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The Land Use in Rural New Zealand Model Version 1 (LURNZv1): Model Description

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Abstract

This paper documents the first version of the Land Use in Rural New Zealand Model (LURNZv1). It describes the overall modelling approach, the database underlying the model, and the construction of each module within the model. The model is econometrically estimated from national time series data and spatially extrapolated using economic and geophysical variables. It is primarily a simulation model but is also set up to produce predictions based on future price scenarios. The model output includes projections of four types of rural land use under different scenarios and 25 ha grid maps of where land use, and changes in land use, are likely to occur.

JEL classification
C88, Q25, Q28, R14

Keywords
simulation model, land use, dairy, sheep, beef, forestry, reverting indigenous forest

Key related papers/resources from the Land Use, Climate Change and Kyoto programme:

Model Development
National land use
Intensity paper
Baisden paper.
National rural database.

Model Applications
PIMs
Sin et al

Derived policy papers
Chapman Brunton.

Website: www.motu.org/landuse_nz
Contains publications, presentations, data information and more.

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1 Introduction

This paper details the development of our land-use change simulation model: Land Use in Rural New Zealand (LURNZ). LURNZ is a computer model that predicts land-use change at a fine spatial scale over the whole country, producing dynamic paths of rural land-use change and maps of rural land use across New Zealand with an annual time step. In this paper we describe the initial version, LURNZv1, which focuses on change in four major rural land uses (sheep/beef farms; dairy farms; plantation forests; and regenerating scrubland) on 25ha grid-cells in a grid covering New Zealand.

The ultimate purpose of LURNZ is to empirically investigate the potential impacts of policies designed to alter land-use decisions. These include policies such as charging farmers in proportion to their livestock greenhouse gas emissions, or rewarding them to encourage regeneration of indigenous scrubland. LURNZ, when combined with additional components relating to specific issues, e.g. LURNZ: climate, is able to compare environmental policies related to land use that depend on science and that impact on the environment in scientifically measurable way. For example, if the government charged farmers for their GHG emissions, the amount each farmer would have to pay would depend on scientific estimates of their emissions, and measuring the effectiveness of the policy as a whole would require estimates of total emission reductions. Examples of other land-use related environmental policy issues that we could examine with LURNZ include those aimed at reducing erosion, reducing agricultural runoff, or increasing biodiversity.

The initial motivation for developing LURNZ came from the low levels of understanding of the drivers of both forest sinks and methane emissions, and from confused debate on appropriate domestic and international rules relating to these in a climate mitigation accord such as the Kyoto Protocol. No global climate model currently includes land-use change in an econometrically-based dynamic way. This is recognised to be a major omission. An improved understanding of the dynamics of land use in New Zealand could also have significant ancillary benefits for our ability to manage other environmental issues. Our programme is helping to build and integrate the databases for longer-term integrated research. It is also forming an interdisciplinary research team that can explore both the potential and the challenges of truly integrated interdisciplinary work between natural and social sciences in New Zealand.

LURNZ is dynamic and so is able to consider questions concerning the timing of policies that effect land-use, questions such as “how long does it take land use to adjust once a policy is in place?”, “what is the long-term effect on land use of the policy?” and “what is the cost of delaying the implementation of a policy?”. LURNZ is spatial and so is able to help answer questions about spatial impacts of policies that effect land-use, questions such as “which communities bear the most costs of the policy?”, “how big is the impact on the most vulnerable communities?”, and “which areas gain the most environmentally?”.

In the remainder of this section we describe briefly the main characteristics of LURNZ and some other New Zealand based models related to agricultural production. We also discuss how they could potentially complement each other. In the second section we outline the land use, production, and geophysical data that we have collected and that LURNZ is built on. We also document the ways in which those data are processed including how we combine various data to produce a map of our major land-uses in 2002; this is the starting point for our spatial simulations. LURNZ is made up of three modules: a land-use change module; a land-use intensity module; and a spatial allocation module. In section three, we discuss how the three different modules fit together, describe the land-use change and spatial allocation modules, and illustrate how the modules function and fit together by stepping through a scenario.

1.1 Characteristics of LURNZ

LURNZ predicts land-use change based on a micro-economic theoretical model where landowners choose land use to maximise future returns to their land. We derive hypotheses from the theoretical model, which we then test econometrically by taking observations of actual historical land use and statistically relating them to economic factors that we expect to drive land use decisions. LURNZ predicts land-use change by projecting the underlying economic drivers and applying these statistical relationships. LURNZv1 uses a model econometrically estimated at the national level to predict national level land-use change (Kerr and Hendy 2004). In the econometric model, national land-use change responds to changes in commodity prices, interest rates, and time.

LURNZ is dynamic. Land use change does not happen instantaneously. Accordingly, we estimate and model gradual land-use change adjustment for each land use. We allow for the evolution of factors that alter the national-average returns to land uses, such as the evolution of production technologies, though these are currently limited to historical trends.

The advantage of this statistical approach is that we derive relationships based on actual behaviour rather than assuming that we are able to accurately model what each individual's optimal response should be. We do this by relying on 'natural experiments', where prices change exogenously and we observe responses to these changes. Although our theoretical model is based on economic optimisation, our simulation model includes the effects of all other drivers of behaviour in terms of the magnitude of response.

Our approach is partial equilibrium. We focus only on the changes in rural land use and we assume that New Zealand farmers are price takers. We do not model downstream effects of price shocks on the New Zealand economy, or feedback effects.

LURNZ is spatial. LURNZv1 uses an algorithm to spatially allocate the national predictions. The algorithm is based on the same microeconomic theoretical model so that the spatial distribution of land use depends on the spatial distribution of relative land productivity.

This allows analysis of policy where the spatial distribution of certain land uses matters. For example, the existence of local areas with high concentrations of dairy farming matter when considering the damage caused by nitrogen run-off. Similarly, working at a disaggregated level enables us to consider impacts on surrounding communities. For example, if much of the impact is felt in areas where levels of deprivation are high, such as in East Cape, Northland or Taranaki, poorer people might be heavily affected by these policies.

Instead of explicitly modelling rural production systems, we use a reduced form model to predict land-use change in which production is implicit. We include explicit constraints on the amount of land available to be farmed in our econometric model. Other production constraints, such as processing capacity, are included only implicitly in the estimated relationships. This reduced form approach makes our model simpler and our results easier to interpret, with the underlying drivers of land-use change very obvious. It also means LURNZ is easier to integrate consistently with other models. To integrate, we need explicit links between the impact in question and land use. We have already created an integrated land use and greenhouse gas emissions model, LURNZv1: climate, where greenhouse gas emissions are calculated using dynamic functions that depend on land-use type and intensity. The details of LURNZv1: climate are given in Hendy and Kerr (2006). LURNZv1: climate can be used to analyse specific policy scenarios and provide empirical insight into the magnitude of effects on greenhouse gases and tradeoffs.

We can use LURNZv1 to consider any policies that can be modelled as a commodity price or interest rate shock. These include policies such as taxes or subsidies. Using LURNZv1: climate we have modelled the impacts of an emissions tax for agriculture, and a policy designed to reward scrubland reversion. In Hendy et al (2006), we have produced dynamic paths of emissions for these two policies. We can also produce corresponding cost paths and supply curves. In Sin et al (2005), we have begun to analyse which communities would be most affected by a greenhouse gas emissions charge.

1.2 Other models designed to assess impacts of policies on rural New Zealand.

We designed LURNZ to give insight into policies relating to rural land use in New Zealand. A number of other empirically based economic models related to agricultural primary production in New Zealand can also give some policy insight. Each model uses a different approach and covers different aspects of agricultural production. Each model is able to provide detailed views on different issues, such as regional employment impacts, timing of adjustment, or economy-wide impacts. LURNZ is the only one that models land use directly or that is spatially explicit. However, comparing results between these models, and in some cases linking them together, could broaden our view of the effects of land-use policies.

All the models we discuss here predict economic events using parameters that have been estimated from past behaviour and trends. Some are dynamic and others static. They are either computable general equilibrium models (CGE), which model all sectors of an economy, or partial equilibrium models, which model individual sectors, leaving the rest of the economy exogenous. They have different aggregations of sectors and regions, and can represent single or multiple sectors and regions across a country or the globe. In

Figure 1 we summarise the sectoral and regional coverage of the models discussed in this section.

CGE models are able to quantify the cross-sectoral and cross-regional effects of policies. They can quantify policy effects on the economy as a whole, giving impacts on variables such as GDP and employment. The Global Trade Analysis Project (GTAP) model is an example of a widely used CGE model. It is commonly used to consider agricultural trade policy issues and is adaptable for other issues (GTAP (2006)). Two New Zealand researchers, Allan Rae and Anna Strutt, have done extensive trade-related work with this model. The Global Trade and Environment Model (GTEM) developed from GTAP by the Australian Bureau of Agricultural and Resource Economics (ABARE) has been used to assess the impacts of ratifying the Kyoto Protocol on different New Zealand sectors and on the economy as a whole.[1]

Aggregations of commodities in the agricultural sector used for analysis in global CGE models do not necessarily match well New Zealand's mix of agriculture. Single region CGE models focussed on New Zealand have more flexibility in how they aggregate commodities, as they do not have to be aggregated to achieve consistency with data from other countries. NZIER, Infometrics (the ESSEM model) and BERL currently use comparative static,

[1] For example, see Hansard et al (2003)

single region, CGE models of New Zealand. None of these includes a land use constraint.

Sectors and regions tend to be highly aggregated in CGE models because of the large amount of consistent across-sector data required. The range of policies that can be analysed using CGE models is constrained by the lack of industry and spatial detail. Most CGEs, including the current NZ ones, are not strongly linked to econometric work. The elasticities used are based on old data. They are heavily driven by the equilibrium assumptions implicit in them, and the calibration approach used.

Partial equilibrium models can give more sectoral and spatial detail than CGE models as their narrower specification means that they require less data. Also, CGE results can be difficult to interpret and the assumptions that drive them can be obscured. Partial equilibrium models generally are simpler so are easier to interpret and more transparent. However, they do not capture effects on the rest of economy. They can give approximations of specific sectoral and regional effects of policies but their analysis is only appropriate when the flow-on effects between different sectors and regions are likely to be small.

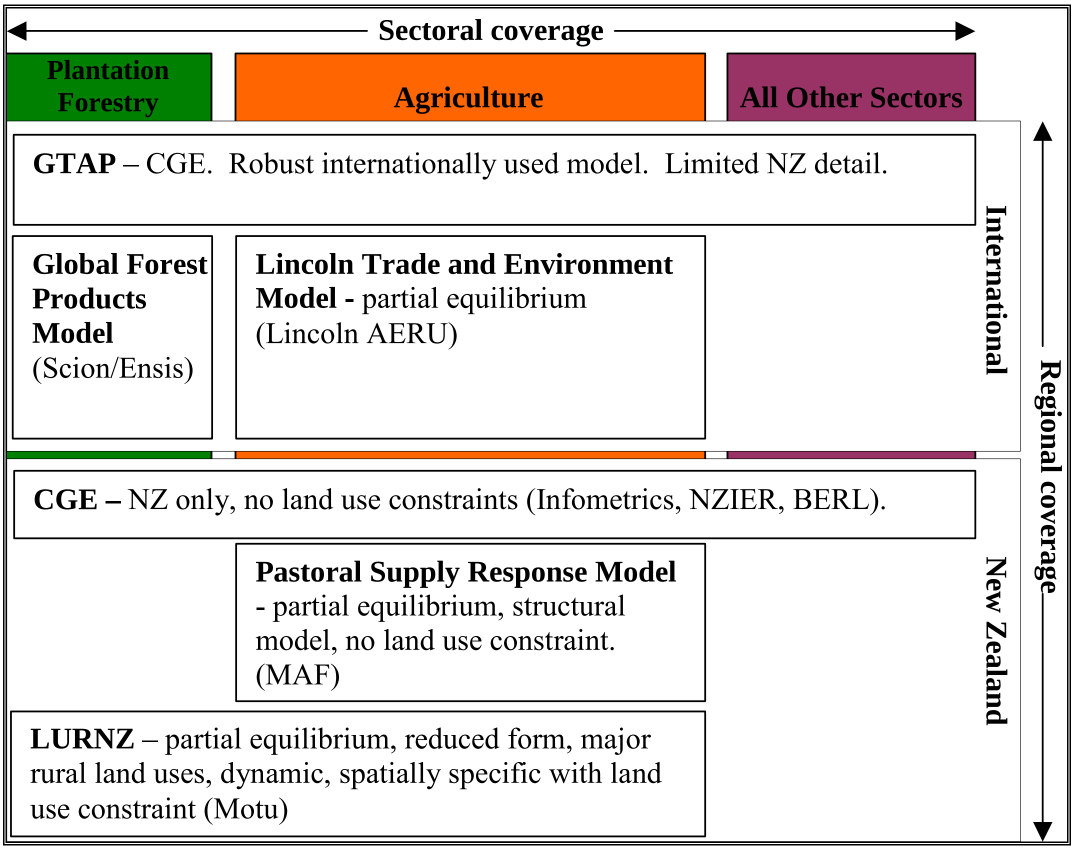

Figure 1 Sectoral and regional coverage of models used to model New Zealand rural production

A number of well-used partial equilibrium models relate to rural production in New Zealand. The Lincoln Trade and Environment Model (LTEM) is a multi-country, multi-commodity trade model (Cagatay et al (2003)). It is comparative static but can be run iteratively to create dynamic simulations. It focuses on the agriculture and horticulture sectors and disaggregates agricultural commodities further than the other New Zealand CGE models. It simulates changes in supply, demand, and trade in response to changes in agricultural and border policies. It has been adapted to include agricultural production systems and their environmental consequences.[2]

The Global Forestry Products Model (GFPM) is another multi-country, multi-commodity, trade model (Turner (2004)). It focuses solely on the forestry sector. Forecasts of the demand, supply, and trade of each of the 14 forest products are made for 180 countries, including New Zealand. From year-to-year, the supply and demand for products change through exogenous shifts driven by assumptions about the evolution of technology and national development.

The Ministry of Agriculture and Forestry (MAF) uses the Pastoral Supply Response Model (PSRM) for short-term forecasting of changes in the New Zealand pastoral sector (Forbes and Gardiner (2004)). Demand is exogenous and supply adjusts in sheep, beef, dairy, and deer production in response to price changes. The PSRM incorporates detailed structural information on processes that constrain the timing of adjustment to price shocks, taking into account interdependencies between production types.

In LURNZ we are able to model land use policies, such as taxes and subsidies, as price shocks, and then consider national and spatially specific land use implications.

Comparing LURNZ results with those from other models can provide insight into policies and increase the robustness of results. For example, LURNZ and PSRM both forecast animal numbers for dairy, sheep, and beef production; LURNZ and GFPM forecast forest area. These models could run the same policy scenarios, simulating responses in production to price shocks, to produce a range of results. The PSRM includes no land constraint but does include much more detail about production, including the time it takes to adjust to shocks. It implicitly allows stocking rates to be endogenous whereas they are exogenous in LURNZ. Predictions from PSRM provide an upper bound on production, showing how much we would produce if productive land were infinitely available. GFPM models forestry production in more detail than LURNZ, but does not model the impact of other agricultural production decisions, which may be significant drivers of forestry decisions. GFPM may provide an upper bound in forestry production. With MAF help, we ran a simple comparison between PSRM and LURNZ where we used the same price forecasts to create reference case forecasts and then ran an experiment where we raised prices in all future years. The models were relatively consistent in the first 3-5 years with PSRM better modelling the

[2] For example, Saunders and Catagay (2004) used it to consider the GHG implications of trade reforms.

transition to a higher level of livestock. The PSRM results made no sense beyond this period without additional model restrictions.

The partial equilibrium models could be linked to CGE models to provide more detail in the specific sectors to which they relate. For example, LURNZ could model the agricultural production change in response to a policy and this could be fed exogenously into a New Zealand CGE, giving an economy-wide response. Alternatively LURNZ and a CGE could be fully integrated, with the CGE feeding input and output prices into LURNZ net return functions and LURNZ returning production responses to the CGE. CGE and LTEM (agricultural prices only) price forecasts could be used as scenarios for models where price is exogenous. In particular, global CGE model scenarios produce sets of international prices that can be used to create scenarios within New Zealand models and explore the impact of international trade or environmental policies on New Zealand.

2 LURNZv1 Database

The LURNZv1 database includes data on land cover/use, economic variables, geophysical productivity of the land, and land governance. We collected the data from a wide range of sources, with different temporal and spatial resolutions. The final LURNZv1 database consists of data at three levels of aggregation: national, Territorial Authority, and 25ha grid-cell.

The national level data is annual from 1974 to 2002 and includes land use areas, livestock numbers, fertiliser use, export prices, producer subsidy equivalents (PSE), interest rates, and a consumer price index (CPI). We have land use area for dairy farming, sheep/beef farming, plantation forestry, and reverting scrubland. Our livestock categories are dairy, sheep, and beef. We have tonnes of nitrogen fertiliser use for dairy and sheep/beef farming. Our export prices are cents per kg of milksolids for dairy, cents per kg of composite sheep/beef product (including prime beef, mutton, lamb, and wool) for sheep/beef, and cents per m3 of round wood equivalent for plantation forestry. We have producer subsidy equivalents for dairy and sheep/beef. The Consumer Price Index (CPI) excludes

Goods and Services Tax and includes interest rates, and the interest rate series is the 5-year government bond yield series.

The Territorial Authority level data is for 1996 and 2002 and includes land use area and livestock numbers. The land use and livestock categories are the same as those at the national level.

The 25ha grid-cell data includes land cover, conservation land, land use capability (LUC), an agricultural productivity index, and an exotic forestry productivity index. Land cover is for 2002. The Conservation land map shows land protected in 2003. Land use capability, the Agricultural Productivity Index, and the Exotic Forestry Productivity Index are static and describe the spatial distribution of geophysical productivity.

In the remainder of this section, we describe the different data sources. In addition, we detail the procedures we used to produce spatial and temporal consistency where needed. We also describe the variables in more detail and how we derive new variables.

2.1 Data Sources

2.1.1 Agricultural Production Survey

Over our period of interest, 1974-2002, Statistics New Zealand (SNZ) conducted censuses of agricultural production in 1974-1987, 1990, 1994, and 2002, and sample surveys in the years 1988, 1989, 1991-1993, and 1995-1996.[3] For each of these years, they measured rural production and land use on June 30th, including measuring livestock numbers and fertiliser use for dairy, beef cattle, and sheep and area of 'pasture', 'plantation', and 'other' rural land uses.[4] The data is available down to the spatial resolution of a Territorial Authority (TA) (Statistics New Zealand, 2003).[5]

[3] A survey was also conducted in 1999 but it had a different population base. It did not include enterprises that were mainly exotic forestry or horticulture. It also was based on the Agribase Frame. This means the land use data, with the exception of pasture, is not comparable with other years.
[4] Exotic forestry is an exception to this. Before 1977 it was measured at January 30th.
[5] Unit record data has been kept for most variables for census years 1994 and 2002 and for the units sampled in the 1995, 1996, 1999 and 2000 surveys.

From 1972-2002, SNZ published tables giving area of land in ‘pasture’, where ‘pasture’ includes rural land that is in grass, lucerne, or tussock. However, in some years ‘land for crops’ was also included in this category.[6] SNZ published area of ‘plantation forestry’, which includes plantations of exotic trees grown for timber (and harvested areas), but excludes plantations of native trees, conservation plantings, and shelterbelts (Statistics New Zealand, 1997). SNZ also published area of ‘other’ rural land, which includes mature and regenerating native bush, native scrub, and all other land (encompassing farm building area, houses, domestic gardens, shelterbelts, conservation plantings). In 1987 a significant amount of ‘other’ rural land was reclassified as conservation land. Consequently, it was not included in the ‘other’ category from that point on (Statistics New Zealand, 1997; personal communication with Andrew McLaren, Statistics New Zealand, 2004).

The Agricultural Production Survey population frame changed in 1994 and again in 2002.[7] Prior to 1994, the population included all units in Statistics New Zealand’s Business Directory engaged in agricultural activity, where agricultural activity included horticulture, grain and arable cropping, livestock farming, and exotic forestry operations. From 1994, the population changed to include only units that were registered for Goods and Services Tax. This resulted in a decline in the number of farms in scope. The 2002 census used the 1994 population definition but, in addition, included units on the Inland Revenue Department’s Client Register engaged in agriculture activity (Statistics New Zealand 2003).[8]

2.1.2 Meat and Wool New Zealand: Economic Service Farm Surveys

Meat and Wool New Zealand: Economic Service (MWES) has conducted annual sheep and beef farm surveys since about 1950. They randomly sample about 550 farms, collecting data linking physical production with financial returns and capital structure. The sample is stratified by geographical regions and

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[6] ‘Land for crops’ was generally separated out after 1983.
[7] For 1999, a completely different frame was used so we exclude this year from our database.
[8] It was also supplemented with information from other sources such as Agribase and Meat and Wool New Zealand: Economic Service farm surveys.

by livestock numbers. The survey frame is based on a comprehensive list of sheep owners (Meat and Wool Economic Service, 2002).[9]

MWES has also collected SNZ Agricultural Production Survey data as it was publicly released, and has endeavoured to improve the time-series consistency and enhance the land-use detail by supplementing the SNZ data with information from their own farm surveys. Specifically, they improved the time-series consistency in the 'pasture' area category by including 'land for crops' in the 'pasture' category for the entire period. In addition, they used their survey data to construct national level data designed to be consistent with the Agricultural Production Statistics for 2000 and 2001. MWES linearly interpolated the years 1997 and 1998 to provide a complete national series.

Using their farm survey data on average farm size and total farm numbers, they estimated the proportion of pasture that is used for each of 'dairy', 'sheep and beef', and 'other pastoral' farming at the national level, for the years 1980-1996, 2000, 2001, and 2002. 'Other' pastoral includes lifestyle blocks, government farms, and all other livestock types (e.g. deer and goats).[10] In addition, they estimated national 'plantation forestry' and 'other rural' land for 2000 and 2001.

The LURNZv1 database incorporates both the farm survey data and the enhanced SNZ data at national level for the years 1980-1996, 2000, 2001, and 2002; and at TA level for the years 1980-1996 and 2002.

2.1.3 Ministry of Agriculture and Forestry's Pastoral Supply Response Model (PSRM) Database

The New Zealand Ministry of Agriculture and Forestry (MAF) has a database containing national-level commodity price and production data compiled for estimation of their Pastoral Supply Response Model (PSRM) (Gardiner and Su

[9] To be included a farm has to winter at least 750 sheep or their equivalent sheep plus cattle stock units and must not be run in conjunction with another property. Also at least 70% of the farm revenues must be derived from sheep or sheep plus beef cattle, at least 80% of the stock units on the property must be sheep and/or beef cattle stock units, and the farm must be run as an ordinary commercial sheep and beef farm.

[10] Personal communication, Matthew Newman at Meat and Wool New Zealand: Economic Service, 2003.

(2003)). The data is annual, from 1972-2002. This database includes annual average price per kilogram and total kilograms produced for: prime beef, wool, lamb, and mutton, from MWES; and milksolids, from the Livestock Improvement Corporation. In addition it contains livestock numbers for dairy, beef, and sheep, based on SNZ survey/census data and also includes estimates for years that did not have surveys. It includes stock unit ratios for sheep, beef, and dairy. A stock unit is a relative measure based on the feed requirements of different livestock types. Regardless of species, one stock unit should require approximately the same amount of feed. Thus, converting livestock numbers into stock units allows us to aggregate different species. These ratios take into account the different stock age compositions.[11] The database also includes average cents per metre cubed of round-wood equivalent for plantation forestry.

The PSRM database also includes measures of the subsidies that were received by farmers during the 1970s and early 1980s, measured in terms of a Producer Subsidy Equivalent (PSE). The PSE series measures the extent to which border and domestic output-related policies increase gross income to firms (Lattimore (2003)). The database includes PSEs for the years 1970, 1975, and annually between 1980-1990.

2.1.4 National Exotic Forestry Description

The National Exotic Forest Description (NEFD) began in 1983. It describes area, age-class, and management information for planted production forest as at 1 April.

The NEFD is compiled primarily from an annual postal census of forest owners and managers of large planted production forests. Every year, MAF carries out a census of larger forests, with the forest area threshold alternating between 40ha and 1000ha in consecutive years.[12] In years where the census includes forests greater than 40ha, the coverage of total forest area is

[11] 1 sheep = 0.923 stock units; 1 dairy cow = 6.150 stock units; 1 beef animal = 4.874 stock units. These come from the MAF PSRM database.

[12] E.g. the 2002 survey included forests over 1000ha, and the 2001 survey included forests over 40ha.

approximately 80%, and in the other years, it is nearer 70%.[13] When the threshold is 1000ha, the survey data is supplemented with information on smaller forests from the previous year's survey (Ministry of Agriculture and Forestry, 2003).

The remaining 20% of forest area includes forests under 40ha and newly planted area. Since 1992, new planting has been imputed using a survey of the sale of planting stock from commercial forest nurseries. Since 1995, forests smaller than 40ha are accounted for using the 1995 Statistics New Zealand small forest grower survey and imputation of new planting (Ministry of Agriculture and Forestry, 2003). Because the data coverage is variable, the time-series consistency is not good.[14]

2.1.5 CPI and Interest Rates

The LURNZv1 database includes a Consumer Price Index that excludes Goods and Services Tax and includes interest rates, and a 5-year government bond yield series. Both are from the Reserve Bank of New Zealand and for the years 1974-2002.

2.1.6 Fertiliser use - the National Inventory Report

The National Inventory Report (Brown and Plume, 2004) produces a national level time-series of the amount of nitrogen applied as fertiliser to pasture annually from 1990-2002. These data were originally sourced from FertResearch.

2.1.7 Land cover database 2 (LCDB2)

The Land Cover Database 2 (LCDB2) is a Geographic Information Systems map classifying 42 land cover and land use classes for mainland New Zealand, the Chatham Islands, and near-shore islands for the summer of 2001/2002. The database consists of spatially explicit polygon features that represent homogeneous contiguous areas of land use or land cover (Thompson, 2005).[15]

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[13] Initially, the survey had 90% coverage when the Forest Service and large companies dominated the industry (Personal communication with Paul Lane, 2003).
[14] Personal communication with Paul Lane at MAF, 2003.
[15] A similar satellite map of land use classes, LCDB1, is available for the summer of 1996/7.

The map was derived from a composite of Landsat 7 Enhanced Thematic Mapper (ETM+) satellite images acquired between September 2001 and March 2002. Cloud affected areas were infilled using either aerial photography from summer 2001 or, when photographs were not available, more recent Landsat ETM+ images, up to 31 December 2002 (Terralink International Limited, 2005). Terralink International Ltd generated a draft classification based on the images and then Agriquality carried out extensive field checking both to help develop the relationship between the satellite signatures and the land use classes and to verify the draft classifications (Grüner and Gapare, 2004).

The classes were mapped uniquely down to a 1ha (100m×100m) area; this is referred to as the minimum mapping unit.[16] The map has a root mean squared positional accuracy of 20m. The classification accuracy has not been established but the probability that the class indicated on the map is actually that class on the ground is given in Table 1 (Thompson, Grüner and Gapare, 2003).

Table 1 Probability that the map class in LCDB2 matches the class on the ground

Land use/cover	Probability of Correct Mapping (%)
Bare Ground	94
Indigenous Forest	96
Mangrove	97
Other	94
Planted Forest	95
Horticultural	81
Pastoral	95
Scrub	89
Tussock	91
Wetlands	94
Source: Thompson (2005)	

[16] An exception to this is areas classed as Minor Shelterbelts, which were captured as line strings if they exceeded 150m in length.

2.1.8 Conservation land register

The Department of Conservation (DOC) land register is a GIS database of conservation land, covering the New Zealand mainland and offshore islands. Conservation land includes Crown land held under the Conservation Act, Reserves Act, National Parks Act, Wildlife Act, Marine Reserves Act, and the Marine Mammals Protection Act. It excludes seabed or foreshore not set aside for a particular purpose. The map also includes private or Maori land that has legal protection through a conservation covenant or Nga Whenua Rahui kawenata, a lease to the Minister of Conservation, agreement under s76 Reserves Act, easement held by the Minister of Conservation, sanctuary refuge or management area under the Wildlife Act. In addition, the map includes other conservancy land for which DOC has information (mostly local authority reserves). The database contains approximately 18,000 polygons referred to as "conservation units". Polygon areas are recorded in hectares to 4 decimal places, but are not very accurate (Froude, 1999).

The register is not time-stamped, and is updated when conservation units change. It is kept current. We acquired the file from DOC in May 2003.

2.1.9 Land-use capability

Landcare Research developed a GIS database that classifies land based on its limitations for productive use measured by climate and geology. This classification, referred to as Land Use Capability (LUC), gives an indication of what uses the land is capable of supporting in the long term.

To make the classification, areas of land that are essentially homogeneous in rock type, soil unit, and slope were identified; these areas were defined as homogeneous polygons. Experts then intuitively assessed each polygon in the database using aerial photographs, existing information (e.g. soil information) and additional fieldwork (Froude, 1999). They based their assessment on physical characteristics, which, in addition to rock type, soil type, slope group, included erosion, vegetation, and climate information, past land-use effects, and the potential for erosion.

Each polygon was classified on a discrete scale from 1 to 8, with class 1 land being the best for sustained agricultural production and class 8 being land with severely limited uses (Froude, 1999); each class is described in Table 2. Classes 1 to 4 are suitable for cultivation. Classes 5 to 7 are not suitable for cultivation, but may be better suited to farming or forestry. Class 8 is not suitable for any productive use (Environment Waikato, 2005).

Table 2 Description of the LUC Classes

LUC Class	Description
1	Good multi-use land, flat to very gently sloping, deep, easily worked soil, negligible risk of erosion.
2	Flat to gently rolling land with slight physical limitations, may be used for cultivated cropping, horticulture, pastoral farming or forestry.
3	Land with moderate physical limitations for cultivation; may be used for cultivated cropping, horticulture, pastoral farming or forestry.
4	Land with severe physical limitation for cultivation; constraints on the choice of crops able to be grown; may require intensive soil and water conservation treatment and careful management practices.
5	Too many limitations to be cultivated for cropping. Negligible to slight erosion risk under pastoral or forestry use. Typically stony, wet or sloping land with high quality, stable soils. Where slopes prevent cultivation, some horticulture may be suitable.
6	Moderate limitations for pastoral use. Suitable for forestry.
7	Severe limitations for pastoral use. Suitable for forestry.
8	Severe physical limitations; not suitable for any form of cropping, pastoral or production forestry use; only suitable for watershed protection.
Source: Environment Waikato (2005)	

The database consists of about 100,000 polygons, with the minimum polygon resolution equal to 25 hectares and average polygon size approximately equal to 300 hectares {Leathwick, 2002 6661 /id}. The database covers the North and South Island and inshore islands, but excludes Stewart Island. The database began in 1973 and new information is added when it comes available (Froude, 1999). We acquired it in May 2003.

The LUC is part of a larger database that has been used primarily by regional councils as a basis for guiding soil management and other related functions (Froude, 1999). A number of councils have also used the LUC as a basis for rules within statutory plans. LUC provides well-tested and widely used information on where dairy, sheep/beef, and plantation forestry, are likely to be feasible and to be best suited.

2.1.10 Agricultural and Forestry productivity indices

Baisden (2006) developed indices designed to estimate the biological productivity of land when used for pastoral and forestry production. He used a 'Storie Index' approach, where indices of co-limiting soil and climate factors are multiplied together to give a productivity index. The Storie Index approach has been actively in use in California for over 60 years and has been a useful tool for determining rural land values.

Indices that help describe spatial variation in biological productivity already exist in the Land Environments in New Zealand (LENZ) GIS database; an example is the LUC map. However, the average size of a polygon in the LENZ database is approximately equal to 300 hectares and thus the maps of these indices are not detailed enough to describe spatial variation within farms. Baisden's aim was to create indices that give greater spatial detail. He reinterpreted data layers from LENZ, to design productivity indices that give sensible results at 1 ha.

To create the indices, Baisden correlated soil and climate indices with recently updated Storie Index rating tables reported for parts of northern California, using areas that are suitably similar to New Zealand. Each of the underlying indices was measured as a percentage where 100% corresponds to no limitations. The indices were recalibrated against a map of average biological Net Primary Production (NPP) in New Zealand, derived from data from the NASA MODIS sensor averaged over the years 2000 to 2003. The process is described in detail in Baisden (2006).

The final Forestry Storie Index is the product of slope, soil water deficit, and drainage indices. The Agricultural Storie Index is the product of slope, soil moisture deficit, drainage, particle size, and growing-degree-day indices.

2.2 Data Processing

Using the data described above, we created datasets at three levels of aggregation: national, TA, and 25ha grid. This section describes the processes involved in creating the datasets and deriving the new variables within the datasets.

2.2.1 National level data

As mentioned earlier, the national level data includes variables describing land use area, fertiliser use, export prices, production amounts, livestock numbers, 5-year bond interest rate, Consumer Price Index, and Producer Subsidy Equivalent. The dataset is annual, and covers the period 1974-2002; land use and animal numbers represent the situation as at June 30th of the appropriate year and the export prices are annual averages over the year ending June 30th. We describe the derivation of each of the variables in detail below. Final datasets complete with documentation are available at www.motu.org.nz/land_use_changedatabase.htm

2.2.1.a Land use areas

We designed the land-use area variables in the LURNZ database to reflect the actual hectares of land used for 'dairy' farming, 'sheep/beef' farming, 'plantation forestry', and 'scrub'. [17]

Pasture: Dairy and Sheep/Beef

Our pasture area is mostly based on MWES/SNZ pasture. For 1981-2002, we used the MWES/SNZ pasture area that includes arable land. For 1974-1980, we extrapolated back the MWES/SNZ series using changes in the published SNZ pasture area. Finally, we scaled the entire series by *0.798*, so that it matched LCDB2 pasture area in 2002.

For 1980-1996, 1999 and 2002, we divided the pasture into dairy and sheep/beef area by multiplying MWES estimates of the pastoral share of each by our new pasture variable. To fill in the remaining years, 1974-1979, 1997, 1998, 2000 and 2001, we estimated a linear relationship between dairy area and dairy livestock numbers; and sheep/beef area and sheep/beef stock units and

[17] This is as opposed to farm type area, which is measured as the heterogeneous "farm" level with type classification being the major land-use on the farm.

extrapolated/interpolated the missing years based on changes in livestock numbers and stock units respectively.[18]

Plantation forestry

For 1980-1996, and 2000-2002, we used the MWES/SNZ plantation area. For 1974-1979, we extrapolated back the MWES/SNZ series using changes in the published SNZ plantation area. To fill in the remaining years 1997-1999, we estimated a linear relationship between plantation area and NEFD plantation area and extrapolated/interpolated the missing years based on changes in NEFD plantation area.[19] Finally, we scaled the entire series by *0.779*, to match LCDB2 plantation forest area in 2002.

Reverting scrubland

For 1980-1996 and 2000-2002, we based on our estimate on the MWES/SNZ 'other rural' area. For the years 1980-1986 we subtracted the change in "other" land that occurred between 1986 and 1987.[20] For 1974-1979, we calculated a SNZ residual category by subtracting "pasture", "plantation", and "horticulture" from "land in agriculture". We then extrapolated our "other" area back based on changes in the residual category. For 1997-1999, we linearly interpolated "other" land area. Finally, we scaled the entire series by *1.1*, to match LCDB2 scrub area in 2002.

This gives us our land use variables for our national-level time-series dataset. The final data for the area of dairy, sheep/beef, other pastoral land, plantation forestry, scrub, and other rural land for the years 1974-2002 are given in

[18] area_dairy = 8.25 L – 0.004 Ly – 86.5y (N=19; R2=0.99) ; area_sheep/beef = 0.60 L – 0.0027 Ly – 2991y (N=19; R2=0.99). L is the number of livestock/stock units and y is the year.
[19] SNZ_area_plantation = 1.05 NEFD_ area_plantation (N=14; R2=0.99)
[20] In 1987, a significant amount of rural land was reclassified as conservation land, resulting in some land that had been administered by the Department of Lands and Survey being passed over to the Department of Conservation (Agricultural Statistics, 1996). This land was all classified in the Survey as 'other' (Personal communication with Andrew McLaren, SNZ, 2004). We smoothed this out by subtracting the total change in the "other" category between 1986 and 1987 from all the previous years.

Table 3.

Table 3 Land use areas ***(1000s of Hectares)***

Year	Dairy	Plantation	Scrub	Sheep/beef	Total Rural
1974	1,122	449	2,297	8,605	12,474
1975	1,091	507	2,393	8,593	12,584
1976	1,062	553	2,636	8,571	12,822
1977	1,050	572	2,694	8,653	12,968
1978	1,055	598	2,459	8,709	12,821
1979	1,050	628	2,476	8,680	12,834
1980	1,078	685	2,235	8,913	12,911
1981	1,060	742	2,156	8,738	12,695
1982	1,076	750	2,125	8,685	12,637
1983	1,101	780	2,158	8,545	12,584
1984	1,081	811	2,194	8,545	12,631
1985	1,072	855	2,372	8,545	12,844
1986	1,172	896	2,327	8,632	13,028
1987	1,089	918	2,382	8,808	13,197
1988	1,050	986	2,312	8,239	12,586
1989	1,066	973	2,323	8,273	12,635
1990	1,122	1,016	2,305	8,035	12,477
1991	1,111	1,036	2,337	8,066	12,549
1992	1,095	1,040	2,054	8,035	12,224
1993	1,118	1,087	1,918	7,595	11,718
1994	1,212	1,159	1,493	7,905	11,770
1995	1,291	1,246	1,348	7,834	11,718
1996	1,301	1,311	1,489	7,364	11,466
1997	1,371	1,380	1,469	7,457	11,677
1998	1,401	1,418	1,449	7,346	11,613
1999	1,391	1,458	1,428	7,379	11,656
2000	1,386	1,479	1,408	7,393	11,666
2001	1,469	1,517	1,408	7,309	11,703
2002	1,575	1,552	1,408	7,231	11,765

2.2.1.b Animal numbers and Prices

The PSRM database includes livestock numbers and stock units for dairy cattle, beef cattle, and sheep annually from 1974-2002. We use these data directly to give livestock numbers and stock units in the LURNZ database.

The PSRM database also includes export prices for dairy cattle, beef cattle, and sheep and corresponding export prices covering the years 1974-2002. In the LURNZ database, our dairy price, cents per kg of milksolids, and our 'plantation forestry' price, cents per m^3 of roundwood equivalent, both come directly from the PSRM. We derived our sheep/beef price from a number of other prices in the PSRM database. We created the composite sheep/beef price by taking a weighted average of the price for prime beef (cents/kg), price for wool (cents/kg clean wool), price for sheep meat (cents/kg, itself a weighted average of lamb and mutton prices). We weighted by volume of product (kgs) in 2002.[21]

To account for the effect of subsidies on prices received by farmers, we multiplied each export price by the corresponding PSE series, as PSEs are formulated as a % increase in returns farmers receive. From the PSRM, we have annual PSE data from 1980-1990. For the 1970s, the PSRM database has PSE estimates for 1970, 1975, and 1980; to create a complete series we linearly interpolated between these points.

We deflated the adjusted export prices using the RBNZ CPI series that excludes GST and includes interest rates. The prices are in 2002 New Zealand cents. Thus, our final price variables (shown in Table 4) are real, and include an adjustment to account for government subsidisation of agriculture.

Table 4 Commodity prices and interest rates

Year	**Dairy price**	**Plantation forestry price**	**Sheep/beef price**	**5-year government bond yield**	
	Cents per kilogram of milksolids	*Cents per m3 of roundwood equivalent*	*Cents per kilogram of composite sheep/beef product*	*Nominal*	*Real*
1974	714	16,811	625	5.2	-6.3

---

[21] The composite price is derived from total hot weight kgs of slaughtered beef cattle excluding bobby calves (Q_{beef}), schedule price cents per kg of prime beef (P_{beef}), total hot weight kgs of slaughtered lambs (Q_{lamb}), schedule price cents per kg of lamb (P_{lamb}), total hot weight kgs of slaughtered adult sheep (Q_{mutton}), schedule price cent per kg of mutton (P_{mutton}), total kgs of clean wool (Q_{wool}), cents per kg clean wool price at auction (P_{wool}). First, we combine annual mutton and lamb prices:

$$P_{sheep} = \left(\frac{P_{lamb} Q_{lamb} + P_{mutton} Q_{mutton}}{Q_{lamb} + Q_{mutton}} \right)$$

$$Q_{sheep} = Q_{lamb} + Q_{mutton}$$

Then, we create a composite sheep/beef price as a weighted average of the beef, wool and sheep prices, weighted by their 2002 quantities:

$$P_{sheepbeef} = \frac{P_{beef} Q_{beef}(2002) + P_{wool} Q_{wool}(2002) + P_{sheep} Q_{sheep}(2002)}{Q_{beef}(2002) + Q_{wool}(2002) Q_{sheep}(2002)}$$

where $Q_{beef}(2002)$ =555 million kgs, $Q_{wool}(2002)$ =174 million kgs, and $Q_{sheep}(2002)$ =529 million kgs. These data were supplied by MAF and originally sourced from MWES.

1975	652	15,698	349	5.4	-9.4
1976	608	14,242	487	5.7	-11.5
1977	551	12,862	549	7.5	-7.0
1978	552	14,698	455	9.0	-2.1
1979	497	14,133	515	9.8	-5.4
1980	500	15,472	498	12.2	-4.1
1981	447	16,455	442	13.0	-3.1
1982	524	14,043	493	12.7	-3.9
1983	542	14,021	559	12.5	7.2
1984	481	14,873	559	11.9	4.9
1985	452	18,052	548	12.3	-4.0
1986	546	16,132	359	18.5	7.4
1987	337	14,319	333	17.1	9.0
1988	361	13,488	312	16.7	11.1
1989	452	10,996	334	13.5	8.4
1990	462	11,916	360	12.8	7.8
1991	296	12,276	296	12.5	10.3
1992	405	11,807	296	10.0	9.0
1993	437	17,678	339	7.9	6.4
1994	378	21,290	329	6.7	4.9
1995	385	14,667	288	7.5	3.9
1996	442	13,574	252	7.9	5.6
1997	398	12,494	264	8.0	7.0
1998	368	11,957	264	7.2	5.5
1999	388	9,744	278	6.5	7.0
2000	397	10,397	315	6.1	3.1
2001	514	12,358	375	6.9	4.4
2002	532	9,670	398	6.1	3.5

2.2.2 Territorial Authority Data

At the Territorial Authority (TA) level for 2002, we use data on numbers/stock units of dairy, sheep, and beef livestock, and land-use area of dairy, sheep/beef, other pastoral, plantation forestry, scrub, and other rural land.[22]

The data are based on the MWES version of the SNZ areas of pasture, plantation forestry, and other rural land, and the numbers of dairy, sheep, and beef

[22] Kawerau and Invercargill city are not included as no data were available for those TAs.

livestock. First, we scaled the pasture, plantation forestry, and scrubland areas so that each land use's total area was equal to the associated area in the national dataset. In each TA, we scaled pasture area by *0.798*, plantation forestry area by *0.779*, and other area by *1.01*.[23]

Next, we used the national dairy and sheep/beef areas in conjunction with MWES/SNZ livestock stock units and pasture areas by TA, to infer the area of dairy and sheep/beef land in each TA. We began by calculating an initial guess at the area of each land-use *(lu)* in each TA=*i.* This 'first' guess was based on assuming that the dairy and sheep/beef area are distributed over TAs in proportion to livestock stock units, i.e.

$$FirstGuessArea_{i,lu} = \frac{SU_{i,lu}}{SU_{lu}} Area_{lu}$$

where $SU_{i,lu}$ denotes the stock units for land use *lu* in TA *i*, SU_{lu} denotes national stock units associated with *lu,* and $Area_{lu}$ denotes the national area of *lu.* Implicitly, with this first guess we are assuming that stocking rates are uniform over the country.

For consistency, we require the area of dairy, sheep/beef, and other land to equal the observed total pasture in each TA. Unsurprisingly, the 'first' guess areas calculated above did not exactly equal the observed pasture. So, we adjusted the initial guesses to fit the observed data using the simple method detailed below.

The observed area in a *TA=i* will equal the sum of the implied pastoral land use areas plus a residual term, r_i:

$$Area_{i,pasture} = FirstGuessArea_{i,dairy} + FirstGuessArea_{i,sheepbeef} + r_i$$

The residual, r_i, is equal to the area of 'other pasture' plus an error term.

[23] It would have been better to do this scaling for each TA separately. There would be considerable variation in deviation from LCDB and will be correlated with the quality of the land. With this method, the amount of rural land in each TA will not sum up. This is a not a problem for the current version but will need to be addressed in later versions of the model.

If $r_i < 0$, this implies we over-estimated the total pastoral land in the TA. We adjusted the land use areas down for any TAs where this was true. Lowering the land-use area will raise the implied stocking rate in the TA. Dairy land has much less variation in stocking rates than sheep/beef land.[24] Consequently, we adjusted the sheep/beef areas to fit the data and left dairy land area the same. Specifically, we subtracted the absolute value of the residual, $|r_i|$, from the estimated sheep/beef area.

$$Area_{i,sheepbeef} = FirstGuessArea_{i,sheepbeef} - |r_i|$$

Also, we assumed there is no 'other pasture' in these TAs.

However, having done this adjustment, the total national sheep/beef area was no longer equal to the observed national area. It falls short by $\sum |r_i|$ over all TAs where $r_i < 0$; we refer to this short fall as R^{-ve}. So, we needed to increase the inferred sheep/beef area in TAs where $r_i > 0$. We did this by apportioning R^{-ve} between these TAs, in proportion to r_i / R^{+ve} where R^{+ve} is the sum of the residuals over all TAs where $r_i > 0$. Thus, in each TA with $r_i > 0$, the sheep/beef area would become:

$$Area_{i,sheepbeef} = FirstGuessArea_{i,sheepbeef} + R^{-ve} \frac{r_i}{R^{+ve}},$$

Finally, we set 'other pasture' equal to the size of the remaining residual term:

$$Area_{i,otherpasture} = r_i - R^{-ve} \frac{r_i}{R^{+ve}}.$$

This gave us a dataset with the area of dairy, sheep/beef, and other pastoral land, plantation forestry, and scrub at the TA level, for 1996 and 2002. Implicitly, we also had derived sheep/beef stock rates that vary by TA.

[24] Using data from the Livestock Improvement Corporation (Livestock Improvement Corporation (2001)) on dairy stocking rates, we found that the standard deviation in dairy stock units per hectare across TAs in 2001 was *1.7*. Using data from MWES farm surveys (see section 2.1.2), we found the standard deviation in sheep/beef stock units per hectare across farm-classes in 2002 was *3.6*.

2.2.3 25ha grid data

Our raw GIS data includes six data layers: Conservation Land, LCDB2, LUC, Agricultural Productivity Index, Exotic Forestry Productivity Index, and the TA boundaries. For consistency, all the GIS data in the LURNZ database has been converted to a grid format, by being overlaid onto the LURNZ 25ha grid. The LURNZ grid covers New Zealand's North Island, South Island and inshore islands with square grid cells, 25ha in area.[25] We chose a 25ha resolution because it was close to the level at which individuals make land-use decisions and the associated data was feasible to work with, with the dataset small enough so that computation was not too time-consuming. For each layer, we overlaid it onto the LURNZ grid and assigned a unique value as an attribute to each grid cell. The value of the original data layer that coincided with the geometric centre of the grid cell determined the value of the associated grid cell attribute.[26]

We created the 2002 land-use map in the following way. First, we identified the conservation grid-cells using the Conservation land register (described in 2.1.8).[27] We classified the remainder of the grid-cells as either urban, pasture, forestry or scrub using the LCDB2 (described in 2.1.7), aggregating the LCDB2 land cover categories to match the LURNZ broader classifications of land use (shown in Table 5).

Table 5 Land Cover Database 2[28]

Map Colour	LURNZ	LCDB2
Yellow, red and white	Pasture (includes sheep/beef, dairy, other-pasture)	Depleted Tussock Grassland, High Producing Exotic Grassland, Low Producing Grassland, Tall Tussock Grassland, Alpine Grass-/Herbfield
Cyan	Plantations	Afforestation (imaged, post LCDB 1), Afforestation (not imaged), Deciduous Hardwoods, Forest Harvested, Other Exotic Forest, Pine Forest - Closed Canopy,Pine

[25] The grid excludes Stewart Island.

[26] We used this approach to avoid bias; the other option, using a majority rule or mean, would introduce bias for land uses that are thin and long. We will still have introduced error in the process we chose but it is likely to be unbiased error.

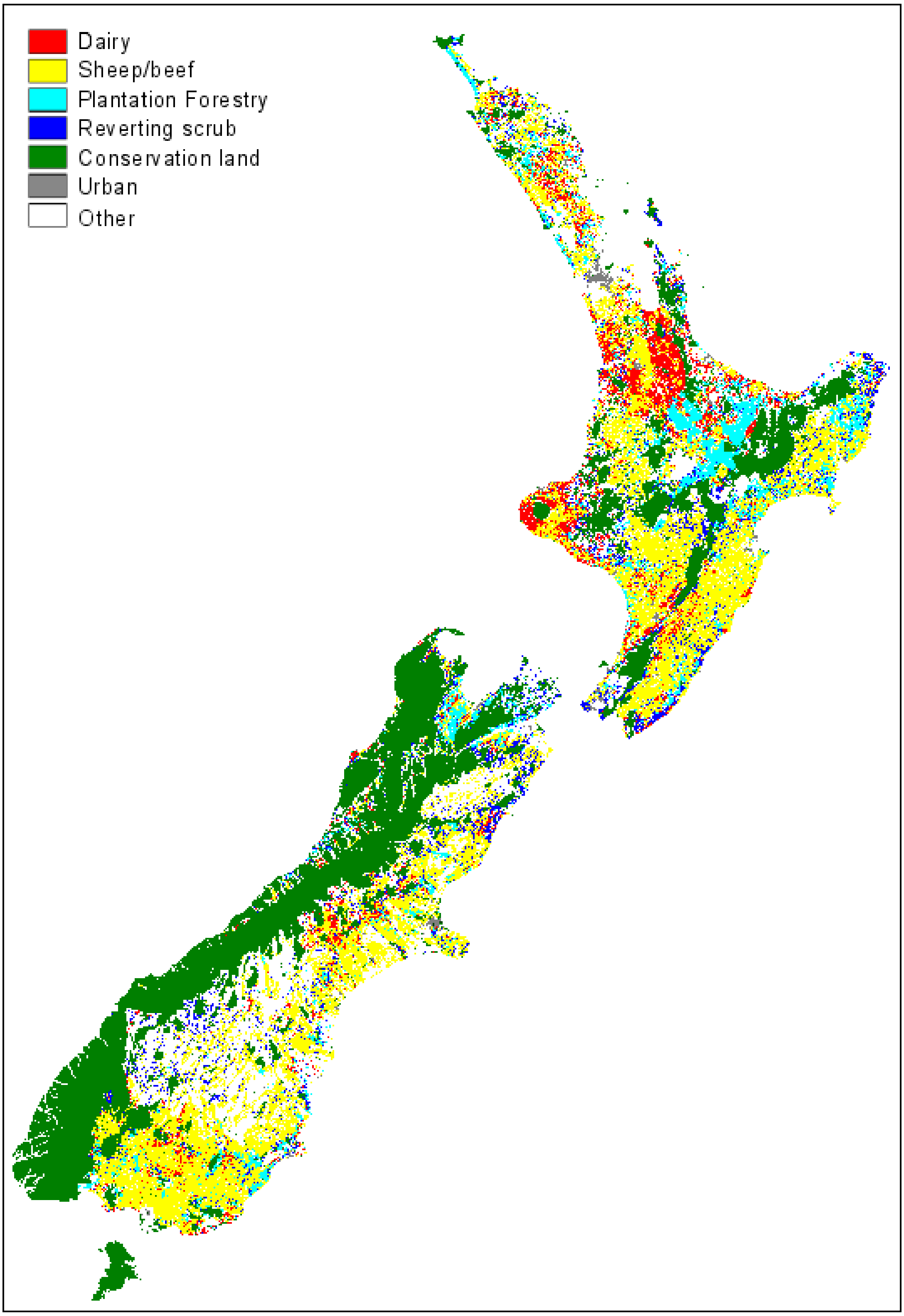
[27] Some conservation land may be in use as agriculture or forestry. But, because the drivers of land-use change on conservation land are different to those on private land and our focus is only on private land-use making decisions, we do not determine the land-use of any grid-cell that is identified to be in the conservation estate.

[28] We exclude conservation land. Also, flaxland, sub alpine shrubland, and landslides are not necessarily in the best categories. Next time we might put these in different categories.

		Forest - Open Canopy
Blue	Scrub	Broadleaved Indigenous Hardwoods, Flaxland, Gorse and Broom, Grey Scrub, Manuka and or Kanuka, Matagouri, Mixed Exotic Shrubland, Sub Alpine Shrubland, Fernland, Major Shelterbelts
Grey	Urban	Built-up Area, Urban Parkland/ Open Space
White	Horticulture	
White	Non-productive	Alpine Gravel and Rock, Coastal Sand and Gravel, Dump, Estuarine Open Water, Herbaceous Freshwater Vegetation, Herbaceous Saline Vegetation, Lake and Pond, Landslide, Mangrove, Permanent Snow and Ice, River, River and Lakeshore Gravel and Rock, Surface Mine, Transport Infrastructure

Finally, to identify whether the pastoral grid cells were dairy, sheep/beef, or 'other pasture', we used the land use areas from the TA dataset in conjunction with LUC and the agricultural productivity index. Within each TA, we sorted each grid-cell from most productive to least. We used a nested sort, where each grid-cell was primarily sorted based on its LUC classification, and then within the LUC groups, each grid-cell was sorted based on its agricultural productivity index. After sorting, we assumed that land-use is distributed optimally within TAs based on land-quality. We assigned the TA dairy area to the highest ranked grid cells, the 'other pasture' area to the next highest ranked grid cells, and the sheep/beef area to the worst ranked grid-cells.

This process gave us our 2002 map that gives a unique land-use to each of the grid-cells at a 25ha resolution. Each pixel is classified as conservation, dairy, sheep/beef, 'other pasture', plantation forestry, indigenous scrubland, urban, or 'other' (non-rural). The map below shows the result of our initial allocation. It displays the probable location of our four land-uses in 2002, with all other land uses masked out. One critical problem with our current algorithm is that the geophysical productivity measures ignore the possibility of irrigation – thus we misallocate dairy land within territorial authorities, especially in Canterbury.


Dairy
Sheep/beef
Plantation Forestry
Reverting scrub
Conservation land
Urban
Other

For every grid-cell we calculated the proportion of the grid-cell's neighbours in each land use. We defined neighbouring grid-cells as the eight closest grid cells to a particular grid cell. In our grid dataset, we have four neighbourhood variables; these are counts of the number of neighbouring grid cells in dairy, sheep/beef, plantation forestry, and reverting scrub.

Thus the processed GIS data in the LURNZ database includes areas of conservation land, urban land, dairy, sheep/beef, other pastoral, plantation forestry, scrub, and other for 2002; neighbourhood variables; and geophysical productivity measures including land use capability, an agricultural productivity index, and an exotic forestry index.

3 Model Construction

LURNZv1 simulates change in land use and land-use intensity for dairy, sheep/beef, plantation forestry, and scrub, based on exogenous forecasts of changes in export prices, interest rate, and total 'rural land'. Non 'rural land' includes conservation land, urban, horticulture, and roads. Based on these inputs, LURNZv1 produces maps and national-level paths of land-use change, livestock numbers, and fertiliser use.

To simulate, LURNZ uses three main modules, a land use module, a land-use intensity module, and a spatial module. Figure 2 illustrates the inputs and outputs of LURNZ, the three main modules in LURNZ, and their links.

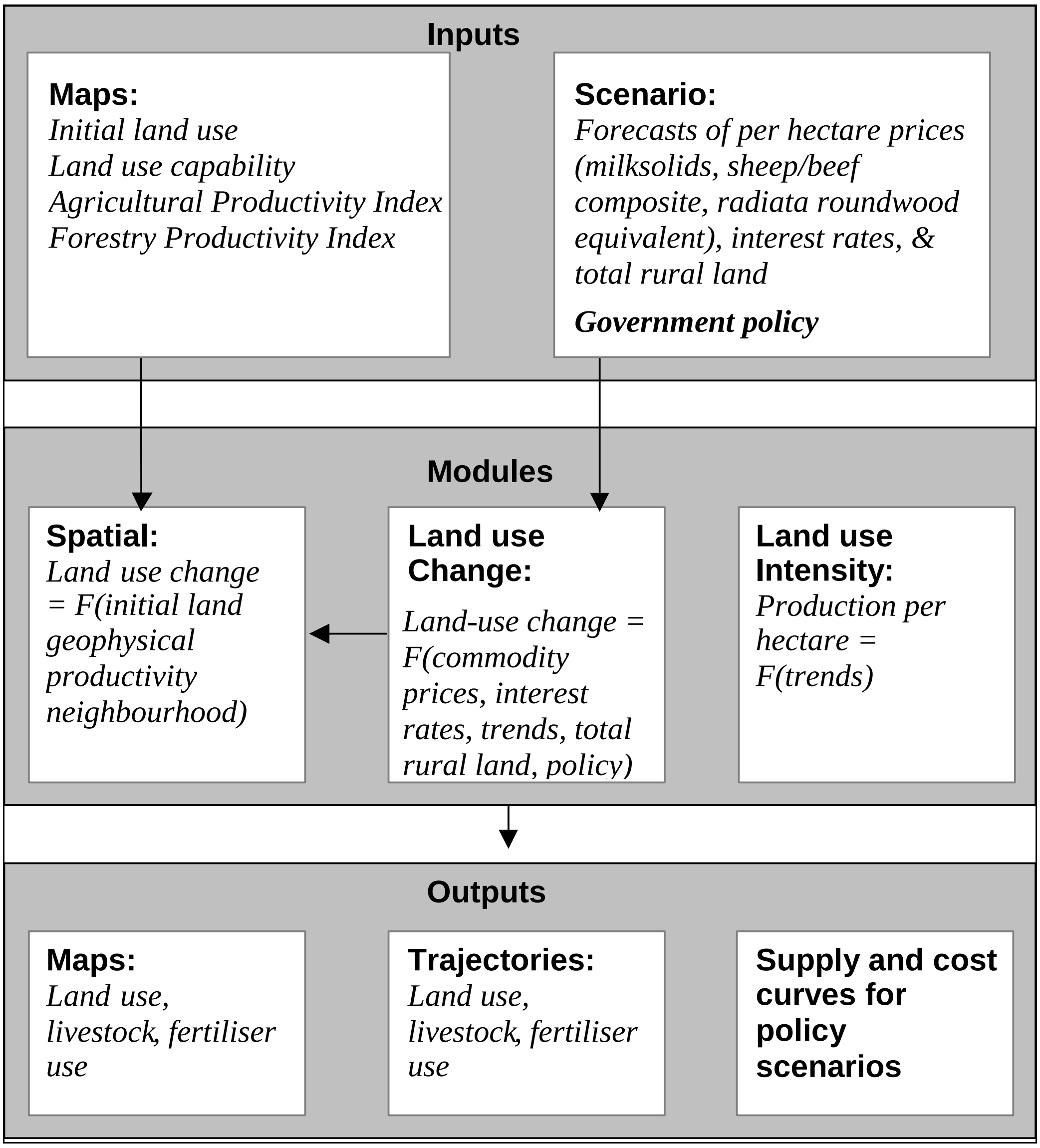


Figure 2 Components of LURNZ

The land-use change module uses an econometrically estimated microeconomic model that predicts short and long run land-use change at the national level. We based the specification of the econometric module on a heuristic microeconomic model, which assumes that landowners choose the land use that will give them the highest economic return, which depends on potential economic returns, conversion costs, and relative uncertainties associated with the different land uses. Apart from changes in commodity prices, interest rates and total 'rural land', the current econometric model responds only to average trends in all unobserved factors such as costs and relative uncertainties and assumes that conversion costs are symmetric; the cost of getting out of dairy is the same as the cost of getting in. We discuss the heuristic model in more detail in 3.1 and the derivation of the econometric model in 3.1.1.

Our current land-use change module implicitly allows for changes in land use intensity. However, to calculate certain environmental impacts, and to compare LURNZ with other models of rural activity levels, we need to calculate land-use intensity explicitly. So, in parallel with the land-use change module, LURNZ runs the land-use intensity module to predict changes in the intensity related variables: stocking rates and fertiliser intensity. The module predicts changes by extrapolating past trends in intensification of land use. The development of the land-use intensity module is discussed in greater detail in Hendy and Kerr (2006).

By combining the predictions of land-use change with the output from the land-use intensity module, LURNZ calculates changes in land-use area, livestock numbers, and fertiliser use at the national level. Based on these predictions, LURNZ uses the spatial module to map the changes on the LURNZv1 grid. The spatial model is founded on the same heuristic microeconomic model as the national time series. This model predicts that when economic conditions change, it is land lying on the margin (with respect to expected returns) between two land uses that will be the most likely to change use. The spatial module uses algorithms based on this concept, in conjunction with maps capturing variation in geophysical and socio-economic productivity, to identify the land that is most likely to change. We discuss the underlying conceptual model in 3.1.2 and the algorithms in 3.1.3.

We designed LURNZ to allow us to analyse the effectiveness and potential impacts of different policy scenarios. With LURNZv1, we can simulate any policy that can be modelled as a direct effect on the exogenous variables, commodity prices, interest rates, trends, and other land. For example, we can model a tax (or subsidy) as a reduction (increase) in commodity price, if we assume that landowners will respond to a tax in the same as a commodity price shock. For policy scenarios, LURNZv1 produces supply and cost curves associated with the policy, as well as maps and trajectories.

Under certain policy scenarios, outputs from the land-use intensity module will affect simulation results on land use. An example is a policy where landowners are charged in proportion to their agricultural greenhouse gas emissions. The charge would influence the economic conditions that landowners face, and thus affect the land use module. The amount a landowner has to pay would depend on land use but also on the livestock numbers and the amount of fertiliser used on that land, both of which are predicted by the land-use intensity module. Because land use intensity is currently exogenous, these results need to be interpreted with care.

In sections 3.2 and 3.3, we step through the procedures that LURNZ uses to simulate. These sections illustrate in more detail how the three modules interact to produce maps and trajectories of land-use and land-use intensity change.

3.1 Modelling land-use change

We assume that landowners solve a dynamic optimisation problem and choose the land use that brings them the highest net present value of expected utility (Stavins and Jaffe (1990)). Based on this, we assume that landowners care about expected net returns, conversion costs from one use to another, and relative uncertainty. For simplicity, here we discuss the static optimisation problem.

At any point in time, returns per hectare to a particular land use on a farm are given by:

$$R = py - w'x$$

where p is the output price, y is the yield per hectare, w is a vector of input prices, and x is a vector of input quantities. Landowners choose y^*, the optimal yield, to maximise their net future returns where y^* is constrained by the potential yield (or more technically the 'production function').

Potential yield depends on production technologies and the available inputs, which include land. Because land is heterogeneous, potential yield varies across space. The variation is driven by the variation of the natural capital of the land, where natural capital includes a mix of land characteristics such as soil type, climate, topography, altitude, and access to water. The variation in natural capital means it is possible to produce high yields on some pieces of land while no production is possible on others. In general, the better the natural capital of the land the more that can be potentially produced and vice versa.

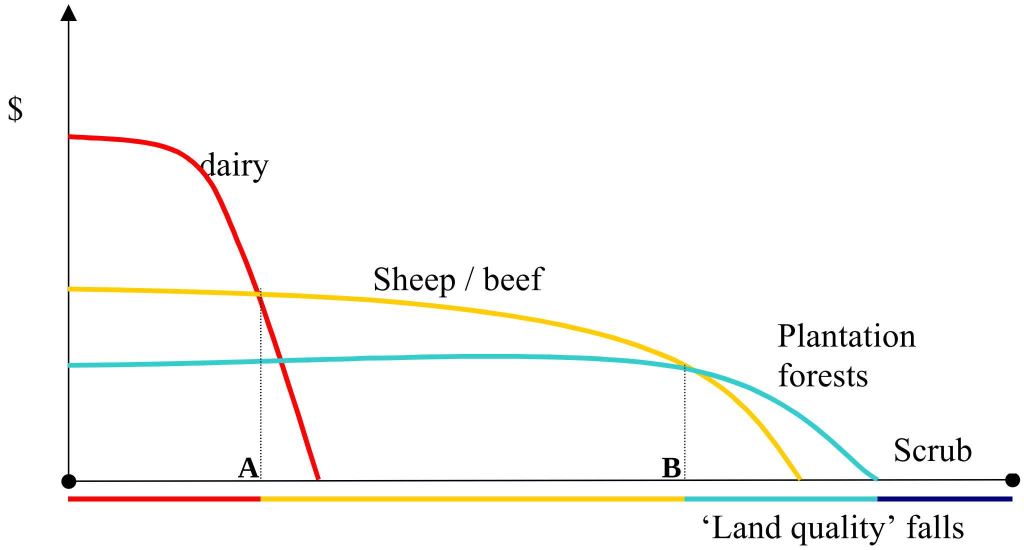
The optimal yield, $y*$, will be less than or equal to the potential yield. Like potential yield, $y*$ will depend on production technologies and the available inputs. But $y*$ also depends on input prices w. y* and $x*$ will be jointly determined. The cost of production is then $c = w'x*$ and net returns are $R = p'y* - w'x*$.

Optimal yields and costs are jointly determined by the mix of natural capital and socioeconomic characteristics, which we refer to jointly as 'land quality'. The socio-economic characteristics of land include availability of local infrastructure, services, and information/support networks. For a given yield, the better the land quality, the lower the costs. The better is the quality of land and the lower are the costs, the higher is the yield chosen.

Thus spatial variation in land quality also drives spatial variation in optimal returns. Figure 3 illustrates the hypothesised heuristic relationship between optimal returns and land quality along one-dimension, land quality. The real relationships are multi-dimensional. The y-axis indicates the expected return to the landowner from each hectare of land. The x-axis represents land quality, moving from the 'best' land on the left, to the 'worst' land on the right. Each curve represents the optimal return on land of that land quality from one particular use. According to our model, the landowner will choose the land use that will give the highest return. At the point where each curve intersects we can drop a line to the horizontal axis to indicate the transition point from one land use to another in terms of land quality.

For example, point A in Figure 3 indicates a transition point between dairy and sheep/beef farms. On a land parcel of this land quality the returns to dairy and sheep/beef would be the same, so a farmer on this type of land would be indifferent between dairy and sheep/beef. Slightly to the left of point A, the land quality is better, the returns to dairy would be higher than the returns to sheep/beef, and so a farmer would choose dairying as the optimal land use. Slightly to the right, the land quality is worse and sheep/beef would give the highest returns. Point B illustrates another transition point, this time between sheep/beef and forestry.

Figure 3 Economic returns and land use



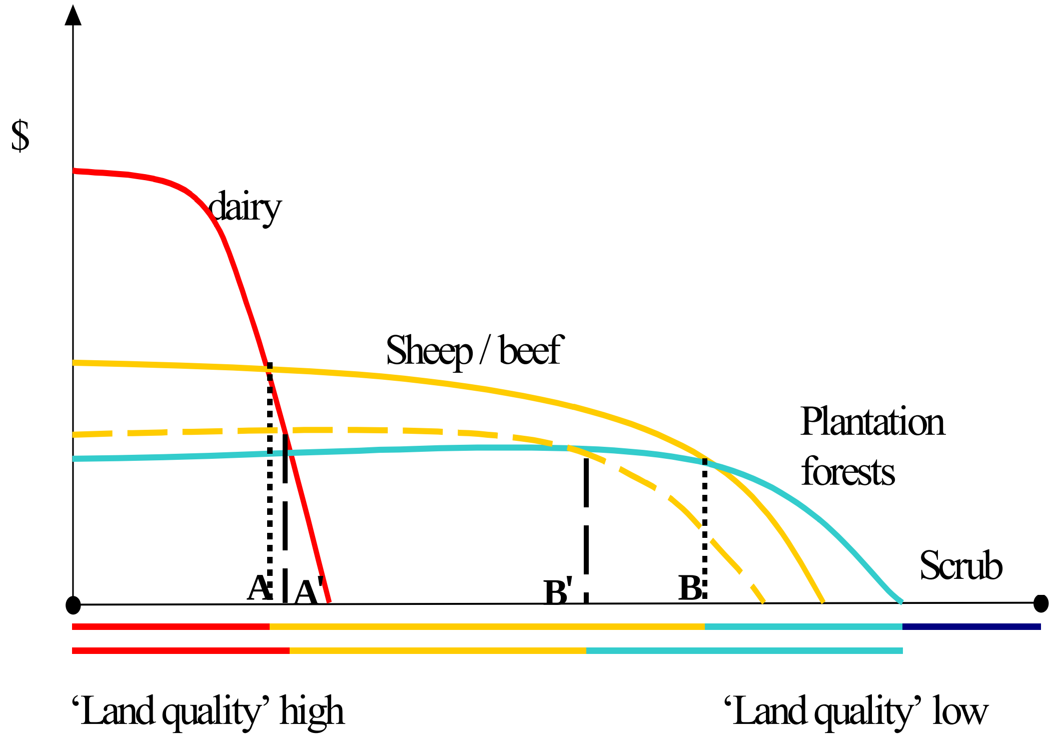
If prices, production technologies, or costs change, the optimal returns functions will change. The points of intersection between the different curves will shift, and the optimal land use will change for land parcels that are near transition points.[29]

Marginal land parcels are parcels that lie close to the transition points. Figure 4 illustrates the effect of a reduction in the output price for sheep/beef farming on the potential returns curves shown in Figure 3. The transition between sheep/beef and forestry, which previously occurred on land with quality at point B, would shift to the left. Now forestry would be the optimal choice on the better land of quality between point B and point B'. Marginal land lies between these points.

[29] The ordering of land quality depends on production technologies and costs. Changes in these could alter the ordinal relationship between the varying qualities of land. Land quality is not related to output price. A change in output price will monotonically transform the potential returns curves; it will shift the potential returns curves up or down and change the slope of the curves, but the slope will remain negative. We model policies as price changes, so we can assume that the ordinal relationship between the varying qualities of land does not change.

Similarly, the transition between sheep/beef and dairy, which previously occurred on the land quality at point A, would shift to the right to point A'. Now, dairy would be the optimal choice on the lower quality land between point A and point A'. The transition points between optimal land uses will alter in terms of land quality. The optimal use of marginal land will change.

Figure 4 Changes in optimal land use



Fixed costs associated with converting between different land uses mean that these curves will be state dependent. Land uses that require a lot of upfront capital investment would be relatively less attractive before the investment occurs. After the investment is made, because the cost is sunk, the land use would be relatively more attractive.

For example, consider a piece of land currently in sheep/beef that lies on a transition point between sheep/beef and dairy. The potential returns to sheep/beef are:

$$R_{sb} = p_{sb} y_{sb} - w'_{sb} x_{sb}$$

The potential returns to dairy, given that the land is currently in sheep/beef are:

$$R_{d|sb} = p_d y_d - w_d' x_d - rI_{d|sb}$$

where $I_{d|sb}$ is the capital investment needed to convert to dairy given that the land is currently in sheep/beef and r is the cost of the capital. Because the land is on a transition point, the returns to sheep/beef equal the returns to dairy given that the land is currently in sheep/beef. So:

$$\begin{aligned} R_{sb} &= p_{sb} y_{sb} - w_{sb}' x_{sb} \\ &= p_d y_d - w_d' x_d - rI_{d|sb} \\ &= R_{d|sb} \end{aligned}$$

If the same piece of land were actually in dairy to begin with, the return to dairy would not include a conversion cost. The investment is now a sunk cost. It would be given by:

$$\begin{aligned} R_d &= p_d y_d - w_d' x_d \\ &> R_{sb} \end{aligned}$$

So, in this case, the same piece of land would not lie on a transition point between sheep/beef and dairy. Thus, the potential-returns curves are state dependent.

We have discussed examples along one dimension of land-quality. However, the potential return curves actually vary along multiple dimensions. This is because land quality is determined by multiple land characteristics and the potential return to a piece of land depends on the quality mix of the land characteristics. For example, a farm that is close to a town may have higher potential returns than a farm that has better soil but is further from a town.

3.1.1 Empirical Model

To create our national model of land-use change, we model land use area responses in each of our rural land-uses to exogenous shocks in commodity prices. This model was developed and econometrically-estimated (using 29 years of data) by Kerr and Hendy (2004).

For each of four land uses, i, we assume that the share of rural land in use i, s_i, depends linearly on a constant, the share of 1974 rural land not used for the four major land uses, *OL* (to account for changes in total rural land) the output prices for each of the major land uses, p_i, and the nominal interest rate r.

$$s_i = \alpha_i + \beta_i OL + \sum_j \gamma_{ij} \log p_j + \delta_{1i} r + \delta_{2i} time \qquad \forall i$$

Estimating these as a system with cross equation restrictions gives us an estimate of the long-run response to price shocks. The estimated residuals from the long-run equation give a measure of the degree to which land use is out of equilibrium at each point in time.

We estimate short run land use responses using the estimated residuals from the long-run equation $\varepsilon_{LR,i}$, and the same explanatory variables differenced between years, giving:

$$\Delta s_i = \phi_i \varepsilon_{LR,i} + \beta_i \Delta OL + \sum_j \gamma_{ij} \Delta \log p_j + \delta_{1i} \Delta r + \delta_{2i}$$

We estimate the system of equations using a time-series of land-use shares from the Agricultural Production Survey. Our commodity price data come from the MAF Pasture Supply Response Model database, and our interest rates are from the Reserve Bank 5-year bond interest rate series.

3.1.2 Land quality

The characteristics of land parcels that affect returns vary in different ways at each geographic scale. Variation in yields and costs between territorial authorities (TAs) is driven by the natural capital of the TA, the TA infrastructure, services, and the strength of relevant information/support networks. Variation in yields and costs between and within farms is based on the spatial natural capital of the farm, access to infrastructure and services within the TA, on-farm infrastructure, farm-scale, and the farmer's networks.

We can relatively easily map variation in natural capital; scientists at Landcare Research have developed and mapped a number of different indices to capture the variation relevant for rural production (as discussed in 2.1). Mapping socio-economic characteristics is less straightforward, but we can use proxies to capture likely variation in the quality of and access to infrastructure and services, and access to relevant information/support networks.

3.1.2.a Mapping Natural Capital

As we described in section 2.1.9, the Land Use Capability (LUC) map captures regional variation in climate and geology and is designed to tell us the suitability of land for different uses as well as its limitations.

Dairy is the highest-value production system relative to sheep/beef and forestry, and relies on highly productive, rotationally grazed pastures (Parliamentary Commissioner for the Environment, 2004). As a consequence, much pasture in New Zealand is likely to be unsuitable for dairy. In contrast, many sheep/beef farms are still productive on much lower quality land. Traditionally, sheep/beef farms have been run on low input pasture grazing production systems, sometimes supplemented with other feed. Production systems vary according to land type, topography, climate, and scale. These vary from high-value intensive systems, which are feasible only on higher quality land, to low-value extensive systems, for which much lower quality land is feasible. For plantation forestry, even though soil and topography are important, they are less limiting than for the other uses.

So, we use the LUC map to indicate areas that are feasible for different land uses and to indicate their relative productivity. For example, all four land uses modelled in LURNZ are feasible on LUC 1 and LUC 2 land, and each land use will be more productive on LUC 1 than LUC 2. We assume that dairy is feasible only on LUC 1-3 land; some type of sheep/beef farming is generally feasible up to and including LUC 6 land; and plantation forestry is feasible up to and including LUC 7 land.

LUC 1 land allows the highest-value, most intensive sheep/beef production. As we move towards LUC 6 land, only lower-value, extensive sheep/beef production is feasible. So, we assume that plantation forestry generally competes with extensive sheep/beef farming for land. For all land uses, we assume that LUC 1 will bring the highest returns and those that are LUC 8 will bring the lowest.

Within a farm, some areas may be suitable for a particular land use but other areas may not be. For example, dairy cows cannot be run on steep portions of the farm. And even when feasible, some paddocks will be more productive than others. For example, animals need supplemental energy on steeper, colder, less-fertile paddocks, for a given level of milk production.

Although reliable at the broad level, the LUC classification is not reliable for individual farm planning. According to the MWES farm survey in 2002-2003, the average farm size was around 600ha; the average polygon size in the LUC is 300ha. While the LUC has the advantage of being well known and robustly developed, the LUC mapping is not precise enough to capture variation at the farm level.

Consequently, Baisden (2006) has developed separate productivity indices for agriculture and exotic forestry that can be used to map local variability in land productivity. The indices capture local variation in topography and soils. They are designed to give reasonable accuracy to 100ha precision, and be robust at a resolution 5 times greater than the LUC.

So, we use the productivity indices to give us a unique ranking of our 25ha grid-cells. For each of our land uses, we assume that the greater is the productivity value, the lower is the cost of producing a given amount, and the greater are the potential returns. We use the agricultural productivity index to rank land for dairy and sheep/beef, and the exotic forestry productivity index to rank land for plantation forestry.

3.1.2.b Proxies for mapping variation in infrastructure, services and information/support networks

TA infrastructure that supports agricultural production includes ports, roads, electricity, water supply, and processing industries. Supporting service industries include stock agents, freight firms, fertiliser supplies, banking and accounting services, veterinary services, transportation services, top-dressing services, skilled-labour, and retail outlets. A high level of these infrastructure and services directly increase returns by reducing production costs. Some infrastructure and services will benefit only specific land uses; examples include sawmills, freezing works, dairy factories. Others will benefit all land uses, but may have a greater marginal benefit for particular land uses. For instance, electricity will generally benefit all land uses but it is a much more valuable input for a dairy farm than a forestry plantation.

The area of a specific land use within the TA will likely be correlated with the strength of infrastructure, services, and networks. For example, if there is a large amount of dairy land in a TA, it is likely that a dairy factory has been built to process the milk, services have been developed to supply fertiliser and supplemental feed, and the electricity grid has good coverage of the TA. Thus, we use the area in the TA that is devoted to each specific land use as a measure of the variation in infrastructure, service and network factors relevant to that land use between TAs. This measure is endogenous but at each point in time it is historically determined and not affected by current prices.

The potential returns for all land uses will be higher the closer they are to supporting infrastructure and services. Of our four land uses, dairy is the most intensive user of public roads, electricity, water, and upstream servicing industries supplying fertiliser and supplemental feed. Furthermore, dairy production has become increasingly more dependent on inputs as dairy land has expanded onto lower quality land, which needs more irrigation, supplemental feed, and fertiliser. Thus, because dairy is the highest valued and most intensive user of these inputs, it will have the greatest marginal benefit from locating close to supporting infrastructure and services. In contrast, forestry is generally the least intensive and lowest-valued land use so will tend to be pushed onto land further away from general infrastructure and services.

Agricultural information/support networks, which include formal organisations such as Federated Farmers as well as informal networks of farmers or foresters, help increase returns by providing a mechanism to disseminate information (including information about new production techniques and the use and value of new technologies or services). They lower the learning costs associated with changing land uses. Farmers who have already converted to dairy will have learned about the appropriate production techniques for the local area. Dissemination of that knowledge will reduce the learning costs of other farmers who choose to convert later. Consequently, the greater the area of a particular land use in a TA, the lower are likely to be the learning costs associated with land use conversion.

Potential returns will also be affected by on-farm infrastructure and by farm scale. To be productive, farms need infrastructure such as milking sheds, shearing sheds, fences, farm roads, and irrigation systems. Once the infrastructure supporting a land use is built, the marginal cost of converting neighbouring paddocks to that land use is much smaller. Dairy production depends on the existence of a milking shed and in many cases access to irrigation schemes. If a farmer has already built a milking shed and there is excess capacity from the milking shed, the marginal cost of expanding dairy into neighbouring paddocks will be much lower. Sheep/beef farms require less costly infrastructure than dairy but they do require infrastructure such as fences and shearing sheds. Roads are the most critical farm-level infrastructure for forestry. Forestry needs access for planting, pruning, thinning, and most importantly harvesting. Once roads are built, the marginal cost of expanding the forest will be reduced.

A farmer may benefit from increasing returns to scale if she expands the area of a particular land use in her farm, resulting in increasing the per hectare returns for the land use. For example, on a 100ha farm, if 75ha are already in forest then the marginal cost of planting, pruning, and harvesting another 25ha might be small relative to the cost of maintaining 25ha in sheep.

To capture farm-level variation in on-farm infrastructure and land use scale, we use the current spatial patterns of land use near each grid cell. If there are dairy paddocks in an area then it is likely that the manager of the land has access to a milking shed, the electricity grid, and an irrigation system (if required). As a proxy for these farm-level factors, we count the number of neighbouring grid-cells in each type of land use for each grid cell.

3.1.3 Ranking land quality

Identifying marginal land will tell us where land-use change is likely to occur. We do not need to know the exact potential returns functions to identify marginal land. All we need to be able to do is to compare the characteristics of any two pieces of land and identify which has the greater potential return, for each land use. Thus, for each land use, we create an ordinal relationship among all land parcels in terms of observable characteristics. Then, we use an algorithm based on our heuristic model (See section 3.1 for more details) to identify the marginal land.

We create quality rankings using data from the LURNZ spatial database described in section 2.2.3. We have maps of the variation of quality as measured by different characteristics, discussed in the previous two sections, and we have a map of land use (see section 2.2.3 for more details). We use these maps to create land-use specific summary quality rankings for each piece of land. The summary quality rankings are based on a combination of measures that describe different aspects of land quality using observable land characteristics. We base the relative importance of each characteristic in the quality ranking on ad hoc assumptions.

We use five characteristics to create our summary land-quality rankings. First, we use a measure that characterises land-use feasibility. We create this measure by aggregating the eight LUC categories into land-use feasibility groupings A to C. Category A includes LUC 1-3; these are grid-cells that are feasible for dairy, sheep/beef, plantation forestry, and scrub. Category B includes LUC 4-6; these are grid-cells feasible for sheep/beef, plantation forestry, and scrub. And category C includes LUC 7-8; these are grid-cells feasible for forestry and scrub only. Second, we use the area of the specific land use in a TA to characterise the availability of TA level infrastructure, services, and information/support networks that support the specific land use. Third, we use the LUC 1-8 indices to characterise geophysical limitations of the land for the specific use. Fourth, for each grid-cell we identify the land use of the neighbouring eight grid-cells and count the number of neighbours in the specific land use. We use this to characterise the likely existence of farm-level infrastructure, economies of scale and local networks that support the specific land use. Fifth, we use the productivity index value of each grid-cell to characterise relative productivity at 25 ha scale.

We create our summary ranking by sorting grid-cells according to these characteristics. We use a nested sorting process.[30] Column 1 of Table 6 shows the order that the characteristics (shown in Column 2) are included in the nested sort.

Table 6 Characteristics included in general ranking

Order in Nested Sort	Characteristic	Quality Measure of Characteristics	Sort Scale
1	Productive feasibility	**LUC A:** LUC 1-3 feasible for dairy, sheep/beef, plantation forestry **LUC B:** LUC 4-6 feasible for sheep/beef, plantation forestry **LUC C:** LUC 7-8 plantation forestry	Between feasible groups, within NZ
2	TA infrastructure, services, and networks.	**Current area of land use**	Between TAs, within feasible groups
3	Geophysical limitations	**LUC classes:** 1-8	Between LUC classes, within TAs
4	Farm-level infrastructure, economies of scale and, networks.	**Number of neighbours** Group M: 50% or more of neighbouring grid-cells currently in land use Group L: Remainder	Between grid-cells, within LUC classes.
5	Physical productivity	**Productivity index**	Between grid-cells within neighbourhood groups.

In a nested sort, the order by which we choose to sort the charactistics determines the relative importance of each characteristic in our ranking. The order determines how far a characteristic can move the grid-cell up or down the ranking. For example, we could generate a ranking by sorting grid-cells by the area of a specific land use in the TA they belong to and then within this, sort grid-cells by their LUC value from least (1) to most (8) geophysically restricted land. Using this ranking, a grid-cell that is in LUC 2 land in a TA with a lot of dairy would be

[30] The sorting of numbers in the phone book is an example of a nested sort. Phone numbers are sorted alphabetically by surnames first, and then within these groupings they are sorted alphabetically by first names.

higher in quality than a grid-cell that is in LUC 1 land in a TA with slightly less dairy area. Thus this ranking implies that TA infrastructure is more important than natural capital. Alternatively, we could generate a ranking by sorting grid-cells by their LUC 1-8 value first and then sorting grid-cells by their TA's land-use area within these LUC groups. Using this ranking, a grid-cell that is in LUC 1 land in a TA with no dairy area would be higher in quality that a grid-cell that is on LUC 2 land in a TA with a lot of dairy. Thus, this ranking would imply that natural capital is more important than TA infrastructure.

We base our order of sorting in part on the resolution at which the data varies. This maximises our degrees of freedom meaning we can include more characteristics in our summary. For example, if we sort first by a characteristic that varies by TA, then we can also sort within this grouping by a characteristic that varies by grid-cell. But if we sort by a characteristic that varies by grid-cell first we have a unique ordering so we cannot then sort within by the TA characteristics.

If we were purely to use the resolution of the characteristics' variation to determine the order of the nesting, we would order by LUC then TA area within LUC, then neighbourhoods within LUC groups, and finally productivity within neighbourhood groups. The downside to this approach is that the order of importance is fixed by resolution only and so unrealistic rankings could result. For example, if we order by LUC 1-8 first then by TA land-use area, a grid-cell that is in LUC 2 in a TA with a lot of dairy would be lower in quality that a grid-cell that is in LUC 1 in a TA with no dairy area. The fact that there is a lot of dairy in the TA of the first grid-cell suggests that the potential returns in that TA are likely to be relatively high. And the fact that dairy does not exist in the TA of the second grid-cell suggests that the potential returns to dairy are likely to be relatively low. This ranking puts very little weight on previous land use area and may not be realistic.

Another option would be to rank by TA land use area first then by LUC 1-8. But with this order, we also may end up with unrealistic rankings. For example, a grid-cell that is in LUC 8 in a TA with a lot of dairy would be higher in quality than a grid-cell that is in LUC 1 in a TA with slightly less dairy area.

Expert evidence would suggest that this quality ranking is not realistic; dairy is simply not feasible on LUC 8 but is feasible on LUC 1.

To avoid extremes, we aggregate the LUC 1-8 groupings into the feasibility groupings A-C. We sort by these first. Within this, we then sort by TA land-use area, and then within these groups we sort by LUC 1-8. This means that a grid-cell that is in LUC 4 in a TA with a lot of dairy would be lower in quality than a grid-cell that is in LUC 1 with less dairy area. But a grid-cell that is in LUC 2 in the TA with a lot of dairy would be higher in quality than the grid-cell that is in LUC 1 but in a TA with slightly less dairy area.

To maintain degrees of freedom for the next sort, for our local neighbourhood characteristic we aggregate the number of grid-cells neighbours in a specific land use into two neighbourhood groups: group M includes those that have more than 50% of their 8 neighbours in the specific land use and group L includes those that do not. We rank group M above group L.

Thus, to create a dairy ranking, we first sort grid-cells from feasibility A through C. Within feasibility classes, we then sort grid-cells by the area of dairy in the TA to which they belong. Then, within each TA, we sort grid-cells by their LUC class from 1-8. Within each LUC class, we sort all the grid-cells by their dairy neighbourhood group, M then L. Finally within the dairy neighbourhood groups, we sort grid-cells from most productive to least productive, based on the agricultural productivity index. We do the equivalent thing for sheep/beef, and forestry. For forestry we use the exotic forestry productivity index instead of the agricultural productivity index for the final sort.

For scrub, we create a slightly different ranking. We define the suitability of a piece of land for scrub by its unsuitability for other land uses. We sort each grid-cell by categories C to A first, then sort grid-cells by the area of scrub in the TA to which they belong. Within each TA we sort the grid-cells by their LUC class from most (8) to least (1) geophysically restricted land. Within this, we sort all the grid-cells by their scrub neighbourhood group, M then L. Finally within the scrub neighbourhood groupings, we sort grid-cells from least productive to most productive, based on the agricultural productivity index.

3.2 Simulating land-use and intensity-level change

Here, we step through the process of an iteration of LURNZv1, simulating change in national-level land use and intensity levels between two consecutive years.

We begin in the base year t_0 = 2002 with our initial map of land use. To project and simulate, the user first inputs forecast values for the exogenous variables for all future years of interest for each scenario.[31] The model requires forecasts of real commodity prices for dairy, sheep/beef, and plantation forestry, the real interest rate, and the total area of 'rural land'. The price and interest rate forecasts are annual average values measured at June 30 of each year.[32] Prices are defined as prices for a hectare of output, with output values set at 2002 levels, so changes in productivity are reflected only in the time trend. The forecast of the total area of 'rural land' is a snapshot value at June 30 of each year.[33]

Policy scenarios are represented as changes in these price forecasts, for example a methane tax leads to a lower dairy price in each year. The method for modelling greenhouse gas emissions in relation to agriculture is given in Hendy and Kerr (2005) and some preliminary results of simulations of the effects of agricultural charges are presented in Hendy, Kerr and Baisden (2006).

LURNZ evaluates the long-run land-use share equations for dairy, sheep/beef, plantation forestry, and scrubland (given in 3.1.1) with the exogenous variables equal to their $t=t_0$ values. This gives us the long-run equilibrium land-use shares at June 30 of the year t_0. These are compared to actual land use to give us a measure of the degree to which land use is out of equilibrium when the simulation begins.

LURNZ then calculates the change in the exogenous variables, between t_0 and t_0+1. It uses these to evaluate the short-run land-use share change equations

[31] The current model does not allow data on actual land use or animal numbers between 2002 and the current date to be incorporated. This feature will be added in the next version.

[32] The units of the prices must be consistent with the units of the prices used to estimate the land-use share equations. See section 2.2.1.b for derivation of the prices.

[33] Currently, we need to keep of the level of rural land and hence the share of 'other-non-rural' land fixed at its 2002 level in any forecasts that involve spatial allocation. This is because our allocation module does not include rules for allocating other-non-rural land-use change.

for dairy, sheep/beef, plantation forestry, and scrubland (given in 3.1.1) with prices, interest rates, and the total rural land shares at their differenced values between t_0 and t_0+1, and the lagged distance from equilibrium at its $t=t_0$ value. This gives us the change in short-run land-use shares between t_0 and t_0+1. LURNZ adds these to the initial shares for $t=t_0$ giving us land-use shares at June 30 of the year $t=t_0+1$ which can then be converted into national land-use areas.

LURNZ then evaluates the intensity level equations for dairy and sheep/beef stock unit stocking rates, sheep/beef stock unit ratio, and fertiliser intensity equations (given in Hendy and Kerr (2006)) at $t=t_0+1$. LURNZ multiplies the stocking rates by the land-use areas to give stock unit predictions. LURNZ separates the overall sheep/beef stock units into sheep and beef using the predicted sheep to sheep/beef ratio and then converts all stock units to national dairy, sheep, and beef animal numbers. LURNZ multiplies predicted fertiliser intensity (use per hectare) by total land-use area for dairy and sheep/beef to give total fertiliser use.

LURNZ then resets the base year to t_0+1 using updated land-use areas and iterates. The new long run estimate will be compared to this updated LURNZ projection to create the new measure of the extent to which each land use is out of equilibrium.

3.3 Spatially allocating land-use change

We allocate the land-use change predicted at the national level to grid-cells using an algorithm based on the heuristic model discussed in section 3.1 and the land-use specific land quality rankings developed in section 3.1.3.

The allocation algorithm is a stepwise process; LURNZ allocates national level change predictions to grid-cells for one land use at a time. For each land use, LURNZ orders grid-cells in terms of the quality ranking, finds grid-cells that lie near transition points between land uses, and allocates the national land use changes to the grid-cells next, in a quality ranking sense, to those points. We step through the algorithm in detail in section 3.3.1.

In our heuristic model, it is possible for any land use to have multiple transition points. Land quality is multi-dimensional so transition points will occur at different grid-cells for different quality rankings. At a mechanical level, this means that the outcome will depend on which land use we allocate changes to first. We rely on the following set of assumptions to dictate the order in which we allocate land-use changes.

We assume that dairy is the highest-value land use and landowners will optimise their returns if the best dairy land is used for dairy. So, we allocate changes related to dairy first. If dairy area is predicted to increase nationally, we allocate the highest quality non-dairy land to dairy. If dairy area is predicted to decrease nationally, we allocate the lowest quality dairy land to non-dairy uses.

We choose to allocate to scrubland next for exactly the opposite reason. We assume that scrubland is the lowest-value land use and landowners will optimise their returns if the best scrubland, which is by definition the worst land for everything else, is used as scrub. So, we allocate changes related to scrubland second.

The final assumption, between whether to allocate sheep/beef or forestry changes first, is not so straightforward. Suppose plantation forestry increases at the expense of sheep/beef. Does the sheep/beef land that is best suited for plantation forestry change to plantation forestry? Or does the sheep/beef land that is worst suited for sheep/beef change to plantation forestry? We find no obvious hypothesis to support either assumption. So, our final assumption is arbitrary. We assume that returns will be optimised if the land use that has increased the most (or decreased the least) since the last year goes on land best suited for that land use; we allocate that land-use first.[34]

3.3.1 Allocation algorithm

In section 3.2 we stepped through the process of simulating national level changes in land use between consecutive years, t_0 and t_0+1. Here we follow

[34] The model does not currently include spatial information on the age of forests so we are unable to assume that transitions out of forestry occur on recently harvested forest land, although this seems likely.

on from this point by stepping through the spatial allocation process in LURNZ to predict which grid-cells change use between t_0 and t_0+1.

We enter the LURNZ simulation again after the national level predictions have been made.

LURNZ calculates the number of grid-cells that need to change, by dividing the predicted change area by the size of a cell (25ha). Suppose that LURNZ predicts that dairy area needs to increase by the equivalent of D grid-cells, scrubland area needs to increase by the equivalent of S grid-cells, sheep/beef area needs to increase by the equivalent of B grid-cells, and plantation forestry area needs to increase by the equivalent of F grid-cells. The sum of $D, S, B,$ and F will be zero. Because of this, some land uses will 'negatively increase' (i.e. decrease).

LURNZ begins the allocation process with the land use of each grid-cell in our grid set equal to its land use in $t=t_0$. LURNZ allocates the dairy land-use change first. LURNZ sorts all the grid-cells by the dairy quality ranking. If D is positive, LURNZ changes the D best quality grid-cells that were not assigned to dairy at t_0, reassigning them to dairy at t_0+1. Of the D grid-cells that changed to dairy, s were in scrub at t_0, b were in sheep/beef at t_0, and f were in plantation forestry at t_0. If D is negative, LURNZ changes the $|D|$ worst quality grid-cells that were assigned to dairy at t_0, reassigning them temporarily to 'unclassified' at t_0+1. In this case s, b, and f are all equal to zero.

From this point, all grid-cells that are dairy are fixed and so will not change for the rest of the process. Now, LURNZ will change only grid-cells that are not assigned to dairy at t_0+1.

Second, LURNZ allocates national level changes in scrubland area to grid-cells. The number of grid-cells that need to change is $S+s$. LURNZ sorts all the "non-dairy" grid-cells by the scrubland quality ranking. If $S+s$ is positive, LURNZ changes the $S+s$ worst quality grid-cells (i.e. best for scrub) that were not assigned to scrubland at t_0 and have not been assigned to dairy at t_0+1 (i.e. the $S+s$ highest scrub-ranked grid-cells that are sheep/beef, forestry, or unclassified), reassigning them to scrubland at t_0+1. Of these, c were in sheep/beef at t_0 and g

were in plantation forestry at t_0. If $S+s$ is negative, LURNZ changes the $|S+s|$ highest quality (lowest scrub-ranked) grid-cells that were assigned as scrubland at t_0, reassigning them as unclassified at t_0+1. In this case, c and g equal zero. From this point, all grid-cells that are dairy or scrubland are fixed and will not change for the rest of the process.

If B is greater than F, then the third step is for LURNZ to allocate national level changes in sheep/beef. LURNZ sorts all the "non-dairy" and "non-scrubland" grid-cells by the sheep/beef ranking. If $B+b+c$ is positive, LURNZ changes the $B+b+c$ best quality forestry and unclassified grid-cells, reassigning them as sheep/beef at t_0+1. If $B+b+c$ is negative, LURNZ changes the $|B+b+c|$ worst quality sheep/beef grid-cells, reassigning them as unclassified at t_0+1. Finally, LURNZ reassigns all the unclassified grid-cells as plantation forestry.

Otherwise, if F is greater than B, the third step is for LURNZ to allocate national level changes in plantation forestry changes instead of sheep/beef. The process is the same, with the plantation forestry quality ranking used in place of the sheep/beef ranking. In the final step, LURNZ reassigns all the unclassified grid-cells as sheep/beef.

At this point all changes have been allocated to grid-cells. This final step gives us a map of land-use across New Zealand at a 25ha resolution that reflects the land use changes that were predicted at the national level. Before beginning a new iteration to spatially allocate land use changes for the following year, the land quality ratings will all be updated to reflect the changing TA output levels and the changes in neighbouring grid cells' land use.

4 Conclusion

LURNZv1 currently produces reference scenarios for four major New Zealand land uses. These can go as far forward as the user is willing to predict commodity prices, interest rates and urban expansion but will get progressively weaker further out. LURNZv1 combined with policy scenarios that are defined as price changes can simulate the potential effect and cost of different policies. For example we have already simulated the effects of emissions charges in agriculture and explored the likely regional distributional effects of such a programme. Many other simulations are possible within LURNZv1 but we are less confident of their robustness.

We are now beginning to work on Version 2. First we are reestimating the econometric model at a territorial authority level to capture spatial variation in costs, in the distribution of land quality and differences in competition for land from alternative uses. A second step will be to make land use intensity (stocking rates and production levels) responsive to prices in such as way that this is consistent with the land use responsiveness. Third to improve our representation of current land use we plan to move from a simply grid based framework to one that takes account of cadastral boundaries and hence real farming units. We will begin to model the use of urban and horticultural land and its spatial distribution. These will be regarded as exogenous. Finally we will introduce uncertainty into each stop of the modelling to explore the model’s strengths and weaknesses and do systematic comparisons with out of sample data.

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