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Economic and Land Use Impacts of Synthetic Dairy Production on a Dairy-Intensive Economy: New Technology Moo-ving In

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ABSTRACT

Synthetic dairy products are promoted as an environmentally sustainable alternative to conventional dairy goods. This paper examines the potential economic, employment and land use impacts of large-scale synthetic dairy production on Aotearoa New Zealand—the world's leading dairy exporter. Using a global, economy-wide model, we simulate a case in which synthetic dairy products are cost-competitive with conventional dairy products. Our results show that, under this scenario, New Zealand's GDP would decline by 0.5%–0.7%, and national welfare would fall by 1.2%–1.5%, with significant employment impacts on dairy-related and other sectors. The reallocation of dairy land to other uses offers limited mitigation, as global shifts in production depress the prices of other agricultural commodities. Moreover, policies aimed at preserving dairy employment are costly. These findings suggest that, if synthetic dairy products are produced at scale, policy should prioritise adaptation strategies—such as retraining and skills development—to support workers and landowners in adjusting to the resulting changes.

JEL Classification: Q15, Q16, Q17

1 | Introduction

In recent years, animal agriculture has come under increasing scrutiny as it seeks to meet global population demands and reduce its environmental footprint and animal welfare impacts (Stephens and Ellis 2020). In response to these pressures, synthetic agricultural products (also known as cellular agricultural products), such as imitation cow milk and meat products, have entered the market.

Synthetic dairy products can be produced without any inputs from livestock (Bojovic and McGregor 2023). They are produced using precision fermentation (Vanhercke and Colgrave 2022), also referred to as fermentation-based cellular agriculture (Stephens and Ellis 2020). Precision fermentation typically involves the genetic modification of microbes to produce a protein that mimics the protein found in a desired dairy product. This protein is then combined with other ingredients to imitate the texture and taste of the traditional dairy product (Vanhercke and Colgrave 2022).

Although synthetic dairy products are not yet cost-effective enough to capture a significant proportion of the market, the potential benefits of scaling them up and replacing traditional dairy products include environmental gains from reduced livestock use, a reduction in agricultural land use, fewer cases of human diseases from agricultural products and consumer cost savings (Stephens and Ellis 2020). However, an increase in the production of synthetic dairy products could have implications for GDP, welfare, employment, land use and trade in regions where the dairy industry makes up a significant proportion of the economy.

Given the current size and market penetration of synthetic dairy products, there is little evidence of their impact on the traditional dairy industry and the wider economy (Stephens and Ellis 2020). However, the rapid growth of plant-based alternatives to dairy products (Mäkinen et al. 2016) has motivated research into the potential environmental, economic and land use implications of synthetic dairy products (Stephens and Ellis 2020; Mendly-Zambo et al. 2021). For example, several studies have conducted life cycle analyses of synthetic agricultural products (Tuomisto and de Mattos 2011; Lynch and Pierrehumbert 2019). They find that synthetic agriculture could use significantly less water, energy and land than traditional alternatives. Tuomisto and de Mattos (2011) estimate that synthetic agricultural products use approximately 1% of the land required by the equivalent traditional agricultural products. Therefore, even small shifts in production towards synthetic dairy would likely result in a relatively large amount of land use change.

Bojovic and McGregor (2023) and Lonkila and Kaljonen (2021) discuss the high capital intensity of synthetic dairy production, which could reduce the prevalence of traditional family-based farming and increase the number of agricultural businesses owned by large corporations. This could shift employment in agricultural sectors from the fields into fermentation laboratories or other sectors of the economy. Tubb and Seba (2019) estimate that the fermentation industry related to synthetic agriculture could support up to 700,000 jobs in the United States by 2030.

In 2023/2024, New Zealand produced 32% of the world's whole milk powder (USDA 2024). In 2023, dairy contributed 3.2% to New Zealand's GDP, supported 55,000 jobs and accounted for approximately 25% of New Zealand's exports (Sense Partners 2023). Consequently, any shocks to traditional dairy production in New Zealand are likely to have significant impacts on the economy and land use.

Manhire et al. (2024) examine the impact of production of alternative proteins in New Zealand, including precision fermentation for dairy products, plant-based products and emerging proteins (including laboratory-grown meat). Their analysis uses a partial equilibrium model—the Lincoln Trade and Environment Model—a regional model of land use outcomes and stakeholder engagement. In their simulations related to cost-competitive production and demand of precision fermentation for dairy ingredients, land shifts from sheep and dairy to beef and arable land in New Zealand. When demand for all alternative proteins increases above the current trends, land shifts from sheep, beef and dairy land to arable and forestry land. They also estimate changes in GDP, employment, soil nitrogen and phosphorus loss, and GHG emissions. Precision fermentation reduces all these measures, whereas all alternative proteins increase economic outcomes and reduce environmental impacts. Although Manhire et al. (2024) provide a comprehensive overview of projected changes to the New Zealand agricultural industry, they do not provide insight into the potential spillover effects to other sectors in New Zealand and the rest of the world (RoW). They also do not consider the cost and effectiveness of potential policies intended to protect employment in the New Zealand dairy industry from increases in alternative protein production.

We expand on the existing literature by developing an economy-wide model to estimate the impacts of global synthetic dairy production on the New Zealand economy. Although synthetic dairy products are currently more expensive than conventional dairy products, this may change in the future. Mirroring cost decreases for other technologies with environmental benefits (e.g., solar panels), we consider a future scenario where synthetic dairy products are cost-competitive and produced at large scale. Key features of the model include the following: (1) detailed representation of both conventional dairy and synthetic dairy products, (2) land use change, (3) unemployment and (4) endogenous labour subsidies to mitigate employment impacts from synthetic dairy production.

This paper has four further sections. Section 2 provides an overview of the economy-wide model used for our analysis. Section 3 describes the scenarios simulated in the model. Section 4 presents and discusses the results. Concluding remarks are offered in Section 5.

2 | Methodology

We develop a global computable general equilibrium (CGE) model to estimate the economic impacts of synthetic dairy on the New Zealand economy. As the core structure of the model follows Lanz and Rutherford (2016), this section provides a brief overview of that framework and describes key augmentations made for our analysis in detail. Further modifications to the model required to implement certain scenarios are described in Section 3.

2.1 | Core Model Structure

The model is a static CGE model that represents multiple sectors and regions. Production in each sector is represented using nested constant elasticity of substitution (CES) functions, with sector-specific structures and substitution elasticities. Final demand is determined by a representative consumer who allocates expenditure across investment, government and private consumption. International trade follows the Armington assumption (Armington 1969), allowing for substitution between domestic and imported goods by source. Decision-making in the model is based on real prices.

Land is represented as a factor of production in the model. Each type of agriculture has an associated land use type and rent. For each of the scenarios, the model endogenously determines the rent for each type of agriculture on the basis of productivity of the associated land type.

Turning to closures, in the core version of the model, there is full employment of labour with flexible real wages, but alternative labour market closures are specified in some scenarios (see Section 3). In the external closure, the real exchange rate adjusts to maintain a fixed trade balance. Under the fiscal closure, endogenous government deficits (surpluses) are funded by lump sum transfers from (to) households.

The model is calibrated using Version 11 of the Global Trade Analysis Project (GTAP) database (Aguiar et al. 2022), which provides a representation of the world economy in 2017. The model simulates outcomes for 2030 using a forward calibration routine described in Section 3. It is written using the Mathematical Programming System for General Equilibrium (Rutherford 1999), a subsystem within the General Algebraic Modeling System.

2.2 | Bespoke Model Features

As our analysis focuses on New Zealand, the model represents two regions—New Zealand and the RoW. The model recognises 34 sectors (Table 1) in each region. Pertinent to our analysis, the model represents six primary agricultural sectors that compete for land use (dairy farming, beef and sheep farming, other animal products, fruit and vegetables, other horticulture and forestry). Food manufacturing sectors in the model include conventional dairy products, synthetic dairy products, meat products and other food processing.

Each sector produces output from hiring primary factors including labour, capital, natural resources and land, as well as the purchase of intermediate inputs from other sectors. The production function for agricultural sectors is sketched in Figure 1. In this diagram, σ_n denotes the elasticity of substitution between inputs included in nest n.

In the left branch of the nest, a CES function combines land and an intermediate input aggregate, where this aggregate is a Leontief nest of non-energy intermediate inputs. The substitution between land and intermediate inputs, such as fertiliser and feed, in this nest enables endogenous yield changes in the model. The right branch of the production function combines capital, labour and energy inputs, with substitution between these inputs governed by various elasticity parameters. The top-level nest facilitates further endogenous yield responses through substitution between the land–other inputs and energy–capital–labour aggregates.

The production function for manufacturing sectors—including dairy products—is illustrated in Figure 2. In this specification, the energy–capital–labour aggregate is combined with other intermediate inputs in a Leontief nest, implying that these intermediate inputs are used in fixed proportions to output. A key intermediate input for (conventional) dairy products is raw milk produced by the dairy farming sector.

TABLE 1 | Sectors represented in the model.

Agriculture	**Energy-intensive manufacturing**
Dairy farming (rmk)	Chemical, rubber and plastic products (crp)
Beef and sheep farming (b_s)	Cement manufacturing (nmm)
Other animal products (oap)	Non-ferrous metals (e.g., aluminium) (nfm)
Fruit and vegetables (v_f)	Iron & steel (i_s)
Other horticulture (hor)	Fabricated metal products (fmp)
Forestry (frs)	
Fishing (fsh)	**Other manufacturing**
	Mining of metal ores (oxt)
	Conventional dairy products (mil) Synthetic dairy products (nt_mil)
Energy extraction and distribution	Meat products (mtp)
Crude oil extraction (cru)	Other food processing (ofd)
Refined oil products (oil)	Wood and paper products (w_p)
Coal extraction (col)	Textiles, clothing & footwear (tcf)
Natural gas extraction and distribution (gas)	Motor vehicles and parts (mvh)
Electricity, transmission and distribution (ely)	Other manufacturing (omf)
Transport	**Construction and services**
Road transport (rtp)	Construction (cns)
Air transport (atp)	Accommodation and food services (afs)
Water transport (wtp)	Business services (bus)
Private transport (hht)	Other services (ser)

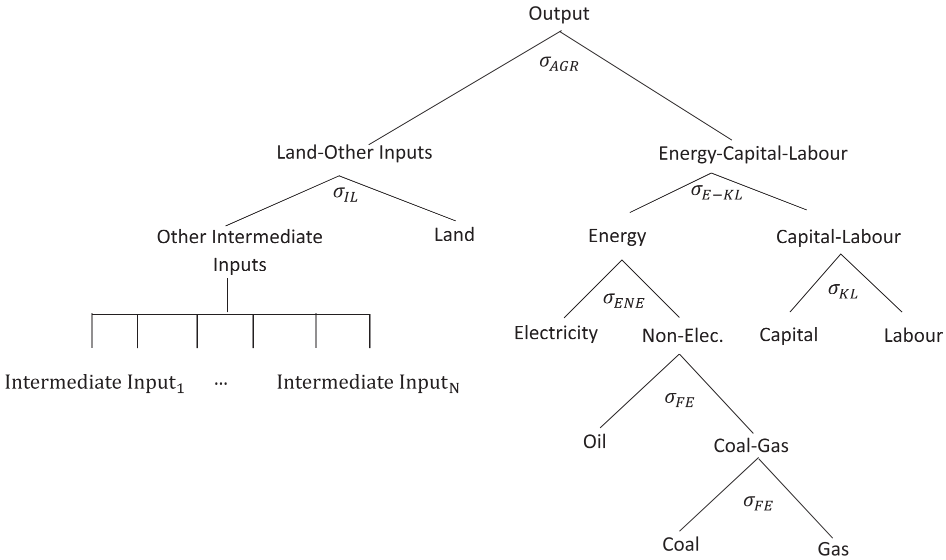

FIGURE 1 | Production structure for agriculture and forestry sectors. σ_n denotes the elasticity of substitution between inputs included in nest n. Vertical lines in the input nest signify a Leontief or fixed coefficient production structure where the elasticity of substitution is zero. *Source*: Winchester and White (2022).

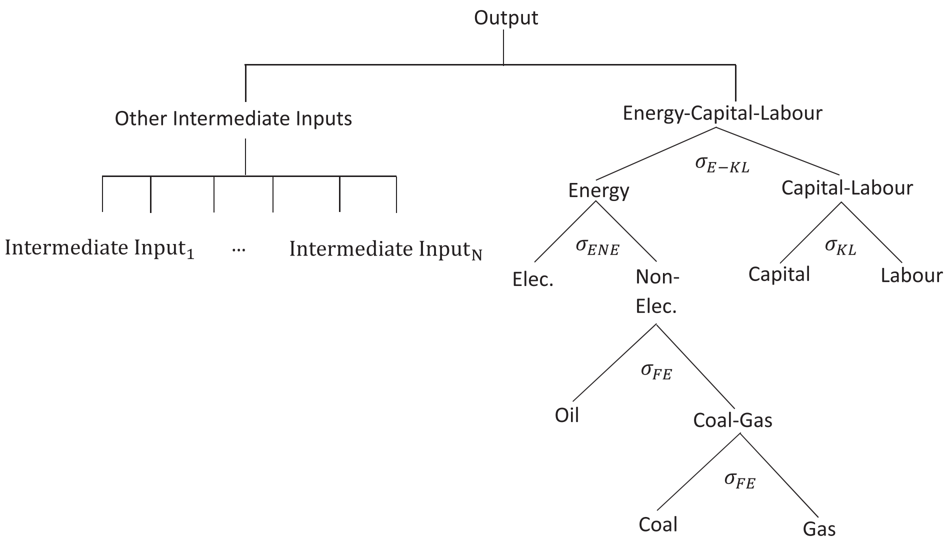

FIGURE 2 | Production structure for manufacturing sectors. See notes for Figure 1. *Source*: Winchester and White (2022).

This representation of dairy farming and dairy products is based on information from the GTAP database (Aguiar et al. 2022) and the Climate PoLicy ANalysis model (Winchester and White 2022). Dairy farming refers to the 'raw' goods produced on a farm and dairy products refer to goods that process those 'raw' products into items, such as pasteurised milk, cheese and milk powder. They are separated in the model to allow for a more detailed analysis of the impacts of synthetic dairy production on agricultural supply chains. This includes an estimation of labour and land use changes at both farm and factory levels.

The production of synthetic dairy products is only available in selected scenarios and is modelled as a new technology. New technologies are potential production options that are not yet deployed at scale because of high costs, technological limitations or other constraints, but may become viable in the future. Output from the synthetic dairy sector is a perfect substitute for conventional dairy products in the model. Cost-competitive synthetic dairy products are contingent on technological advances and do not use land, so we assume that they are only produced in the RoW.

As there is no commercial production of synthetic dairy products, it is not included in the GTAP database and input requirements for this sector must be specified separately. We assume that it is produced using capital, labour, and, to allow output targeting, a technology-specific factor (TSF). As in other sectors, using capital and labour for synthetic dairy production reduces output elsewhere.[1]

In the synthetic dairy production function, capital and labour are combined using a CES function and the capital–labour aggregate is combined with the TSF using a Leontief/fixed proportions function. As the TSF input and output move in fixed proportions, the level of synthetic dairy production is controlled by the availability of the TSF endowment (Morris et al. 2019). For example, if $5 million of the TSF is required to produce $100 million of synthetic dairy products, assigning a TSF endowment of $25 million will result in synthetic dairy production of $500 million (providing that the technology is profitable). In our analysis, we set the TSF endowment to target a desired production quantity, as described in Section 3.

3 | Scenarios and Extensions to the Core Model

We evaluate the impact of large-scale, cost-competitive production of synthetic dairy products in 2030. To do this, we first simulate a baseline scenario for this year that does not include the production of synthetic dairy products. This baseline is used as a reference for comparison with the 'shock' scenarios. This scenario imposes changes in GDP and land use between 2017 (the benchmark for the model) and 2030, as used by Winchester and White (2022).

Other scenarios simulate high-volume, economically viable production of synthetic dairy products in the RoW in 2030. The production of synthetic dairy products is limited to the amount of global dairy production in the baseline. This is done by appropriately assigning the endowment of the TSF for synthetic dairy production, as noted in Section 2.

The impacts of synthetic dairy products will be influenced by how the New Zealand economy can adjust to the shock. Important channels through which the New Zealand economy may respond to synthetic dairy production include changes in sectoral employment and land use. Among other factors, these adjustment mechanisms will be shaped by the extent to which synthetic dairy production is anticipated, how willing workers are to relocate and/or retrain, the capacity of retirements to absorb declining sectoral employment and the degree to which farmers allocate land across uses to maximise profits.

We do not model these adjustment mechanisms in detail, but instead capture their essential features through a parsimonious modelling of unemployment and land use change. Unemployment is considered in the model by assuming that 50% of workers displaced by the production of synthetic dairy products are unable to find employment in other sectors.

Including this feature in the model is based on the geographic structure of New Zealand, whereby geographic communities are typically linked to a small number of job types. When individuals decide to change jobs, it usually involves moving to a different town or city within the country (Coleman and Zheng 2020).

To represent unemployment in the model, the labour endowment is reduced on the basis of workforce displacement, thereby limiting the availability of this factor of production across all sectors. Although setting the proportion of displaced workers that become unemployed at 50% may exceed realistic levels, it enables exploration of the impacts of synthetic dairy production under a relatively extreme unemployment assumption.

Our land use change specification assumes that farmers allocate land between dairy and other uses to maximise land rents. In this formulation, the amount of dairy land converted is determined endogenously in the model, and each hectare (ha) of dairy land can be converted to other uses in constant proportions observed in the baseline projection. Specifically, in New Zealand, each 100 ha of dairy land can be converted to 72.7 ha of beef and sheep land, 3.7 ha for other animal products, 1.4 ha for fruit and vegetables, 5.2 ha for other horticultural crops and 17.0 ha of forest land. This is represented in the model using a land transformation function. In this function, dairy farmers have the option to change their land use to other forms of agriculture. The ability to change to different types of land is controlled by the existing proportions of land use in New Zealand, described above and informed by Winchester and White (2022). This approach avoids unrealistic land conversions and inconsistencies in physical land units across equilibria when land is allocated using a constant elasticity of transformation approach (Taheripour et al. 2020).

Using the modelling framework, we examine 'Rigid' and 'Adaptive' cases. In the Rigid scenario, there is no land use change and there is unemployment. In the Adaptive scenario, there is land use change[2] and full employment.[3] The Rigid scenario approximates short-run impacts, whereas the Adaptive scenario is more suited to capturing long-run impacts.

During the COVID-19 pandemic, New Zealand, like many countries, implemented wage subsidy programmes to reduce the employment and economic impacts of lockdowns and other restrictions. Consequently, our analysis also explores the impacts of labour subsidies for workers in the dairy farming and dairy processing sectors. In these scenarios, ad valorem subsidies are determined endogenously to maintain employment at baseline levels in the targeted sectors.

4 | Results

We estimate the impacts from large-scale production of synthetic dairy in 2030 by comparing results from each scenario to a 2030 baseline that represents business as usual (without synthetic dairy products), as noted in Section 3. Results for the Rigid and Adaptive scenarios are presented in Tables 2 and 3, and Figures 3 and 4.

4.1 | Results for the Rigid Scenario

In the Rigid scenario, New Zealand GDP and welfare decrease by 0.73% and 1.48%, respectively (Table 2), where welfare

TABLE 2 | GDP, welfare and dairy output in New Zealand in 2030, percentage relative to baseline.

Scenario	Rigid	Adaptive
GDP	−0.73	−0.50
Welfare	−1.48	−1.20
Output of dairy farming	−8.90	−29.72
Output of dairy products	−11.60	−35.48

Note: Welfare is defined in the model as the Hicksian-equivalent variation in income (Hicks 1941, 1943).

TABLE 3 | Land use in New Zealand in 2030, Mha.

	Baseline	Adaptive	Change
Dairy farming	2.22	1.61	−0.61
Beef and sheep farming	6.82	7.26	0.44
Other animal products	0.35	0.37	0.02
Vegetables and fruit	0.13	0.14	0.01
Horticulture	0.49	0.52	0.03
Forestry	1.60	1.70	0.10

changes are measured as the Hicksian equivalent variations in consumer income. Output of dairy farming and dairy products decreases by 8.9% and 11.6%, respectively. In this scenario, some dairy land is unused and the return to dairy land falls to zero.

Employment changes by sector in the Rigid scenario are illustrated in Figure 3. For presentation purposes, results for some similar sectors with comparable employment changes are aggregated into composite sectors. The composite sectors are non-agricultural manufacturing, transport, energy extraction and distribution, and services. The compositions of these aggregates are described in the notes to Figure 3.

The largest proportional employment decreases are observed for dairy farming (9.1%) and dairy processing (12.7%). These sectors also experience relatively large employment decreases: 4592 and 3249, respectively.

The largest absolute employment decrease is observed for the (aggregated) services sector. This is because a large share of services production is for domestic consumption, so the decrease in GDP has a relatively large impact on employment in this sector. However, as a large share of the total workforce is employed in these activities, there is only a small proportional change in employment in the services sector.

New Zealand dairy exports decrease by $6.1 billion in the Rigid scenario and $11.8 billion in the Adaptive scenario. Due to the fixed current account closure, the output of other sectors that

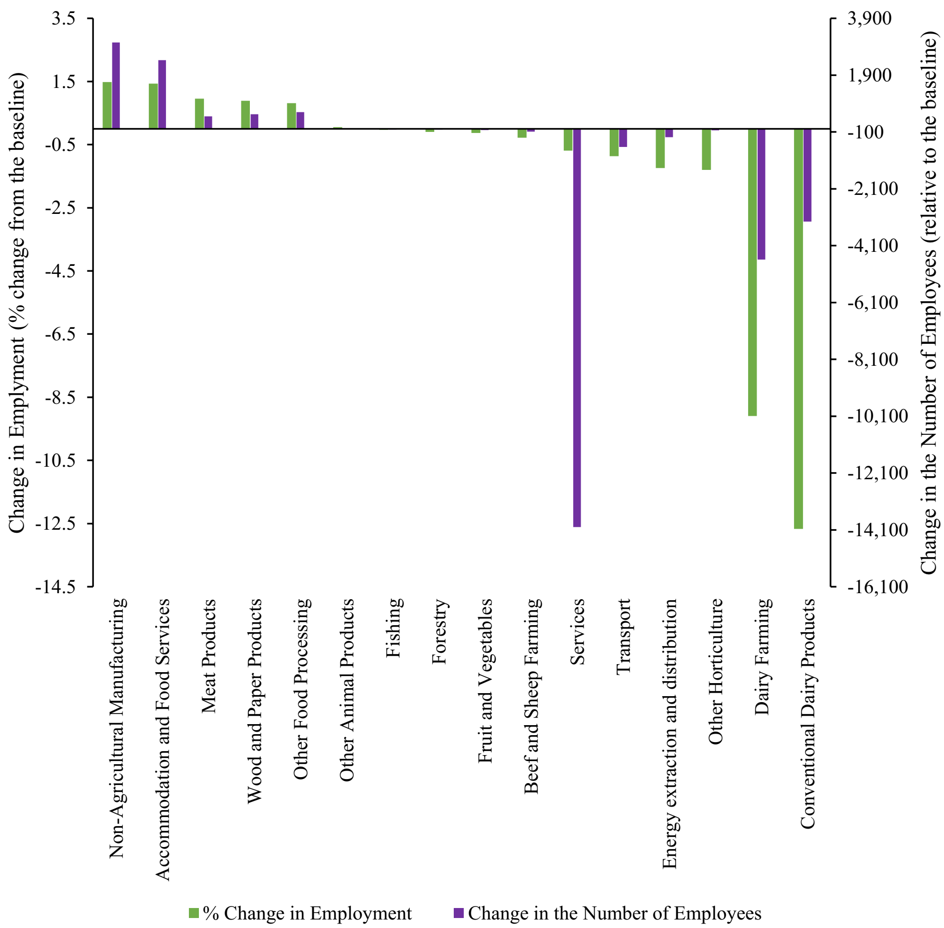

FIGURE 3 | New Zealand employment changes relative to the baseline in the Rigid scenario, per cent (left axis) and number of workers (right axis). Aggregated sectors in the figure represent the following individual sectors. Non-agricultural manufacturing: chemical, rubber and plastic products (crp); cement manufacturing (nmm); non-ferrous metals (nfm); iron and steel (i_s); fabricated metal products (fmp); mining of metal ores (oxt); textiles, clothing and footwear (tcf); motor vehicles and parts (mvh); and other manufacturing (omf). Transport: road transport (rtp), air transport (atp) and water transport (wtp). Energy extraction and distribution: crude oil extraction (cru); refined oil products (oil); coal extraction (col); natural gas extraction and distribution (gas); and electricity, transmission and distribution (ely). Services: construction (cns), business services (bus) and other services (ser).

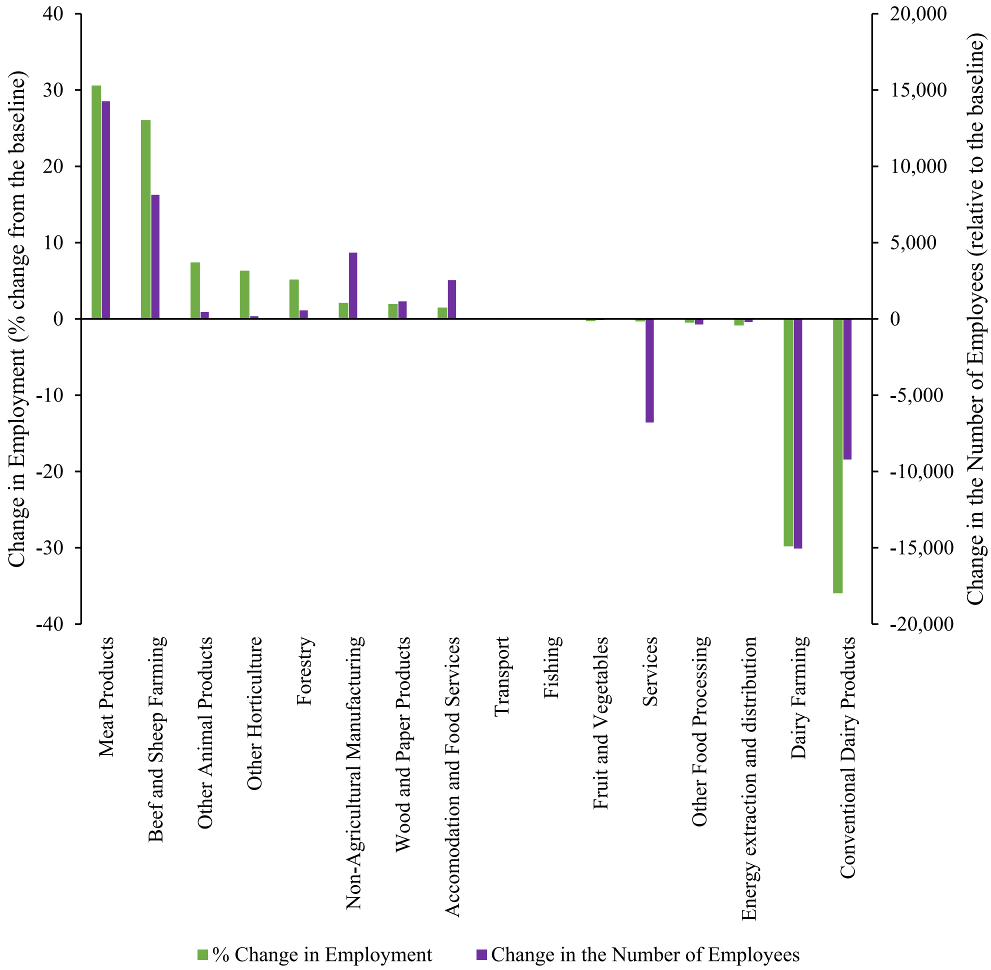

FIGURE 4 | New Zealand employment changes relative to the baseline in the Adaptive scenario, per cent (left axis) and number of workers (right axis). See notes for Figure 3.

generate foreign exchange earnings or substitute for imports increases. As a result, employment increases in non-agricultural manufacturing sectors (3049, 1.5%) and accommodation and food services (2429, 1.4%). There are also employment increases in most non-dairy agro-food sectors—for example, employment in the meat products sector increases by 447 workers (1.0%). However, fixed land use in the Rigid scenario limits output and ultimately employment responses in agro-food sectors.

4.2 | Results for the Adaptive Scenario

In the Adaptive scenario, the impact of synthetic dairy production reduces New Zealand GDP and welfare by 0.5% and 1.2%, respectively (Table 2). The GDP decrease is around two-thirds of that in the Rigid scenario, and the welfare decline is about four-fifths. This indicates that the ability of farmers to change land use and for all displaced workers to find re-employment elsewhere only provides limited relief for the New Zealand economy. A key reason for this is that land use change from dairy farming to other uses in New Zealand is mirrored in the RoW, which decreases global prices for meat and other agricultural products.

Land allocated to different uses in the Baseline and Adaptive scenarios is presented in Table 3. The largest land users are beef and sheep farming (58.7% of baseline land use), dairy farming (19.1%) and forestry (13.8%). In the adaptive scenario, land used for dairy farming decreases by 0.61 million hectares (Mha) or 27.5%. As land is allocated to other uses in proportion to baseline use, most of this land is converted to beef and sheep farming (0.44 Mha), followed by forestry (0.10 Mha).

Employment changes in the adaptive scenario are illustrated in Figure 4. Dairy farming (15,053, 29.8%) and conventional dairy products (9219, 36.0%) again experience the largest employment decreases. These changes are about three times larger than the corresponding changes in the Rigid scenario.

Employment increases are largest for meat products (14,266, 30.6%) and beef and sheep farming (8132, 26.1%). There are also employment increases for all other agro-food sectors—for example, there are 564 (5.2%) more forestry workers than in the baseline.

Employment increases for accommodation and food services (2541, 1.50%) and non-agricultural manufacturing (4347, 2.1%) in the Adaptive scenario are less than those in the Rigid scenario. This is because land use change in the Adaptive scenario drives larger output and employment increases in non-dairy agro-food sectors.

4.3 | Results With Labour Subsidies

Our final set of results examines outcomes when labour subsidies are used in New Zealand to maintain employment in dairy farming and dairy processing at the levels in the 2030 baseline. Labour subsidies are more relevant for the Rigid (short-run) case, but we also report results for the Adaptive (long-run) case to illustrate the impact of ongoing assistance.

As shown in Table 4, in the Rigid case, labour subsidies of 36.4% and 12.2% are needed to maintain constant employment in the dairy farming and dairy products sectors, respectively. The total value of these subsidies is $1.6 billion per year. For comparison, New Zealand spent $19.4 billion on COVID-19 wage subsidy schemes between March 2020 and July 2022 (Ministry for Social Development 2022). Dividing the total subsidy cost by the 7841 workers that would otherwise have been displaced from the two dairy sectors, the subsidy payment per job saved is $200,000.

A key reason why the subsidy payment per job saved is high is that the wage subsidy must be offered to all workers in targeted industries, not just those workers that would otherwise lose their jobs. Total employment across the two dairy sectors is 120,916, so the average subsidy per employee is $12,970.

Subsidy rates in the Adaptive case are higher than in the Rigid one, as more workers would be displaced in the Adaptive scenario without the subsidies. The total value of subsidy payments in the Adaptive scenario ($3.4 billion) is more than double that in the Rigid case. However, the cost per job saved is lower in the Adaptive case compared to the Rigid scenario, as 24,273 rather than 7841 employees would be displaced without the subsidy.

By reducing dairy production costs, the subsidy also reduces incentives for land use change. In the Adaptive case, only 0.12 Mha of dairy land is converted to other uses when there are labour subsidies (compared with 0.61 without them).

In both cases, labour subsidies required to maintain employment in dairy sectors are much higher for dairy farming than dairy products. This is because the dairy farming subsidy—by lowering the cost of raw milk—is an indirect subsidy on dairy products. Labour subsidies also curtail employment increases in expanding sectors in both cases, although different sectors expand in each case.

5 | Conclusions

Given the pressures on agriculture to meet rising food demands while reducing their carbon footprint, synthetic dairy products have become an increasingly viable alternative to the traditional products currently on the market (Stephens and Ellis 2020). If synthetic dairy products offer a cheap substitute for traditional dairy products, they could take market share away from those traditional products. This could particularly impact jurisdictions such as New Zealand where dairy makes up a significant proportion of total economic output (Sense Partners 2023). In this paper, we developed an economy-wide model to examine the economic and employment impacts on New Zealand from large-scale production of synthetic dairy products in the RoW in 2030.

The analysis considered two core scenarios: a Rigid (short-run) scenario with fixed land use and 50% of displaced workers becoming unemployed, and an Adaptive (long-run) scenario with land use change and full employment.

In the Rigid scenario, the shock to global dairy production decreased New Zealand welfare by 1.5% relative to the 2030 baseline. Flexibility mechanisms in the Adaptive scenario—where the welfare decrease was 1.2%—reduced the economy-wide impact by a relatively small amount. A key reason for this result is that global land use change in this scenario decreases the global price of meat products.

In both scenarios, sectoral employment decreases were largest in dairy farming and dairy products. In the Rigid scenario, the

TABLE 4 | Labour subsidies from maintaining baseline employment in dairy sectors.

	Rigid	Adaptive
Ad valorem subsidy (percentage)		
Dairy farming	36.4	82.6
Dairy products	12.2	20.3
Average	27.2	58.9
Annual subsidy payments (2020 NZD, million)		
Dairy farming	1340.7	3040.8
Dairy products	227.6	379.2
Total	1568.3	3420.0
Annual value of subsidy per job saved (2020 NZD)		
Dairy farming	291,938	202,001
Dairy products	70,057	41,131
Average	200,008	140,899

largest employment increases were in the non-food manufacturing sectors, whereas employment gains were largest in beef and sheep farming and meat products in the Adaptive scenario. In both scenarios, there were relatively large employment gains in accommodation and food services.

The analysis also considered labour subsidies to maintain baseline employment levels in dairy farming and dairy products. Labour subsidies required in the Adaptive scenario amounted to $200,000 per dairy farming-related job saved.

Overall, our results show that large-scale production of synthetic dairy products—a technology shock that decreases the price of New Zealand's largest export commodity—will have a significant negative impact on this economy. Using dairy land for alternative uses will have a muted cushioning effect as global land use changes decrease the price of other agricultural commodities, and government support to maintain current dairy employment is expensive. These findings indicate that policy responses should focus on preparing landowners and workers to adapt to a world with synthetic dairy production (e.g., retraining workers and ensuring that the next generation of workers has skills relevant for expanding sectors).

Our results are comparable with those described in Manhire et al. (2024). Even though they represent the production of alternative proteins in both New Zealand and the RoW (rather than just the RoW), they also find that the increased production of synthetic dairy is likely to reduce gross output and employment, as well as greenhouse gas emissions and nitrogen and phosphorus loss in New Zealand. Their report further estimates that the production of other alternative proteins (such as laboratory-grown meat and plant-based proteins) improves both economic and environmental outcomes in New Zealand. Our study adds to this research by expanding the representation of sectors in New Zealand and exploring land use change, unemployment and government labour subsidy scenarios. Future research could expand the economy-wide model employed here to analyse the production of all alternative proteins in the RoW and compare those results with Manhire et al. (2024).

An important avenue for future research is to explore a land use change specification that takes into account the increased value of forest land (both production and permanent forestry) from the inclusion of forestry in the New Zealand emissions trading scheme (White and Winchester 2023). Future research could explore the expected land use incentives created by the New Zealand emissions trading scheme and how synthetic dairy could result in more dairy land shifting to forestry than other agricultural products.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the Global Trade Analysis Project (GTAP). Restrictions apply to the availability of these data, which were used under licence for this study. Data are available at https://www.gtap.agecon.purdue.edu/ with the permission of the GTAP. To gain access to the GTAP data, users need to purchase a GTAP licence.

Endnotes

[1] In practice, synthetic dairy products could be produced using intermediate inputs, in addition to capital and labour. As synthetic dairy production, when it operates, is a small share of global production and is not produced in New Zealand, alternative input requirements would have little impact on our results.

[2] Land use change using a land transformation function is only available in the Adaptive scenario. This function does not operate in the Rigid scenario, and any reduction in the productivity of dairy land is captured by changes in rent.

[3] Under the Adaptive scenario, it is assumed that all employees displaced by the production of synthetic dairy products are able to find work in other sectors. CGE models typically assume full employment both before and after the implementation of a production shock.

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