066
ln(FTE Price)*ln(PG/EFTS)			0.162***	0.049			0.176***	0.045
ln(Capital Price)*ln(PG/EFTS)			-0.070*	0.039			-0.079**	0.039
ln(FTE Price)*ln(RI/EFTS)			-0.097***	0.024			-0.089***	0.024
ln(Capital Price)*ln(RI/EFTS)			0.029	0.025			0.027	0.024
Inefficiency effect:								
Constant	0.014	0.050	-0.109*	0.057	0.034	0.051	0.106	3.218
Medical School	0.010	0.011	-0.002	0.009	0.005	0.008	0.009	0.007
Share of Overseas students	0.049	0.056	-0.034	0.080	0.035	0.057	-0.077	0.055
NZ_South Island	0.078***	0.016	-0.013	0.021	0.077***	0.014	0.004	0.015
AUS_NewSouthWales	-0.138***	0.017	-0.004	0.023	-0.147***	0.019	-0.031	0.022
AUS_Victoria	-0.127***	0.016	0.017	0.024	-0.128***	0.020	-0.017	0.023
AUS_Queensland	-0.072***	0.015	0.047**	0.020	-0.079***	0.016	0.024	0.020
AUS_Western	-0.082***	0.019	0.045**	0.022	-0.082***	0.019	0.016	0.023
AUS_South	-0.071***	0.023	0.061**	0.025	-0.083***	0.020	0.033	0.022
AUS_Tasmania	-0.095***	0.026	0.053*	0.028	-0.107***	0.024	0.032	0.025
AUS_NorthTerritory	-0.184***	0.016	0.056	0.038	-0.176***	0.037	0.049	0.044
AUS_capitalTerritory	-0.059***	0.022	0.009	0.033	-0.059***	0.022	-0.004	0.024
Ratio of general to academics	-0.060***	0.011	0.021	0.017	-0.078***	0.019	-0.003	0.012
Rate of Female students	0.451***	0.063	0.342***	0.100	0.457***	0.075	0.296***	0.068
Log Likelihood	711.771		818.074		708.207		825.678	
sigma-squared	0.003		0.002		0.003		0.002	
gamma	0.013		0.004		0.019		0.180	
Likelihood ratio test of the one-sided error	162.578		146.599		160.277		169.331	
Mean efficiency	1.102		1.0699		1.100		1.2414	
Observations	495		495		495		495	

Note: 1. Source: Universities annual reports. 2. Capital prices use non-labour expenses per EFTS as a proxy for capital price. 3. Research output refers to CNCI-weighted WoS research publications. 4. Standard errors are in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01.