Land Use Scenarios in LURNZ

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Motu Working Paper ##-##

Motu Economic and Public Policy Research

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Abstract

Motu Economic Research has developed an integrated model to look at the impacts of climate change policy such as the New Zealand Emissions Trading Scheme. This model is called LURNZ, which stands for Land Use In Rural New Zealand. The model uses a range of econometric and modelling work. We estimate how land use responds to changing economic returns using national level time series data, Olssen and Kerr (forthcoming). A cross sectional data set on land use in 2002 is used to develop a model of the geophysical determinants of land use allocation, Timar (2011). We then model land use in New Zealand under various climate change policy scenarios. Modelling techniques are used to estimate land use intensity and green house gas emissions under various scenarios. In forthcoming work we model a range of impacts on rural communities under different carbon prices. We also generate marginal abatement curves. In this note we present a sample of the output that can be produced by LURNZ. Also, of interest to the research community, we discuss several key aspects of our methodology.

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1. Introduction

Motu Economic Research has developed an integrated model to look at the impacts of climate change policy such as the New Zealand Emissions Trading Scheme. This model is called LURNZ, which stands for Land Use In Rural New Zealand. The model uses a range of econometric and modelling work. We estimate how land use responds to changing economic returns using national level time series data, Olssen and Kerr (*forthcoming*). A cross sectional data set on land use in 2002 is used to develop a model of the geophysical determinants of land use allocation, Timar (2011). We then model land use in New Zealand under various climate change policy scenarios. Modelling techniques are used to estimate land use intensity and green house gas emissions under various scenarios. In forthcoming work we model a range of impacts on rural communities under different carbon prices. We also generate marginal abatement curves. In this note we present a sample of the output that can be produced by LURNZ. Also, of interest to the research community, we discuss several key aspects of our methodology.

The rest of this note is structured as follows. In section 2 we look at the output from the land use change module and discuss some key modelling decisions. Section 3 looks at land use allocation, while Sections 4 and 5 look at land use intensity and greenhouse gas emissions. Section 6 comments on the current version of LURNZ and proposes directions for future work.

2. The land use change module

The land use change module is based on the econometric time series work of Olssen and Kerr (*forthcoming*). They estimate a dynamic singular equation system to look at how land shares have responded to changing economic returns, as proxied by relevant commodity prices, using national level time series data. Fortunately, New Zealand's small size means that commodity prices are likely to be exogenous. On the other hand, as national level time series on land use are quite short not many regressors could be used, leaving open the possibility of omitted variable bias. With regards to the LURNZ model, the econometric estimates of Olssen and Kerr (*forthcoming*) are crucial because they are used to estimate national level land shares to each major rural use under different carbon price scenarios.

2.1. Land use change module output

Figure 1 provides an example of land use projections using a $25 carbon price. Modelling decisions that were used to generate such a projection are discussed below; for now let us focus on the output. The vertical line splits the graph into the section where land use shares are observed and where they are estimated. We see that under a $25 carbon price we project continued reductions in the sheep-beef share, which eventually tapers off. Dairy and forestry shares rise gradually, but also eventually level off. A comparison with a $0 carbon price scenario shows that the major changes are increasing forestry and decreasing sheep-beef and scrub. We make a modelling decision to modify the dairy share; we discuss this below as well.

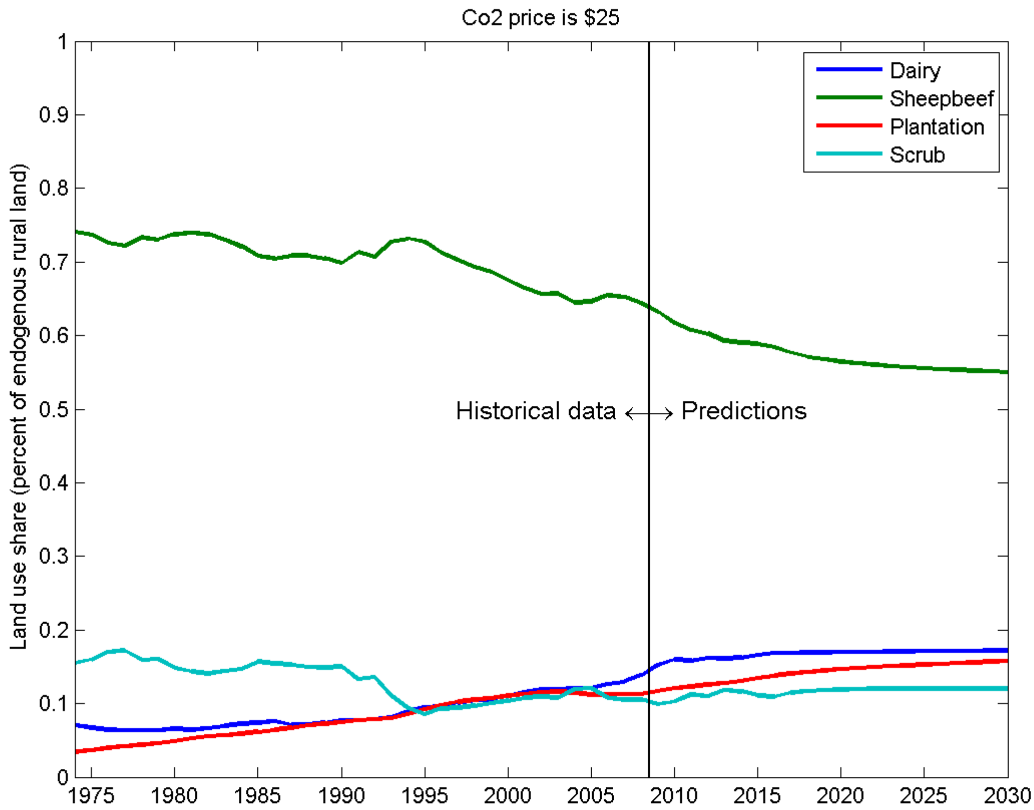

Figure 1: National land share projections with a $25 carbon price

2.2. Land use change module modelling decisions

In this section we discuss a number of decisions that we made in calculating our land use projections such as the one shown in Figure 1. 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 carbon prices on land-use shares. Finally we discuss some modelling decisions that we made because we felt they made the projections more reasonable.

2.2.1. Price projections

Modelling commodity prices and projecting commodity price paths would be a large undertaking. Instead of doing this ourselves we use price projections (and the associated monetary projections) provided by the Ministry of Agriculture and Forestry's Situational Outlook for New Zealand Agriculture and Forestry (SONZAF). Figure 3 compares the prices from 2003 to 2008 using these two different data sources. Our milk solids prices match exactly (LURNZ uses milk solids prices that match those reported in the Livestock Improvement Corporation's (LIC) Dairy Statistics reports). Sheep-beef prices match very closely. LURNZ uses export unit values calculated from New Zealand's Overseas Merchandise Trade data set.[1] The log prices match the least well. We use export unit values that match MAF's values for logs and poles for every year that they report data. The LURNZ prices and the SONZAF prices move together, however in the early 2000s the LURNZ prices are substantially larger. By 2008 this difference has vanished. Because the LURNZ and SONZAF prices agree so well, we use the SONZAF projections when calculating land use projections into the future. We use SONZAF projections until 2015, when they stop, and then we hold prices constant at their 2015 levels.[2]

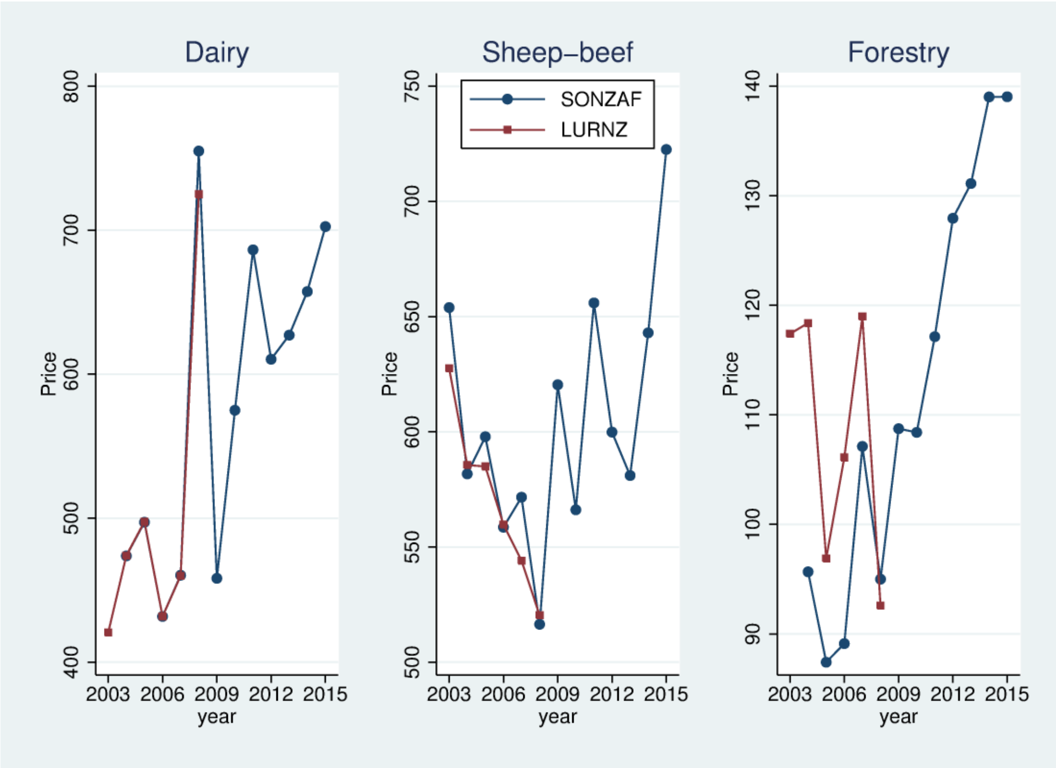

Figure 2: A comparison of actual prices as used in LURNZ and as reported by SONZAF, as well as SONZAF price projections

[1] The exact details for all LURNZ prices can be found in Olssen and Kerr (*forthcoming*).
[2] This would be our best estimate if we modelled prices from then on as a random walk.

2.2.2. 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. It is worth noting upfront that incidence is not clear, and that several simplifying assumptions have been made. Currently in LURNZ, we calculate the kilograms of emissions per kilogram of output in 2008 and assume this stays constant over time.[3] We do this for a constant real carbon price of $25. In every projection with non-zero carbon prices we use the follow policy environment. Forestry enters the ETS in 2008. Agriculture enters in 2015. Agriculture receives a free allocation that starts at 90 per cent in 2015 and decreases annually by 1.3 per cent of the previous year's free allocation. A two for one policy does not apply to agriculture.

For dairy and sheep-beef we model the effect of carbon prices on commodity prices by using MAF's emissions factors[4], dairy statistics from LIC, and detailed data on slaughter weight and animal numbers from Statistics New Zealand (SNZ). This enables us to calculate the kilograms of emissions per kilogram of output from meat and milk. 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 age that a cow lives to using LIC data on survival rates.[5] This gives us a median life span of 6.31 years. We assume that a cow milks 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 the lifetime emissions from a cow over its lifetime, 10,554 kilograms. 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 number of milk solids a cow produces over its lifetime we get an emission per milk solid of 8.23. This number does not account for fertiliser. For sheep-beef emissions we

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[3] In future work we may incorporate some modelling of how output per emission has changed over time.
[4] http://www.maf.govt.nz/portals/0/documents/agriculture/agri-ets/agets-emissions-factors.pdf
[5] We use data from the LIC Dairy Statistics report for the year 2008 to 2009.

use SNZ data on slaughter weights and numbers for each category of meat that MAF provides emissions factors for.[6] 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 kilograms of emissions per kilogram of lamb meat (excluding fertiliser) is 22.71. To account for fertiliser we use the national inventory data. Timar (*forthcoming*) calculates the average fertiliser intensity in kilograms of N per hectare on dairy and sheep-beef land. Using estimates of the average output per hectare we get an estimate of the fertiliser per output. We add .58 kilograms of emissions per kilogram of milk solid production and .52 kilograms of emissions per kilogram of sheep-beef meat.

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 return to carbon forestry is. However capitalising on this carbon return can expose land owners to risk. Two major risks are due to price risk and policy uncertainty. On the price risk side, 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 increased enough.[7] Policy uncertainty around the ETS means that it is possible that the scheme could be removed, and then forest owners would receive no return for sequestration.

In this note, 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 carbon real carbon prices, which are assumed in every LURNZ scenario. It is hard to know whether such an evaluation is too large or too small. Many parameters that are difficult to model enter into land managers' actual valuations of carbon return. These include parameters for risk aversion, as well as expectations over future carbon prices, which may depend heavily on expectations over future policy. However using there is an important way in which using the net present value of the first 10 years is conservative. The fact is that 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. Of course, the value of those credits still depends on carbon prices and policy.

[6] We use the adult sheep emissions factor instead of calculating emissions for ewes and wethers separately.
[7] 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.

We calculate the net present value to the first 10 years of carbon credits using the unweighted regional average carbon stock from MAF look-up tables,[8] a constant carbon price, and a real discount rate of 8 per cent. Suppose that a forest owner could find somebody who valued the future stream of carbon credits this much. They could sell the future rights to the credits, get the present value and store it in the bank to receive the risk free return, which we assume to be 5 per cent. 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 rate. This is the value we add to our projected forest prices.

Finally, under the ETS scrub land can earn a return for its sequestration. There is no data on historical responses to scrub returns; scrub has never had a return before. Thus we model scrub returns as 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 of agricultural carbon costs. Thus, while our previous discussion focused on the direct impacts of the ETS on each of our projected price series, we further adjust these series to reflect that 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 return in a similar manner to the forestry return. We use only the first 10 years of credits.[9] Some scrub land may be of such a low quality of production that it is highly unlikely to ever be converted to productive uses. If conversion would never occur with certainty then the land owner would do best to sell all credits earned from the land. We calculate the net present value from selling the first 10 years of credits, given in MAF's look-up tables, as they are received using our assumed carbon price and an 8 per cent real discount rate. Suppose that a scrub owner sold the 10 years of future carbon credits, to somebody who valued them at a carbon price of 25 dollars and used an 8 per cent discount rate, and put the money in the bank. They would earn the risk free return. Thus we annualise the net present value of the first 10 years of carbon credits from scrub in this way. This is what we subtract from the agricultural price projections. Forestry conversion depends on anticipated returns at harvest. Thus we find the future value of the carbon return on scrub at harvest time using the money interest rate – once

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

[9] We did this for two reasons. Firstly, any policy uncertainty around the ETS at all would increase the probability that the sequestration returns to scrub would not be realised. Only valuing the sequestration returns for the first 10 years can be thought of as a crude approximation to this. Secondly, because although scrub is unlikely to be harvested, and hence is unlikely to face a carbon liability at harvest, land that will never be harvested could also be planted as forest. Thus we need a fair comparison to the carbon returns to forest.

again think of selling the future rights to carbon credits and banking the money. This is what we subtract from the forestry price projections.

2.2.3. Modelling decisions

Olssen and Kerr (*forthcoming*) estimated the responses of rural land use shares to economic returns as proxied by relevant commodity prices. The econometric model was estimated on national level time series data, primarily for the reason that no consistent disaggregated data set exists to examine the influence of the economic determinants of land use choices. However, as a result the analysis has little data to work with. One uncomfortable result is that in every model we ran the share of land in dairy farming increases when forestry export prices increase. We do not think that this represents a causal relationship. However it has implications for any ETS scenario. In particular, if we did not do anything about this relationship, then the dairy share in all our projections would increase as a result of carbon prices pushing up the effective forestry price. Because of the MAF emissions factors and free allocation the impact of a carbon price is not very large. On the other hand, the net present value of carbon under constant prices is typically quite large. This means that if we left the dairy share and forestry price relationship unaltered, that 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. This means that the change in dairy share in this scenario is not being driven by changing forestry prices. We use this as our dairy share for our final scenario. For the other series we use their shares with the full ETS model on plus a third of difference from dairy calibration to each land use.[10] 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.

3. Land use allocation module

The LURNZ national land use module produces land use projections given a carbon price. Using the econometric work of Timar (2011) the land use allocation module spatially allocates the year to year land use changes. A fuller description of the algorithms is given below.

Figure 3 shows an example of land use transitions between 2008 and 2030 under a $25 carbon price. Currently maps showing the difference between a carbon scenario and baseline are

[10] The change in the dairy share must be reallocated in sum manner to ensure that the land use shares sum to one.

not produced automatically. The total amount of transitions is completely determined in the land use change module. This module only deals with allocation. We see that most of the new dairy conversions are projected to occur in the Central North Island. Forestry conversion are projected to occur south of Auckland and on the lower North Island. Scrub conversions are all projected to occur in the far north and the bottom of the South Island.

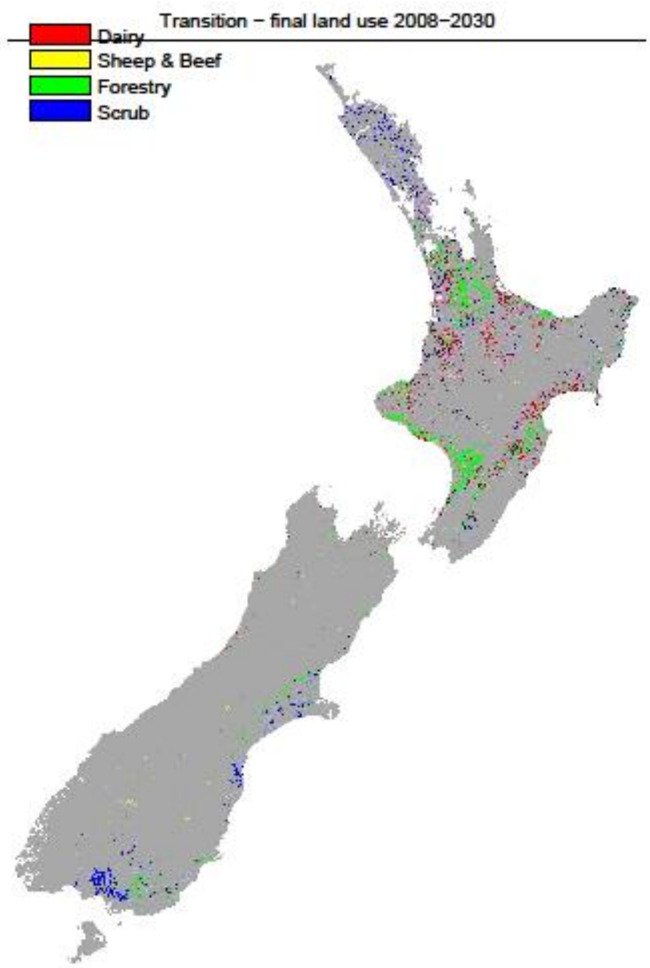

Figure 3: Land use transitions from 2008 to 2030 under a $25 carbon price

3.1. The Allocation Algorithm

The allocation algorithm is the part of the Land Use Allocation module that determines which map pixels change land use. It runs on a yearly time step.

3.1.1. The underlying intuition

Considering only dairy, sheep & beef and scrub land there appears to be a land quality continuum along which these can be arranged. The best land will be used for dairy farming. The worst land will be left as scrub. The remaining land will be split between sheep & beef farming and plantation forestry.

Changes in the returns to dairy farming relative to the returns to sheep & beef farming will determine how much of the best land is used for dairy farming. Changes in the returns to sheep & beef farming and plantation forestry relative to the return to scrub will determine how much of the worst land is left as scrub.

We can therefore imagine thresholds with regard to land quality, where land over a certain threshold is all dairy land, land below a certain threshold is all scrub land, and land between the two thresholds is sheep & beef and forestry land. The diagram in **Error! Reference source not found.** illustrates this. The locations of the thresholds are determined by the relative returns to the different land uses in the Land Use Change module.

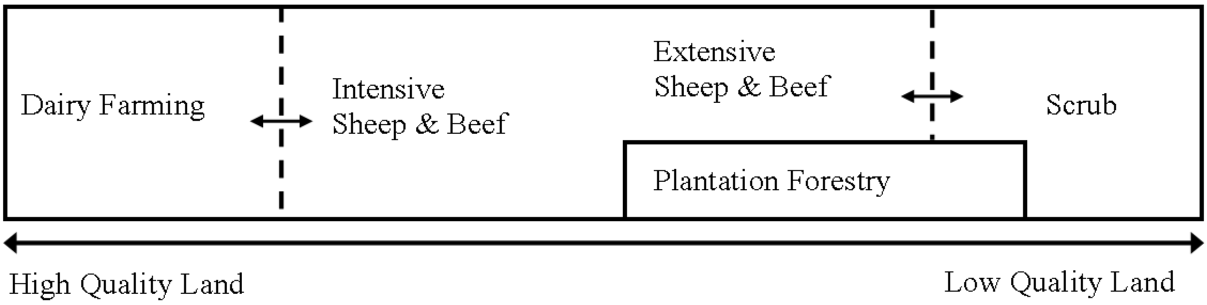

Figure 4: A heuristic diagram of land use as a function of land quality

LURNZ only allocates changes in land use, minimising the number of pixels that change land use. There are two reasons why we do not reallocate all land uses each year. Firstly, many unobservable factors drive land use and our models are unable to perfectly explain current land use. Secondly, conversion costs make transitions between land uses costly. This is particularly true for dairy and forestry land.

For dairy farming, while the cost of capital to convert to dairy is included in estimates of dairy profitability, if land were to transition out of dairy the loss of 'stranded assets' would not be included. If land must be moved out of dairy farming, we expect it to be converted to sheep & beef farming.

For plantation forestry, there are high costs to transition out of forestry before the plantation has reach maturity. In addition converting land into forestry involves the giving up of potentially significant option value of the land. We therefore minimise the conversion of land out of dairy, and out of immature forest.

In contrast, there may be relatively low costs for converting land between extensive sheep & beef farming and scrub land. When returns to sheep & beef farming are low a farmer could close off less productive paddocks, allowing them to revert to scrub. When returns to sheep & beef farming are high the farmer could open up these closed off paddocks and clear scrub, enabling them to run more animals over the increased area.

3.1.2. The algorithm

The allocation algorithm uses probabilities of being in each land use as indicators of the attractiveness of pixels for dairy, sheep & beef, plantation forestry and scrub. These probabilities are used to spatially allocate changes in land use, and are calculated for each pixel according to results from the multinomial logistic model of land use choice estimated by Timar (2011).

Consider a change in a given type of land use. We sort those pixels eligible to change land use according to their probability of being in the land use of interest. Those pixels with the greatest probability are considered the most suitable for the given land use; those pixels with the least probability are considered the least suitable for the given land use. The allocation algorithm specifies the pixels that will change land use.

For each year, given the total change for each land use, the allocation algorithm is as follows:

Step 1) We restrict plantation forestry to change to other land uses only where forestry is harvestable and deforestation is permitted.

Step 2) If dairy land increases: the sheep & beef, eligible forestry and scrub land that have the highest dairy probabilities change to dairy land. If dairy land decreases: the dairy land with the lowest dairy probabilities changes to sheep & beef land.

Step 3) If sheep & beef land increases: the eligible forestry and scrub land that has the highest sheep & beef probabilities changes to sheep & beef land, subject to an additional control on forestry land. If sheep & beef land decreases: the sheep & beef land with the lowest sheep & beef probabilities changes to scrub land (and is possibly subject to further change in step 4).

- The conversion of forestry land to sheep & beef is restricted as follows: If forestry land is increasing, no forestry land may change to sheep & beef. If forestry land is decreasing then the amount of forestry land that changes to sheep & beef must not exceed the total decrease in forestry land net of forestry land converted to dairy (e.g. if sheep & beef land is increasing by 300 ha, forestry is decreasing by 150 ha overall and 50 ha of forest was converted to dairy land during step 2, then at most 100 ha of forestry land can change to sheep & beef land).

Step 4) If forestry land increases: the scrub land (including any land released from sheep & beef during step 2) with the highest forestry probabilities changes to forestry land. If forestry land decreases, beyond any conversion of forestry land in steps 1 and 2: the forestry land with the lowest forestry probabilities changes to scrub land.

3.1.3. LUCAS Adjustment

The Ministry for the Environment (MfE) produces the Land Use and Carbon Analysis System (LUCAS) map. This map includes pre-1990 forest, post-1989 forest, indigenous forest, cropland and wetlands in 2008.

For simulating years post 2008 (from 2009 onwards) we use a baseline / start map dated 2008. This map is constructed via simulation from a map of land use in 2002. This 2008 map is simulated at a territorial authority (TA) level and corrected using LUCAS. This means that our baseline 2008 map has consistent total of land in each land use within each TA and that the land observed as forestry in 2008 is recorded as forestry on our simulation map.

In this section we go on to detail how we adjust the map simulated by LURNZ from 2002 to 2008 (referred to as the LURNZ map) using the LUCAS map.

All pixels that are pre-1990 or post-1989 forestry (classes 72 and 73) according to LUCAS that are not forestry according to LURNZ are changed to be forestry. The number of dairy, sheep & beef and scrub pixels that are changed in this way is available from the authors upon request.

All remaining pixels in LUCAS, other than grassland, that are forestry in LURNZ are changed to exogenous land uses as follows: Perennial cropland (class 77) in LUCAS is changed to horticulture (class 5) in LURNZ; Natural forest, open water wetland, vegetated non-forest wet land and other (classes 71, 79, 80 and 82 respectively) in LUCAS are changed to Other non-productive land (class 6) in LURNZ. Annual cropland (class 78) in LUCAS is changed to other animal and lifestyle land (class 8) in LURNZ. Settlements or built-up area (class 81) in LUCAS is changed to Urban (class 7) in LURNZ. The number of forestry pixels that are changed in this way is available from the authors upon request.

The pixels classified as grassland in LUCAS (classes 74, 75 and 76) that are forestry according to LURNZ are reallocated between all four endogenous land uses. The number of these pixels changed to each of the endogenous land uses depends on the number of pixels in each endogenous land use changed according to the other LUCAS classes.

We want to allocate the same number of grassland in LUCAS / forestry in LURNZ pixels to dairy, sheep & beef and scrub as we changed pixels from these land uses to forestry using the pre-1990 and post-1989 LUCAS classes, and the same number of grassland in LUCAS / forestry in LURNZ pixels to forestry as we changed pixels from forestry to exogenous land uses less the number of pixels we changed from dairy, sheep & beef and scrub land to forestry using the pre-a990 and post-1989 classes. We prioritise allocating this grassland in LUCAS to dairy, sheep & beef and scrub land and allocate any remainder to forestry.[11]

This allocation of land is conducted according to probabilities. The pixels with the highest dairy land are allocated to dairy farming first. Of the remaining pixels, those with the highest sheep & beef probability are allocated to sheep & beef farming. Of the pixels that are not allocated to dairy or sheep & beef farming, those with the greatest probability of forestry are allocated to forestry and the remainder are allocated to scrub land.

It follows that prior to adjusting the LURNZ simulated 2008 map the number of pixels of each land use in each TA and for the entire country are consistent with historic data. Following the adjustment of the simulated map using LUCAS the locations of the pixels are consistent with observed land use in 2008. There are some differences in the number of pixels of each land use in each TA between the LUCAS adjusted map and observed data. There are minimal differences in the number of pixels in each land use over the entire country between the two maps.

3.1.4. Forestry Adjustment

Wei Zhang (*forthcoming*) has developed a map of forestry ages. Including this map in LURNZ will enable us to determine when a forestry pixel is of harvestable age (around 28 years old).

[11] If there is insufficient land to allocate to dairy, sheep & beef and scrub land we allocate these all an equal proportional share of the available land. If there is insufficient dairy, sheep & beef, forestry and scrub land to allocate, then we allocate forestry a fixed quantity of land and allocate dairy, sheep & beef and scrub a proportion of the remaining land.

4. Land use intensity module

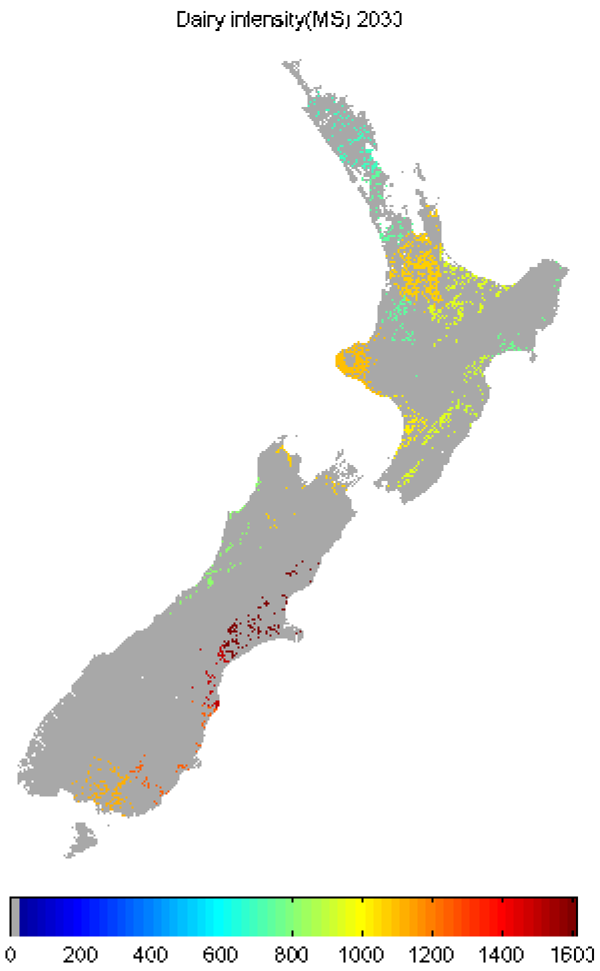

Figure 5: Milk solids projection per hectare in 2030 under a $25 carbon price

5. Greenhouse gas module

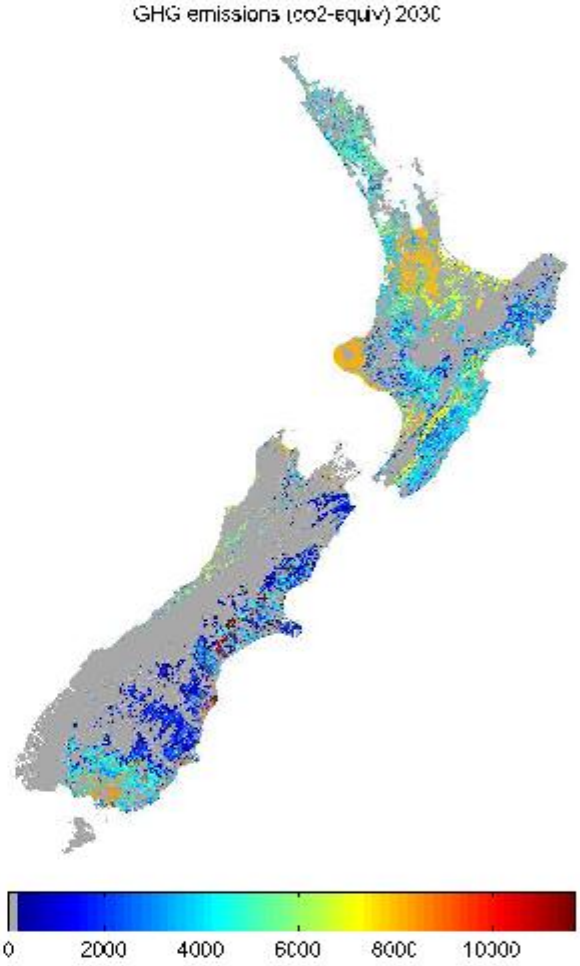

Figure 6: Net emission in 2030 under a $25 carbon price

6. Discussion

This note has discussed how we generate our ETS scenarios to 2030. The policy environment we have modelled matches closely the environment proposed for the NZ ETS as of early August 2011. Modelling the impact of the ETS on anticipated forestry and scrub returns is tricky and sensitive to assumptions. This is because anticipated returns depend on carbon price expectations as well as policy expectations. Also, scrub land has never earned economic returns before, so we have not directly estimated the effect of scrub returns on land use shares. Obtaining data and analysing how the carbon returns for forest and scrub are actually being valued would be a useful avenue for future research.