Does money grow on trees? Mitigation under climate policy in a heterogeneous sheep-beef sector

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Abstract

I use simulations from the Land Use in Rural New Zealand model to consider mitigation for different classes of sheep-beef farms under climate policy. Farmers in the model can respond to carbon prices by abandoning or afforesting marginal land. In assessing carbon credits against liabilities, I consider only the income a farmer would be able to get with certainty without taking a carbon price risk. Farmers in intensive farm classes tend to bear the costs of emissions because their opportunity cost of exiting pastoral agriculture is high. The dominant land-use response in more extensive systems is land abandonment or afforestation, depending on location. Less profitable farm classes generally face higher average liabilities in relation to profits, both before and after the land-use response. Results indicate that farmers in North Island hill country may benefit most from afforestation opportunities. In this farm class, income from rewards could offset over half of farmers' emission liabilities.

JEL codes

Q52, Q54, Q58, R14

Keywords

Climate change policy, sheep-beef farming, farm classes, mitigation, cost distribution

Summary haiku

Ruminating on
Methane. Land use will change and
Someone's gotta pay.

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1 Introduction

Methane and nitrous oxide emissions make up about half of New Zealand's overall greenhouse gas emissions. Most of these emissions come from ruminant livestock agriculture. At the same time, much of the land that could be suitable for reforestation is currently pasture used to graze sheep and beef cattle. This unique emissions profile has lead New Zealand's policymakers to consider extending climate change policy to cover emissions from pastoral agriculture. Internalising the cost of those emissions and the mitigation that is likely to occur as New Zealand moves toward a lower net emissions rural sector will have significant effects on farmers, farm owners and rural communities.

Around a third of the country's land area is devoted to sheep-beef farming, and the sector's products constitute about 13% of total merchandise export earnings. The amount of mitigation achievable in pastoral agriculture, the manner in which that mitigation might take place and the degree to which it might disrupt rural sectors and communities are questions of critical importance not only to farmers, butfor the entire New Zealand economy. Two previous Motu studies (Sin et al., 2005; Kerr and Zhang, 2009) deal with the implications of climate policy for rural sectors. However, neither of these papers accounts for the possibility of land-use change that occurs in response to the reduced returns to pastoral agriculture and the increased returns to plantation forestry.

In this paper, I use the Land Use in Rural New Zealand (LURNZ) model[1] to simulate land-use change in response to domestic climate change policy. The model enables a spatially explicit partial equilibrium analysis. I primarily focus on sheep-beef farmers' ability to respond to carbon prices by abandoning previously grazed pasture or by establishing plantation forests on marginal land.[2] I develop a simple framework to calculate the extent to which rewards (carbon credits for new plantation forests) could be used to offset emissions liabilities and then consider the likely impact on profits. The analysis is carried out at the level of representative farm classes that differ systematically in their land-use intensity, profitability and suitability for forestry.

I find that intensive farm classes mitigate little. Farmers in these classes tend to bear the costs of emissions because the opportunity cost of exiting pastoral agriculture would be high – in fact, on high quality land, the policy may generate further conversions to dairy. The dominant land-use response in more extensive systems is land abandonment or afforestation, but opportunities for afforestation are not evenly distributed. Lower profitability systems tend to face higher liabilities in relation to profits, both before and after the land-use response. The

1 http://motu.nz/our-work/environment-and-resources/lurnz

2 Adding on-farm mitigation to the suite of available mitigation options would tend to lessen the impact of the policy. Unfortunately, evidence on the costs of potential on-farm mitigation, particularly on sheep-beef land, is still weak so LURNZ excludes this. No major mitigation options other than land-use change have been identified for sheep-beef land.

simulations suggest that farmers in less intensive North Island farm classes are in the best position to take advantage of opportunities presented by carbon rewards. With a 50% free allocation tied to historic emissions, farmers in these areas could, on average, benefit from the policy.

The next section describes the modelling framework. Section 3 provides a brief overview of the data and assesses the suitability of a map of potential sheep-beef farm classes to classify sheep-beef production systems. Section 4 discusses the level of emission liabilities within different farm classes in the sheep-beef sector and the potential for land-use change in each, as well as the likely net consequences for farm profitability in each farm class.

2 Scope of analysis and methodology

I simulate land-use change at the 25-hectare scale in LURNZ for two scenarios, baseline and policy, to infer agricultural emissions and forestry credits in 2030. The baseline scenario is used as a counterfactual in which land-use does not respond to the policy. Comparing the two scenarios allows me to assess how the land-use response affects net liabilities in relation to average profits. I group sheep-beef areas by potential farm class to show how the results vary across different types of land.

The LURNZ model is built around econometrically estimated relationships and does not make assumptions about farmers' objectives and decision processes – its results are mostly driven by how land use has responded to its main drivers in the past. The empirical basis of the framework and its limited data needs lend transparency and robustness to the results. LURNZ's underlying datasets and processes have been validated (Anastasiadis et al., 2014), and its results are consistent with data and trends at the national scale, including New Zealand's Greenhouse Gas Inventory (Timar and Kerr, 2014).

At the same time, LURNZ does not explicitly include or enable me to quantify land conversion costs and any resulting changes in profitability. For land that was already on the margin before the policy, the net present value of conversion costs and profit changes is close to zero. Therefore, at low carbon prices, these omitted costs could be expected to be relatively low. If they respond to the policy, farmers must by definition do no worse than they would have done otherwise, so net gains from the land-use response must be positive (irrespective of any omitted costs).

The climate change policy environment specified in this paper is chiefly illustrative. Although motivated by it, the policy is not intended to match New Zealand's proposed (and now indefinitely deferred) ETS for agriculture. In modelling, it is implemented as a $25 charge per tonne of CO_2-equivalent emission applied in full from the first simulation year. New Zealand farmers are largely price takers in international markets (Woods and Coleman, 2011), so commodity prices are the same across the scenarios.[3] Mitigation in LURNZ is possible only via land-use change.[4] To allow sufficient time for a land-use response to unfold – a gradual process in reality and in the model – simulation outcomes are evaluated in 2030.

In considering farmers' ability to respond to the policy, emissions and rewards earned for carbon sequestration need to be expressed in comparable terms. To do this, rewards are converted to an annuity, A, corresponding to a perpetual flow of income. Similar to Kerr et al. (2012), this is based on rewards, R, earned during the first ten years of a newly planted forest:

$$A = \left[\sum_{t=1}^{10} \frac{R_t}{(1+\delta)^t} \right] r$$

A landowner intending a permanent land-use change would be able to sell credits earned during this period without taking a carbon price risk because, if a forest is replanted immediately after harvest, its carbon stock never decreases below this level. In other words, the stock of carbon in a ten-year-old plantation forest represents the amount of sequestration a risk-averse owner would be able to receive reward for with certainty. Rewards earned in future are discounted at a rate δ, so the term in brackets represents the discounted net present value of rewards. Deposited in a bank account, this amount of money could earn a risk-free return at rate r. Although it does not relate to physical abatement in specific years, the annuity is relevant for considering ability to mitigate as it captures the theoretical minimum extent to which a risk-averse farmer can offset emission liabilities indefinitely through planting trees.[5]

I assume that only newly planted forests are rewarded with credits for sequestration as part of the policy: there is no windfall gain to owners of existing forests.[6] Further, I focus on plantation forestry – native forest regenerating on abandoned pasture (scrub) is not rewarded. The reasons for this are twofold. First, the potential gains are much larger in plantation forestry: the policy leads to a large increase in forestry area but a net loss of scrub area in the simulations. Moreover, carbon storage per unit land area is higher in plantation forestry. Second, scrub is a residual land-use in the spatial algorithm resulting in some reshuffling of scrub cells over

3 Lack of international action coupled with strong domestic policy in New Zealand could be strategically used to reinforce the country's clean green image in an increasingly environmentally conscious world. Product differentiation building on this image could potentially enable farmers to charge a price premium for their produce. This possibility is not considered in the modelling.
4 The model does not allow for on-farm mitigation by reductions in land-use intensity. The intensification of dairy is modelled using exogenous time trends, but intensity is not a choice variable (Timar and Kerr, 2014).
5 I allow the discount rate to differ from the interest rate and use $\delta = 0.08$ and $r = 0.05$ to calculate the annuity with region-specific data on forestry carbon flows. A less conservative (lower) discount rate would lead to a higher annuity value and hence greater net gains from conversion to forestry. If the discount rate was set to equal r, the annuity would be around 20% higher.
6 Carver et al. (2016) explore the magnitude of windfall gains to forest owners in New Zealand.

simulation years, making it difficult to identify additional scrub. As a result of the churn, predictions of sequestration and loss in scrub may be unreliable. [7,8]

In addition to the abandonment and afforestation of productive land, I allow sheep-beef farmers to mitigate through the establishment of plantation forests on scrubland. The rewards associated with this afforestation are allocated to the sheep-beef sector on the assumption that there is significant overlap between the ownership of scrub and marginal sheep-beef land.[9] To the extent that scrub is not in fact owned by sheep-beef farmers, this assumption will lead to an overstatement of potential benefits to farmers in the sector (but it does not affect the estimate of overall benefits that accrue to landowners within a geographic area).

Finally, in evaluating the policy's effects on sheep-beef farms, I include only land that is under sheep-beef or scrub use both in the baseline 2030 scenario and in the base year, 2012. That is, only areas that were in sheep-beef or scrub use in 2012 and are also expected to remain in one of these uses without climate policy in 2030 are included. The policy evaluation is naturally relative to the baseline scenario, so the condition on baseline land use is self-explanatory. The condition on 2012 land use is for simplicity and concreteness – it makes the discussion more relevant to present-day sheep-beef farmers (as opposed to a set of hypothetical future sheep-beef farmers).[10]

3 Data

The underlying data for the LURNZ model have been extensively documented by Timar (2011), Kerr and Olssen (2012), Anastasiadis et al. (2014) and Timar and Kerr (2014). The spatial model is built on detailed GIS data on land use and geophysical land attributes. Data of similarly fine resolution on farm profits is not available. In considering some of the financial implications of the policy for farmers, I rely on industry figures of average profitability for certain types of farms and classify land areas accordingly.

I use a map of potential farm classes (Hendy et al., dataset, 2009) as the basis to classify sheep and beef farms. The classification is derived from the farm classes Beef + Lamb New Zealand (B+L) have developed to categorise farm types in economic reports. The actual location

7 There is an asymmetry in LURNZ with regard to scrub reward. The amount of land-use change in the national module is estimated with the assumption that native sequestration is rewarded, but accounting for these rewards spatially and allocating them to specific farm types is problematic.
8 Establishing native vegetation on abandoned pasture can be a low cost mitigation option. Unless the land is converted again, the amount of carbon stored in native forests accumulates year after year because these forests are not harvested. By ignoring native sequestration, I therefore potentially underestimate farmers' ability to benefit from the policy. However, native sequestration is slow, and pine forests can also be permanent so this omission is unlikely to be large relative to the impacts of potential pine plantations which are the focus of this paper.
9 Marginal sheep-beef land and scrub are often similar in land quality and location. Land-use data suggest that some of the current scrub area is formerly abandoned sheep-beef pasture.
10 As it turns out, this condition is not very restrictive. Because of an expected decreasing trend in sheep-beef area, nearly all baseline sheep-beef was in the same use in 2012. Scrub area increases under the baseline, but practically all of the increase comes from the abandonment of sheep-beef pasture. Overall, less than 1% (around 80,000 hectares) of baseline sheep-beef or scrub is excluded from the analysis by specifying conditions on 2012 land use.

of land corresponding to each B+L farm class is not known, so Hendy et al. utilise supplementary information on assessed land type (from meshblock-level valuations data by Quotable Value New Zealand), biological land productivity (Baisden, 2006) and slope to map potential farm classes nationally. These aim to identify the farm class that the land would likely be in if it were used as a sheep-beef farm.

Observing the distribution of (actual) land uses across (potential) farm classes provides a simple robustness check on the map. Table 1 contains statistics based on overlaying the 2012 LURNZ basemap, the most current map available in LURNZ, with the potential farm class map. It confirms that more intensive farm classes tend to be associated with more intensive land-use types. In a similar manner, geophysical land attributes are expected to vary systematically with land-use intensity.

Table 1: Land use shares (percentage in 2012) by potential farm class

Farm class	Dairy	Sheep-beef	Forestry	Scrub
SI high country	0.09	88.76	1.63	9.52
SI hill country	1.18	79.46	7.15	12.21
NI hard hill country	1.45	67.19	11.77	19.60
NI hill country	6.02	52.57	19.84	21.57
NI intensive finishing	22.20	57.65	11.37	8.77
SI finishing-breeding	9.74	72.53	8.86	8.87
SI mixed/intensive finishing	16.49	73.09	5.93	4.48

Notes: SI and NI stand for South Island and North Island. Farm classes are ordered by B+L's ranking of sheep-beef land-use intensity.

Table 2 summarises two measures of land quality for sheep-beef land within each potential farm class. Both slope and land use capability (LUC) show the expected patterns across the various farm classes.

Table 2: Sheep-beef land attributes by potential farm class (based on 2012 land use)

Farm class	Mean slope	Mean LUC
SI high country	15.66	6.45
SI hill country	13.63	6.00
NI hard hill country	10.21	5.75
NI hill country	9.79	5.66
NI intensive finishing	6.39	4.80
SI finishing-breeding	7.28	4.83
SI mixed/intensive finishing	5.43	4.25

The total area of sheep-beef land in each potential farm class can also be determined using the LURNZ basemap. The third data column of Table 3 contains this information (with the preceding two columns providing a break-down by land ownership type). The final column of Table 3 lists B+L area estimates against which mapped area can be compared. It appears that land areas by (potential) farm class in the 2012 map differ, in some cases markedly, from the land areas provided by B+L.

Table 3: A comparison of mapped sheep-beef area to Beef + Lamb area estimates by farm class in 2012 (hectares)

Farm class	Map area			B+L area
	Private	Public	Total	
SI high country	128,500	394,750	523,250	1,758,800
SI hill country	604,050	735,750	1,339,800	1,264,900
NI hard hill country	513,775	15,450	529,225	1,057,400
NI hill country	814,150	47,650	861,800	1,799,300
NI intensive finishing	2,311,775	157,750	2,469,525	482,100
SI finishing-breeding	1,619,625	309,325	1,928,950	1,373,500
SI mixed/intensive finishing	925,575	205,075	1,130,650	594,900
Total New Zealand	6,917,450	1,865,750	8,783,200	8,330,900

In general, B+L estimate that that there is less intensive and more extensive sheep-beef than suggested by the intersection of the two maps. In addition, the total area of sheep-beef pasture differs by about 5% across the data sources. At spatial scales more detailed than farm class areas, previous LURNZ land-use maps have been found to be highly consistent with data from Statistics New Zealand and DairyNZ (Anastasiadis et al., 2014), and the 2012 map is expected to be of similarly high quality. Although the potential farm class map is also based on geographic information, it was not actually designed to reflect the current management of the land. In theory, differences between map and B+L farm class areas could therefore indicate that some land is underutilised and not used to its full potential.[11] The magnitude of the differences seen in the table is nonetheless surprising.

These statistics suggest that despite the generally robust patterns observed in the potential farm class map, the classification may not be perfectly aligned with the definitions used by B+L: based on land characteristics and QVNZ assessments, some areas should be able to support more intensive types of sheep-beef farming, but B+L tend to classify them as extensive. This issue does not affect modelled emissions and liabilities in LURNZ.[12] However, in this paper I assign profits to sheep-beef farmers based on potential farm class. If B+L profit figures consistently reflect the B+L farm class definitions, then my analysis will potentially overstate profits in relation to liabilities for some sheep-beef farmers – this would bias the relative impact of emission charges for the affected farm classes downward. In section 4.3, I address the problem by reweighting B+L profit per hectare values to reflect discrepancies in farm class areas.

4 Results

4.1 Land-use response

Table 4 displays national land-use summaries for the key land-use types in LURNZ in 2012 and both future scenarios. Comparing the baseline and policy columns, the land-use impact of the policy is largest, both in absolute and relative terms, for forestry. For other land uses, the impact is similar in magnitude to the amount of land-use change expected to occur between 2012 and 2030 with no climate change policy (that is, under the baseline scenario).[13] These results are based entirely on the econometrically estimated national land-use change model within LURNZ and provide context to further analysis.

11 If this were the case, the differences would represent an actual phenomenon rather than data problems. Unfortunately, it is not possible to assess the degree to which this explanation contributes to the patterns observed across the last two columns of Table 3. The accuracy of the B+L area estimates is not known either.
12 Overall emissions are calibrated to the National Inventory in the model. Spatially, sheep-beef emissions are primarily determined by the stocking rate. Farm class has only a small impact through the average ratio of sheep and beef stock units.
13 The area of public sheep and beef land is fixed by assumption.

Table 4: National land use areas in 2012 and land-use change under both simulation scenarios (thousand hectares).

Land use	2012	Baseline 2030	Policy 2030
Dairy	1,596	95	62
Sheep-beef: private	6,917	-284	-241
Sheep-beef: public	1,866	0	0
Forestry	1,363	-25	371
Scrub	1,451	214	-192

Note: Land-use change under the baseline is relative to 2012; land-use change under the policy scenario is relative to the baseline.

The increase in dairy area induced by the policy is a surprising result (also discussed in Kerr et al., 2012). Econometrically, it happens because the positive effect of falling sheep-beef returns outweighs the negative effect of falling dairy returns on dairy land use. This outcome is incompatible with simple profit-maximisation, but it reflects the way in which land use has historically responded to changing returns driven by commodity prices.

The spatial pattern of land-use change is determined by the land-use allocation algorithm of LURNZ. The algorithm utilises results of an empirical land-use choice model (Timar, 2011), but other assumptions embedded in it also affect the simulated transitions. While it is not expected to pinpoint where exactly land-use change will take place, the model has been shown to be able to identify the type and general location of land that would be subject to pressure to change (Anastasiadis et al., 2014).

Most of the land-use response affects land in sheep-beef and scrub use. Table 5and Table 6 shed further light on the amount and type of land-use change generated by the policy, focusing on these two uses, respectively.[14]

Figure 1 and Figure 2 present the same information visually and in proportional terms. Land abandonment (land-use change to scrub) is the dominant response on low quality sheep-beef pasture as some parts of farms may become unprofitable in the face of emission charges. There is also a limited amount of afforestation, particularly in the North Island. As discussed previously, some sheep-beef land in intensive farm classes undergoes further intensification in the simulations and is converted to dairying.

14 The baseline areas in Table 5 and Table 6 do not exactly aggregate to the national areas shown in Table 4. This is due to a constraint involving 2012 land use which will be covered in the next section.

Table 5: Land-use response to policy on private sheep-beef land (thousand hectares)

Farm class	Baseline		Changing to	
	2030 area	Dairy	Forestry	Scrub
SI high country	113	0.0	0.2	4.9
SI hill country	567	0.4	2.1	16.6
NI hard hill country	473	0.6	3.1	17.4
NI hill country	761	0.6	14.4	17.9
NI intensive finishing	2,198	17.3	14.6	28.5
SI finishing-breeding	1,554	13.3	3.6	17.3
SI mixed/intensive finishing	905	13.7	0.9	5.4

Figure 1: Percentage of private sheep-beef area converting to another use by farm class

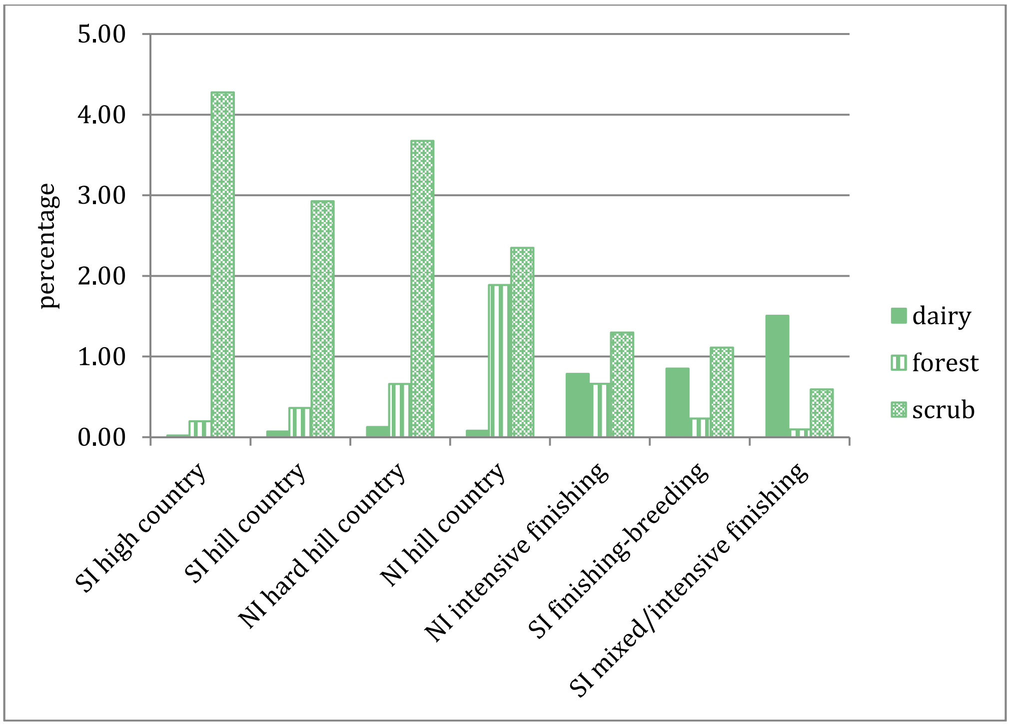


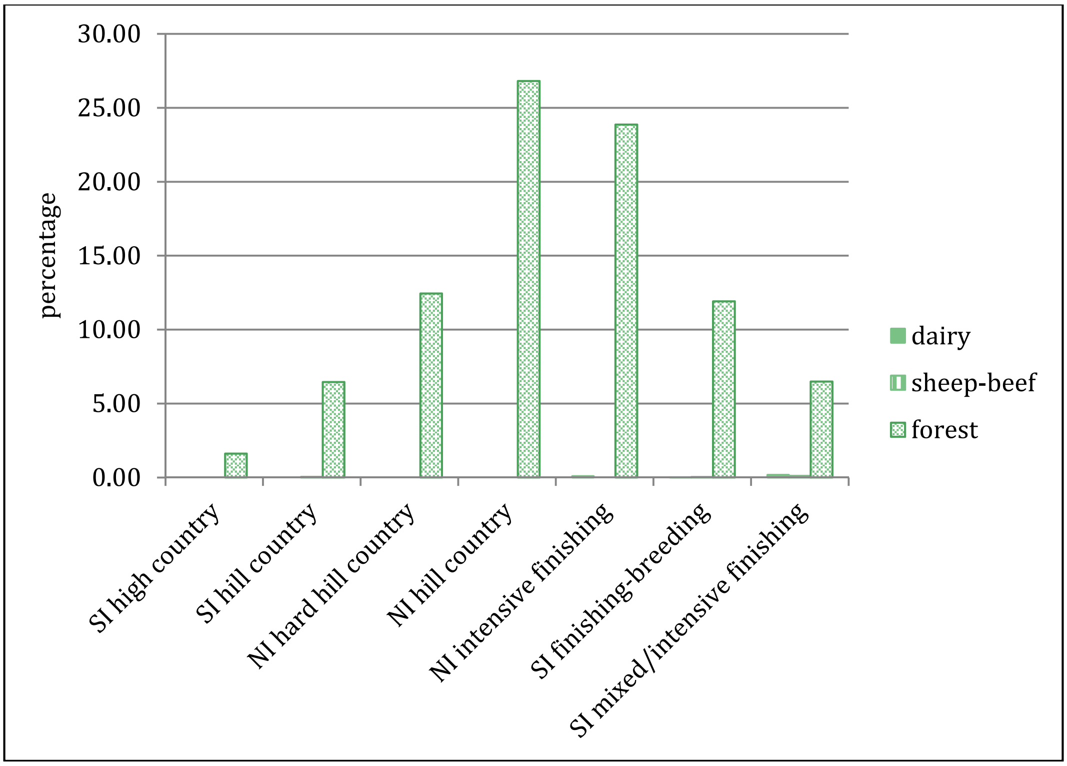
Table 6 and Figure 2 show that, in both absolute and relative terms, the simulated land-use response is largest for scrub, and nearly all of this response is associated with afforestation. The ability to earn rewards for carbon sequestration under the policy could present a significant opportunity to owners of this land (many of whom are sheep-beef farmers).[15]

15 Model validation suggests that for a given amount of afforestation, LURNZ tends to overestimate the proportion that comes from scrub, and, conversely, it tends to underestimate the proportion that comes from sheep-beef (Anastasiadis et al., 2014). All else equal, the cost of establishing forestry on sheep-beef land is higher due to the opportunity cost of lost production. Note, however, that in LURNZ results close to 20% of afforestation affecting baseline scrub takes place on land that was actually in sheep-beef use in 2012: rather than being abandoned (as under the baseline) this land is afforested under the policy.

Table 6: Land-use response to policy on scrub land (thousand hectares)

Farm class	Baseline 2030 area	Changing to Dairy	Changing to Sheep-beef	Changing to Forestry
SI high country	71	0.0	0.0	1.2
SI hill country	241	0.0	0.1	15.6
NI hard hill country	193	0.0	0.0	24.0
NI hill country	396	0.0	0.0	106.2
NI intensive finishing	421	0.4	0.0	100.4
SI finishing-breeding	253	0.1	0.1	30.1
SI mixed/intensive finishing	71	0.1	0.1	4.6

Figure 2: Percentage of scrub area converting to another use by farm class



These land-use changes directly determine the evolution of land-based emissions in LURNZ. Table 7 contrasts pastoral emissions in the base year as well as both future scenarios. Modelled emissions at the national level are broadly consistent with NZ's national inventory (Timar, 2014).[16]

16 The figures exclude emissions associated with the production of wool (around 4 Mt CO2e annually). Dairy intensification over time is captured by region-specific trends, but sheep-beef intensity is assumed constant, so changes in emissions associated with the sector reflect changes in land use. Compared to the baseline, total pastoral emissions rise slightly under the policy because the increase in emissions due to additional dairy conversions outweighs the decrease due to lost sheep-beef.

Table 7: Simulated pastoral emissions (million tonnes of CO_2-equivalent)

Land use	2012	Baseline 2030	Policy 2030
Dairy	14.25	16.35	16.97
Sheep-beef	11.76	11.46	11.10
Total pastoral	26.01	27.81	28.07

4.2 Implications for farm profitability

To set the scene in considering impacts on farmers, Table 8 contrasts sector-level average profits to liabilities for pastoral emissions under a hypothetical policy in 2012. Emissions cost $25 per tonne CO_2-equivalent and there is no free allocation of allowances. Given the observed land use in 2012, the average impact of this policy would be around 11% loss of profit for dairy farmers and 17% loss of profit for sheep-beef famers.[17,18]

Table 8: Sector-level average profits and emission liabilities ($) under a hypothetical 2012 policy

Land use	Profit/ha	Liability/ha	% impact
Dairy	2033.67	223.24	-10.98
Sheep-beef	194.00	33.47	-17.25

Note: The hypothetical 2012 policy is a $25 carbon price with no free allocation and no land-use response

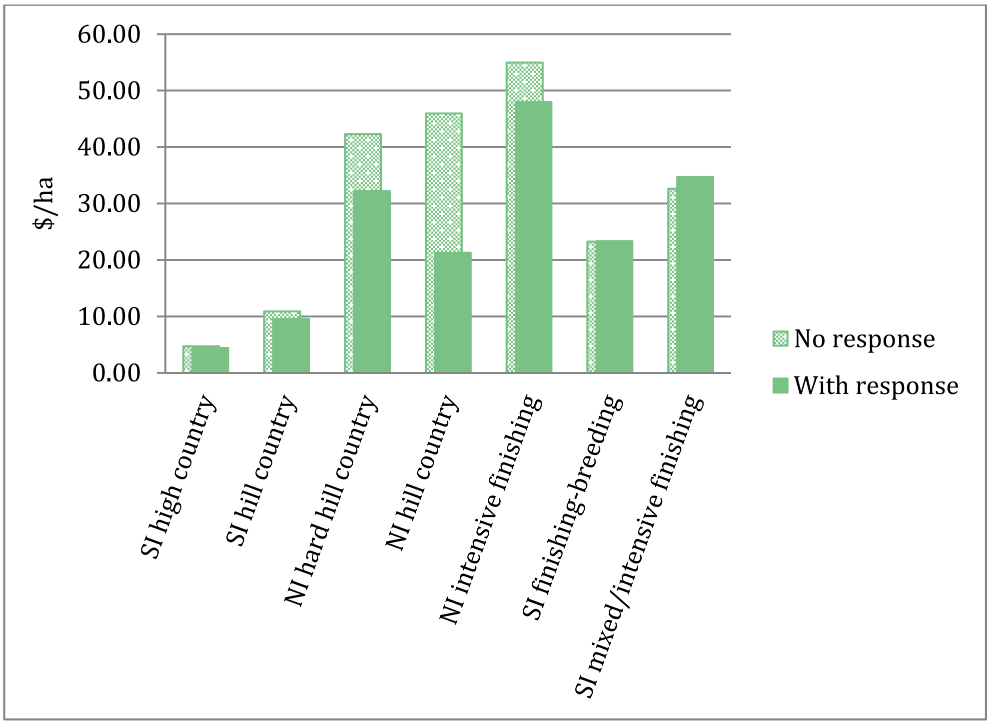
These national-level statistics are consistent with results based on a different methodology in Kerr and Zhang (2009). However, the averages mask a wide distribution of potential outcomes, particularly in the sheep-beef sector. The figures in Table 8 also ignore the possibility of mitigation via land-use change. Different farmers will tend to respond differently: as we have seen, some will find it profitable to plant trees, and some others may choose to abandon parts of previously grazed land. These land-use responses were summarised in Table 5 and Table 6.

Ability to mitigate emission liabilities by changing land use is represented in Figure 3. The figure compares net liabilities under the baseline (no land-use response) and the policy (land-use response) scenarios for sheep-beef farms in 2030. For each farm class, the background bar in the chart represents average liability per hectare under the baseline scenario in 2030. The

17 Average profits are based on multiple years of data to address annual variation reflecting patterns in weather and changes in economic conditions. In both sectors, the figures represent the mean of national-level profits over the seven seasons 2005/2006 to 2011/2012. Earnings Before Interest and Tax (EBIT) from B+L Economic Service is used for sheep-beef profits and Economic Farm Surplus (EFS) from MPI monitor farm reports is used for dairy profits. (All but one of the monitor farm reports indicate that EFS is identical to EBIT.)
18 Emission liabilities shown in the table are spatially aggregated from the LURNZ emissions module output for the base year, 2012 (Timar and Kerr, 2014). Figures shown are per effective hectare.

foreground bar represents net liabilities in 2030 when land-use is allowed to respond to the policy. Net liabilities include emissions associated with meat production (Timar and Kerr, 2014) as well as any rewards earned under the policy for the afforestation of land that was previously used for sheep-beef farming or left to scrub. The figure illustrates the large heterogeneity that exists both in terms of emissions per hectare and the ability to respond across farm classes.

Figure 3: Simulated net emission liabilities per hectare for sheep-beef farms in 2030 (with and without a land-use response)



For most farm classes, the land-use response reduces liabilities. This is due to a combination of lower pastoral emissions (abandoned or afforested sheep-beef land) and rewards earned for carbon sequestration (for new forests planted on sheep-beef or scrub). The reward component dominates on North Island hill country farms, where a large fraction of simulated afforestation happens, leading to a particularly effective mitigation response there. The reward associated with forestry offsets a large proportion of liabilities here. In the South Island mixed/intensive finishing farm class, the land-use response increases net emission liabilities because the effect of additional dairy conversions under the policy dominates that of other land-use changes.

Liabilities are related to stocking rates, so intensive production systems naturally face higher liabilities than extensive ones. However, they are also more profitable and their losses tend to be smaller as a percentage of profit. This pattern is seen in Table 9, where losses are expressed in proportion to (current) average profit. As previously, losses include changes in emission liabilities net of any (appropriately annualised) reward for sequestration earned during the first ten years of newly established plantation forests.

Table 9: Average profits ($) and the relative impact of the policy in 2030 (without and with a land-use response) by sheep-beef farm class

Farm class	Profit/ha	% change with	
		No Response	Response
SI high country	20.06	-23.54	-21.99
SI hill country	75.74	-14.36	-12.58
NI hard hill country	168.45	-25.11	-19.12
NI hill country	254.94	-18.03	-8.34
NI intensive finishing	334.80	-16.42	-14.33
SI finishing-breeding	275.63	-8.44	-8.47
SI mixed/intensive finishing	582.02	-5.60	-5.96

Notes: Farm class profits reflect the definition of farm classes as used by B+L. Because emissions and sequestration are modelled geographically, percentage changes are calculated based on the areas defined in the map of potential farm classes.

High country and hill country farm classes on average lose a higher proportion of their pre-policy profits to emission liabilities. The final column indicates that in some cases, especially in North Island hill country, sequestration rewards allow farmers to offset a significant fraction of liabilities: here, annualised rewards (for the first 10 years of forest growth) are projected to equal more than half of sheep-beef farmers' liabilities.

The potential inconsistency in farm class definitions outlined in the data section affects the analysis in Table 9 because profits are determined based on B+L farm class. The inconsistency would cause higher than actual profits to be assigned to some areas making the proportional impact of the policy seem less severe. Exploiting the land area differences in Table 3, I therefore revise profits for better consistency with the potential farm class map.

In order of increasing intensity by island, I determine the area of each B+L farm class that would need to be reclassified to match map area.[19] Assuming homogeneity in profits within each B+L farm class, I assign the profit value characteristic of the original (lower) B+L class to the amount of land reclassified. For example, Table 3 indicates that the B+L estimate for South Island hill country area (1,758,800 ha) exceeds map area (523,250 ha) by 1,235,550 hectares. I therefore assign the $20.06 profit per hectare associated with high country to 1,235,550 hectares of South Island hill country land (as well as to the 523,250 hectares of high country in

19 The calculation actually performed is based on map area scaled to match total B+L area by island. For the sake of simplicity, the example that follows ignores the scaling.

the map). To match hill country map area, this in turn means that hill country profitability needs to be assigned to a similar amount of South Island finishing-breeding land, and so on. I calculate a weighted average profit for each potential farm class based on the amount of land that is associated with the profitability of the previous (more extensive) farm class. The revised profits thus take account of the area discrepancies across the data sources.

Unless profits are homogenous within B+L farm classes, the method outlined above suggests that the revised (weighted) profits will be likely overestimates for the most extensive potential farm class on each island and underestimates for all other farm classes. Table 10 repeats the analysis from the previous page with the revised profit figures, providing an additional robustness check on the results.[20]

Table 10: Weighted average profits ($) and the relative impact of the policy in 2030 (without and with a land-use response) by sheep-beef farm class

Farm class	Profit/ha	% change with	
		No Response	Response
SI high country	20.06	-23.54	-21.99
SI hill country	25.41	-42.79	-37.51
NI hard hill country	168.45	-25.11	-19.12
NI hill country	185.35	-24.79	-11.47
NI intensive finishing	312.38	-17.60	-15.36
SI finishing-breeding	150.13	-15.49	-15.54
SI mixed/intensive finishing	275.63	-11.82	-12.59

Note: Farm class profits in this table represent weighted B+L figures to address land area discrepancies across the datasets.

As before, extensive farm classes tend to lose a higher proportion of their pre-policy profits to emission liabilities.[21] The profits for some farm classes are significantly lower than before, and consequently the policy impact is larger. These impacts are based on primarily conservative assumptions made at different stages of modelling, including assumptions about mitigation options, rewards for sequestration and average profits – for most farm classes they likely represent pessimistic outcomes. The impacts also do not include any complementary policies such as free allocation of allowances. For comparison, a 50% free allocation tied to historic emissions would be sufficient to make the average farmer in North Island hill country

20 With the weighting, the implied national average is $184.50 profit per hectare of sheep-beef land, about $10 lower than the value calculated from observed data in Table 8. This confirms that, overall, the weighted profits represent conservative estimates.
21 South Island high country is an exception to the pattern, but this is not surprising in light of the discussion in the previous paragraph.

better off than before the policy, and it would significantly reduce losses in other farm classes as well.

5 Conclusion

Using simulations from the LURNZ model, I assess sheep-beef farmers' mitigation responses to climate change policy and show how the results vary across various types of land. There is large heterogeneity in the land-use response and the magnitude of impact experienced in different sheep-beef farm classes.

The land-use change elicited by climate policy imposes costs on farmers, but it can also present some opportunities. Farmers in intensive farm classes tend to mitigate little and bear the costs of emissions because the opportunity cost of exiting pastoral agriculture would be high. The dominant land-use response in more extensive systems is land abandonment or afforestation, but opportunities for carbon credits from afforestation are not evenly distributed.

In comparing carbon credits to liabilities, I convert the credits a farmer would be able to sell with certainty (without taking a carbon price risk) to an indefinite annual flow of income. Relative to average profits, lower profitability systems tend to face higher liabilities both before and after the land-use response. Farmers in less intensive North Island farm classes may benefit most from carbon rewards. Results suggest that income from rewards could on average offset as much as half of emission liabilities on North Island hill country farms.

Complementary policies to assist with community transition are also important. A key factor for farmers is whether (and how) allowances are allocated. The potential transfer of wealth through allocation is large, and farms that can also take advantage of opportunities presented by carbon credits could actually benefit from the policy with free allocation tied to historical emissions. This would be most likely on North Island hill country areas, where forestry is already an important part of the local economy.

Loss of rural profit is likely to translate into lower land values affecting current owners of agricultural land (Allan and Kerr, 2016). The sensitivity of land values to profit loss depends on location. Specifically, amenity values (the attractiveness of the land as a place to live) and option values (for example, the potential for future residential development) are not directly affected by the policy, so these would tend to mitigate the impact on land values in some places. All else equal, rural land close to cities is therefore expected to be less affected. On the other hand, a given loss of profit would result in a larger proportional decrease in value for land farther away from population centres and amenities.

Urban areas are also not completely immune to changes in rural profitability. Some of the effects of agricultural greenhouse gas mitigation could trickle down into urban markets, and not just through food prices. Grimes and Hyland (2013), for example, find empirical evidence that lost rural profit can affect nearby urban communities in the form of depressed housing values.

My analysis identifies some plausible differences in the impact of climate policy across regions and sheep-beef farm types in New Zealand. If the international community does not act on agricultural emissions as strongly as New Zealand does, farmers here will likely lose because they are largely price takers in international markets (Woods and Coleman, 2011). With strong international policy, the liabilities faced by farmers would be at least partially offset by higher commodity prices. While the overall impact of climate policy ultimately depends on international action (Reisinger and Stroombergen, 2012; Dorner and Kerr, 2015), the heterogeneity in sheep-beef farmers' response to carbon pricing remains. Qualitatively, the patterns of impact identified in this paper are therefore expected to hold for a range of assumptions about international action.

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