Spatial and Temporal Responses to an Emissions Trading System Covering Agriculture and Forestry: Simulation Results from New Zealand

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Abstract

We perform simulations using the integrated Land Use in Rural New Zealand (LURNZ) model to analyse the effect of various New Zealand emissions trading scheme (ETS) scenarios on land-use, emissions, and output in a temporally and spatially explicit manner. We compare the impact of afforestation to the impact of other land-use change on net greenhouse gas emissions, and evaluate the importance of the forestry component of the ETS relative to the agricultural component. We also examine the effect of land-use change on the time profile of net emissions from the forestry sector. Our projections for the mid-2020s suggest that under a comprehensive ETS, sequestration associated with new planting could be significant; it may approach 20 percent of national inventory agricultural emissions in 2008. Most of this is driven by the reward for forestry rather than a liability for agricultural emissions. Finally, we present projections of future agricultural output under various policy scenarios.

JEL codes

Q15, Q18, Q23, Q54

Keywords

land use; land-use change; LURNZ; greenhouse-gas emissions; afforestation; forestry removals; New Zealand Emissions Trading Scheme; integrated modelling; agricultural production

Contents

Figures and Tables

1. Introduction

We perform simulations to analyse the effect of various New Zealand emissions trading scheme (ETS) scenarios on land-use, emissions, and output until 2030 in a temporally and spatially explicit manner. We use the integrated model called Land Use in Rural New Zealand (LURNZ), which is being developed at Motu Economic and Public Policy Research. By modelling New Zealand's major rural land uses we compare the impact of afforestation to the impact of other land-use change on net greenhouse gas emissions. We also examine the effect of land-use change on the time profile of net emissions from the forestry sector. In the mid-2020s, forestry emissions in New Zealand are expected to rise as forests planted in the 1990s reach harvestable age. Our projections for this period imply that under a comprehensive ETS, sequestration associated with new planting could be significant; it may approach 20 percent of national inventory agricultural emissions in 2008. Finally, we present projections of agricultural output in 2030 under various policy scenarios. In our simulations we ignore any policy-induced on-farm mitigation or changes in production per hectare because the empirical basis for this modelling is still weak (Anastasiadis and Kerr, 2012).

We analyse three policy scenarios. First, we consider a baseline scenario where there is no emissions trading scheme. Second, we analyse a policy environment very similar to the current New Zealand ETS: forestry earns carbon credits (New Zealand Units) for sequestration, and agriculture enters the ETS in 2015; however, in our scenario there is no free allocation to agriculture. Finally, we analyse a scenario without agriculture in the ETS; this allows us to evaluate the importance of the forestry component of the ETS relative to the agricultural component.

Throughout the 2000s the amount of land used for dairy farming increased, while the amount of land used for sheep-beef farming decreased. In our baseline projections these trends continue, albeit at a slowing rate. In all ETS scenarios the amount of land used for sheep-beef farming decreases further, while there is a substantial increase in the amount of land used for plantation forestry; however, significant heterogeneity exists in the geographic distribution of these changes.

Under both ETS scenarios New Zealand's net greenhouse gas emissions are lower than in the baseline because of land-use change. The reduction in greenhouse gas emissions can be attributed to two main sources. First more marginal sheep-beef land is abandoned under an ETS. Second, there is more afforestation when forest sequestration earns carbon credits.

We analyse the time profile of net forestry emissions relative to baseline. Accounting for land-use change, we project net emissions in the mid-2020s (from the pastoral and forestry sectors) under the forestry-only ETS and full ETS scenarios to be lower by 6.3 Gg and 7.1 Gg carbon dioxide equivalent, respectively. For comparison, these correspond to 18.2 percent and 20.5 percent of New Zealand's 2008 gross agricultural emissions. If rotation lengths are extended in response to the carbon price as suggested by Manley and Maclaren (2010) and Turner et al. (2008), then our projections underestimate the effect of the ETS on forestry removals throughout the projection period.

The rest of the paper is structured as follows. In section 2 we briefly describe the simulation model LURNZ. In section 3 we compare simulated land use outcomes across policy scenarios, including a baseline scenario. In section 4 we decompose simulated agricultural greenhouse gas impacts by land use. In section 5 we look at the time profile of forestry greenhouse gas removals. Section 6 reports results on production under the different scenarios. We conclude in section 7. The appendix contains details on how LURNZ models national level land-use change. Details for other components of the LURNZ model are in Kerr and Olssen (2012), Tímár (2011), Tímár (2012) and Zhang et al (2011) .

2. Model Description

LURNZ simulates land use, rural production, and greenhouse gases for all private rural land in New Zealand annually at a 25 hectare resolution; the current model builds on earlier foundational work in Hendy et al. (2007). The model takes an emissions trading environment as its input; this is specified as a real carbon price, a list of rural sectors included in the trading scheme, and free allocation rules (although we do not allow for free allocation in any of the scenarios in this paper).

LURNZ produces national level land-use projections for each of New Zealand's major rural land uses: dairy farming, sheep-beef farming, plantation forestry, and unproductive scrub. These projections are generated using coefficients from a dynamic econometric model of land use (Kerr and Olssen, 2012) that generalises the models in Pfaff et al. (2008) and Irwin and Bockstael (2002) to multiple land uses.[1] We model the effect of emissions trading through adjustments to output prices received in each rural sector. For plantation forestry, we model the carbon return as the net present value of carbon credits from the first 10 years of forest growth, and calculate it using the unweighted regional average carbon stock from the New Zealand

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[1] We do not face the same challenges for estimating the response of land-use to economic returns as United States-based studies, e.g. Lubowski et al. (2008), because commodity prices in New Zealand are credibly exogenous.

Ministry of Agriculture and Forestry (MAF) look-up tables,[2] a constant carbon price, and a real discount rate of 8 percent. Although many parameters that are difficult to model enter into land managers' actual valuations of carbon return, there is an important way in which using this valuation is conservative: the carbon stock at 10 years coincides with the minimum carbon stock held on land that is always replanted; thus there is no liability risk from selling the first 10 years of carbon credits. Additional details of the national level land-use modelling are in the appendix.

The national level changes in land use are allocated spatially across New Zealand based on coefficients from a multinomial choice model relating land use decisions to geophysical characteristics, location and land tenure (Tímár, 2011). The overall structure of the choice model follows, with some modifications, other studies in the discrete choice land use literature, for example Chomitz and Gray (1996) and Nelson et al. (2001). LURNZ then uses the predicted choice probabilities from this model in an allocation algorithm that is consistent with the intuition that if a land use is expanding, cells most suitable for the use will be converted first. The algorithm also minimises the amount of land-use shuffling across cells; a detailed description of the allocation methodology can be found in Zhang et al. (2011).

Using the spatial projections of land use, LURNZ then calculates the associated spatial patterns of production and emissions. This is described in Tímár (2012). Projected production changes involve the use of estimated trends in productivity; dairy production varies by region, and sheep-beef production varies by farm class and the carrying capacity of the land. LURNZ does not model on-farm mitigation, so that all changes in emissions are ultimately the result of land-use change; however, the timing and location of land-use change matter.

Our modelling is similar to Stavins (1999) in that it is based on an econometric approach using observed land-use choices of landowners. An alternative method to generate sequestration responses is to use an optimisation model such as Sohngen and Sedjo (2006). In the New Zealand context, few studies have addressed spatial land use and consequent net emissions responses to climate change policy. An optimisation model, The New Zealand Forest and Agriculture Regional Model (NZ-FARM) (Daigneault et al., 2012), has a catchment-level focus (and additional capabilities to analyse nutrient leaching); it does not model national outcomes. Another important difference is that our land-use responses are estimated via an econometric revealed preference approach. It can therefore implicitly account for factors that affect land use in New Zealand but are difficult or impossible to capture in an optimisation framework.

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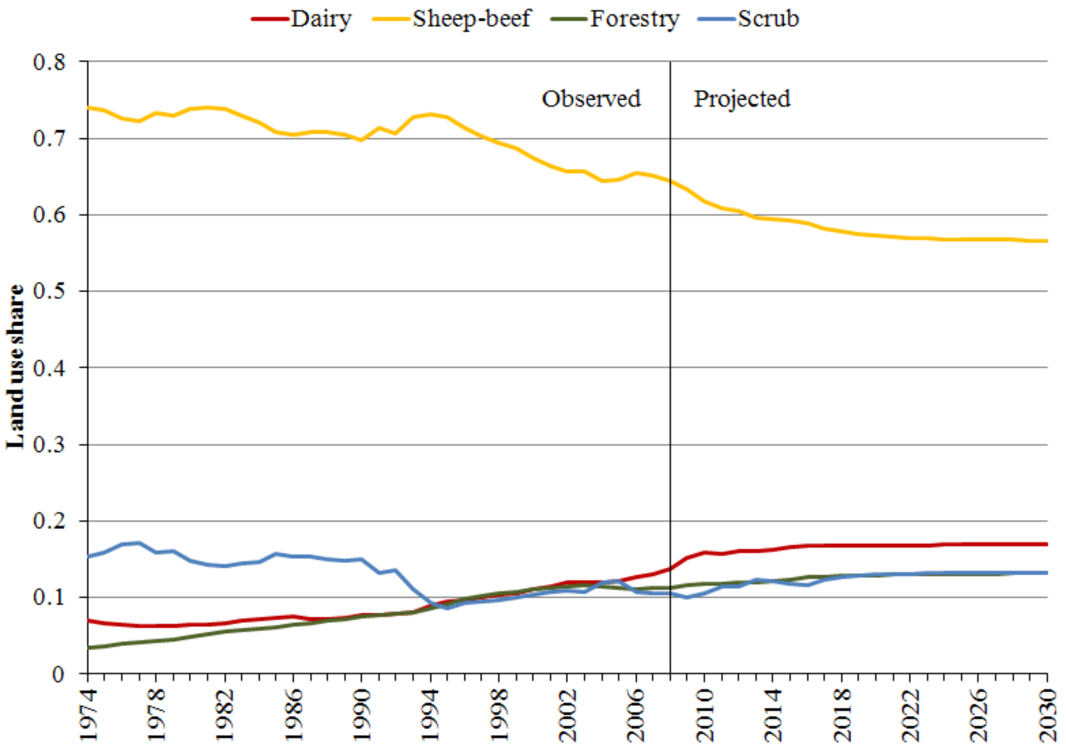
[2] http://www.maf.govt.nz/portals/0/documents/forestry/forestry-ets/2011-ETS-look-up-tables-guide.pdf

3. Land Use Results

3.1. National Level Land-use Change

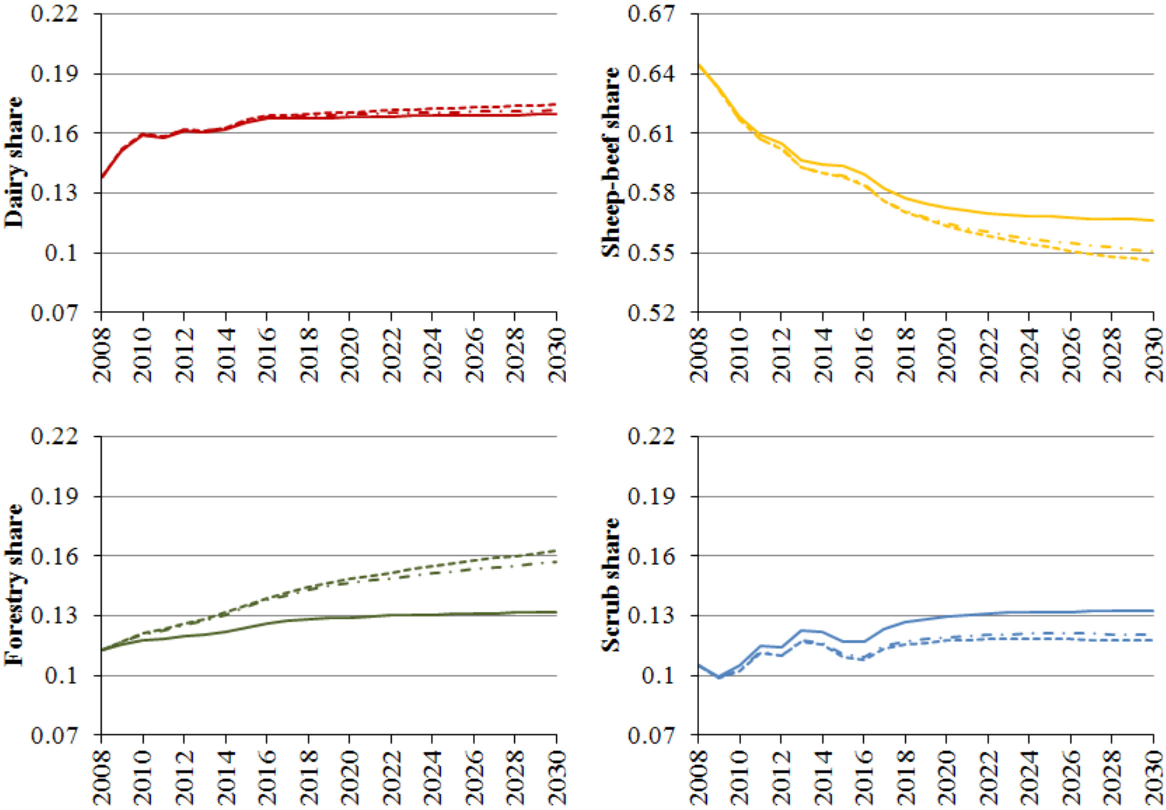
Figure 1 presents historical land use as well as baseline projections. The sheep-beef sector's land share fell by 9 percentage points in fourteen years, from its peak of 73 percent of private rural land in 1994 to 64 percent in 2008. Even without any policy changes we project the sheep-beef share to fall by a further 7 percentage points so that it will account for 57 percent of private rural land by 2030. The dairy land share has steadily increased in recent history. We project that this increase will continue, from 13.8 percent to 16.9 percent of rural land by 2030, under the baseline scenario. Forestry's land share will rise, and we also project an increase in scrub. We interpret the increasing scrub share as abandoned sheep-beef land. As noted in Kerr and Olssen (2012), our dynamic results for gradual land-use change are similar to those of Stavins and Jaffe (1990) and consistent with Hornbeck (2009).

Figure 1: Baseline national-level land-share projections, 2009–2030



Notes. Details on the projections are in the appendix.

Figure 2: National land-share projections by policy scenario, 2009–2030



Notes. Solid lines give baseline projections. Short-dash-dot lines give an ETS without agriculture. Dashed lines give the full ETS. Note that the y-axis does not extend to zero; however, the vertical spread of each y-axis is the same so that comparisons can be made across graphs.

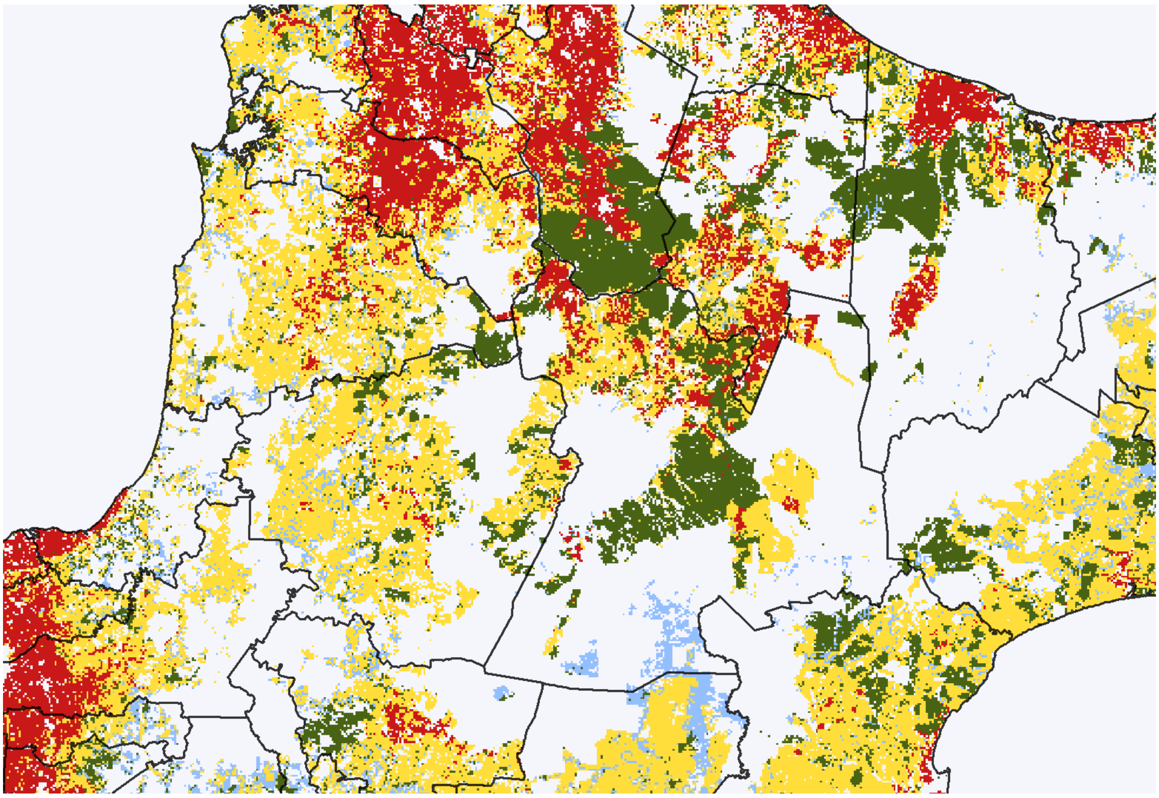
Figure 2 focuses on the projected period and shows land-use shares by sector in each of the three scenarios. As expected, the ETS policies increase the amount of land in forestry and decrease the amount of land used for sheep-beef farming (mainly through conversions of marginal sheep-beef farms to forestry). Under both ETS scenarios the total amount of land in scrub falls (as the decomposition in the next subsection makes it clear, this is despite our projection that some marginal sheep-beef land is abandoned to scrub). The dairy share increases marginally in both ETS scenarios. The increase in dairy between the scenario with and without agriculture is plausible: when agriculture is included it is possible that some high quality sheep-beef farms convert to dairy because, in percentage terms, the impact of the ETS on sheep-beef profits is larger than its impact on dairy profits (Kerr and Zhang, 2009).

There are two other important inferences to draw from Figure 2. Firstly, in every sector, the impact of including agriculture in the ETS is to magnify the effect that would have occurred without agriculture (while the direction of the effects remains the same). However, having an ETS that rewards forest owners (and scrub owners) for sequestration has far larger impacts on land use than incrementally extending the ETS to also include agriculture. Secondly, in all sectors except forestry, the difference in land use across scenarios is smaller than the difference in land use across time within the baseline. Thus, while the LURNZ projections imply that the ETS matters for land-use decisions, its effect is relatively small in the context of wider changes in the economic environment.[3]

3.2. Regional Land-use Change

Given the land-share projections presented in the previous section, the LURNZ model allocates land to different uses spatially for each year of the simulation. Figure 3 shows central North Island land use in the baseline scenario in 2030. This map illustrates the spatial resolution at which LURNZ makes projections.

Figure 3: Baseline land use in 2030



Notes. The figure shows baseline land use projections for central North Island in 2030. Dairy land is red. Sheep-beef land is yellow. Forestry land is green. Scrub land is blue. White land is exogenous in LURNZ.

Making use of the spatial mapping capability of LURNZ, Table 1 breaks down baseline land-use change in hectares over time by regional council (note that the amount of private rural land varies from council to council). For the Bay of Plenty Region, for example, we project that

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[3] Our projected economic environment is taken from the Ministry of Agriculture and Forestry's Situational Outlook for New Zealand Agriculture and Forestry, as is discussed in the appendix.

12,225 hectares of sheep-beef land will convert to forestry and 5,250 hectares of sheep-beef land will be abandoned to scrub by 2030. In general, most land-use change is projected to take place on sheep-beef land. Most of the increase in baseline dairy shown in Figure 1 comes from sheep-beef; large areas of marginal sheep-beef land also convert to forestry and scrub. Additional new forest planting takes place on scrub land.

Table 2 summarises land-use results under the full ETS and the baseline in 2030 by regional council; the table shows land use *differences*, and not *transitions*.[4] The net changes are the same as in Figure 2. Land-use responses are spatially heterogeneous and depend on the geophysical and other characteristics of the land in each region. We project the ETS to have an especially large effect on land use in Northland; 72,425 ha of land that is scrub in the baseline is forestry in the full ETS and 16,075 ha of land that is sheep-beef in the baseline is scrub in the full ETS in this region. (Northland is projected to experience large land-use changes over time under the baseline scenario as well, as shown in Table 1.)

Table 3 shows land-use differences between the two ETS scenarios (with and without agriculture). The spatial distribution of land uses is similar across the two policy scenarios. In general, forest area is larger in the full ETS than in the scenario without agriculture, due to forestry's increased relative attractiveness under the full ETS.

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[4] This is because a cell could be forest in 2030 under the baseline and scrub in 2030 under the full ETS, but it need not have ever converted from forest to scrub; there could have been a sheep-beef to forest conversion in the former case and a sheep-beef to scrub conversion in the latter.

Table 1: Baseline land-use change between 2008 and 2030 by regional council

Baseline 2030	**Dairy**				**Sheep-beef**				**Forestry**				**Scrub**			
2008 land-use	Dairy	Sheep-beef	Forestry	Scrub	Dairy	Sheep-beef	Forestry	Scrub	Dairy	Sheep-beef	Forestry	Scrub	Dairy	Sheep-beef	Forestry	Scrub
Northland	152,430	28,800	250	1,975	0	161,430	0	0	0	4,925	140,180	2,175	0	210,450	0	88,000
Auckland	56,350	25,425	125	1,500	0	95,275	0	650	0	2,950	37,550	1,375	0	31,325	0	29,675
Waikato	481,950	33,975	150	4,650	8,775	647,980	0	600	825	17,700	229,600	21,850	0	16,025	0	78,275
Bay of Plenty	92,000	5,725	25	275	1,900	127,780	0	50	175	12,225	139,750	10,200	0	5,250	0	17,225
Gisborne	2,100	6,575	25	0	0	264,630	0	0	0	21,625	137,730	10,350	0	64,775	0	85,050
Hawkes Bay	19,275	9,750	0	6,850	3,225	656,600	0	4,350	25	10,275	109,350	12,175	0	9,800	0	64,500
Taranaki	197,200	4,875	25	0	200	148,280	0	3,550	0	75	24,150	16,675	0	850	0	42,125
Manawatu	133,680	57,375	150	1,775	1,425	964,280	0	175	25	31,825	112,050	12,125	100	72,125	0	81,875
Wellington	33,300	28,275	0	1,250	0	278,280	0	600	0	6,475	48,125	4,025	0	17,500	0	97,250
West Coast	76,775	0	25	0	1,250	63,375	0	750	125	1,250	29,450	7,475	25	225	0	9,075
Canterbury	201,980	76,800	425	2,050	1,525	1,261,000	0	14,100	0	675	93,450	4,375	0	21,550	0	197,480
Otago	79,550	26,775	75	7,550	700	1,211,300	0	3,750	25	7,400	111,600	1,175	75	61,250	0	60,900
Southland	153,230	59,150	100	1,175	0	600,550	0	4,850	0	25	66,825	1,950	0	0	0	29,425
Tasman	24,425	7,200	0	675	2,900	71,275	0	5,700	225	1,050	70,800	3,175	0	475	0	30,450
Nelson	325	175	0	0	50	3,550	0	225	0	25	7,050	125	0	25	0	3,375
Marlborough	10,925	5,775	0	225	1,875	206,150	0	800	0	0	55,550	3,100	0	0	0	77,900
New Zealand	1,715,495	376,650	1,375	29,950	23,825	6,761,735	0	40,150	1,425	118,500	1,413,210	112,325	200	511,625	0	992,580

Notes. Each cell shows the difference in land use (in hectares) between 2008 and 2030 in the baseline. The determination of national-level land-use is described in the appendix. The algorithm that spatially allocates uses is described in [7]. The Manawatu row refers to the Manawatu-Wanganui Regional Council.

Table 2: 2030 land-use differences between the baseline and the full ETS scenarios by regional council

Full ETS 2030	**Dairy**				**Sheep-beef**				**Forestry**				**Scrub**			
Baseline 2030	Dairy	Sheep-beef	Forestry	Scrub	Dairy	Sheep-beef	Forestry	Scrub	Dairy	Sheep-beef	Forestry	Scrub	Dairy	Sheep-beef	Forestry	Scrub
Northland	183,450	1,650	25	1,525	0	142,430	0	0	0	1,275	147,250	72,425	0	16,075	0	224,500
Auckland	83,400	1,750	0	0	0	80,175	0	0	0	10,725	41,875	28,225	0	3,275	0	32,775
Waikato	520,730	6,950	125	50	0	633,700	0	0	0	11,850	269,850	28,300	0	4,850	0	65,950
Bay of Plenty	98,025	1,825	200	0	0	122,500	0	0	0	3,375	162,150	3,525	0	2,025	0	18,950
Gisborne	8,700	800	0	0	0	237,750	0	0	0	10,700	169,700	29,625	0	15,375	0	120,200
Hawkes Bay	35,875	1,950	0	50	0	653,550	0	0	0	3,925	131,830	12,775	0	4,750	0	61,475
Taranaki	202,100	625	0	0	0	147,900	0	0	0	1,725	40,900	15,075	0	1,775	0	27,900
Manawatu	192,980	5,050	75	0	0	917,680	0	0	0	28,725	155,950	42,225	0	14,425	0	111,880
Wellington	62,825	2,950	0	0	0	259,930	0	0	0	6,825	58,625	20,475	0	9,175	0	94,275
West Coast	76,800	475	25	25	0	63,450	0	0	0	1,300	38,275	1,875	0	150	0	7,425
Canterbury	281,250	11,875	75	175	0	1,251,300	0	0	0	1,050	98,425	5,375	0	12,425	0	213,480
Otago	113,950	7,825	0	100	0	1,187,200	0	0	0	8,575	120,200	7,075	0	12,175	0	115,050
Southland	213,650	10,650	0	300	0	592,380	0	0	0	600	68,800	150	0	1,775	0	28,975
Tasman	32,300	1,425	0	125	0	74,400	0	0	0	2,225	75,250	6,925	0	1,825	0	23,875
Nelson	500	25	0	0	0	3,550	0	0	0	75	7,200	800	0	175	0	2,600
Marlborough	16,925	675	0	0	0	206,500	0	0	0	850	58,650	1,750	0	800	0	76,150
New Zealand	2,123,460	56,500	525	2,350	0	6,574,395	0	0	0	93,800	1,644,930	276,600	0	101,050	0	1,225,460

Notes. Each cell shows the difference in land use (in hectares) between two scenarios: the baseline and the full ETS. The determination of national-level land-use is described in the appendix. The algorithm that spatially allocates uses is described in [7]. The Manawatu row refers to the Manawatu-Wanganui Regional Council.

Table 3: 2030 land-use differences between the full ETS and an ETS without agriculture scenarios by regional council

Full ETS 2030	**Dairy**				**Sheep-beef**				**Forestry**				**Scrub**			
ETS no ag 2030	Dairy	Sheep-beef	Forestry	Scrub	Dairy	Sheep-beef	Forestry	Scrub	Dairy	Sheep-beef	Forestry	Scrub	Dairy	Sheep-beef	Forestry	Scrub
Northland	184,580	775	25	1,275	0	142,430	0	0	0	0	198,430	22,525	0	3,050	0	237,530
Auckland	84,000	1,150	0	0	0	80,175	0	0	0	1,350	75,975	3,500	0	475	0	35,575
Waikato	524,900	2,850	75	25	0	633,700	0	0	0	2,650	302,830	4,525	0	1,250	0	69,550
Bay of Plenty	99,125	800	125	0	0	122,500	0	0	0	625	168,050	375	0	500	0	20,475
Gisborne	9,000	500	0	0	0	237,750	0	0	0	1,850	203,950	4,225	0	2,150	0	133,430
Hawkes Bay	36,825	1,000	0	50	0	653,530	0	25	0	500	146,400	1,625	0	450	0	65,775
Taranaki	202,330	400	0	0	0	147,900	0	0	0	150	55,900	1,650	0	100	0	29,575
Manawatu	195,000	3,050	50	0	0	917,680	0	0	0	4,650	216,750	5,500	0	2,250	0	124,050
Wellington	63,950	1,825	0	0	0	259,930	0	0	0	1,425	81,050	3,450	0	1,550	0	101,900
West Coast	77,150	150	25	0	0	63,450	0	0	0	475	40,625	350	0	25	0	7,550
Canterbury	285,630	7,675	25	50	0	1,251,200	0	50	0	275	103,650	925	0	1,300	0	224,600
Otago	117,030	4,825	0	25	0	1,187,200	0	25	0	1,425	133,280	1,150	0	1,750	0	125,480
Southland	218,100	6,275	0	225	0	592,380	0	0	0	225	69,300	25	0	75	0	30,675
Tasman	33,150	675	0	25	0	74,400	0	0	0	625	82,500	1,275	0	25	0	25,675
Nelson	525	0	0	0	0	3,550	0	0	0	25	7,900	150	0	0	0	2,775
Marlborough	17,250	350	0	0	0	206,500	0	0	0	275	60,875	100	0	175	0	76,775
New Zealand	2,148,545	32,300	325	1,675	0	6,574,275	0	100	0	16,525	1,947,465	51,350	0	15,125	0	1,311,390

Notes. Each cell shows the difference in land use (in hectares) between two scenarios: the full ETS and the ETS without agriculture. The determination of national-level land-use is described in the appendix. The algorithm that spatially allocates uses is described in [7]. The Manawatu row refers to the Manawatu-Wanganui Regional Council.

4. Agricultural Emissions

Projected 2030 agricultural emissions are about 0.25 Gg lower under the full ETS than they are under the baseline. Table 4 decomposes this reduction by land use. Land that is sheep-beef in the baseline but forestry or scrub in the full ETS scenario achieves a reduction in agricultural emissions under the policy. At the national level the policy slightly increases dairy land share; the land on which conversions to dairy take place has higher emissions under the policy. Overall the reduction in agricultural emissions corresponds to less than 1 percent of the 2008 inventory of agricultural emissions.

Agricultural emissions in the two ETS scenarios are very similar because the increase in emissions from additional conversions to dairy under the full ETS approximately balances out the reduction achieved by additional conversions to forestry and scrub. That is, most of the reduction in sheep-beef emissions in Table 4 is achieved by rewarding forestry and scrub.

Table 4: Differences in agricultural emissions (Gg CO_2-equivalent) decomposed by 2030 land use

	Baseline land use			
Full ETS land use	**Dairy**	**Sheep-beef**	**Forest**	**Scrub**
Dairy	0	0.232	0.004[1]	0.016[1]
Sheep-beef	0	0	0	0
Forest	0	-0.240	0	0
Scrub	0	-0.263	0	0
Net	0	-0.271	0.004	0.016

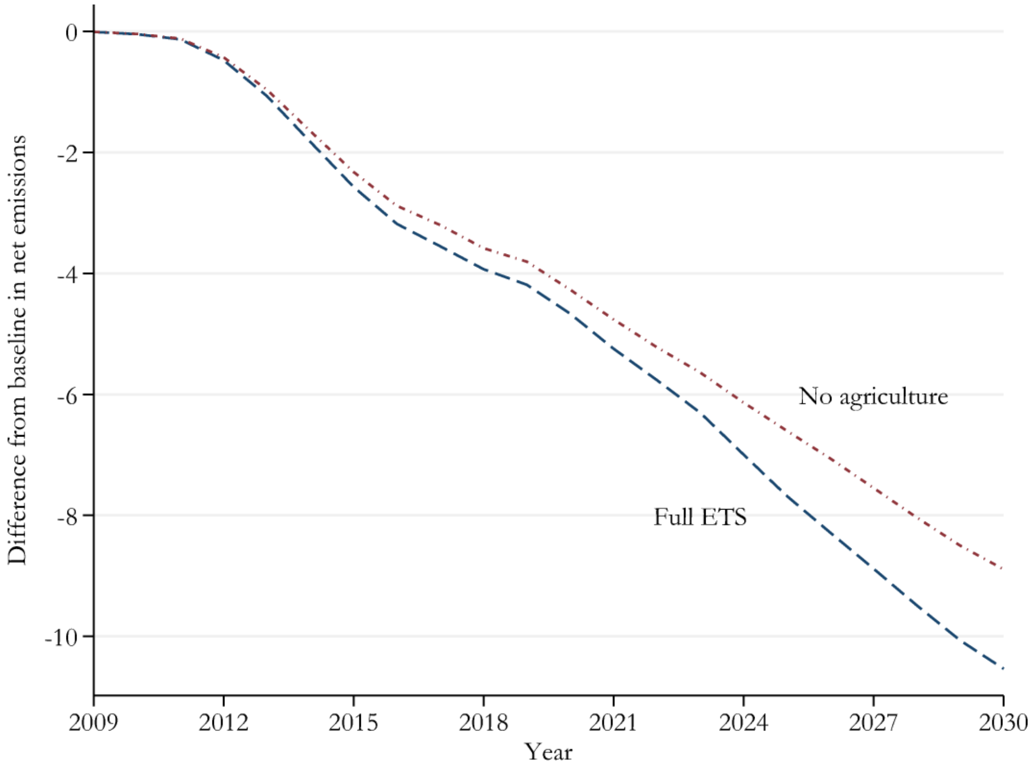
[1] These values represent a modelling anomaly and do not have a meaningful interpretation

Notes. Differences in emissions between scenarios are all due to land-use change; there is no on-farm mitigation. Details about emissions calculations can be found in [6].

5. The Time Path of Policy-Induced Net Forestry Emissions

As forests grow, they sequester carbon. In this section we present projections on the difference in net removals from private plantation forests in LURNZ between the baseline and each policy scenario, as illustrated by Figure 4. The difference in removals across scenarios is driven by the quantity, timing, and location of afforestation since 2008. This is because in 2008 the quantity, location, and age distribution of forests are the same across scenarios. Consequently, removals and emissions from New Zealand's legacy of afforestation are the same across scenarios, except for new planting. In 2024 (at the expected peak of emissions from forestry) LURNZ projects that private forests sequester 7 megatonnes more carbon in the full ETS than in the baseline, and slightly over 6 megatonnes more carbon in the ETS without agriculture than in the baseline. These correspond to 17.6 percent and 20 percent, respectively, of New Zealand's 2008 gross agricultural emissions.[5]

Figure 4: Annual differences from baseline in the net flow of emissions from forestry (Gg CO_2)



Notes. All pre-1990 and post-1989 forest on private land is included. By the early 2040s emissions are higher than the baseline, because new forests planted in the policy scenarios are harvested.

6. Production

LURNZ simulates land use at a fine spatial resolution, allowing us to examine rural production at a regional level. We are therefore able to look at the differential impacts by region of ETS policies on rural production.[6] Because rural production affects local labour market opportunities and regional incomes, this is important in determining the regional welfare effects of the ETS.

Figure 5 shows projected milk solids production by regional council in 2030 under each policy scenario. We also present milk solids production by regional council in 2008 to serve as a reference point. Regional milk solids production in 2030 depends on the amount of dairy land in

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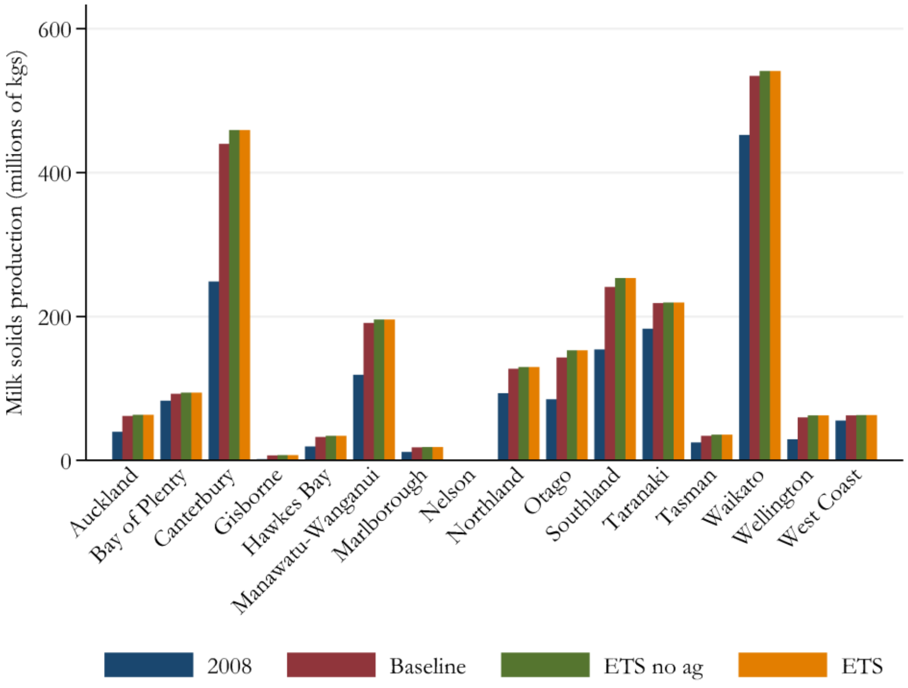
[5] By some accounts, climate change could have a similar proportional impact on pasture growth and forest growth in New Zealand (Kaye-Blake et al., 2009). Therefore, the extent to which future sequestration by forestry is able to offset future emissions from agriculture may not change much even if carbon fertilisation is taken into account.

[6] We are not accounting for potential climate change-induced increases in New Zealand's pasture production (Kaye-Blake et al., 2009; Baisden et al., 2010). Such an increase would affect both our baseline and policy scenarios and can be considered a second order effect.

the region, as well as on estimated increases in dairy productivity between 2008 and 2030; for details on productivity estimates in LURNZ see Tímár (2012). Canterbury, Manawatu-Wanganui, Southland, and Taranaki Regional Councils all increase milk solids production substantially within the baseline. However, it is clear from the graphs that milk solids production does not change much across policy scenarios, because dairy land use does not respond strongly to the ETS.

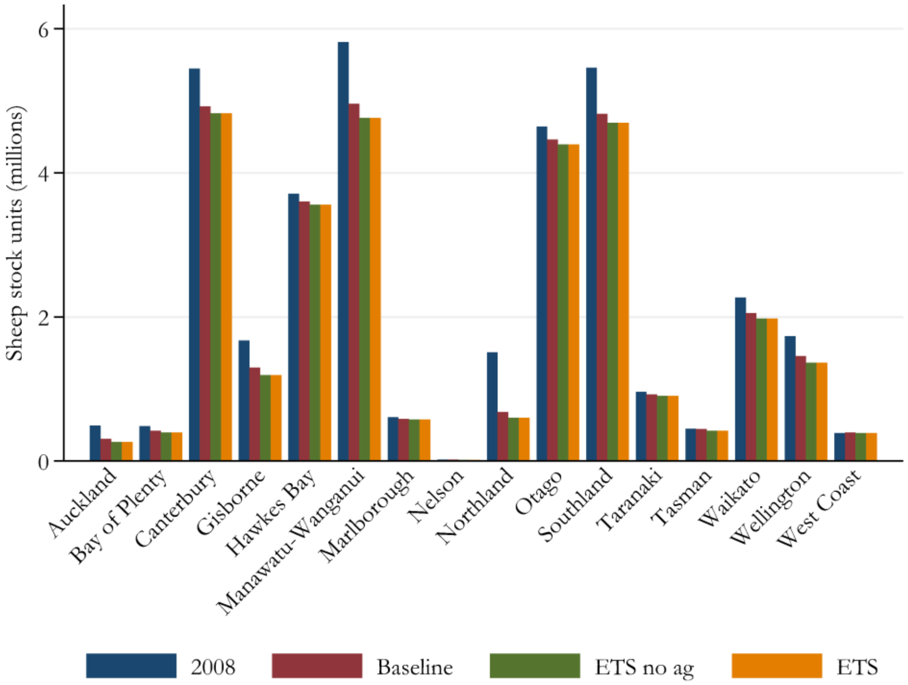
Figure 6 and Figure 7 show projected sheep and beef stock units by regional council in 2030 under each policy scenario. Once again, differences within the baseline are larger than differences across scenarios; recall from Figure 2 that the change in the sheep-beef land share within the baseline is also larger than the change across scenarios. There are reductions in sheep stock units and beef stock units in most regional councils. Northland and Manawatu-Wanganui are both projected to reduce sheep and beef stock units, and this is consistent with these regional councils having relatively more land in forestry and scrub compared to in sheep-beef under the ETS scenarios.

Figure 5: Milk solids production by region in 2008 and in 2030 policy scenarios



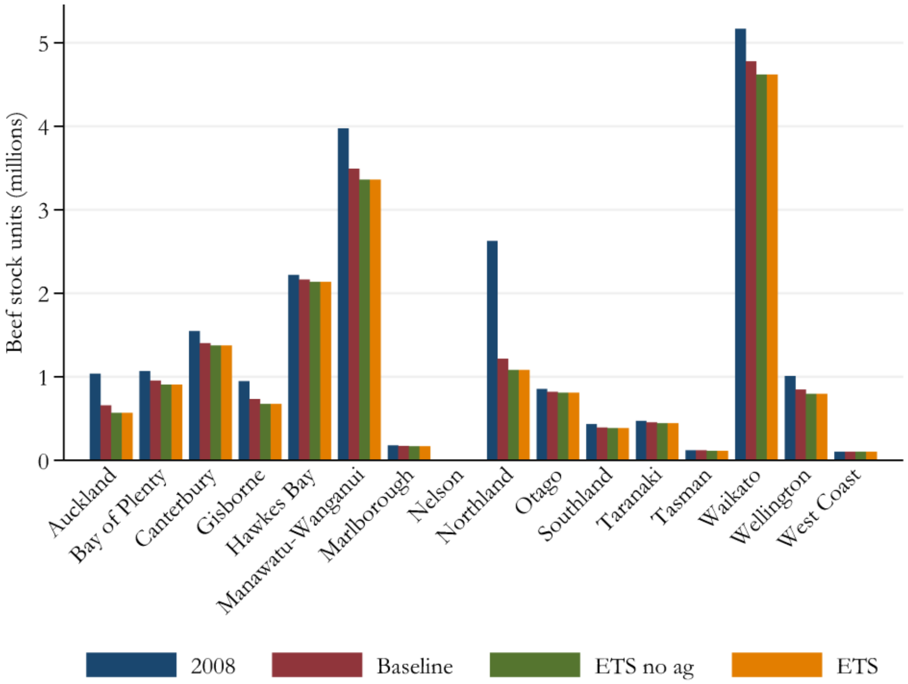
Notes. Blue bars show LURNZ estimates of the total output by regional council in 2008. Red, green, and orange bars show projected output in 2030 under the baseline, with an ETS that does not include agriculture, and under the full ETS. Details on output projections are in Tímár (2012).

Figure 6: Sheep stock units by region in 2008 and in 2030 policy scenarios



Notes. Blue bars show LURNZ estimates of the total stock units by regional council in 2008. Red, green, and orange bars show projected output in 2030 under the baseline, with an ETS that does not include agriculture, and under the full ETS. Details on stock unit projections are in Tímár (2012).

Figure 7: Beef stock units by region in 2008 and in 2030 policy scenarios



Notes. Blue bars show LURNZ estimates of the total stock units by regional council in 2008. Red, green, and orange bars show projected output in 2030 under the baseline, with an ETS that does not include agriculture, and under the full ETS. Details on stock unit projections are in Tímár (2012).

At the national level, the full ETS causes a reduction in sheep-beef land area by 3.7 percent and an overall reduction in sheep and beef stock units by 3.6 percent relative to the baseline. The reduction in stock units is relatively smaller than the reduction in land area because the land that converts to another use has, on average, lower carrying capacity.

7. Conclusion

Motu has developed an integrated model, LURNZ, to look at land-use change and associated environmental issues. In this paper we have compared two different ETS scenarios with a baseline scenario using this simulation model. We project land-use change and consequent emissions and production changes across policy scenarios. Our model highlights that the economic environment that is not directly related to the ETS is also crucial to future land use decisions.

We project that in every ETS scenario, forestry land area increases relative to the baseline and sheep-beef land area falls. Associated with this, the sheep-beef sector's contribution to national agricultural emissions falls under each scenario. On the other hand, when sheep-beef and dairy are both included in the ETS, we project that some land will convert from sheep-beef to dairy, increasing the contribution that dairy farming makes to New Zealand's total emissions. Production is affected in the same direction as land use, but to a relatively smaller extent (for sheep-beef farming) because the land-use response takes place on marginal land.

Under our ETS scenarios there is substantial reforestation. The extra removals associated with this new planting mean that the additional sequestration in 2024 is from 17.6 to 20 percent of national inventory agricultural emissions in 2008. Thus, LURNZ suggests that the ETS has considerable ability to reduce the liabilities that New Zealand will face when a significant number of post-1989 forests reach harvestable age.

Our simulation model lets us evaluate the relative importance of including agriculture in the ETS. The size of the land-use response depends on how we model the value of carbon credits to plantation forestry; the simulated reduction in net emissions reflects only the land-use response, as we do not model on-farm mitigation. In all of our results, the effect of including agriculture is small relative to the effect from having any ETS at all.

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9. Appendix on National Land-use Modelling in LURNZ

In this appendix we discuss a number of decisions that we made in calculating our land use projections. Firstly, we need to make some assumptions about future commodity prices and interest rates, as these are key explanatory variables used to estimate changes in land-use shares. Secondly, in order to model the effect of various carbon prices, we must make some assumptions about how carbon prices feed through to commodity prices. This is because we have estimates of the effects of commodity prices on land-use shares, but clearly we cannot have direct estimates of the effects of carbon prices on land-use shares. We also discuss modelling decisions we felt were necessary to make the projections more reasonable.

9.1. Price Projections

The coefficients of the dynamic econometric model (Kerr and Olssen, 2012) are estimated using historical commodity prices. Milk solids prices are reported in the Livestock Improvement Corporation's (LIC) Dairy Statistics reports; the sheep-beef price is a composite export unit value calculated from New Zealand's Overseas Merchandise Trade data set; forestry log prices are export unit values that match MAF's values for logs and poles for every year that they report data.[7] For simulations of future periods, we use commodity price projections provided by MAF's Situational Outlook for New Zealand Agriculture and Forestry (SONZAF). Figure 8 presents the price series used in the econometric estimation of price responsiveness, as well as the observed and projected SONZAF prices. We do not use historical SONZAF prices

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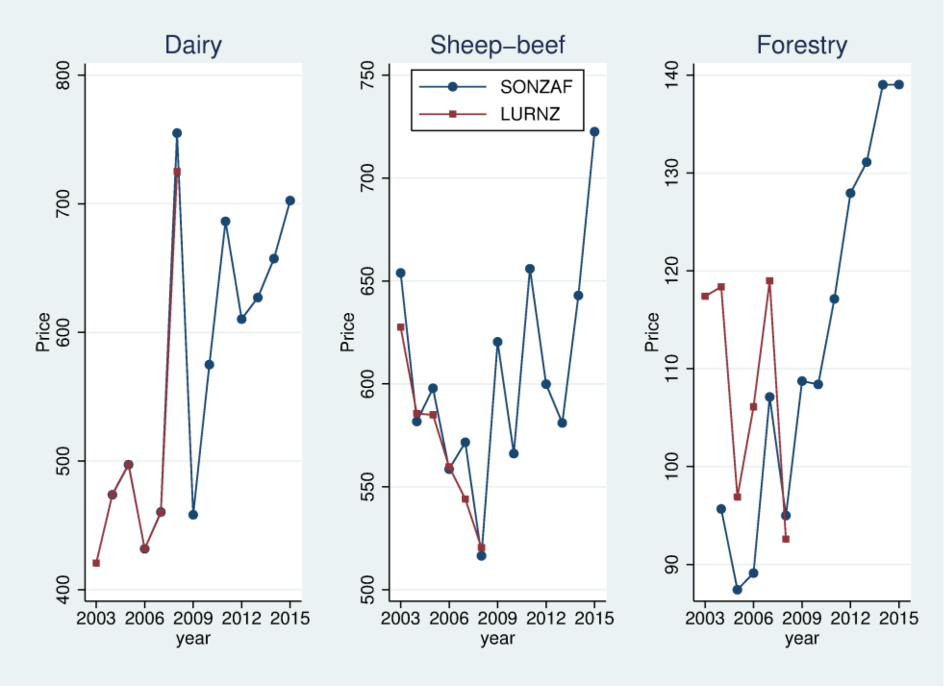
[7] The exact details for all LURNZ prices can be found in Kerr and Olssen (2012).

in estimation because they are only available for a short period of time. We justify our use of SONZAF price projections for calculating future projections of land use by noting that the corresponding historical portions of the series are reasonably consistent (though the match is not perfect for forestry). SONZAF projections are available until 2015, when they stop; for subsequent simulation years we hold prices constant at their 2015 levels.[8]

Figure 8: A comparison of observed prices as used in the econometric estimation of price responsiveness (LURNZ) and as reported by SONZAF, as well as SONZAF price projections



9.2. Modelling the Impact of Carbon Prices

We now discuss how we convert carbon prices into changes in the commodity prices that are used to model land-use change. We assume that carbon costs affect farm decision-making in exactly the same way as commodity prices do through their effect on profits. Incidence of costs between the dairy and sheep-beef sectors is not clear, and we make several simplifying assumptions.

For dairy and sheep-beef we model the effect of carbon prices on commodity prices by using MAF's 2012 emissions factors[9], dairy statistics from LIC, and detailed data on slaughter weight and animal numbers from Statistics New Zealand (SNZ). This enables us to calculate kilograms of CO_2-equivalent greenhouse gas emissions per kilogram of milk solids and meat; we

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[8] This would be our best estimate if we modelled prices from then on as a random walk.

[9] http://www.maf.govt.nz/portals/0/documents/agriculture/agri-ets/agets-emissions-factors.pdf

assume these stay constant over time. What remains is to add in the component of emissions from fertiliser. We do not have data on the average amount of fertiliser used per kilogram of milk solids or sheep-beef meat composite, so we use data from the national inventory.

Some example calculations will make things concrete. To calculate the kilograms of emissions per kilogram of milk solids we proceed as follows. Firstly we calculate the median lifespan of a cow using LIC data on survival rates.[10] This gives us a median life span of 6.31 years. We assume that a cow is milked for every year beyond its first; this gives us median milking years per cow to be 5.31 years. Multiplying this by 323, the average number of milk solids per cow, and 6.14, the MAF emissions factor for dairy milk solids, we get an estimate of the amount of lifetime emissions from a cow, 10,554 kilograms CO_2-equivalent. In 2008, SNZ report that the mean average carcass weight for cows was 203.73 kilograms. This allows us to estimate a number for the emissions associated with the slaughter of a cow. We multiply 203.73 by 7.9, the MAF emissions factor for cow carcass weight, and add 1980, the MAF emissions factor per cow head. This gives us total emissions per cow of 14,133.52 kilograms in CO_2-equivalent. Dividing this by the estimated amount of milk solids a cow produces over its lifetime, we calculate emissions per kilogram of milk solid as 8.23 kilograms CO_2-equivalent. This number does not yet account for fertiliser-related emissions.

For sheep-beef emissions we use SNZ data on slaughter weights and numbers for each category of meat for which MAF provides emissions factors.[11] For example, we use a carcass weight of 16.47 kilograms per lamb. Multiplying this by 4.5, the MAF emissions factor per kilogram of meat, and adding 300, the MAF emissions factor per head, and dividing by the total amount of meat per lamb we estimate that the emissions per kilogram of lamb meat (excluding fertiliser) are 22.71 kilograms CO_2-equivalent.

To account for fertiliser we use the national inventory data as documented in [6] to calculate the average fertiliser intensity in kilograms of N per hectare on dairy and sheep-beef land. Using estimates of average output per hectare, we calculate an estimate of fertiliser-related emissions per output: 0.58 kilograms CO_2-equivalent per kilogram of milk solids and 0.52 kilograms CO_2-equivalent per kilogram of sheep-beef meat. We add these to the appropriate livestock-related emissions.

Afforestation decisions have historically depended on anticipated timber returns at harvest time. Under the ETS, forests can also make a carbon return. In order to model the impact of the ETS on the amount of land used in forestry, it is necessary to model what the

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[10] We use data from the LIC Dairy Statistics report for the year 2008 to 2009.

[11] We use the adult sheep emissions factor instead of calculating emissions for ewes and wethers separately.

return to carbon forestry is. However, capitalising on this carbon return can expose land owners to two types of risk. The first is a price risk: land owners who opt into the ETS and sell their carbon credits as they receive them could face large liabilities at harvest time if the carbon price has increased sufficiently.[12] The second type of risk has to do with policy uncertainty around the ETS, and arises in the years when owners are selling credits. It is possible that the scheme could be removed (or the value of credits could fall dramatically); forest owners would then receive little or no return for sequestration.

We model the carbon return to plantation forestry as the net present value of carbon credits from the first 10 years of forest growth using constant real carbon prices. Land managers' actual valuations of carbon return depend on idiosyncratic parameters that are difficult to model; these include parameters for risk aversion, as well as expectations over future carbon prices, which may depend heavily on expectations over future policy. However, there is an important way in which using the net present value of carbon credits from the first 10 years provides a conservative valuation. The carbon stock at 10 years coincides with the minimum carbon stock held on land that is always replanted; thus, there is no liability risk from selling the carbon credits accumulated during the first 10 years. Of course, the value of those credits still depends on carbon prices and policy.

We perform the net present value calculations using the unweighted average of regional carbon stock from MAF look-up tables,[13] a constant carbon price, and a real discount rate of 8 percent. The net present value thus represents the amount of money for which a forest owner could sell the future rights to the credits. If deposited in the bank, this money could earn a risk-free return, which we assume to be 5 percent. Because timber returns are realised at harvest time, we convert the net present value of the carbon return to a future return using the risk-free 5 percent rate. This is the value we add to our projected forest prices to account for the value of sequestration credits earned.

Finally, under the ETS scrub land can earn a return for its sequestration. There is no data on historical responses to scrub returns, as scrub had never earned a monetary return. We model scrub returns through changing the value of the outside option in other land uses. The carbon return from sequestration increases incentives for land to be used as plantation forestry, but the fact that carbon returns can be earned from regenerative scrub reduces this incentive; the potential for carbon returns on scrub compounds the disincentive from agricultural carbon costs.

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[12] This risk is potentially less relevant to large forest owners who can stagger harvest times or develop forests with equal age distributions so that sequestration in each year offsets harvest liabilities (Turner et al., 2008).

[13] http://www.maf.govt.nz/portals/0/documents/forestry/forestry-ets/2011-ETS-look-up-tables-guide.pdf

Thus, we further adjust each of our projected price series to reflect the fact that the value of the outside option has changed. In particular we subtract off the potential carbon reward to scrub from the (already adjusted) price projections.

We calculate the scrub carbon return in a manner identical to the method we use for determining the forestry carbon return: we use only the first 10 years of credits.[14] We annualise the net present value of these credits and subtract the result from the agricultural price projections. As forestry decisions depend on anticipated returns at harvest, we find the appropriate future value of the carbon return to scrub using the money interest rate; this is the value we use to adjust forestry price projections.

9.3. Modelling Decisions

Dairy share is handled specially in LURNZ. One uncomfortable result in the dynamic land-use model is that in every specification we estimate, the share of land in dairy farming increases when forestry export prices increase. We attribute this result to the fact that our national analysis has little data to work with, and do not think that it represents a causal relationship. If we did not do anything about this relationship, most of the change from baseline in our dairy share projections would be driven by the ETS effect on forestry returns. We do not think this is reasonable. Thus we calibrate our projections. In particular, we run an auxiliary scenario in which we do not let forestry prices change in response to the ETS. The change in dairy share in this scenario is therefore not driven by changing forestry prices. We use this as our dairy share for our final scenario; for the other land-uses we use their shares with the full ETS model on, plus a third of difference from dairy calibration to each land-use, to ensure that the adding-up constraint is met.

Finally, different carbon price scenarios result in different dynamics. We linearise the dynamics in the first 10 years to focus on the long-run pattern.

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[14] We proceed in this way for two reasons. First, any policy uncertainty around the ETS would increase the probability that sequestration returns to scrub would not be realised. Valuing the sequestration returns for the first 10 years only can be thought of as accounting for policy uncertainty. Second, although scrub is unlikely to be harvested (and hence unlikely to face a carbon liability in the future), scrub land could also be used to establish a permanent forest. We therefore need a fair comparison to the carbon returns to forestry.

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