The Economic and Emissions Impacts of Border Carbon Adjustments for New Zealand

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2023

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A research component submitted to
Auckland University of Technology in partial
fulfilment of the requirements for the degree
of the degree of Master of Business

Abstract

The issue of emissions leakage has been widely debated by economists, yet there are few studies which consider the potential for leakage with respect to the New Zealand Emissions Trading Scheme (NZ ETS). Using the Climate PoLicy ANalysis (C-PLAN) model, this paper evaluates the impacts of a border carbon adjustment (BCA) on high energy-intensive (HEI) sector imports going into New Zealand. These results are directly compared to the existing output-based allocation (OBA) of emissions permits, which also aim to reduce leakage. We consider three different scenarios to compare the relative effects of BCAs to OBAs. When compared to the status quo benchmark case, there were modest welfare and GDP improvements. BCAs are shown to be more favourable than OBAs for mitigating leakage, and loss of domestic output to import substitution. Negative leakage was reported in the HEI sectors for both OBA and BCA scenarios, with the BCA policies having the largest impact. These results were due to many HEI sectors being subject to non-economic constraints that are binding in the baseline and policy scenarios, which prevented their growth throughout the observed period. Our evaluation adds to the literature on the economy-wide analysis of BCAs and sheds some insights into New Zealand climate and trade policy.

Acknowledgements

I would like to express my sincere gratitude to my supervisors Niven Winchester and Lydia Pik Yi Cheung for their unwavering support throughout the study the year. Their invaluable guidance was instrumental in helping me near the completion of my research.

I would also like to thank Dominic White for his valued advice concerning the complexities of CGE modelling and C-PLAN. I have learned a lot about climate policy in such a short amount of time, and I could not have done this much without his help.

Finally, I would also like to thank my Parents for their patience, love, and unending support. They are the bedrock of my life, my foundation from which all good things begin.

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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.

1. Introduction

Climate change is an ongoing concern among policymakers worldwide. In the quest to reach net zero emissions by 2050, the prevailing response among most nations is to set emissions targets and to commit to reducing emissions by this cap. New Zealand has its own scheme known as The New Zealand Emissions Trading Scheme (ETS). Leining (2022) provides a near-exhaustive overview of the NZ ETS. It was in September 2008 that the New Zealand government enacted the amended Climate Change Response Act 2002 (CCRA) and was linked to the international Kyoto market at the time. This linkage has since been dissolved and the NZ ETS is operating as its own autonomous climate policy engine; the unit permits are referred to as New Zealand Units (NZUs) and represent one metric tonne of CO_2 or equivalent greenhouse gas. At present, the scheme covers about 52% of NZ's gross emissions (Leining, 2022). The remainder, consisting entirely of agricultural sector emissions, is yet to be accounted for, with the expectation that these sectors will be incorporated into the system in the near future. The NZ ETS has evolved over time as more amendments seek to modify aspects of the scheme such as pricing and reporting, but the fundamental purpose of managing emissions is intact. At its core, the ETS introduces emissions constraints on all participating sectors.

Apart from capping emissions, there are other policy instruments that may impact every aspect of the economy. The aim of these policies is to promote abatement among firms and polluting sectors. Policies such as output-based allocation (OBAs) and border carbon adjustments (BCAs) exist as viable supplementary tools for existing climate policy frameworks. Our study focuses on these two policies because they are either currently in use or nearing implementation in climate policy. While other policies do exist, we do not consider them relevant to the scope of this study. A BCA functions as a tariff on the carbon embodiment of a good coming into the country or region. This BCA is determined by both the carbon price, usually in dollars per tonne of CO_2 equivalent, and the estimated carbon content of the good. The carbon content of goods can be calculated in several ways. The two distinct categories are direct and indirect emissions. Direct emissions refer to the release of greenhouse gases by a firm or sector. These emissions are directly associated with the firm in question and occur entirely within the boundaries of the firm’s operational scope. On the other hand, indirect emissions comprise of gases released by processes occurring outside the boundaries of a firm's activity and are often linked to intermediate inputs such as (mainly fossil-based) electricity purchased by the polluting firm.

The carbon price varies from policy to policy, but in general, the market decides on a price depending on the supply of and demand for permits. In the case of the NZ ETS, there are three price management measures (Leining, 2022). These include (1) a minimum price in the form of an auction reserve price, (2) a confidential reserve price based on secondary market trends which guides the auction price, and (3) a price ceiling which triggers the release of a fixed volume of NZUs. These price controls help moderate shocks and manage expectations of participants. The reserve price and price ceiling are set to increase by 5 and 10% per year respectively, plus inflation.

BCAs have made a reemergence on the world stage with the EU's proposed implementation of the Carbon Border Adjustment Mechanism (CBAM)[1]. Such a policy would see imports coming into the EU be subject to a compliance cost at the border equal to the carbon content of the good (European Commission, 2021). The logistics of paying the duty will be handled via carbon certificates, similar to how NZUs are handled. It is worth noting that most high energy-intensive (HEI) sectors within the EU are also recipients of OBAs.

OBAs are a system where producers receive free permits equal to a portion of their emissions per unit of output. The level of emissions is usually pegged to a benchmark year and serves as the basis for allocation. In New Zealand, free permits are restricted to high or moderately energy-intensive firms. They are categorised by their emissions intensities ranging from 800-1600 t CO_2e/million NZD revenue for moderately intensive firms, and 1600 t CO2e/million and higher for HEI firms (Leining, 2022). Firms will receive fewer permits overtime as the rate of free allocation is set to decrease; the exact rate varies by sector, but it is expected to be its lowest rate by 2050.

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[1] We use CBAM and BCA synonymously in this paper.

The relative similarities and differences between OBAs and BCAs present an interesting exercise for economic modelers. Using a computable general equilibrium (CGE) model, we can test and evaluate a hypothetical rollout of a unilateral BCA on New Zealand's economy similar in spirit to the EU's CBAM. We use the Climate PoLicy Analysis (C-PLAN) model, which is used by the Climate Change Commission (CCC) to provide policy advice for the New Zealand government. With it we can simulate the impacts of various policy settings and collect the relevant data which may help compare the effectiveness of either having an OBA or a BCA. Utilising a CGE model enables us to capture the bilateral trade between regions and the discrete flow of intermediate goods between sectors. This representation can provide a useful snapshot of trade and production for the simulated regions. This allows us to explore policy implications by observing how the economy reacts to changes in policy and market conditions.

The literature review section discusses some of the work that's already been done. We consider the views of other authors and their findings on the matter and relate this to our own research. We explain some key concepts in this area of study and expand on the function of BCAs and OBAs.

In the methodology section, the theoretical frameworks used in both the model and our analysis are described. Matters concerning how trade is modelled, abatement options, new and advanced technologies, sector constraints, permit allocation, the original findings of Winchester and White (2022), and our own modifications are detailed. We also set out how the emissions intensities and BCAs are calculated. Expanding on this, we outline the different policy scenarios that have been evaluated in this study and provide the specific values for the ad valorem rate and output intensities.

Under the results section we look at the effects of our selected policies and compare their effects to the baseline scenario. We consider the impact of each policy scenario on GDP, consumer welfare, sectoral data such as output, prices, emissions, leakage, and trade. To our knowledge, this is the first study to estimate the economy-wide impacts of BCAs imposed by New Zealand[2]. Our findings behave very much like what is supported by empirical research, with BCAs netting modest improvements (relative to the benchmark) in GDP, welfare, sectoral output, and leakage. Consequently, there are moderate increases in sectoral prices and a reduction in imports for targeted sectors.

The novelty of this study raises some interesting questions, and our study will endeavour to answer the following research questions:

1. *What is the potential for emissions leakage from New Zealand following the imposition of a border carbon adjustment?*
2. *What impact does a border carbon adjustment have on key economic indicators such as GDP, welfare, trade volumes, and high energy-intensive sectoral outputs for the New Zealand economy?*

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[2] Lennox and Van Nieuwkoop (2010) have offered some insight with a similar analysis on the effects of an OBA on the NZ economy. Their work mainly explores a range of calibrations for the OBA system with respect to tax revenue recycling and allocation rates. Our study builds upon this literature by introducing BCAs in a more wholistic approach.

2. Literature Review

2.1 Disputation of Leakage

There is ongoing debate about the efficacy of BCAs, especially when compared to similar policies that aim to reduce leakage, such as OBAs. But the discussion doesn’t start there; numerous academics have raised the question of whether leakage is an issue at all. Emissions leakage is defined as the increase in production and emissions in regions outside the remit of an emissions policy. This can occur when non-constrained regions increase their output and therefore their emissions, as sectors in constrained regions must forgo output. The risk of leakage is a global concern since pollutants and greenhouse gases contribute equally to climate change irrespective of their origin. Another concern with leakage is that the very same dirty goods produced abroad may be imported by countries that had imposed these restrictions in the first place, making the entire exercise fruitless.

Despite these concerns, numerous papers dispute the extent to which emissions leakage is observed in the global environment. A selection of early papers discusses the concept of ‘pollution havens’ and try to understand the prevalence of this effect and its significance. Copeland and Taylor (2004) and Mani and Wheeler (1998) both offered their insights into the pollution haven hypothesis. Copeland and Taylor (2004) suggest that a tightening up of pollution regulations affects plant location decisions and trade flows at the margin. They make a second hypothesis called the pollution haven hypothesis, wherein a reduction in trade barriers leads to a shifting of pollution-intensive industries from countries with strong regulations to those that have weaker ones. Mani and Wheeler (1998) attempt to validate the hypotheses related to pollution havens by looking at past examples of emissions regulation and its subsequent effects on trade, emissions, and industry growth. By analyzing historical cases in Japan, North America, and Western Europe, they found that a decrease in domestic ‘dirty’ sectoral output coincided with rising energy prices and abatement costs. Pollution-intensive output as a percentage of total manufacturing has fallen consistently in the OECD and risen steadily in the developing world. These trends coincided with the rapid increase in the cost of pollution abatement in the OECD countries. In developing nations, most of the dirty-sector production is accounted for by domestic consumption. Mani and Wheeler (1998) would conclude that while there is evidence for the pollution haven effect, it is a transient phenomenon and relatively unimportant.

Branger et al (2016) argue that leakage is not as serious of an issue as once thought. Their study looked at the relationship between carbon prices and leakage rate. Their findings suggest that energy-intensive firms such as the steel and cement industries had accumulated a surplus of emission allowances, effectively sheltering them from competitive pressures and leakage. This does, however, come with the opportunity cost of trading the unit for its market value – governed by the carbon price for that period. This observation is echoed by Kerr et al. (2021) which analysed the delinking of New Zealand’s emissions trading scheme from the Kyoto protocol. Prior to the delinking in 2015, firms had access to very cheap Kyoto units that were used to meet obligations. Throughout that whole period, these firms would be able to bank their NZ units and allowances in anticipation of the delinking of the NZ ETS from the Kyoto Protocol, creating a stockpile of credits that could be surrendered year-on-year, resulting in low participation in the unit auction. Kerr et al. (2021) would go on to stress that having a credible emissions target is critical for a robust emissions trading scheme.

Other papers such as Muñoz and Steininger (2010) argue that leakage is a real concern, their study showed that in 1994, one-fourth of the carbon embodiment in Austrian imports originated in countries that were outside the Kyoto Protocol (non-annex-I regions). This has increased to one-third by 2004. And for each euro spent on Austrian final demand in 2004, it was estimated that two-thirds of CO_2 emissions embodied in final demand occurred outside Austria.

Franzen and Mader (2018) examine the differences in the ratio of emissions under consumption-based accounting (CBA) and production-based accounting (PBA) to determine if there is any carbon leakage. Through their comparisons they conclude that the CBA/PBA ratio reveals there is no empirical evidence for carbon leakage from developed to developing countries. And that increases in CO_2 importation seldom occur in OECD countries or countries with high GDP per capita.

2.2 Economy-wide analyses of BCAs

Many authors have investigated the leakage and economic effects of BCAs and/or OBAs. In the interest of conciseness, we discuss selected studies below and summarise some other studies in Table 1.

Aguiar et al. (2022) explore the implementation of CBAM in the GTAP-E CGE model using the GTAP 11 Data Base. They consider scope 1 and 2 emissions for their simulation. These scopes refer to (1) direct emissions from fuel combustion, and (2) indirect emissions from heat and electricity used in production of commodities covered under CBAM. They do not consider scope 3 emissions (other emissions). They apply the CBAM as a levy on the carbon content of imports from a selection of high energy-intensive trade-exposed (HEITE)[3] sectors. These sectors are imported chemicals, non-metallic minerals, and metals. Their sectoral coverage is a simplified version of the proposed CBAM policy. Their findings suggest that for scope 1 emissions, the ad valorem equivalent tariffs for these chosen sectors ranged from 1.5 – 2.5% for imported chemicals, 3.8 – 13% for non-metallic minerals, 0.1 – 9.5 % for metals. Scope 2 featured rates considerably higher, especially for metals. The implications of their policy simulation were limited at a global level; emissions, trade, and economic activity were effectively reshuffled as producers worked their way around these trade barriers. They reported that there was a reduction in exports to the EU of CBAM-covered commodities, which were redirected to other unconstrained regions. In terms of leakage, an EU-wide carbon price of 83.5 EUR/tonne of CO_2 led to a leakage rate of roughly 20%. With the CBAM this was reduced by a quarter. They note that their simulation was limited in its sectoral coverage, and as such the policy had a modest effect on leakage as opposed to an economy-wide carbon price. The authors conclude that BCAs may incentivise a broader implementation of climate-oriented trade policies globally.

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[3] HEITEs refers to high energy-intensive sectors that compete with overseas producers who do not face the same ETS-related costs as domestic producers.

Winchester et al. (2011) analysed the impacts of a BCA on the US, using a multi-regional CGE model. Their findings showed that BCAs have a modest effect on leakage, and a small yet appreciable effect on emissions reductions. However, these results come at a cost to global welfare. The coalition nations enjoy a welfare increase whilst non-coalition nations experience a significant deterioration in welfare. They remark that BCAs can be an effective coercion strategy and may encourage other economies to adopt more comprehensive climate regulation.

A more recent study from Sun et al. (2023) argues that although a BCA is effective at reducing leakage, the burden falls on less developed countries and drives up inequality. They use the GTAP-E CGE model to simulate an EU-wide CBAM policy and evaluate the economic effects across various scenarios. They considered scope 1 and 2 emissions, higher carbon prices, as well as different carbon accounting methods. Across all their scenarios, they found that emissions reductions originate from unconstrained regions such as Russia, India, Turkey, South Africa, and Ukraine. Furthermore, the EU experiences an increase in GDP of 0.1%; other regions have reduced GDPs consequently. In general, they emphasise the significant welfare costs associated with CBAM, and that pursuing unilateral climate policy such as this is inferior to a cooperative, multilateral approach.

Verde (2020) undertakes a systematic literature review to better understand the impacts of the EU ETS on competitiveness and carbon leakage. Their findings suggest that there isn’t evidence of significant carbon leakage. The author remarks that there are limitations in the studies, and that the evidence largely refers to Phases I (2005-2007) and II (2008-2012) of the EU’s ETS. Further empirical studies may help address the gaps in the literature.

Numerous papers have already explored the implementation and the subsequent effects of OBAs and BCAs – with varying results. Though, there are some consistencies found across all papers that offer a general overview of some of the consequences of either mechanism.

Zhong and Pei (2022) discuss how the implementation of a CBAM yields unequal outcomes and demonstrate how certain regions are disproportionately affected by a CBAM enacted in the EU. They use the input-output (IO) approach to simulate the short-term impacts of CBAM. In their paper they explore various policy settings, mainly looking at different carbon prices and exemptions for regions that have their own carbon pricing schemes. Across various energy-intensive trade-exposed sectors, trading partners such as China, Russia, India, and Brazil suffer enormous losses in trade due to the CBAM, while domestic industries in Germany, France, and Italy enjoy an increased market share as domestic production increases. In the non-metallic minerals sector, China incurs the highest export loss of $5.2B to the EU, followed by Turkey, India, and Indonesia. In the chemicals industry, the largest loss occurs to the rest of the world, while China suffers a drop in exports of $3B. In the basic metals and mining sector Russia’s exports in these two sectors to the EU falls by $6B and $2.1B, respectively, accounting for 4.39 and 4.97 per cent of the sectoral output in 2012. China and Brazil also see moderate declines in their basic metal export.

According to Ghosh et al. (2012), BCAs generated a modest welfare benefit to the country imposing them, while noting that it shifts the abatement costs unto other countries. Their investigation into the implementation of a comprehensive GHG emission targeting scheme has considerable implications for agriculture. GHG-based BCAs are said to have lower welfare and distributional effects than CO2-only BCAs.

Greenhalgh et al. (2007), Monjon and Quirion (2011), and Takeda et al (2014) make comparisons between OBAs and BCAs in terms of their relative strengths and weaknesses. Greenhalgh et al. (2007) points out that OBAs by design do not incentivize firms to reduce output. Because of this, the policy is very effective in preventing leakage. Firms are instead motivated to reduce their emissions intensity and bank the surplus carbon credits or units. OBAs incur a higher social cost because this policy takes away the government's ability to auction units, the implicit subsidy is distortionary and is costlier to correct with revenue.

Monjon and Quirion (2011) mentions that both OBAs and BCAs are effective at reducing leakage, with OBA faring slightly worse than BCAs. The authors go on to say that OBAs are best seen as a transitory measure, best phased-out in favour of just auctioning units. The authors argue that it is equally important for policymakers to reduce consumption of emissions-intensive goods as it is to reduce emissions-intensive production. OBAs, for this reason, are less favoured because they prevent reduced consumption. BCAs introduce trade barriers and limit the consumption of imports, whereas OBAs do not.

Takeda et al (2014) used a CGE model that looked at several scenarios involving different allocation methods for Japan's ETS. When compared to grandfathering, auctioning permits, and a mix of OBAs and auctioning by sector, OBAs alone performed the best in terms of leakage reduction – whereas auctioning was the worst. Auctioning was found to have the best macroeconomic improvements such as GDP, and OBAs were found to be better than grandfathering, but worse than auctioning. The authors conclude that the best policy would be a hybrid policy where there is auctioning of units with OBA for the energy-intensive sectors. This would accord with the findings in Greenhalgh et al. (2007). They recommend implementing an OBA on energy-intensive trade-exposed sectors (EITES), which have the highest risk of leakage, whilst using a permit auction for the rest of the economy.

Branger and Quirion (2014) did a meta-analysis of several CGE and partial equilibrium (PE) studies and found that leakage ratios range from 5% to 25% without BCAs and from -5% to 15% with BCAs (means of 14% and 6% respectively). BCAs were shown to be generally effective at reducing leakage compared to no policy.

Few have opened inquiries into the New Zealand ETS and fewer still have considered the economic impacts of a BCA on NZ and its trading partners. It is understood that we will be among the first to evaluate the effects of a BCA on NZ using a CGE model. Other authors have provided some insight on NZ ETS policy, such as Lennox and Van Nieuwkoop (2010), Kerr et al. (2021), Leining (2022), and Winchester and White (2022). The approach of this study is to offer an empirical, CGE-driven analysis of a BCA in the context of NZ's ETS. Lennox and Van Niewkoop (2010) have only considered the impact of an OBA across a range of different specifications using their own, whereas Kerr et al. (2021) and Leining (2022) are more focused on providing theoretical insights. Our results differ in that we consider BCAs in tandem with modelling the NZ ETS, our findings build upon the extensive groundwork laid by Winchester and White (2022) and utilise the powerful model that is C-PLAN. We focus on salient economic indicators like welfare changes, sectoral output and price, emissions, and trade. Our intention is to examine the results to see if they concur with the existing empirical and theoretical literature that has already been explored in other countries. New Zealand is a small, open economy, making trade an important cornerstone of policy. The findings within this paper can have great implications, and to our knowledge, this is the first economy-wide analysis of BCAs for this country.

2.2.1 Summary of Selected BCA Analysis

Table 1

Summary of Selected BCA Analysis

Authorship	Title	Methodology	Subject	Key Findings
Dwi Pangestu Ramadhani and Yoonmo Koo (2022)	Comparative analysis of carbon border tax adjustment and domestic carbon tax under general equilibrium model: Focusing on the Indonesian economy.	CGE modelling, GTAP-E & CGEBox	This paper analyses the impact of a hypothetical carbon border tax on Indonesia's economy and its trade partners using a CGE model.	(1) Results show that all scenarios reduce global emissions (relative to the baseline) ranging from 14.08% to 14.292%. (2) Indonesia's emissions increased due to their trade partners imposing a carbon tax on domestic production. (3) In response to a BCA, Indonesia should implement its own carbon pricing scheme to qualify for exemptions.
Arik Levinson and M. Scott Taylor (2008)	Unmasking the Pollution Haven Effect	Theory and empirics, statistical analysis	The authors theoretically evaluated the effects of rising abatement costs on industries and their imports using data on US regulations and trade with Canada and Mexico. The authors looked at 130 manufacturing industries between 1977 to 1986.	(1) Found a statistically, and economically significant positive relationship between abatement costs and net imports. (2) They imply that leakage does occur in North America.
Robert N. Stavins (2022)	The Relative Merits of Carbon Pricing Instruments: Taxes versus Trading	Synthesis	This paper is a theoretical exercise in exploring the relative strengths and weaknesses of various carbon pricing instruments such as BCAs, OBAs, and carbon taxation. The author looks at historic cases where emissions schemes have been successful and offers insight into the design and architecture of these policies.	(1) Cap and trade schemes may incur higher compliance costs than taxation. (2) To date, cap-and-trade has been successfully implemented in the US such as the leaded gasoline phasedown (1982-1987), the sulphur dioxide allowance trading system (1994-2010), a trading program for nitrogen oxides (NOx; 1998-2009), and the Californian RECLAIM program (1993-present).
James A. Lennox and Renger van Nieuwkoop (2010)	Output-based allocations and revenue recycling: Implications for the New Zealand Emissions Trading Scheme	CGE modelling, New Zealand Climate Economic Model (NZCEM)	The authors evaluate different climate policy scenarios and their effects on the NZ economy. They consider a baseline, an international climate regime similar to the Kyoto Protocol, and an ETS system with OBAs for EITE sectors.	(1) At fixed carbon prices, OBAs are effective at increasing aggregate output and potentially reducing price of EITE sectors but reduce domestic mitigation and forgo revenue from auctioning. (2) OBAs may not induce abatement from firms and can in some cases reduce environmental effectiveness. (3) The authors emphasise the importance of recycling revenue to minimise distortionary effects of carbon taxes.
Sigit Perdana and Marc Vielle (2023)	Carbon border adjustment mechanism in the transition to net-zero emissions: collective implementation and distributional impacts	CGE modelling, GEMINI-E3 model	The authors simulate a joint implementation of a CBAM policy for three of the world's major emitters (USA, EU, and China). They consider three different scopes (1-3) and report on the distributional effects on energy-intensive industries (EIIs).	(1) The introduction of a CBAM reduces club leakage, increases production of EIIs, and increases club welfare relative to non-CBAM and unilateral scenarios. (2) Going from scope 2 to 3 provides diminishing gains compared to scope 1 to 2. (3) The CBAM reduces EII exports due to the negative income effect and increased costs of imported intermediate goods.

3. Methodology

3.1 The C-PLAN Model Framework

This paper employs the Climate Policy Analysis (C-PLAN) economic model developed for the New Zealand Climate Change Commission (CCC). Winchester and White (2022) go into detail on how the model works; below are some of the more fundamental characteristics. C-PLAN is a computable general equilibrium (CGE) model that, in its base configuration, considers two regions – New Zealand and the Rest of the World. It allows for GHGs to be linked to economic activity, of which there are 7 categories and can be found in Table 2. There are 38 production sectors listed in Table 6, and 3 sources for final demand. Firms in this model will maximise profit, households will maximise utility, and markets will be in equilibrium such that supply equals demand for all commodities. C-PLAN solves for general equilibrium in each year modelled. The simulation commences in the year 2014 – referred to as the 'benchmark' year – and the model is solved in one year increments up until the year 2050.

Table 2

List of Greenhouse Gases in C-PLAN

Name	Description
pco2	Output-related CO2 emissions
co2	CO2 from fossil fuel combustion (coal, gas, and oil)
ch4	Methane
n2o	Nitrous oxide
fgas	F-gases - aggregate

Note. 'co2' gas is further differentiated by the fossil fuel that generated it. F-gases refer to fluorinated gases, also known as hydrofluorocarbons (HFCs).

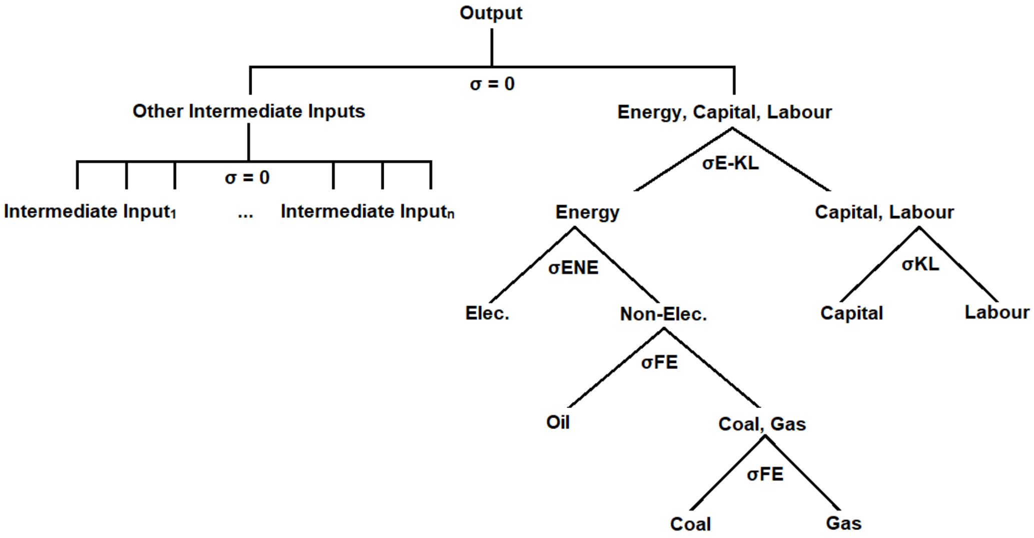
3.1.1 Trade

International trade is modelled using the Armington approach (Armington, 1969) wherein every region produces its own unique variety of each commodity. Imported goods are an amalgam of other imported goods from different regions, and they are differentiated from domestic goods using a constant elasticity of substitution (CES) nest function. Purchases of a commodity is represented as an aggregate “Armington” good of domestic and imported. The elasticities used in these nests are listed in Winchester and White (2022), p. 12.

Figure 1 describes the production nest for *most* sectors in the model. There are some exceptions to this, which are: agriculture and forestry, construction, fossil fuel extraction, electricity, aggregate electricity, and final demand. These vary in their structure but rely on the same formula of having specific, constant elasticities of substitution which represent substitution between inputs.

Figure 1

Production Function for Most Sectors



Note. *This CES function represents most sectors in C-PLAN; vertical lines represent a Leontief or fixed coefficient production structure with an elasticity of substitution of zero. Adapted from "The climate PoLicy ANalysis (C-PLAN) model, version 1.0," N. Winchester and D. White, 2022, Energy Economics, 108, 105896. CC BY-NC-ND.*

3.1.2 Abatement options

Abatement options within the model rely on firms and agents to make decisions that would reduce their net emissions. These modes of abatement include things like (1) technologies, which can be exogenous or induced by changes in relative prices, (2) using less CO2-intensive inputs, (3) implementing new ‘greener’ technologies and less carbon intensive processes, (4) sequestration, and (5) substitution among fossil fuels. To give an example for each of these options, let us first consider (1) efficiency improvements. Firms may be induced through price mechanisms to install more energy-efficient systems like a regenerative furnace. Construction companies can use (2) less CO2-intensive inputs by using wood and timber over steel and cement. (3) ‘Greener’ technologies can be adopted such as electric motors and not internal combustion engines. (4) Sequestration is accomplished mainly by forestry; growers of pine are entitled to a number of units equivalent to the CO2 sequestered. These same units can be purchased by other firms to meet their abatement requirements. (5) Highly emissions-intensive fossil fuels may be substituted for less-polluting ones, such as using natural gas instead of coal. These decisions are made possible in the model by the chosen nesting structures and elasticities of substitution among inputs, and the inclusion of new technologies. Elasticities enable firms in the model to respond to price signals and adapt to rising abatement costs by making any of the decisions discussed above. Winchester and White (2022) highlight the importance of modelling producers’ ability to use energy more efficiently.

3.1.3 New Technologies

The emergence of new technologies is simulated in this model and produce perfect substitutes for conventional technologies. These more advanced technologies produce fewer emissions than conventional technologies. Technologies most relevant to our study are bioheat and electric heat technologies. These two technologies serve as potential substitutes for coal and gas energy. Wood and paper products is one of the sectors that can utilise this technology. Advanced technology can vary in its availability depending on how it is implemented. For example, bioheat is treated as a technology-specific factor for each eligible sector, and there is an effective limit on its use in each sector reflecting factors such maximum limits of the share of biomass in total fuel using current infrastructure. Other new technologies can be summarised in Table 3.

Table 3

List of Advanced Technologies in C-PLAN

Technology	Substitute for		
Electric road transport	Road transport		
Electric household transport	Household transport		
Dairy farming with reduced methane	Dairy farming		
Beef and sheep farming with reduced methane	Beef and sheep farming		
Geothermal electricity with CCS	Geothermal electricity		
Electric heat	Dairy processing	Horticulture	Other food products
	Meat products	Wood and paper	
Bioheat	Dairy processing	Horticulture	Other food products
	Other manufacturing	Meat products	Wood and paper

Note. the only advanced technologies available in the baseline are electric road transport and electric household transport, all other advanced technologies are available only in the policy scenarios TP1, BCA1, and BCA2. Adapted from "The climate PoLicy ANalysis (C-PLAN) model, version 1.0," N. Winchester and D. White, 2022, Energy Economics, 108, 105896. CC BY-NC-ND.

3.1.4 Output-constrained sectors

Several sectors in the model have outputs that are constrained. This is to reflect the realities of certain industries within New Zealand. In the original specification, the firms that have their outputs constrained are fishing; other mining; chemical, rubber, and plastic products; non-metallic minerals; nonferrous metals; iron and steel; water transport – domestic; and water transport - international. These constraints represent either the physical limitations or political/policy barriers which make expansion impossible. For example, there is a New Zealand policy that aims to shut down coal-fired power in NZ by 2026. Another example is that New Zealand's resource endowments are limited, meaning that any more steel mills or aluminium smelters are improbable. There is more discussion on these constraints and is referred to as the resource multiplier parameter. This parameter controls the output of a sector and is exogenously controlled by the operator of the model.

3.1.5 High Energy-Intensive Sectors

The HEI sectors that we refer to are listed in the model as: oil; chemical, rubber, and plastic products; non-metallic minerals; non-ferrous metals; iron and steel; and wood and paper. HEI sectors make up nearly 19% of total trade for New Zealand. Table 4 briefly summarises the share of trade that is made up of HEI sectors. The qualifier for an HEI sector is its energy intensity. Sectors that exceed a threshold of 1600 tonnes of CO2e emissions per million dollars of revenue (NZD) are categorised as HEI sectors (Leining, 2022).

Table 4

Share of Trade for HEI Sectors in New Zealand

	HEIs	Other	Total
Imports	$10.82 B	$38.53 B	$49.34 B
Exports	$7.79 B	$42.11 B	$49.89 B
Total trade	$18.60 B	$80.63 B	$99.23 B
		HEI share of total trade:	18.74%

3.1.6 Output-Based Allocation

The C-PLAN model uses a joint production function that enables firms to produce emissions permits per unit of output – fulfilling the role of an OBA. This is treated as an implicit production subsidy per unit of output. The allocation permits for HEI industries vary by year. HEI firms are entitled to permits up to 97.8% of their emissions in 2022; free allocation rates drop over time and are 1.1% in 2049 and 0% by 2050.

3.1.7 Findings of the Original Model

Winchester and White (2022) present two policy cases that were used in the CCC's advice to government and are used as a starting point for this study. The 'baseline' is a projection that is based on primarily the data found in New Zealand's fourth biennial report under the United Nations Framework Convention on Climate Change (MfE, 2019). This case simulates a 'business as usual' approach, having no deviations from the current policy that were already in place prior to 2022. The results given in the baseline are used for comparison. The second policy is the 'transition pathway 1' (TP1) which includes ETS policies that specify emissions caps from 2022 to 2050 that are consistent with New Zealand's long-term emissions goals, in this study, the TP1 scenario is used as reference for our BCA scenarios. As part of The Zero Carbon Act, the original policy setting has two separate ETSs. One of these is for biogenic methane; dairy farming, beef and sheep farming, and the services sector belong to this ETS. The other ETS includes all other GHGs for all sectors.

The main policy assumption for the rest of the world is a carbon price applied broadly to all GHGs from 2020 onward. This price rises linearly from $8 in 2020 to $250 in 2050 (2014 USD). Furthermore, in the baseline, GDP is calibrated using projections from OECD (2018).

The key findings in their work can be summarised briefly in Table 5. Having run these two scenarios without modification, we find a yardstick which allows us to make worthwhile comparisons to the two policies we introduce in this study.

The enaction of the TP1 policy results in a contraction of several economic indicators. Both GDP and welfare experience a decrease. The main driver of this change is due to the emission caps, which limits the allotment of greenhouse gas emissions over time – with net zero emissions in mind by 2050. Note that C-PLAN treats biogenic methane (CH4) emissions separate to other gases, with ‘other GHG’ representing output-related CO2, CO2 from fossil fuel combustion, F-gases, and nitrous oxide. The TP1 policy aims to further reduce emissions relative to the baseline; consequently, many economic indicators will decrease proportionally.

Table 5

Results Summary of Winchester and White (2022)

	NZL		ROW	
Indicator	Baseline	TP1	Baseline	TP1
GDP - 2017 NZD, b				
2030	$362.33 B	$362.06 B	$157,211.69 B	$157,211.56 B
2035	$396.02 B	$395.41 B	$178,669.59 B	$178,669.34 B
2040	$432.44 B	$431.47 B	$201,006.25 B	$201,005.86 B
2045	$471.85 B	$470.40 B	$224,454.42 B	$224,453.85 B
2050	$512.10 B	$510.36 B	$249,498.25 B	$249,497.35 B
Welfare - 2017 NZD, billion				
2030	$173.92 B	$173.83 B	$75,207.06 B	$75,207.01 B
2035	$190.37 B	$190.18 B	$85,513.12 B	$85,513.00 B
2040	$208.23 B	$207.90 B	$96,202.87 B	$96,202.68 B
2045	$227.36 B	$226.89 B	$107,386.84 B	$107,386.56 B
2050	$246.97 B	$246.34 B	$119,371.99 B	$119,371.57 B
Gross other GHG - MTCO2e				
2030	43.95 MT	39.99 MT	43.95 MT	39.99 MT
2035	41.50 MT	36.06 MT	41.50 MT	36.06 MT
2040	38.97 MT	32.12 MT	38.97 MT	32.12 MT
2045	36.76 MT	28.19 MT	36.76 MT	28.19 MT
2050	34.83 MT	24.25 MT	34.83 MT	24.25 MT
Electricity - TWh				
2030	42.70 TWh	42.59 TWh	26,145.16 TWh	26,145.08 TWh
2035	45.72 TWh	45.59 TWh	27,152.24 TWh	27,152.21 TWh
2040	50.25 TWh	50.17 TWh	28,878.61 TWh	28,878.61 TWh
2045	56.08 TWh	56.14 TWh	31,295.29 TWh	31,295.30 TWh
2050	61.02 TWh	61.11 TWh	33,062.31 TWh	33,062.26 TWh

Adapted from “The climate PoLicy ANalysis (C-PLAN) model, version 1.0,” N. Winchester and D. White, 2022, Energy Economics, 108, 105896. CC BY-NC-ND.

3.1.8 Modifications to the Model

For this study, several changes were made to the C-PLAN model. It is worth noting that some values were adjusted to better reflect the current economic situation. The most notable changes were to the process emissions for the global iron and steel sector (i_s), and oil refinement (oil). The decision to increase process emissions for iron and steel produced overseas was aimed at better representing the rest of world emissions by this sector (IEA, 2023). The original version of the model did not include process CO_2 from this sector in the rest of the world. The resource multiplier parameter was adjusted in an input file; these values adjust the final output of a sector by that amount.

Regarding the oil sector, New Zealand’s only oil refinery (Marsden Point) shut down in 2022. Accordingly, the multiplier for oil refining (oil) is set to 5% of the 2014 value from 2022 onward.

Table 6

List of Sectors in C-PLAN

Agriculture		**Manufactured goods**	
rmk	Dairy farming	crp	Chemical, rubber, and plastic products
b_s	Beef and sheep farming	nmm	Non-metallic minerals (e.g. cement)
oap	Other animal products	nfm	Non-ferrous metals (e.g. aluminium)
hor	Horticulture	i_s	Iron and steel
frs	Forestry	fmp	Fabricated metal products
fsh	Fishing	mil	Dairy processing
Extraction		mtp	Meat products
col	Coal mining	ofd	Other food products
cru	Crude oil extraction	w_p	Wood and paper products
gas	Natural gas extraction and distribution	mvh	Motor vehicles and parts
oxt	Other mining	omf	Other manufacturing
oil	Refined oil products		
Electricity		**Commercial transportation**	
ecoa	Coal electricity	rtp	Road transportation
egas	Gas electricity	wtp	Water transport - domestic
enuc	Nuclear electricity	wtpi	Water transport - international
ehyd	Hydro electricity	atp	Air transport - domestic
ew_s	Wind and solar electricity	atpi	Air transport - international
eoth	Geothermal and other electricity		
tnd	Distribution		
Construction and services		**Household transportation**	
cns	Construction	hht	Household transport
afs	Accommodation and food services		
ser	Other services		

Note. *Adapted from “The climate PoLicy ANalysis (C-PLAN) model, version 1.0,” N. Winchester and D. White, 2022, Energy Economics, 108, 105896. CC BY-NC-ND.*

3.2 Emissions Intensity

We use the C-PLAN model data to calculate the emissions intensity of a given sector in tonnes of CO2 per dollar of output (t/\$). We only consider direct emissions[4], which are the emissions that directly emerge from the production of a good. Indirect emissions are not included in these calculations. The emissions intensity is evaluated to be the sum of the value of production-related emissions in each sector and region – both combustion and non-combustion – divided by the value of output for that sector and region. Therefore, the emissions intensity in tonnes of CO2e per dollar (CO2E/\$) is given by this equation:

$$l_{i,r} = \frac{\varepsilon_{i,r}^{d}}{x_{i,r}}$$

Where $l_{i,r}$ is the emissions intensity of good i in region r,

$\varepsilon_{i,r}^{d}$ are the direct emissions,

And $x_{i,r}$ is the value of output.

Direct emissions are calculated by summing over the different emissions sources in the model. Doing this gives us the formula for direct emissions, which is shown below:

$$\varepsilon_{i,r}^{d} = \sum CO2e_{c} + \sum CO2e_{nc}$$

Where $CO2e_{c}$ is the combustion-related emissions of GHGs,

And $CO2e_{nc}$ is the process-related emissions of GHGs.

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[4] Although the analysis only considers direct emissions, indirect emissions may also be considered when setting CBAMs. For example, EU legislation on CBAM considers only direct emissions during the ‘transition period’. Beyond this point, indirect emissions will then be considered by legislators.

3.3 Ad Valorem Rate

Having worked out the emissions intensity, we then use this value to determine the ad valorem tariff rate for a given sector. It is given by this equation:

$$\tau_{i,r,s} = \left(\frac{l_{i,r}}{pm_i}\right) \cdot pco2_s$$

Where $\tau_{i,r,s}$ is the tariff rate on goods shipped from region r to region s,

pm_i is the price of imports,

$pco2_s$ is the price of carbon dioxide.

3.4 Implementation of A Border Carbon Adjustment

Two policies that we introduce into the model are ‘BCA1’ and ‘BCA2’, which examine BCAs levied on imports coming into New Zealand from the rest of the world. Under the BCA1 scenario, the existing OBA will remain in place, and high energy-intensity sectors will be subject to the tariff rate. These sectors are oil refinement (oil); chemicals, rubber, and plastic (crp); non-metallic minerals (nmm); non-ferrous metals (nfm); iron and steel (i_s); and wood and paper products (w_p). Scenario BCA2 applies the tariff without the OBA. We compare results from BCA1 and BCA2 to decompose the marginal impact of the BCAs. Table 7 provides an overview of the various policies that are presented in this paper along with a summary of what they represent.

The calculated ad valorem rate is added to the value of the existing tariff for each year. In this sense we are retroactively applying the New Zealand carbon price to reflect the carbon content of selected imports.

Table 7

List of Policy Scenarios and Their Characteristics

Scenario	BCA	OBA	Description
Baseline	No	Yes	Business as usual.
TP1	No	Yes	OBA only.
BCA1	Yes	Yes	OBA and BCA are implemented together.
BCA2	Yes	No	BCA only.

The motivation behind our choice in implementing these policies is one of rigorous analysis. To better understand the effects and implications of a BCA, we consider three possible configurations of these policy measures. The TP1 scenario estimates the impacts of ETS policies on the economy (without BCAs) and is discussed in detail in Winchester and White (2022). In this paper, we compare results from the TP1 scenario to those from our BCA scenarios and explore the effects of a BCAs on the HEI sectors and the overall economy, while still maintaining the level of stringency as in policy TP1. The expectation is that the BCA will help contribute to fewer emissions globally by combatting leakage and the import of ‘dirtier’ commodities. Having both an OBA and BCA active in policy BCA1 will help us understand the effects of a BCA alongside an OBA and see what effect at a margin is present.

3.4.1 Calculated Output Intensities and Ad Valorem Rates

We present the calculated emissions intensities and ad valorem tariff rates that were outlined in sections 3.2 and 3.3. Note that the output intensities are consistent across all years of the simulation while the ad valorem rate changes over time due to changes in the carbon price. The ad valorem rates differ very slightly between policies BCA1 and BCA2 (due to changes in simulated carbon prices in the two scenarios), and although they converge to the same values towards 2050, BCA1 on average has a higher tariff rate.

Figure 2

Calculated NZ Ad Valorem Rate

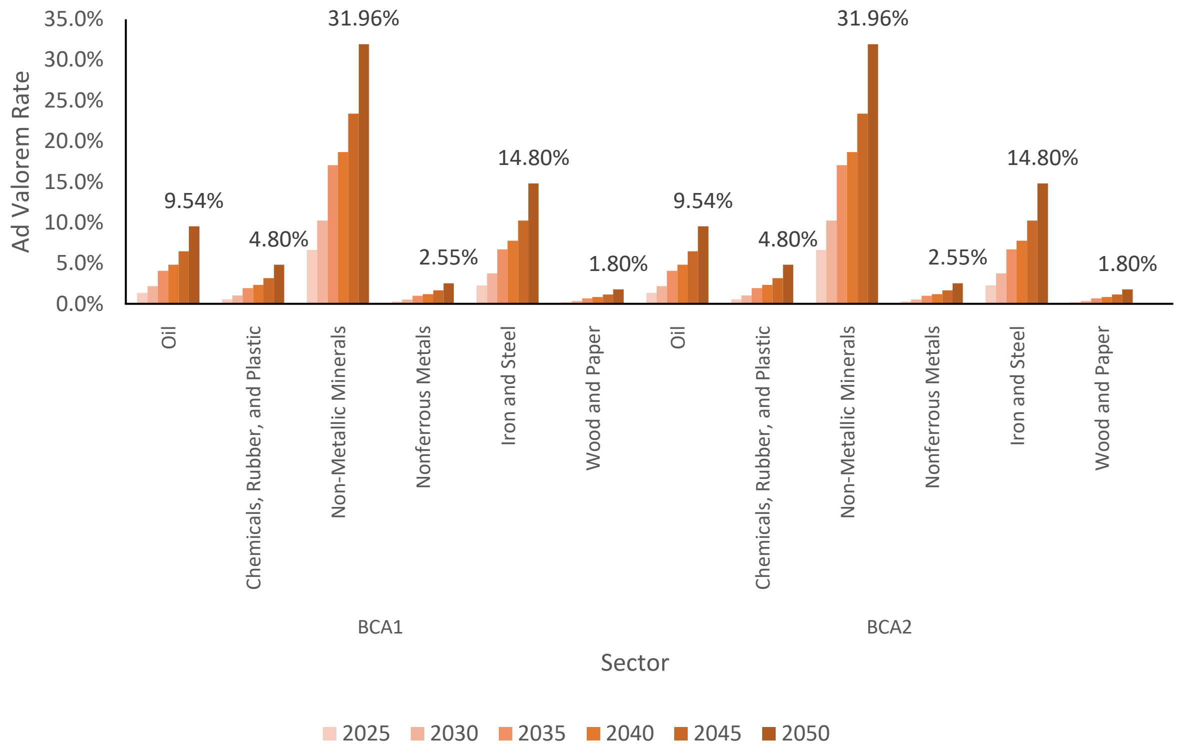
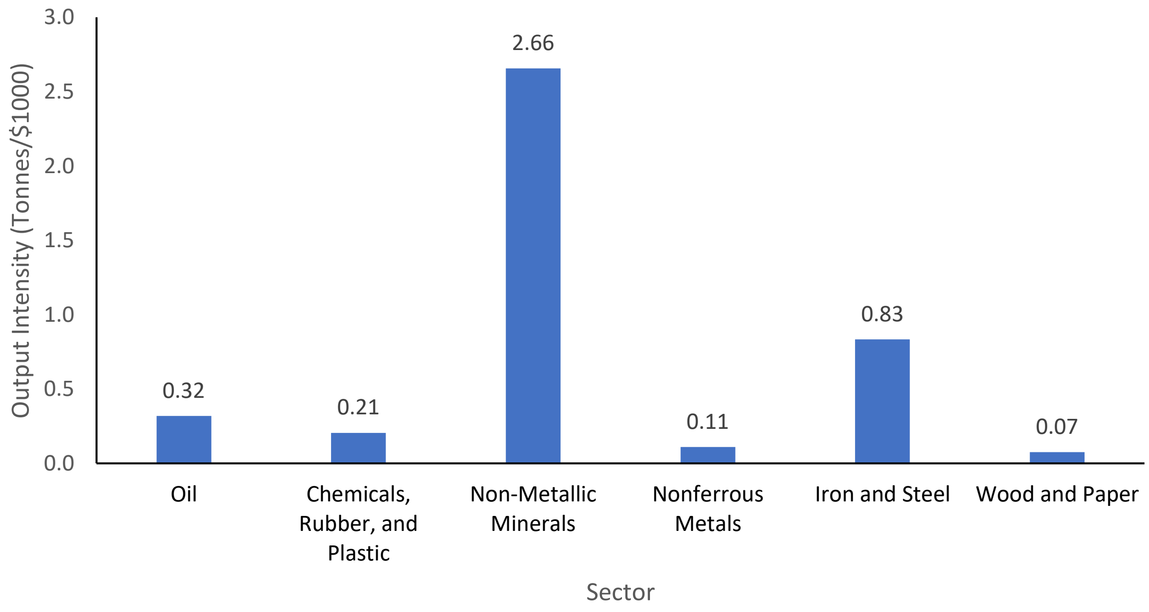


Figure 3

Output Intensities for ROW HEI Sectors (Tonnes CO_2 Per Thousand Dollars)



4. Results

To understand the effects of a BCA on the New Zealand economy and the world at large, we analyse a selection of five indicators and compare them across the four scenarios that were mentioned above. Section 4.1 of the results section looks at the GDP in billions of dollars for the years 2025 to 2050. These years were chosen because 2030 is a widely-set ‘target’ date for most countries’ emissions reductions under the Paris Agreement, and 2050 is the last year for our simulations. The aim is to observe the long-run implications of these policies. This approach is particularly useful considering that the magnitudes can be relatively small when comparing New Zealand’s economy to the rest of the world. Subsection 4.1.1 is an analysis of welfare. Section 4.2 of the results is an analysis of the output levels across various sectoral aggregates[5]. Section 4.3 is an analysis of the prices in each sectoral aggregate. Section 4.4 looks at the emissions in each sectoral aggregate. Section 4.41 and 4.42 look at the sectoral emissions intensities and leakage respectively.

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[5] Across all the results, we have omitted oil production since the sector is effectively non-existent in NZ by 2025 following the shutdown of the Marsden Point refinery in 2023.

4.1 GDP

Within the context of our research on BCAs and climate policy, we've analysed the impacts of each policy on the GDPs of New Zealand (NZL) and the rest of the world (ROW) for the years 2025 to 2050. These values are summarised by Figure 4, which provides the GDP values for each of the three scenarios relative to the baseline. We note that for 2025, TP1 shows GDP improvements relative to baseline, this is due to the carbon price of that year being lower than in the benchmark[6]. Policy TP1 reduces New Zealand's GDP by 0.342% by 2050, whereas BCA1 and BCA2 show an increase in GDP relative to the baseline by 0.165% and 0.168% by 2050 respectively. These results suggest that the BCA policy is protectionist in nature. The reason for this increase can be related to terms of trade. New Zealand as a small country can impose a tariff on a sector and in turn have a negligible impact on the rest of the world (Brown, 1987; Winchester, 2006). A tariff on HEI sectors can have significant reductions for the world's supply of *domestically* produced goods yet cannot significantly reduce the demand for imported goods. This results in a substitution of resources into import-competing goods from exports[7] – which increases the price of exported goods and therefore the terms of trade. Such an increase in the price of exported goods is insignificant to the World and leads to barely appreciable terms of trade effects. This may explain why we see a comparatively larger change in welfare in New Zealand relative to the rest of the world; New Zealand's share of the global market in HEI goods is not very large and cannot have a large impact.

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[6] 'Benchmark' and 'baseline' are used interchangeably throughout this paper.

[7] We note that in table 9, the substitution elasticities for HEI output are appreciably high which may contribute to lowering the terms of trade effects for New Zealand.

Figure 4

Percentage Change in NZ GDP Relative to Baseline

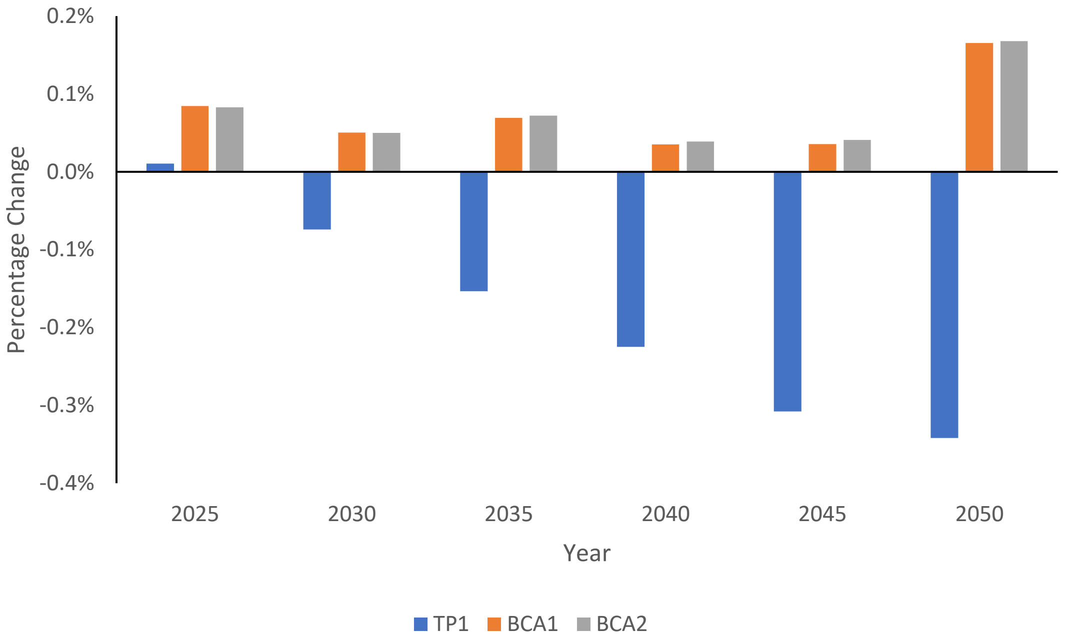

Table 8

Percentage Change in NZ GDP Relative to Baseline

Policy	2025	2030	2035	2040	2045	2050
TP1	0.011%	-0.074%	-0.153%	-0.225%	-0.308%	-0.342%
BCA1	0.084%	0.051%	0.069%	0.035%	0.036%	0.165%
BCA2	0.083%	0.050%	0.072%	0.039%	0.041%	0.168%

Table 9

Elasticity of Substitution (Imports vs Domestic)

Sector	Elasticity
Oil	2.1
Chemicals, Rubber, and Plastic	3.3
Non-metallic Minerals	2.9
Nonferrous Metals	4.2
Iron and Steel	2.95
Wood and Paper	3.09955

4.1.1 Welfare

Welfare effects are important in the context of our research, as the impact on households is meaningful to economists. We measure welfare using the Hicksian equivalent variation in income approach. The effects of each policy on welfare are seen in Table 10. The greatest negative impact on welfare in NZL (relative to baseline) is from policy BCA2, having a value 0.284% smaller. Policy TP1 yields a reduction in welfare of 0.257% and BCA1 yields a 0.263% reduction by 2050. These differences may come down to several factors. The terms of trade effect plays a significant role in this.

For 2025 it may be considered unusual to have the higher welfare in the policy scenarios than in the baseline, and this difference is likely due to the modifications that were made and outlined in section 3.1.5. When we look at the original specification, the baseline consumer welfare for 2025 is \$157.787 billion, whereas under our specification, it is \$157.762 billion. The slight decrease we find is likely to be related to the changes in the output constraints such as the oil sector being effectively shut down. This exit of a sector may have spillover effects for consumers, with a lower carbon permit price at auction and on the market benefitting other active HEI industries. In the baseline policy, there is an exogenous carbon price of \$35 per tonne of CO_2e emissions. In 2025, the TP1 permit price is \$32.26 per tonne, and policies BCA1 and BCA2 share a price of \$31.43 per tonne. Therefore, is it highly likely that the lower carbon price is driving these welfare improvements in 2025, just as they do for GDP in section 4.1. Figure 6 shows the change in carbon price between the years 2025 and 2050, note that the carbon price for TP1 is higher on average than BCA1 and BCA2.

In the years leading up to 2040 that welfare losses under BCA1 and BCA2 are less than TP1. These welfare improvements are driven by the terms of trade effect, similar to how it is behind GDP improvements. Welfare is shown to decrease relative to TP1 by 2040. This reversal is likely driven by rising prices due to the higher carbon prices and tariff rates.

The difference between BCA1 and BCA2 is such that BCA2 has a comparatively lower reduction in welfare. This may be in part due to the combined effect of an OBA and BCA in policy BCA1, with two policies being more distortionary than just one as is the case with BCA2 and TP1. Indeed, with an OBA, the effective subsidy leads to higher carbon prices as consumption of these goods increases. The carbon price directly affects the ad valorem tariff rate, which means that there is a twofold blow to welfare as the tariff rate rises.

Figure 5

Percentage Change in NZ Consumer Welfare Relative to Baseline

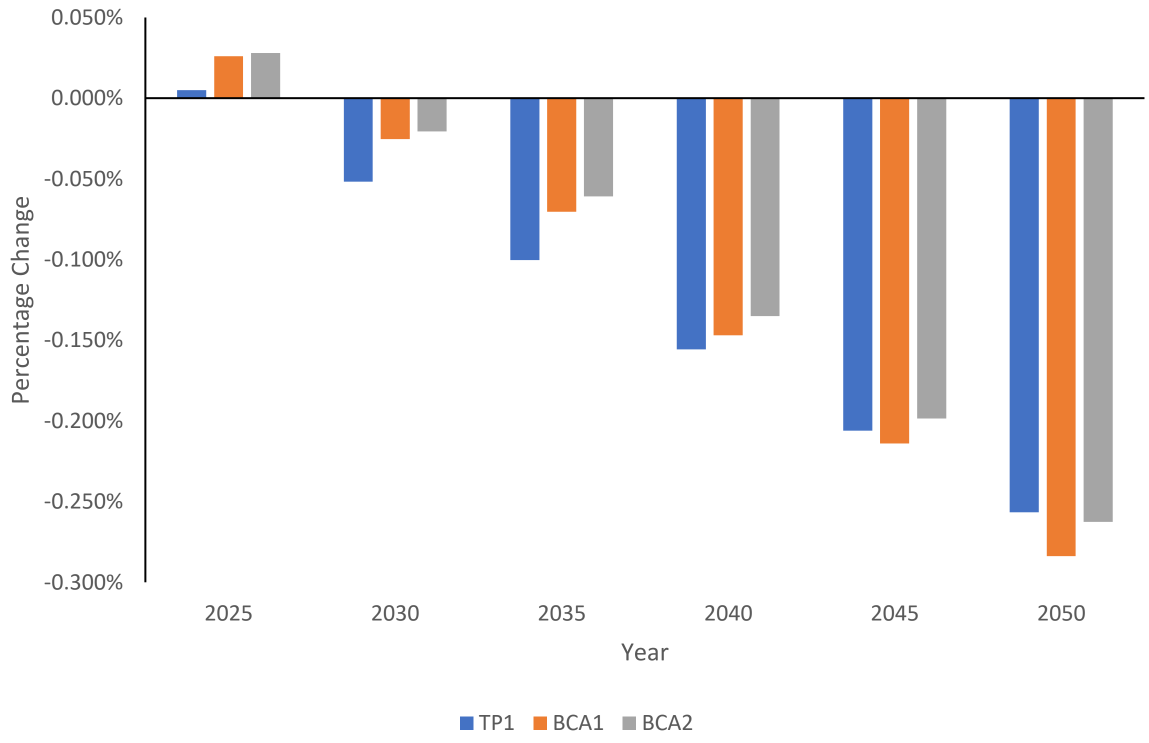

Figure 6

NZ CO2e Carbon Price - 2017 NZD Per Tonne

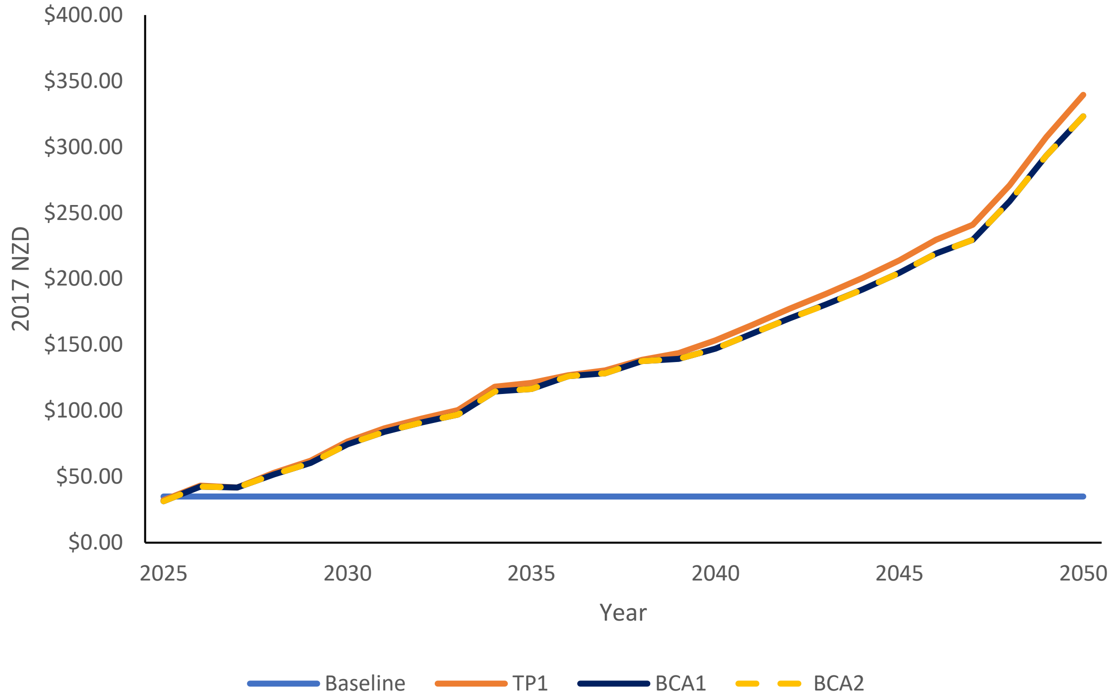

Table 10

Percentage Change in NZ Consumer Welfare Relative to Baseline

Policy	2025	2030	2035	2040	2045	2050
TP1	0.005%	-0.052%	-0.100%	-0.156%	-0.206%	-0.257%
BCA1	0.026%	-0.025%	-0.070%	-0.147%	-0.214%	-0.284%
BCA2	0.028%	-0.021%	-0.061%	-0.135%	-0.199%	-0.263%

Table 11

NZ ETS Carbon Price in Dollars Per Tonne

Policy	2025	2030	2035	2040	2045	2050
Baseline	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00
TP1	$32.26	$76.63	$121.08	$153.47	$214.14	$339.53
BCA1	$31.43	$74.59	$116.60	$147.15	$204.70	$323.24
BCA2	$31.43	$74.59	$116.60	$147.15	$204.70	$323.24

4.2 Output

An important aspect to consider is the sectoral output when implementing BCAs in the model. The response of various firms belonging to New Zealand's HEI sectors differs on the implementation of the policy. Table 12 presents the values of output in billions of 2017 New Zealand dollars for HEI sectors comprising of oil; chemicals, rubber, and plastic; non-metallic minerals; non-ferrous metals; iron and steel; and wood and paper products.

In general, all sectors subject to either policy exhibit a reduction in output relative to the baseline. This shared decline relative to baseline is attributed to rising abatement costs, weighed against their emissions-intensive inputs.

Policy TP1 leads to reduced output for all sectors relative to baseline. This is primarily driven by the lower emissions cap – this policy features a more stringent emissions target and higher a carbon price across the timespan of the simulation. These industries heavily rely on carbon and energy-intensive inputs such as coal, oil, and gas. Rising carbon prices mean that these inputs become progressively more expensive and will therefore increase operating costs. Compared to policies BCA1 and BCA2, Policy TP1 exhibits the greatest magnitude of impact.

Chemical, rubber, and plastic products is seemingly unchanging in output beyond the year of 2030. This is related to the sectoral output being constrained in the model as previously outlined in section 3.1.2 and 3.5.3, such that output decays over time starting in the year 2030. There is a growing anticipation that the chemicals industry will gradually decline over time. This prevailing sentiment has emerged due in part to the projections that methanol production will be zero by 2040 (Climate Change Commission, 2022), and in relation to our points made in section 3.1.2 and 3.5.3, such expansion is unrealistic. At an implementation level, the chemicals, rubber, and plastic products sector is set to decay by 9% annually starting in 2030, held at a constant 10% by 2040. We fail to see any change in output, because the output constraints are binding in these sectors.

Similarly, nonferrous metals show no change in output. Nonferrous metals are a constrained sector, and it is not expected to grow at all in the coming years.

The wood and paper sector shows a very large change in output across all three scenarios. We note in section 3.1.2.1 that there are advanced technologies available for some sectors, and among these is wood and paper products. The two technologies that can be used by this sector are bioheat and electric heat. The decline in output for conventionally produced wood and paper can be partially attributed to a rise in the use of these technologies. By 2050, across all three scenarios, bioheat wood and paper output represents $51.9 million[8]. This is approximately 0.15% of the 2050 output across all three scenarios. The uptake for electric heat is very low; it is effectively zero in our simulations. The prohibitive cost involved in using electric heat is likely preventing wood and paper from embracing this technology, especially since the emissions intensity of wood and paper is comparatively low as outlined in section 3.5.1.

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[8] Bioheat uptake is effectively capped as outlined in section 3.1.2.1; as most firms will use bioheat up to the maximum allowable units.

These technologies fail to account for the rest of the output, since it still has decreased overall. When comparing the original specification with ours, the 2050 baseline output for wood and paper was \$34.53 billion, yet our modified model was \$34.85 billion. This may be due to our output constraints of other sectors making wood and paper more cost-competitive in terms of abatement.

Policies BCA1 and BCA2 have increased output relative to TP1; while still reducing output relative to baseline, the BCAs are mitigating this loss via the terms of trade effect as outlined in section 4.1. These differences reflect the protectionist nature of BCAs on these sectors. Policy TP1 relies on an OBA to alleviate rising abatement costs for select firms, while policies BCA1 and BCA2 offer protection in the form of tariffs on imported goods from HEI sectors. We still have the same cap on emissions as in TP1, meaning that output is guaranteed to decrease relative to baseline, yet these BCAs have mitigated these losses for firms.

Table 12

NZ Sectoral Output Percentage Change Relative to baseline

Sector	Policy	2030	2040	2050
Chemicals, Rubber, and Plastic	TP1	-0.002%	-0.001%	-0.003%
	BCA1	-0.002%	-0.001%	-0.003%
	BCA2	-0.002%	-0.001%	-0.003%
Iron and Steel	TP1	-0.028%	-0.043%	-0.084%
	BCA1	-0.029%	-0.041%	-0.075%
	BCA2	-0.027%	-0.039%	-0.072%
Nonferrous Metals	TP1	0.000%	0.000%	0.000%
	BCA1	-0.009%	-0.017%	-0.035%
	BCA2	0.000%	0.000%	0.000%
Non-metallic Minerals	TP1	-0.006%	-0.009%	-0.015%
	BCA1	-0.006%	-0.008%	-0.012%
	BCA2	-0.006%	-0.007%	-0.011%
Wood and Paper	TP1	-0.377%	-1.232%	-3.466%
	BCA1	0.136%	-0.421%	-2.128%
	BCA2	0.096%	-0.444%	-2.098%

Figure 7

Percentage Change in NZ Sectoral Output Relative to Baseline

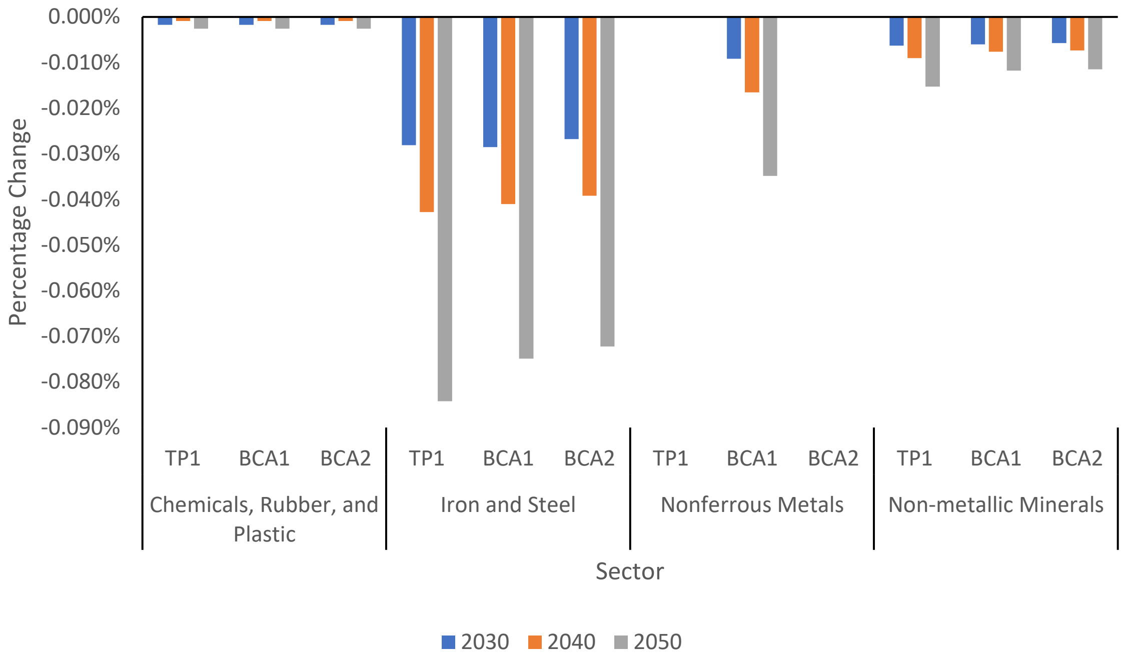
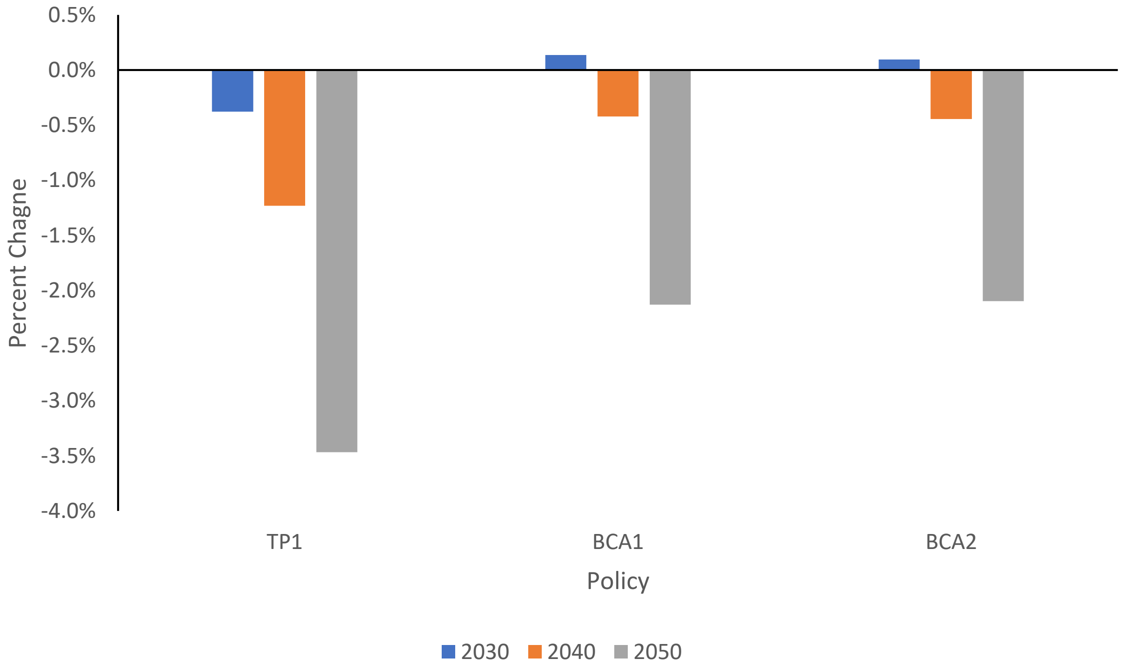


Figure 8

Percentage Change in NZ Wood and Paper Output Relative to Baseline



4.3 Prices

Prices remain an important indicator for the economic implications of our policies. Figure 9 presents the domestic price changes for HEI sectors relative to the baseline, across all three policies. The HEI sectors experience varying levels of price increases, with industries under TP1 having the lowest overall price change. Policy TP1's effect on price ranges from -0.45% to 0.99%, whereas BCA1 and BCA2 have a range of 1.67% to 30.53% and 1.6% to 29.40% respectively. We note that TP1 as a policy involves using the OBA system, and numerous sectors that fall under this category are known to be recipients of large quantities of free allowances, most notably the steel industry as well as non-ferrous metals. As discussed in section 2, OBAs are very much like implicit subsidies that lower abatement costs for qualifying firms. This can subsequently lead to a comparatively lower price increase than other policies. The way that BCA1 and BCA2 may be driving the comparatively higher price change can be attributed to the rising input costs of the firms in these sectors and the fact that BCAs allow producers to sell their output for a higher price. BCA1 and BCA2 employ a carbon tariff on foreign energy-intensive sectors, leading to more expensive imported goods. These policies lead to an increase in price due to import substitution effects that arise from increasing import prices of international HEI products. This increase in demand for domestically produced commodities allows producers to sell at a higher price. Such extreme magnitudes are likely due to domestic production being incapable of meeting the rising demand, given that most HEI sectors have their outputs constrained. Under the current model specification, it is not feasible for domestic sectors to alleviate this price shock.

Figure 9

Percentage Change in NZ Sectoral Price Relative to Baseline

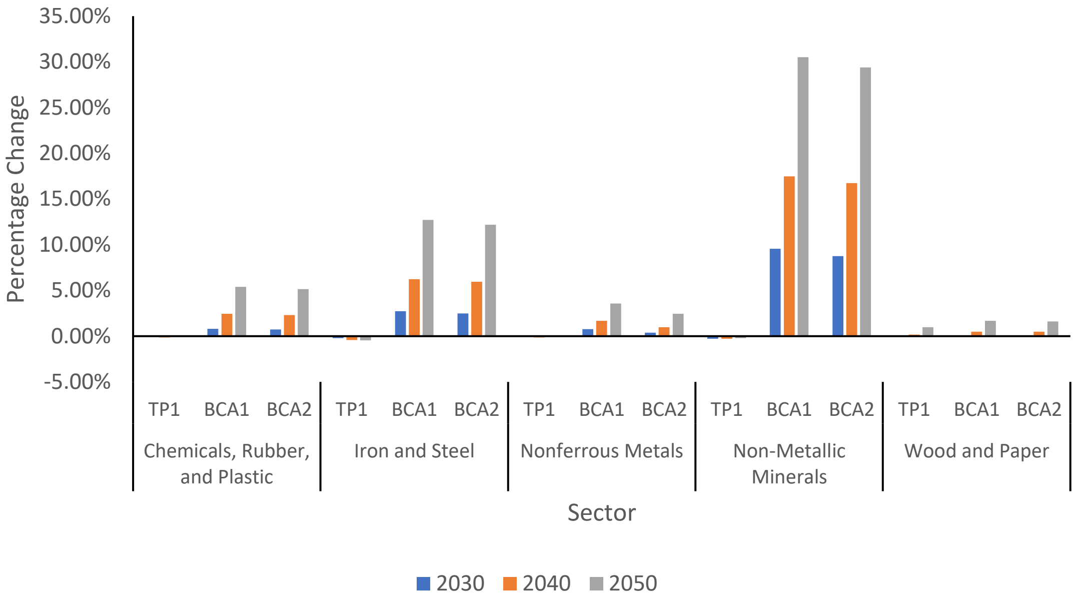


Table 13

Percentage Change in NZ Sectoral Price Relative to Baseline

Sector	Policy	2030	2040	2050
Chemicals, Rubber, and Plastic	TP1	-0.06%	-0.14%	0.06%
	BCA1	0.82%	2.44%	5.40%
	BCA2	0.75%	2.33%	5.16%
Iron and Steel	TP1	-0.21%	-0.41%	-0.45%
	BCA1	2.73%	6.24%	12.73%
	BCA2	2.50%	5.95%	12.19%
Nonferrous Metals	TP1	-0.06%	-0.16%	0.02%
	BCA1	0.78%	1.69%	3.57%
	BCA2	0.40%	0.98%	2.47%
Non-Metallic Minerals	TP1	-0.27%	-0.30%	-0.20%
	BCA1	9.56%	17.49%	30.53%
	BCA2	8.77%	16.74%	29.40%
Wood and Paper	TP1	-0.02%	0.19%	0.99%
	BCA1	0.08%	0.50%	1.67%
	BCA2	0.08%	0.48%	1.60%

4.4 Emissions

We consider the sectoral emissions for the HEI industries that fall under the remit of our policy scenarios. Because of how the ETS is modelled in C-PLAN, the total emissions for any given year is the same across all policies. Therefore, when we examine emissions in this study, we are considering the distribution of permits within the economy. Policy TP1 and BCA1 have the same values across all sectors; only BCA2 shows any difference in value. Policy BCA2 leads to comparatively higher emissions in 2030. This is in line with our expectations of higher domestic output which arises from the terms of trade effect. The higher tariff rate on HEI commodities makes the domestic variety more price-competitive and leads to resources being funnelled into these import-competing goods. This higher level of activity is associated with more emissions.

Most of the reductions seen in Figure 10 is attributed to the emissions cap, hence why the three policies share similar magnitudes. Relative to the baseline, all the policies will invariably show a reduction in emissions over time.

Policy BCA1 shows that HEI sectors are generating fewer emissions than BCA2, and this may be due to firms being more incentivised to reduce their emissions with an OBA. Firms that pursue more efficient technologies and substitute towards inputs with lower emission intensity can benefit from surplus allowances accrued. BCA2 on the other hand offers little to encourage firms to adopt more efficient technologies and instead may be disincentivising them, since using contemporary technologies is cheaper on average and the rising abatement cost is offset by the higher tariff. Figure 6 shows that an OBA on average, leads to higher carbon prices. BCA2 has a slightly lower carbon price than TP1 and BCA1 throughout the observed period.

This pattern isn’t seen in all years though, as by 2050, we find that some HEI sectors under the BCA2 scenario are lower in emissions than either TP1 or BCA1. These sectors are chemicals, rubber, and plastics, and nonferrous metals. This may be due to the output constraints on these sectors reaching their greatest extent, and thus we have a constrained sector with no OBA. We recall that an OBA is an implicit subsidy for firms leading to increased output, it would suggest that by 2050, having a BCA does nothing for these sectors. The remaining sectors remain unchanged in their response to the policies.

4.4.1 Changes in Emissions Intensity

We also consider the emissions intensity of these sectors. Changes in emissions intensity show how firms are responding to these different policies. Lower intensities imply that firms are adopting cleaner inputs or technologies. As seen in Figure 11, all sectors show a decrease in intensity overtime. Compared to the BCAs, policy TP1 demonstrates the most significant decrease for nearly all sectors[9] throughout the observed period. Policy BCA1 has larger reductions in intensities than BCA2 across all sectors.

A BCA on average contributes to comparatively higher emissions intensities than an OBA, whilst an OBA contributes to lower intensities. This observation is supported by theory, as mentioned in section 4.4, firms are encouraged to reduce their emissions intensity and collect output-based permits. A BCA offers less of an incentive to do this and instead raises the price of imports to compensate for the higher cost of producing domestic goods.

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[9] Sector Nonferrous Metals is the only exception, where BCA2 has the greatest reduction.

Figure 10

Percentage Change in NZ Sectoral Emissions Relative to Baseline for 2030

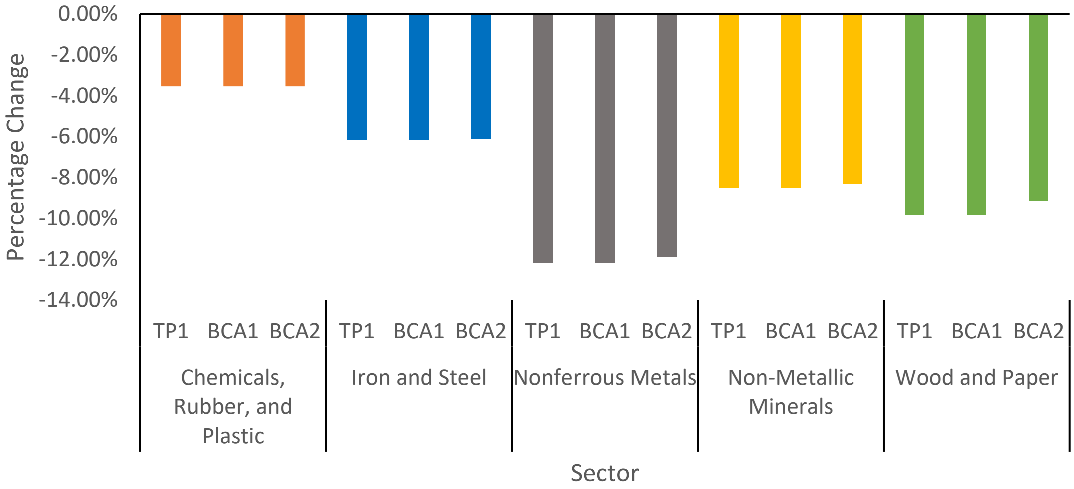

Figure 11

Percentage Change in NZ Sectoral Emissions Intensity (Tonnes CO2e per Dollar Output)

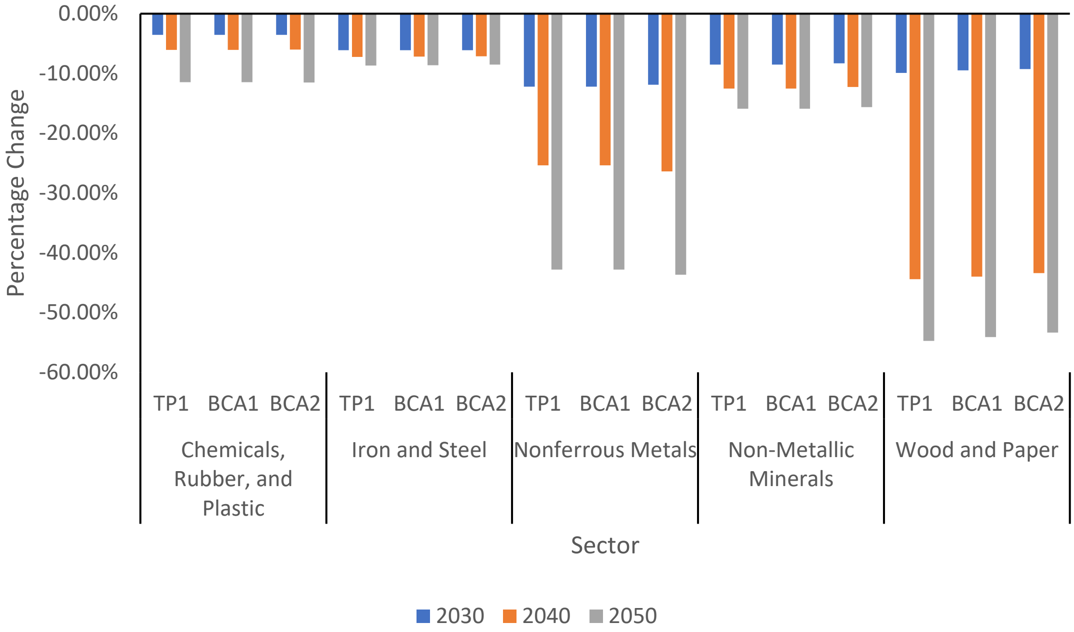

Table 14

NZ Sectoral Price Percentage Change Relative to Baseline

Sector	Policy	2025	2030	2035	2040	2045	2050
Chemicals, Rubber, and Plastic	TP1	-0.83%	-3.54%	-5.97%	-6.03%	-7.97%	-11.49%
	BCA1	-0.83%	-3.54%	-5.97%	-6.03%	-7.97%	-11.49%
	BCA2	-0.85%	-3.53%	-5.96%	-6.02%	-7.97%	-11.51%
Iron and Steel	TP1	-4.87%	-6.16%	-6.95%	-7.24%	-7.84%	-8.72%
	BCA1	-4.87%	-6.16%	-6.95%	-7.24%	-7.84%	-8.72%
	BCA2	-4.83%	-6.11%	-6.88%	-7.16%	-7.74%	-8.60%
Nonferrous Metals	TP1	3.84%	-12.18%	-20.93%	-25.35%	-31.56%	-42.83%
	BCA1	3.84%	-12.18%	-20.93%	-25.35%	-31.56%	-42.83%
	BCA2	4.12%	-11.88%	-20.49%	-26.42%	-31.11%	-43.68%
Non-Metallic Minerals	TP1	-2.61%	-8.52%	-11.65%	-12.54%	-14.13%	-15.92%
	BCA1	-2.61%	-8.52%	-11.65%	-12.54%	-14.13%	-15.92%
	BCA2	-2.44%	-8.31%	-11.37%	-12.25%	-13.85%	-15.64%
Wood and Paper	TP1	0.93%	-9.84%	-17.28%	-44.69%	-48.84%	-55.68%
	BCA1	0.93%	-9.84%	-17.28%	-44.69%	-48.84%	-55.68%
	BCA2	1.37%	-9.15%	-16.23%	-43.62%	-47.64%	-54.36%

4.4.2 Leakage

Emissions leakage is a key concern when evaluating climate policy. We report leakage rates in this section: the increase in global emissions divided by the decrease in New Zealand’s emissions in policy scenarios relative to the baseline scenario. By this definition, leakage represents the overall impact on climate, since it is well-understood that emissions know no borders. Positive rates of leakage imply that there is an increase in emissions globally that offsets any reductions made in the domestic sphere. Negative leakage suggests that there is a reduction in global emissions. High rates of positive leakage are generally undesirable for climate action since it nullifies any reductions made domestically and outsources pollution to countries with lower rates of abatement.

In terms of economy-wide leakage, policy TP1 leads to positive leakage, whereas BCA1 and BCA2 lead to negative rates.

Our results indicate that BCAs will reduce leakage across all the HEI sectors relative to the TP1 policy scenario. We report negative rates of leakage for nearly all HEI sectors across all policy scenarios. The largest among these are chemicals, rubber, and plastic; non-metallic minerals; and iron and steel. These industries exhibit very high rates of negative leakage. Negative leakage can be the result of a variety of factors, one of these may be related to the output constraints. All the aforementioned sectors belong to a set that have constrained outputs. We note that the rest of the world has its own commitment to reducing emissions, such that there are few instances where New Zealand production can offset these global reductions.

Another reason is that New Zealand HEI sectors may produce ‘cleaner’ outputs than the rest of the world. Because of the trade barrier and resultant import substitution, NZ sectors produce their own domestic variety of good which has a lower emissions intensity than the rest of the world. Figure 14 supports this argument, since it shows that most NZ sectors have lower emissions intensities than the rest of the world.

Ultimately, the key driver behind these negative leakage rates are the output constraints. These constraints are binding in both the baseline and policy scenarios[10], and are the main driver behind the negative leakage across all scenarios. For example, policy TP1 shows negative leakage for sectors that are both HEI and have their outputs constrained; BCAs do not operate in this scenario and cannot be attributed to this result. BCAs also reduce leakage but are unlikely to lead to negative leakage on their own. Therefore, the combined effect of a BCA and the output constraints make negative leakage more pronounced in policies BCA1 and BCA2.

Wood and paper differs from other HEI sectors by having positive rates of leakage; without output constraints the carbon price introduced by our policies reduces domestic production, leading to substitution for imports. Between TP1 and the BCA policies we see that BCAs manage to reduce leakage. Policy TP1 has a leakage rate of 3.61% in 2050, whereas both BCA1 and BCA2 share a leakage rate of 3.32% in 2050. These results indicate that for wood and paper, BCAs mitigate leakage more than OBAs.

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[10] We also consider the abatement resource effect (ARE) theory introduced by Fullerton et al. (2011). In this paper they propose that leakage may be negative due to rising abatement costs inducing targeted firms to use cleaner inputs such as ‘abatement capital’. These sectors will draw resources from unconstrained sectors or regions to meet abatement costs. The outflow of capital leads to a reduction in output from these unconstrained sectors or regions, resulting in fewer emissions. The abatement resource effect competes with consumers’ ability to substitute for goods from unconstrained sectors; consumers may overpower this negative effect by shifting their purchases. This effect may be more pronounced with BCAs which introduce more trade barriers which prevent import substitution. The ARE theory is likely not the main driver behind these negative rates, as the findings of Fullerton et al. (2011) stress that leakage mustn’t always be negative, but that this is an effect that can factor into the magnitude of positive leakage. Winchester and Rausch (2013) state that there are limited opportunities for net negative leakage, as it relies on the elasticities of substitution in production and utility functions to fall within certain values. For most calibrated models, net negative leakage is improbable. Therefore, we do not attribute these novel results to the ARE theory.

Figure 12

2050 Sectoral Leakage Rates

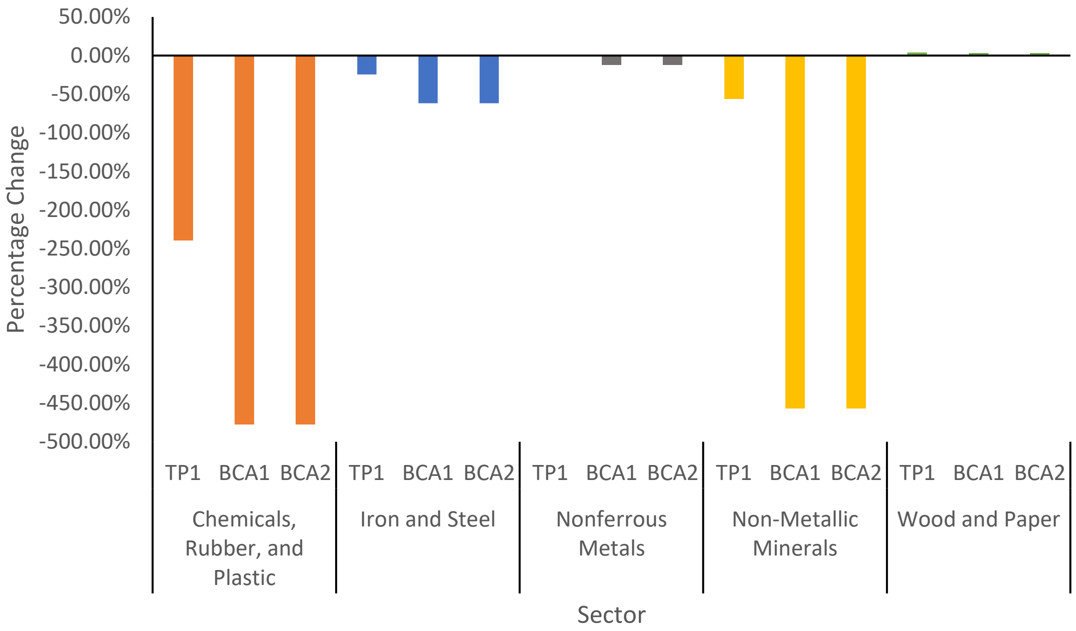

Figure 13

NZ Economy-Wide Leakage Rates

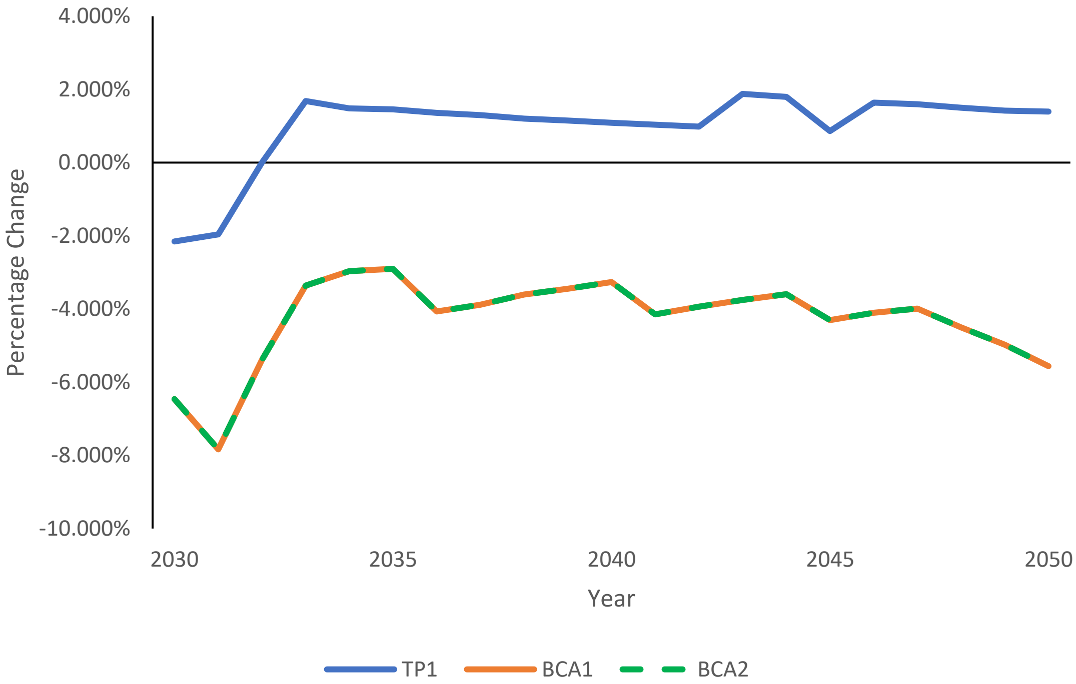

Figure 14

2050 Sectoral Emissions Intensities (Tonnes CO_2e per Thousand Dollars of Output)

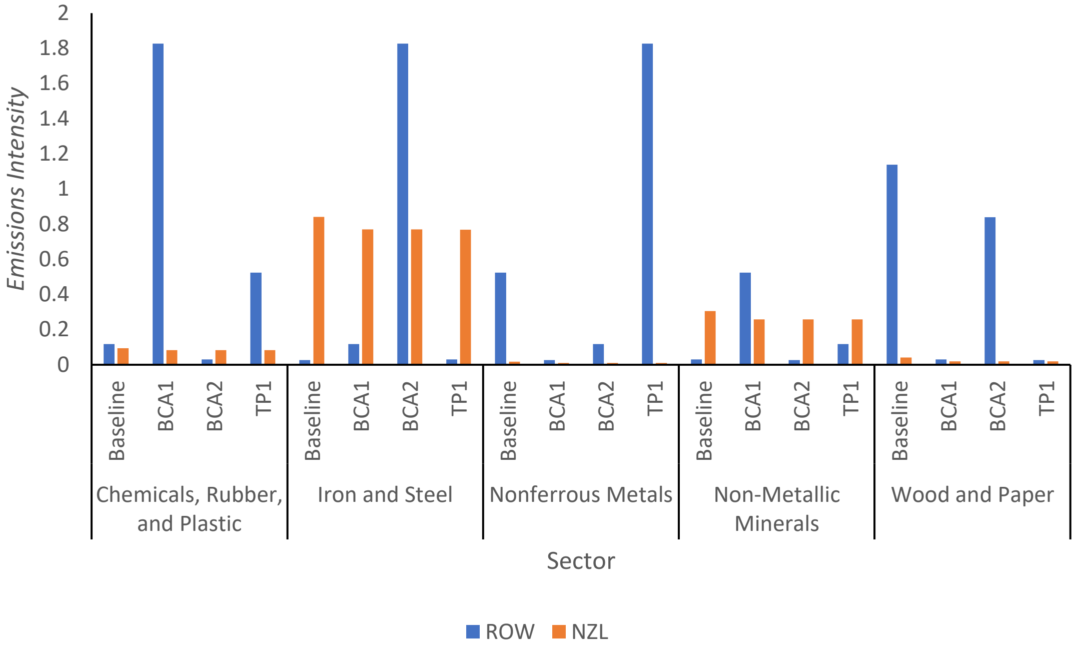

Table 15

NZ 2050 Sectoral Leakage Rates

Sector	Policy	2050
Chemicals, Rubber, and Plastic	TP1	-239.24%
	BCA1	-477.57%
	BCA2	-477.58%
Iron and Steel	TP1	-24.30%
	BCA1	-61.61%
	BCA2	-61.61%
Nonferrous Metals	TP1	0.00%
	BCA1	-11.96%
	BCA2	-11.96%
Non-Metallic Minerals	TP1	-56.09%
	BCA1	-456.79%
	BCA2	-456.80%
Wood and Paper	TP1	3.61%
	BCA1	3.32%
	BCA2	3.32%

4.5 Trade

Trade is important for a small open economy like New Zealand. Since BCAs by their very nature target the imports of selected sectors, we cannot neglect the effects of these policies on trade. We report changes in imports as a percentage change relative to baseline for all three policies. Our results show that BCA1 and BCA2 decrease exports from the rest of the world to NZ considerably more than TP1 for all sectors. This is not unprecedented, since it is well-understood that BCAs reduce imports on affected sectors. The higher tariff rates make imports less attractive, and lead to import substitution as domestically produced goods are more price competitive.

The sectors most affected by either policy are iron and steel, non-metallic minerals, and nonferrous metals. All sectors show an increase in magnitude for imports over time.

We note that policy BCA1 has the greatest reduction in imports. This effect can be attributed to the synergy with OBAs and BCAs leading to domestic sectors being more competitive than imported commodities. Recall that OBAs act as an implicit subsidy for the firm; when combined with a tariff we should expect a greater impact on imports than either policy on its own.

Interestingly, wood and paper shows an increase in imports relative to baseline for policy TP1. This may be due to wood and paper being particularly sensitive to emissions constraints. The rising abatement costs make domestic production for wood and paper products less competitive than the imported variety, leading to a rise in their import. When viewed holistically this result is not unexpected. We note that the domestic output and leakage rates indicate that wood and paper, under policy TP1, is heavily impacted by the more stringent cap, such that we observe demand being filled with imports rather than increased domestic production. This effect is reversed via the BCA policies, as the protectionist measures are sufficient in mitigating this loss in competitiveness.

Figure 15

Percentage Change in Imports ROW - NZ Relative to Baseline

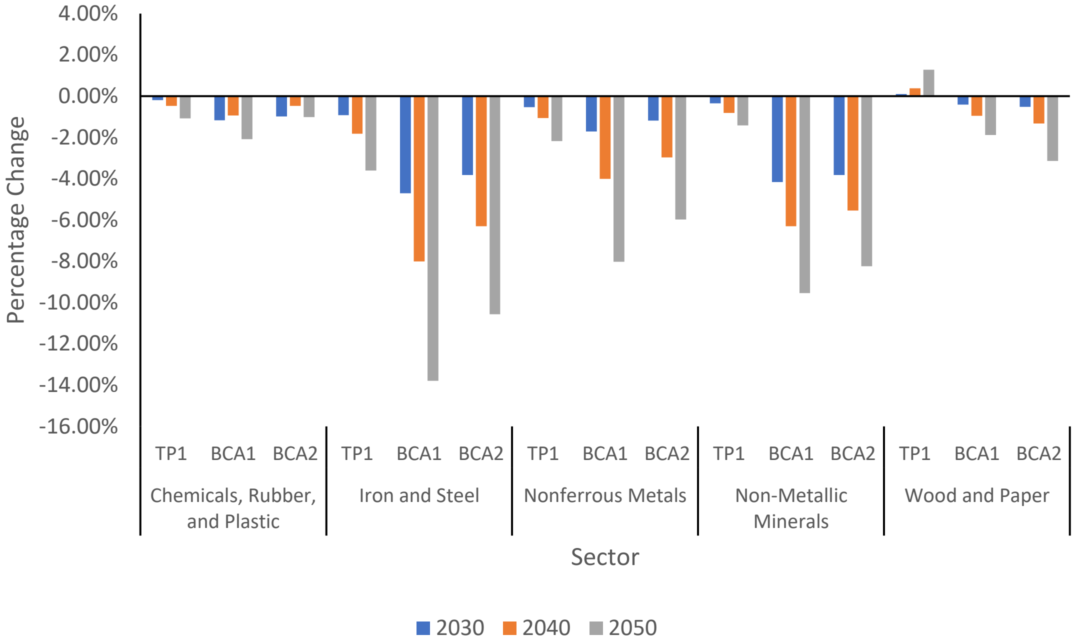

Figure 16

Percentage Change in Oil Imports ROW - NZ Relative to Baseline

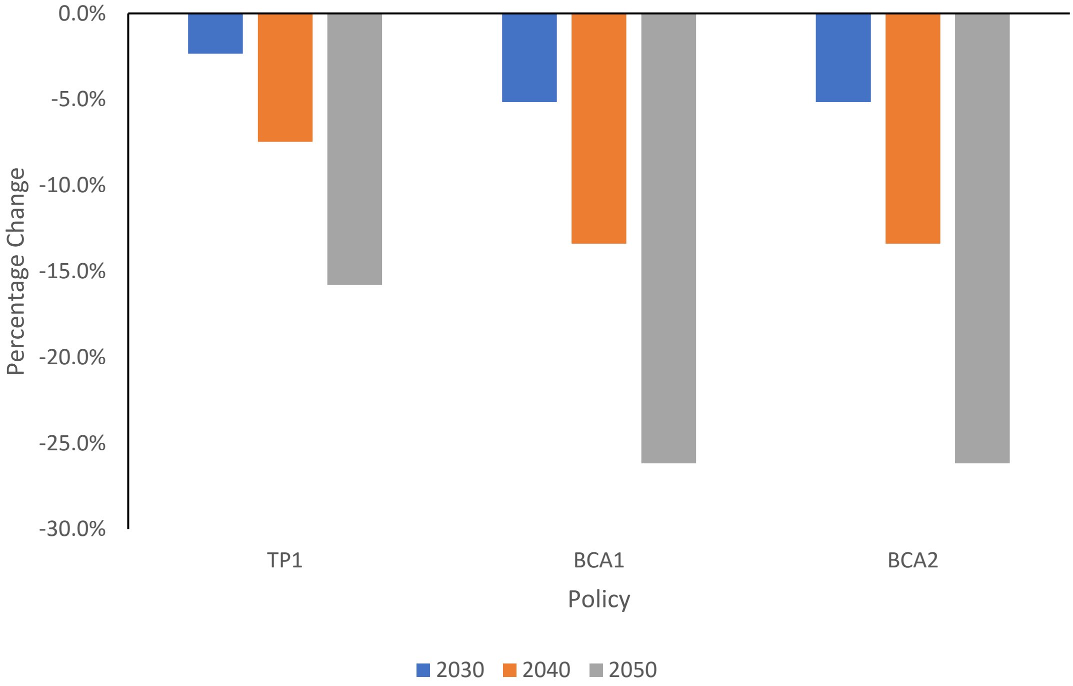

Table 16

NZ Sectoral Percentage Change in Imports ROW - NZ Relative to Baseline

Sector	Policy	2030	2040	2050
Chemicals, Rubber, and Plastic	TP1	-0.19%	-0.46%	-1.08%
	BCA1	-1.18%	-0.93%	-2.09%
	BCA2	-0.99%	-0.47%	-1.02%
Iron and Steel	TP1	-0.92%	-1.83%	-3.60%
	BCA1	-4.71%	-8.01%	-13.80%
	BCA2	-3.82%	-6.30%	-10.57%
Nonferrous Metals	TP1	-0.53%	-1.06%	-2.18%
	BCA1	-1.72%	-4.00%	-8.03%
	BCA2	-1.19%	-2.97%	-5.97%
Non-Metallic Minerals	TP1	-0.35%	-0.81%	-1.42%
	BCA1	-4.17%	-6.30%	-9.54%
	BCA2	-3.83%	-5.54%	-8.24%
Wood and Paper	TP1	0.10%	0.38%	1.29%
	BCA1	-0.41%	-0.95%	-1.89%
	BCA2	-0.51%	-1.33%	-3.13%
Oil	TP1	-2.34%	-7.47%	-15.81%
	BCA1	-5.17%	-13.40%	-26.18%
	BCA2	-5.17%	-13.40%	-26.18%

5. Conclusion

This paper examines the impacts of New Zealand applying BCA on imports from the rest of the world. The paper evaluates macroeconomic changes on both New Zealand and the rest of the world, as well as the sectoral impacts on HEI sectors. Our work builds upon the existing literature and augments modelling tools developed by Winchester and White (2022). We report on changes in GDP, welfare, sectoral output, sectoral prices, sectoral emissions and leakage, and trade. Our results mostly support the findings and expectations of previous studies, showing that a BCA introduces some distortionary effects and can promote higher domestic emissions in sectors targeted by the policy. We find that a BCA can enhance GDP, as shown in section 4.1 and that there are welfare gains that emerge from a BCA due to positive terms-of-trade effects.

The impacts on sectoral output have been shown to be positive, with BCAs promoting relatively higher levels of output than OBAs. Prices were increased considerably under a BCA, with non-metallic minerals showing the greatest increase on average.

In terms of emissions and leakage, we find the output constraints outlined in section 3.1.3 play a key role in facilitating these results, since they are binding across all policy scenarios. This leads to negative leakage even for policy TP1, a scenario that doesn’t include any BCAs.

BCAs reduce leakage but do not generally lead to negative leakage rates, it is when the effects of output constraints and BCAs are considered together that we see these results. When compared to policy TP1, policies BCA1 and BCA2 exhibit greater reductions in the leakage rate, suggesting that BCAs are more effective than an OBA at mitigating leakage.

Overall, this study presents an interesting case for BCAs in the context of climate and trade policy in NZ. However, our assumptions leave out a few important considerations. Our modelling hasn’t accounted for retaliatory tariff measures which may lead to a worse outcome than what is being reported.

Furthermore, the decision to constrain outputs of selected industries may distort our results. These settings reflect the political climate of New Zealand, acknowledging that it is unpopular for the government to allow the opening of a new aluminium smelter, or steel mill. Given that BCAs are tacitly supporting these HEI sectors from international competition, it would be contradictory to maintain these restrictions when the expectation is for these domestic firms to persist into the future while complying with the ETS.

The impact on other countries has not been noted in this study. One of the limitations of the base version of C-PLAN is that it is calibrated for an NZ-ROW aggregation. Key trading partners may be disaggregated in future studies, but we note that the impacts on large markets like China, the EU, and the USA will likely be small given the relative size of New Zealand’s economy to the aforementioned regions.

Policymakers may favour a BCA over OBA due to the apparent leakage reductions, welfare gains, and sectoral output increases. However, the limitations associated with our findings mean that future research is needed to evaluate the feasibility of such a policy change. We note that implementing a BCA in practice is an arduous affair and may require copious political capital to enact, especially considering that the NZ ETS has an extant OBA policy. The implications of such a shift in policy cannot be accurately captured by the model; policymakers would need to consider potential retaliatory measures, the physical constraints of HEI sectors, and the consensus of the public at large over the expansion of pollution-intensive industries. This study merely presents an alternative scenario that explores the hypothetical world of a BCA-driven NZ ETS, and that policymakers will have to carefully consider the relative merits of pursuing a change in course.

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