Yield to Change: Modelling the Land-use Response to Climate-Driven Changes in Pasture Production

Levente Timar

Motu Working Paper 16-15

Motu Economic and Public Policy Research

October 2016

Document information

Author contact details
Levente Timar

Motu Economic and Public Policy Research

levente.timar@motu.org.nz

Acknowledgements
Funding for this work has been provided by the Climate Change Impacts and Implications (CCII) research programme.

Motu Economic and Public Policy Research

PO Box 24390 info@motu.org.nz +64 4 9394250

Wellington www.motu.org.nz

New Zealand

 ISSN 1176-2667 (Print), ISSN 1177-9047 (Online).

Abstract

In contrast to most economic drivers of land-use change, climate-related drivers display substantial geographic variation. Accounting for this spatial heterogeneity is important in simulations of the land-use response to climate change. I use a discrete choice model to estimate the relationship between pasture yields and rural land use. Land-use predictions from the model respond to climate change through its effects on pasture yields. This econometric model provides the foundation for the development of a new module of the Land Use in Rural New Zealand (LURNZ) model, the Yield Change Module. In addition to enabling simulations of overall land-use change under different climate scenarios, the module also draws on the estimation results to allocate land-use change spatially. I employ the Yield Change Module to perform illustrative mid-century and end-of-century simulations of land use in a climate scenario characterised by a high level of greenhouse gas emissions (RCP 8.5). Yield changes in this scenario lead to an expansion (by nearly 600,000 hectares) of dairy area and a fall (by over 800,000 hectares) of sheep-beef area by the end of the century. The implied rate of land-use change is modest relative to that observed in New Zealand's recent past.

JEL codes

Q15, Q54

Keywords

Land use, climate change, pasture production, LURNZ, Yield Change Module

Summary haiku

Yields go up – and down
at times. But farmers respond
and now we know how.

Table of Contents

Table of Figures

1 Introduction

The Land Use in Rural New Zealand (LURNZ) model is a spatially explicit integrated model of national land use (Kerr et al. 2012; Anastasiadis et al. 2014). The development of LURNZ was originally motivated by a desire to inform climate policy, and as such, the model has been focused on the economic drivers of land-use change. While it has been possible to adapt the framework to address most factors that affect the economic returns to various land uses, the model has been ill-suited for simulating the land-use response to climate change itself.

Unlike economic drivers of land-use change which are typically determined in international markets and in national legislation, climate-related drivers display substantial spatial variation. Changes in precipitation, temperature and other atmospheric conditions associated with climate change are expected to affect suitability for primary production in a geographically heterogeneous way within New Zealand.

In this paper, I estimate an econometric model of land use that includes explanatory variables for net primary productivity under pastoral land uses. The model is similar to that specified in (Timar 2011) with three important differences: the inclusion of the yield variables, the addition of horticulture to the choice set and the use of an updated land-use map in estimation. When combined with projections of pasture yields under future climate, the model can be used to predict the magnitude of the land-use response to climate change. I build on this model to develop a new module for LURNZ, the Yield Change Module. In addition to performing simulations of overall land-use change under different climate scenarios, the Yield Change Module also has the ability to produce output spatially.

I use the Yield Change Module to perform mid-century and end-of-century simulations of land use under a climate change scenario characterised by high greenhouse gas emissions (RCP 8.5). In general, future pasture yields are projected to increase in this scenario. As a result, dairy area grows by about 600,000 hectares and sheep-beef area shrinks by about 800,000 hectares by the end of the century. While these changes are significant in proportion to existing land areas, similar amounts of land-use change took place within a decade in New Zealand's recent history.

Section 2 is dedicated to the discussion of pasture yield data – other datasets used in estimating the land-use model are documented in Timar (2011). Section 3 introduces the model, presents estimation results and evaluates the model's predictions at a regional scale. Section 4 outlines the Yield Change Module and describes the technical details of its integration into the rest of the LURNZ model. Section 5 reports the results of an illustrative application of the Yield Change Module, and section 6 concludes the paper.

2 Pasture Yield Data

Maps of net primary productivity (measured as mean annual total production in tonnes of dry matter per hectare) for New Zealand pastures are produced in the Biome-BGC model (Keller et al. 2014). Biome-BGC provides a simulation of the biological and physical processes controlling carbon, water and nitrogen dynamics in terrestrial ecosystems. The most significant inputs to the model are daily temperature, precipitation, solar radiation, vapour pressure deficit (corrected for wind strength), day length, elevation and latitude. Land quality is not an explicit input, though coarse measures of soil type and rooting depth are included. The potential for irrigation and any changes in pasture species composition are not taken into account in the Biome-BGC results.

Separate yield output is produced for dairy and sheep-beef pasture in Biome-BGC (regardless of actual land use). Modelled yields under dairy use are higher with the differences being driven by eco-physiological model parameters. These parameters are calibrated to reflect typically higher rates of fertiliser input and fire mortality accounting for more plant material being removed by livestock under dairy use. The parameters vary between sheep-beef and dairy uses, but they are constant across the whole country (Keller 2016).

Differences in relative yield under the two land uses arise through a complex interaction of nitrogen and water dynamics. Without sufficient precipitation, any increased availability of nitrogen from fertiliser does not lead to additional photosynthesis and pasture growth. Consequently, grass growth at a given location may be nitrogen-limited under sheep-beef use and water-limited under dairy use.

2.1 Baseline yields

In estimating the effect of pasture yields on land use, I make use of a map of (potential) baseline yields from Biome-BGC. Baseline yields represent the average net primary productivity under current climate conditions. The climate input into Biome-BGC in this case is true historical climate from the Virtual Climate Station Network (VCSN): actual observations of the climate variables from 2001 to 2009, extrapolated to the VCSN grid. Biome-BGC predictions have been calibrated to actual pasture yield measurements across New Zealand (Keller et al. 2014).

Baseline yields are modelled irrespective of actual land use, except when the majority of a grid cell is classified as conservation land, water, ice or urban. These categories are exogenous land uses in LURNZ as well. However, Biome-BGC uses a relatively coarse spatial grid, and this difference in resolution results in baseline pasture yields being undefined for some of the land area modelled in LURNZ. These missing values are ignored in the estimation of the relationship between yields and land use, but it is necessary to fill them in to enable LURNZ simulations of future land-use. Therefore, for simulations, missing values are set to equal the minimum baseline yield that occurs within the Territorial Authority of the cell's location. The map of baseline dairy and sheep-beef pasture yields is presented in Appendix Figure 1.

2.2 Simulated-climate yields

Biome-BGC is also used for making mid-century (2065) and end-of-century (2100) yield projections under simulated future climate (Keller and Baisden forthcoming). Globally, climate change is primarily driven by atmospheric concentrations of greenhouse gases, but different climate models produce slightly different results for a given Representative Concentration Pathway (RCP). The National Institute of Water and Atmospheric Research (NIWA) uses regional-scale climate models and statistically downscaled global climate models to produce a suite of climate change simulations for New Zealand (Ministry for the Environment 2016). For each RCP, Biome-BGC runs are completed on simulated climate input variables corresponding to downscaled projections of six different Global Climate Models.[1] The modelled pasture yields from the six runs are then averaged into a model ensemble average for the given scenario.

These future yield projections are not necessarily comparable to baseline yields, so they are not used in LURNZ directly. The projections correspond to simulated future climate inputs, while the baseline corresponds to 'observed' past climate inputs. To establish a better basis for comparison, a set of simulated past climate inputs is also applied to Biome-BGC. These so-called RCP past meteorological files are the output from the six climate models under present-day forcings – rather than capturing actual weather, they are merely representative of past climate. As before, the six runs are then averaged into an RCP past model ensemble average.

The percentage change in production between the RCP past and the future scenario is applied to baseline yields to construct the yield input data for LURNZ simulations.[2] Estimating future pasture production in this way is consistent with the property of Biome-BGC that it is better suited for predicting the change in production than for predicting the absolute level of production.

3 Land-Use Choice Model

I use a multinomial logit land-use choice model to estimate the effect net primary productivity has on land use. The model and the data on which it is estimated are similar to those described in Timar (2011), and this section focuses primarily on points of difference from that study. These include the way in which pasture yields are used as explanatory variables, an expanded

[1] The six climate models include BCC-CSM1.1 (Beijing Climate Center Climate System Model), CESM1-CAM5 (Community Earth System Model 1 - Community Atmosphere Model 5), GFDL-CM3 (Geophysical Fluid Dynamics Laboratory - Coupled Model 3), GISS-EL-R (Goddard Institute for Space Studies - ModelE/Russell), HadGEM2-ES (Hadley Centre Global Environment Model version 2 - Earth System) and NorESM1-M (Norwegian Earth System Model 1).

[2] Where the percentage change cannot be calculated due to missing data, no change in yields is assumed.

choice set with an additional land-use option and the use of an updated land-use basemap. The other datasets have not changed since the previous study.

Land-use choice is modelled as a function of variables characterising accessibility to markets (distance to nearest port and distance to nearest town), land tenure (indicator for Maori freehold tenure), land quality (slope and Land Use Capability class) and pasture yields. Yields under dairy use and yields under sheep-beef use are included as separate variables. In addition to the main effects, the estimation includes an interaction term between each yield variable and each land quality variable. These interaction terms could help resolve differences in data resolution by capturing the effect of varying land quality within a homogenous yield grid cell. All variables and interactions are listed in the table of parameter estimates in Appendix Table 1.

Compared to the specification in Timar (2011), the choice set is expanded from the original four land use types (dairy, sheep-beef, forestry and scrub) to also include horticulture. The horticulture category is broad in that it includes arable, fruit, vegetable and grape farming activities. Other land uses are not modelled.

The estimation is performed on a map of 2012 land use, reproduced in Appendix Figure 2. This land-use basemap combines land-cover data from the 2012 Land Cover Database 4 (LCDB4) with land-use data from the most current Land Use in New Zealand (LUNZ) map (Daigneault et al. forthcoming). In general, the land-use classification in the new basemap is primarily determined by LCDB4 where land cover is expected to accurately reflect land use, and it is mainly based on LUNZ use where land cover is expected to be a poor proxy for land use. Similar to previous versions of the basemap, data on land ownership is used in the process to separate privately owned land from publicly owned land.

The estimation sample consists of 427,728 observations, each representing a 25-hectare grid cell with complete information on all variables. The sample captures over 94% of all cells with the modelled land uses.

3.1 Estimation results

Parameter estimates and standard errors from the multinomial logit model are shown in Appendix Table 1. The coefficients of the base category, scrub, are normalised to zero. Directly interpreting these parameter estimates is difficult as they relate to a latent variable (representative utility) that affects choice probabilities in a non-linear manner. The inclusion of multiple choice alternatives and the interaction terms further complicate interpretation. Therefore, I discuss the results in terms of the estimated (average) marginal effects presented in Table 1.

The marginal effects represent the average change in choice probability for a unit change in the value of the explanatory variable, where the average is taken over all observations.

Location and geophysical land attributes affect land-use choices in largely expected ways: ease of access and high-quality land tend to be important factors for the more intensive land-use types such as dairy and horticulture. Maori freehold land is more likely to be in the relatively underdeveloped uses of scrub and – primarily for historical reasons – forestry (Timar 2011). Therefore it is surprising that the estimated marginal effect of Maori tenure on horticulture probability is positive, however, it is small in absolute value.

As expected, higher dairy pasture yields increase the probability of dairy land use and decrease the probability of sheep-beef land use.[3] Conversely, higher sheep-beef pasture yields decrease dairy probability and increase sheep-beef probability. High statistical significance and the intuitive direction of the estimated effects suggest that relative differences across dairy and sheep-beef yields are meaningful despite the generally high correlation between the two variables.

Table 1. Average marginal effects from the multinomial logit land-use choice model

Variable	Horticulture	Dairy	Sheep-beef	Forestry	Scrub
Distance to port	-0.0023**	-0.0031**	0.0042**	-0.0037**	0.0049**
	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)
Distance to town	-0.0084**	-0.0184**	0.0230**	0.0036**	0.0002
	(0.0002)	(0.0003)	(0.0003)	(0.0002)	(0.0001)
Maori tenure	0.0063**	-0.0712**	-0.1320**	0.0731**	0.1238**
	(0.0024)	(0.0025)	(0.0042)	(0.0030)	(0.0029)
Slope	-0.0010**	-0.0171**	0.0091**	0.0026**	0.0065**
	(0.0001)	(0.0002)	(0.0002)	(0.0001)	(0.0001)
LUC class	-0.0119**	-0.0182**	-0.0258**	0.0301**	0.0258**
	(0.0003)	(0.0004)	(0.0006)	(0.0005)	(0.0005)
Dairy yield	0.0129**	0.0644**	-0.1129**	0.0168**	0.0188**
	(0.0004)	(0.0007)	(0.0011)	(0.0009)	(0.0008)
Sheep-beef yield	-0.0275**	-0.0443**	0.0940**	-0.0025*	-0.0197**
	(0.0006)	(0.0011)	(0.0017)	(0.0013)	(0.0012)

The marginal effect represents the change in choice probability for a unit change in continuous explanatory variables and for a discrete change from 0 to 1 in the Maori tenure indicator variable. Standard errors are shown in parentheses. Stars indicate statistical significance at the 1% (**) and at the 5% (*) level.

Dairy yield also seems to be positively associated with non-pastoral land uses. The effect of sheep-beef yield is the opposite. While these relationships may be spurious, it is also possible that factors contributing to higher dairy yield (relative to sheep-beef) also increase yields in forestry and horticulture. If this is the case, the estimates could be capturing aspects of

[3] Increasing dairy yield by one tonne of dry matter per hectare increases the predicted probability of dairy land-use choice by 0.0644 and decreases the predicted probability of sheep-beef land-use choice by 0.1129. These marginal effects represent averages across the entire sample. Although in absolute value the cross-yield effect is larger, it is applied to a higher base probability: reflecting its land-use share in the sample, sheep-beef has the highest average choice probability. When evaluated at values of the covariates that characterise the median dairy land, the marginal own-yield effect for dairy becomes larger.

otherwise unobserved climate or land quality factors. It is likely that scrub in some areas is imperfectly identified in the data (Timar 2011), so estimates for scrub may also reflect measurement error in the dependent variable. In any event, the size of the estimated effects for these other (non-pastoral) land uses is in all cases relatively small.

Notwithstanding the highly significant parameter estimates (and marginal effects), there is usually large uncertainty around the predicted land-use choice for a particular observation. Table 2 lists the predicted choice probabilities for the median land within each use. For example, the values in the first row of the table suggest that for the median dairy land the probability of dairy land-use choice is around 49%; the probabilities for sheep-beef, forestry, scrub and horticulture are around 40%, 4%, 1% and 6%, respectively.

Table 2. Average predicted land-use choice probabilities by land quality

Land type	Horticulture	Dairy	Sheep-beef	Forestry	Scrub
Median dairy	0.055	0.490	0.399	0.042	0.014
Median sheep-beef	0.004	0.041	0.701	0.160	0.094
Median forestry	0.002	0.039	0.628	0.206	0.125
Median scrub	0.001	0.009	0.648	0.178	0.165
Median horticulture	0.134	0.412	0.409	0.034	0.010

Land-use alternatives are shown in columns. Rows represent the quality of land that characterise each use (with each covariate set to the median value within the given use).

Overall, the probability of sheep-beef use is relatively high on all types of land because of sheep-beef farming's high land-use share and heterogeneity in attributes. On the other hand, dairy farming requires high quality land, and the probability of dairy choice is low when these requirements are not met. Similarly, horticulture choice probability is almost negligible on the average sheep-beef, forestry or scrub land. Reading down the columns, one can verify that the choice probability of each alternative is highest when evaluated at values that actually characterise the given land use.

A limitation of these results stems from the fact that neither the yield model nor the land-use choice model account for the potential of irrigation. If irrigation enables naturally low-producing areas to be used intensively and irrigation is unobserved, yields will seem less important than they actually are in determining land-use outcomes. Therefore, by ignoring irrigation, I may be underestimating the importance of yields in land use decisions (and hence the land-use response to yield changes).

Testing of the original model (Timar 2011) on a subsample chosen by systematic spatial sampling suggested that spatial autocorrelation was not a major problem in that application. While the robustness check is not repeated here, due to the close similarities in data as well as model structure, there is no reason to suspect the same conclusion would not apply.

3.2 Model predictions

The model can be used with simulated pasture yields to predict land-use probabilities in a counterfactual climate scenario (at the observed values of other covariates). A necessary assumption for this use of the estimation results is that the observed cross-sectional relationship between yields and land-use outcomes also applies to changes over time. This is not an inherently strong assumption if yields do not change beyond their current range. However, in the long term, a host of factors including changes in production technology and adaptation to climate change can alter the nature of the current relationship between yields and land use, and the model cannot account for such changes.

A desirable feature of the land-use choice model is the scalability of its predictions. Predicted choice probabilities in a geographic area aggregate to predicted land-use shares for that area (Train 2009). At observed values of all explanatory variables, the model's aggregated predictions exactly match actual land-use shares at the national level (or more precisely, within the estimation sample).

As a way of testing the model visually, the five figures below compare predicted land-use areas to observed land-use areas by region for each of the five modelled land uses. Predicted choice probabilities at observed values of all covariates are used to determine predicted land-use areas for each Regional Council. These are compared to land-use areas represented in the 2012 basemap. Regions are arranged in decreasing order by the size of total modelled land area (the sum of dairy, sheep-beef, forestry, scrub and horticulture land). For reference, the size of each region is also shown (by the grey background shading which is scaled to the secondary, right-hand-side, vertical axis).

As anticipated, predictions at the regional scale are not completely accurate. Nonetheless, they tend to fit the patterns in the observed distribution of land uses across regions: the model is often able to match peaks and troughs in the observed-area bars in each figure. (With random spatial predictions, the height of prediction bars would be expected to decrease from left to right due to the arrangement of regions by size.)

Figure 1. Observed and predicted dairy areas (left axis) and total modelled area (right axis) in hectares by region

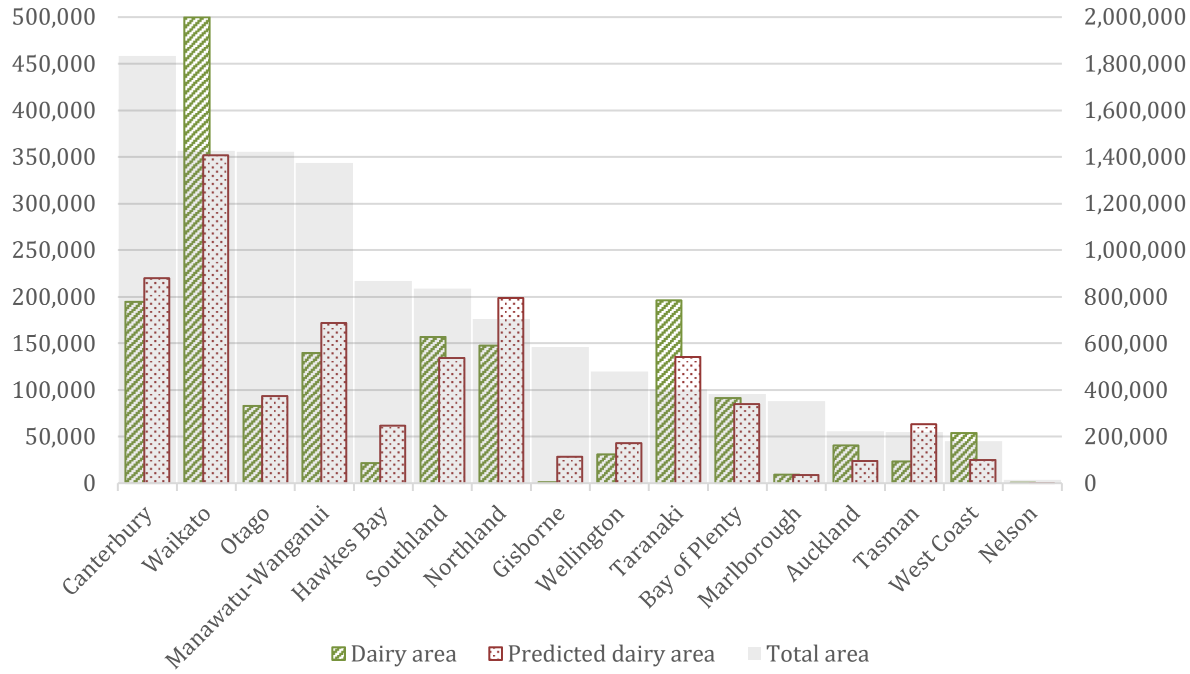


Figure 2. Observed and predicted sheep-beef areas (left axis) and total modelled area (right axis) in hectares by region

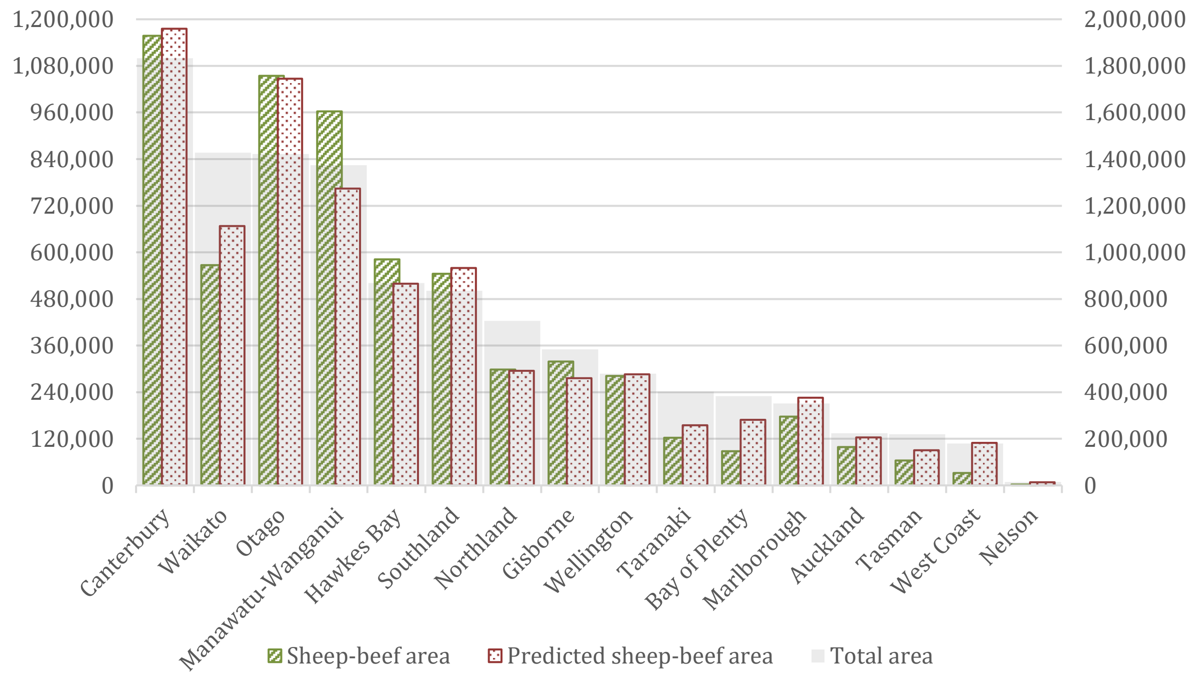


Figure 3. Observed and predicted forestry areas (left axis) and total modelled area (right axis) in hectares by region

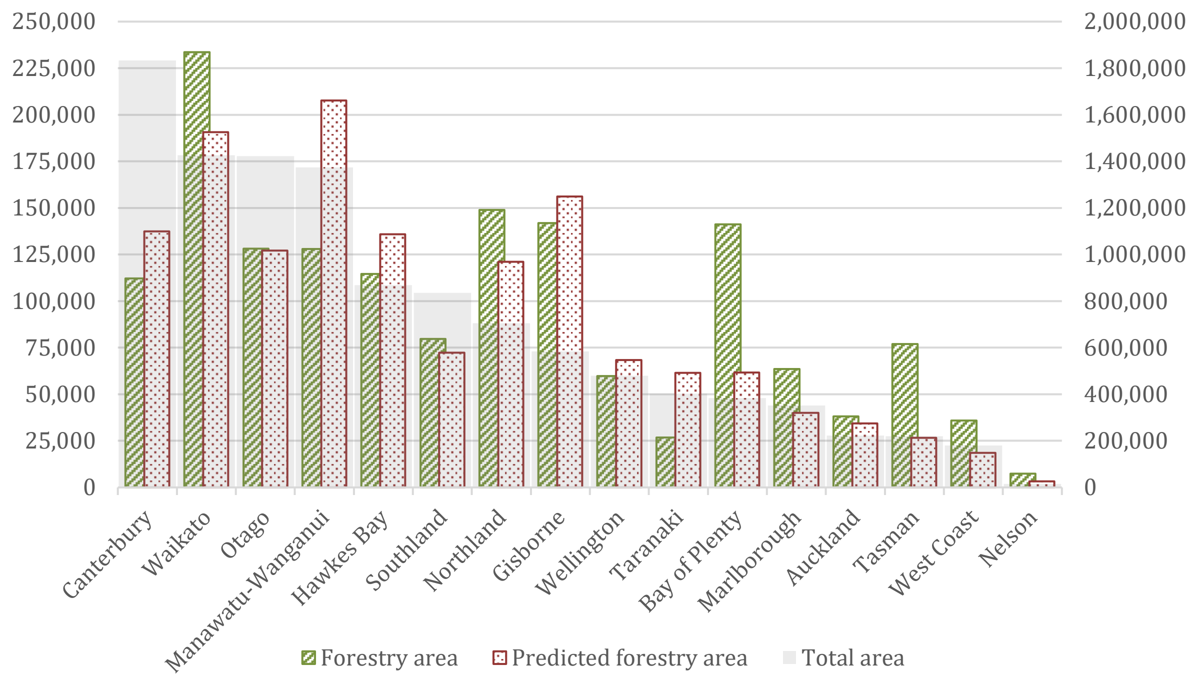


Figure 4. Observed and predicted scrub areas (left axis) and total modelled area (right axis) in hectares by region

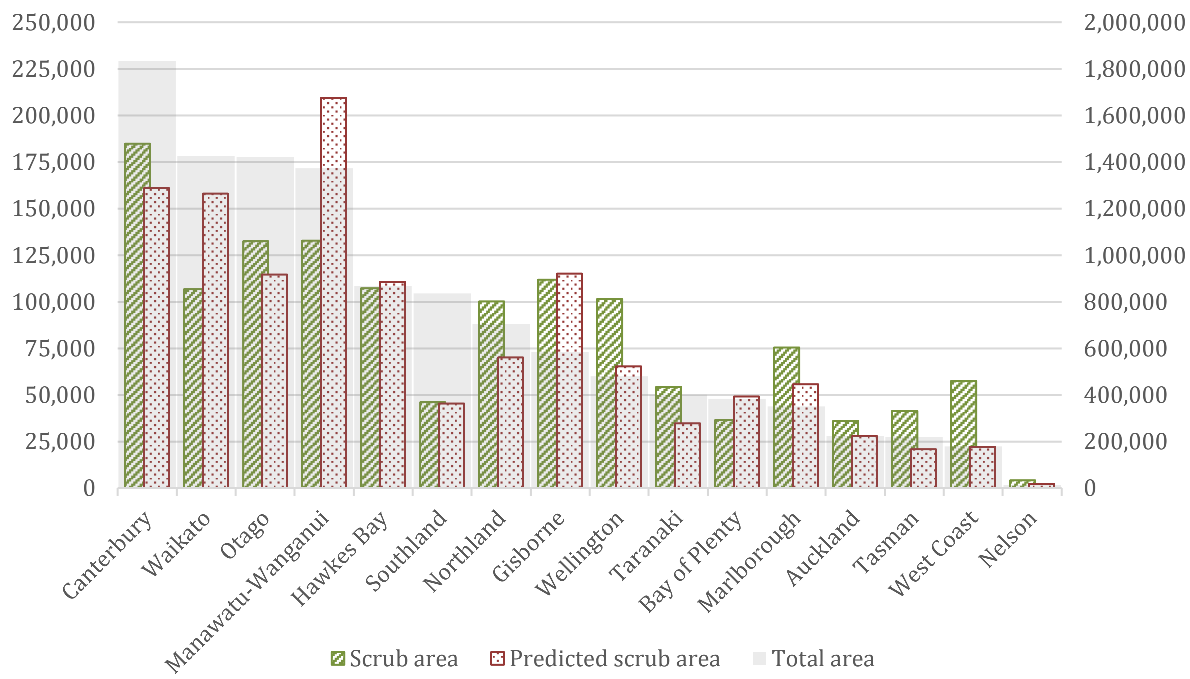
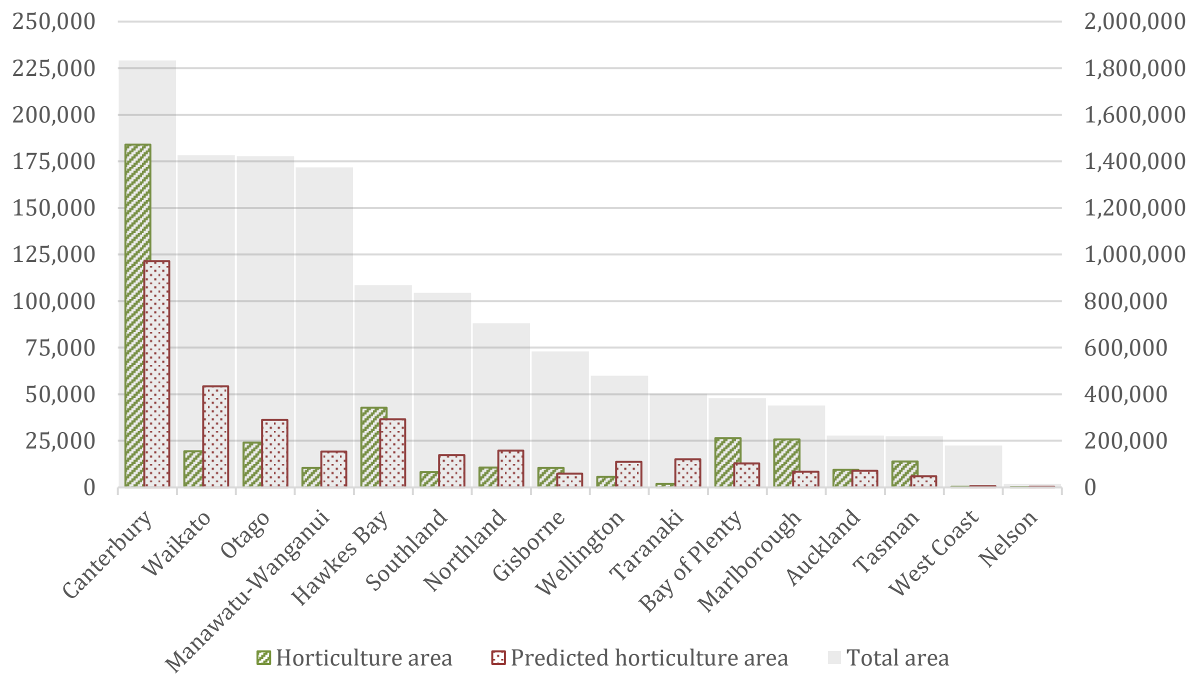


Figure 5. Observed and predicted horticulture areas (left axis) and total modelled area (right axis) in hectares by region



4 The Yield Change Module

The land-use choice model described in the previous section forms the basis of the Yield Change Module of LURNZ. The main use of the module is in long-term modelling involving climate change scenarios. The module performs two distinct modelling functions: first, it carries out simulations of overall land-use change in response to changing pastoral yields, and second, it distributes that amount of change spatially. Both of these functions build on estimation results of the land-use choice model.

4.1 Module structure

Given a map of simulated future pasture yields associated with a climate change scenario, the Yield Change Module first determines the magnitude of the consequent land-use response by region. This is calculated as the difference between predicted land-use shares with climate change and those without climate change. Each set of land-use shares represents choice probabilities aggregated by Regional Council area from the model described in section 3 (with the yield variable being set to the appropriate value for the scenario and all other explanatory variables being held at their observed values in the prediction).

Embedded in the Yield Change Module is a spatial allocation component similar to the Land Use Allocation Module of LURNZ (Anastasiadis et al. 2014). This component assigns the regional land-use responses to yield changes across space.[4] Here, the predicted choice probabilities under the climate change scenario are thought of as indicators of future suitability for each land use. Changes in horticulture area are allocated before changes in dairy area – therefore, horticulture can expand onto land in any other use, but not vice versa. The rest of the algorithm proceeds as described in Anastasiadis et al. (2014).

In contrast to the Land Use Allocation Module, spatial allocation within the Yield Change Module is performed in a single time step. Due to the long-term nature of climate change simulations, the model horizon always extends beyond a full forestry rotation. Because all forests become harvestable at some point before the final simulation year, in this module it is not necessary to track forest age in order to establish harvestability – the spatial allocation of land-use change can therefore be performed all at once. This single-step allocation process is also logically consistent with the non-dynamic nature of overall simulated land-use change (which represents equilibrium responses).

4.2 Integration into LURNZ

The Yield Change Module does not replace any of the existing architecture in LURNZ; it is an auxiliary module that can be run on its own or in various combinations with the other modules. Readers not interested in the technical details of integration may skip this subsection without loss of continuity.

The Yield Change Module may be run in a standalone mode, without calling any of the other modules of LURNZ. In this event, it performs the spatial allocation of simulated land-use changes starting from the 2012 basemap. This mode can be useful in separating out the effect of climate change from the effect of other factors. Results from such a simulation can be thought of as current land-use outcomes in an alternative world with a different climate.

The modelling of yield-change effects may be combined with the non-spatial Land Use Change Module. For consistency of output across the two modules, the Yield Change Module also stops short of spatial allocation in this mode, producing only a table of overall land-use change nationally (aggregating over regions).

Finally, the module can be combined with the existing spatial modelling of land-use change in LURNZ. In this situation, the Land Use Change and Land Use Allocation Modules run as normal before the Yield Change Module is called. The simulated yield impacts are then applied to the output of the Land Use Allocation Module. That is, land-use responses to yield changes are added on top of land-use responses to economic drivers. The modelling therefore includes two

[4] A small number of cells have missing Regional Council identifiers. Land-use change in these areas is also modelled, and in the spatial allocation these cells are treated as if they made up an additional region.

successive rounds of spatial allocation (and the two rounds are based on a different set of probability predictions).

As already noted, the constraint with respect to forest age is not applied to transitions out of forestry within the Yield Change Module's spatial allocation algorithm. However, mirroring their treatment in the Land Use Allocation module, pre-1990 forests are prevented from being deforested here as well if there is a positive carbon price.

The final simulation year in the module must be set to either 2065 or 2100 as yield projections are available for these periods only. However, the mid-century and end-of-century simulations are not completed in succession. Specifically, the spatial allocation of estimated land-use change in the 2100 scenario is carried out in a single step, and any intermediate outcomes in 2065 are ignored. In some circumstances, ignoring intermediate results has no effect on final outcomes, but this is not always the case. Due to the structure of the allocation algorithm, if some land-use-change trends between the two periods reverse, it is possible that simulation outcomes in the final period would differ depending on whether intermediate outcomes were accounted for.

5 Illustrative Climate Change Scenario

In this section, the Yield Change Module is used in standalone mode to simulate land-use outcomes for 2065 and 2100. The yield inputs correspond to the model ensemble average under RCP 8.5, the climate future with the highest greenhouse gas emissions from the fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Figure 6 shows the percentage changes in dairy pasture yields under this scenario, and Figure 7 shows percentage changes in sheep-beef pasture yields. The colour coding for yield changes is identical across the two maps. Areas in light grey are in exogenous land uses and are therefore not modelled. As discussed in section 2.2, the projected percentage changes in these maps are applied to baseline yields (a map is shown in Appendix Figure 1) for the implementation of LURNZ simulations. Mean baseline yields as well as mean percentage changes under the model ensemble average of RCP 8.5 are also summarised by region in Table 3.[5]

[5] The yield projections for this scenario have been slightly revised since the preparation of this paper. Statistics shown here may consequently not exactly match the data hard-coded into the LURNZ Yield Change Module.

Figure 6. Projected percentage change in dairy pasture yields (2065 and 2100)

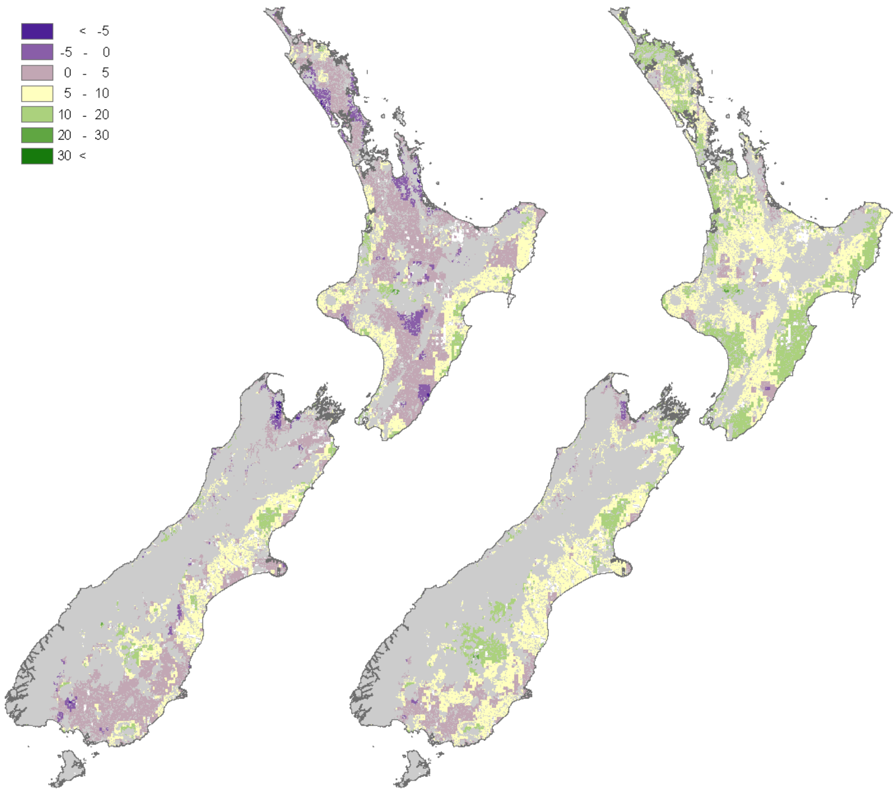


Figure 7. Projected percentage change in sheep-beef pasture yields (2065 and 2100)

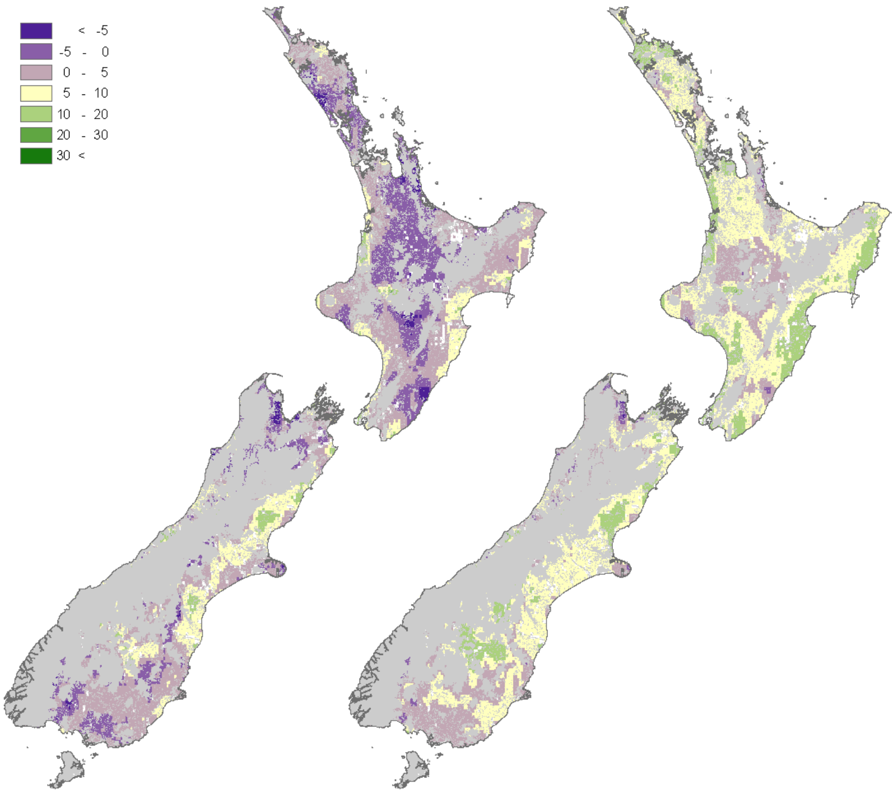


Table 3. Baseline yields (tonne/hectare) and the projected percentage change by region

Region	**Dairy** Baseline	% change 2065	% change 2100	**Sheep-beef** Baseline	% change 2065	% change 2100
Northland	17.13	2.13	9.87	10.61	0.17	8.42
Auckland	17.07	2.07	10.02	10.63	0.28	9.07
Waikato	16.31	3.05	8.12	10.34	-0.44	6.44
Bay of Plenty	15.91	2.88	7.22	10.17	-0.86	5.39
Gisborne	16.27	6.40	9.71	10.50	3.40	9.23
Hawkes Bay	14.04	6.31	10.75	8.77	3.20	9.00
Taranaki	16.97	6.02	7.88	11.15	2.70	6.43
Manawatu-Wanganui	15.77	4.62	8.45	10.50	0.71	6.68
Wellington	14.53	5.07	9.21	9.39	2.15	7.82
West Coast	13.62	10.47	8.19	9.71	7.16	5.83
Canterbury	11.93	7.33	8.85	7.87	4.73	7.60
Otago	12.28	7.25	8.75	8.45	3.89	6.59
Southland	12.42	8.34	7.28	8.82	4.32	4.81
Tasman	12.12	3.28	5.67	7.52	-0.46	3.57
Nelson	14.01	-0.71	3.18	8.87	-2.86	2.55
Marlborough	11.53	4.43	8.04	8.06	1.57	6.90

Changes in pasture production display large geographic variation due to the underlying heterogeneity in simulated climate outcomes. Mid-century changes, especially for sheep-beef, are negative across large areas of the country. However, end-of-century yields show some recovery, becoming generally (but not universally) higher than baseline yields. That is, in this climate scenario, the initial negative trends affecting pasture production in some areas tend to reverse by 2100. Although yields can change by as much as 30-40%, changes of this magnitude (in either direction) tend to be localised and wash out in the regional averages. Despite the extreme nature of the climate scenario, end-of-century dairy yields fall within the sample range of baseline yields at over 95% of grid cells, the proportion being even higher for sheep-beef yields. This suggests that the estimated relationship between yields and land use is, from a data perspective, largely valid to use in the simulations.

Mid-century and end-of-century land-use responses to these yield changes are summarised in Table 4 and Table 5. Results in these tables reflect simulation outcomes from the spatial allocation routine of the Yield Change Module.[6] The last two rows of the tables show absolute and relative changes at the national level, where the percentage changes are relative to land-use areas in the 2012 basemap. Figure 8 and Figure 9 display spatially the simulated land-use transitions associated with the regional changes in Table 4 and Table 5, respectively. In both

[6] In some cases, there may be small differences between simulated land-use changes before and after spatial allocation. There is one example of such a situation in this scenario. The change in aggregated choice probabilities implies a fall of 3,125 hectares in Taranaki horticulture area by 2100. However, this exceeds the existing horticulture area in the region by about 1,250 hectares, so it is impossible to implement the simulated change spatially. The excess change is ignored during allocation (and an offsetting change is applied to sheep-beef land area to keep total modelled area constant).

figures, initial land use is revealed in the left-hand-side map, and final land use is revealed in the right-hand-side map.

Simulations for both time horizons indicate an overall increase in dairy, forestry and scrub areas, and a decrease in sheep-beef area. End-of-century changes are larger in absolute value than mid-century changes for dairy, sheep-beef and forestry. Horticulture area increases initially, but this trend reverses leading to an overall decrease in the longer-term simulations.[7] As expected from the size of the marginal effects in Table 1, dairy and sheep-beef experience the largest response to changes in pasture production (in both absolute and relative terms). Spatially, the simulated transitions tend to occur in areas where one would expect to observe them. For example, the majority of new dairy conversions are near existing dairy producing areas where suitable land is still available for conversion. On the other hand, land-use changes into scrub and forestry appear on marginal land in more remote areas. These types of transitions are qualitatively consistent with those identified and validated in previous research (Anastasiadis et al. 2014).

The magnitude of the land-use response is large relative to current land-use areas (and given the discussion in section 3.1, it may be an underestimate because the model does not account for irrigation). However, the size of the response must be considered in context of the high climate change scenario and the length of the simulation. The implied rate of land-use change over the simulation horizon is much lower than the rate at which land use in New Zealand has been changing historically: in fact, the land-use change experienced in the last decade alone exceeds that projected to take place by 2100 in these simulations.

[7] As noted at the end of section 4.2, this reversal of horticulture trend means that final (2100) outcomes may not be entirely consistent with intermediate (2065) outcomes spatially.

Table 4. Simulated land-use change in response to pasture yield changes by 2065 (hectares)

Region	Horticulture	Dairy	Sheep-beef	Forestry	Scrub
Northland	2,075	27,675	-31,200	575	875
Auckland	550	6,700	-8,250	375	625
Waikato	9,400	59,825	-86,475	7,075	10,175
Bay of Plenty	1,000	13,350	-17,625	1,750	1,525
Gisborne	200	11,075	-42,325	24,775	6,275
Hawkes Bay	1,300	23,700	-55,075	20,425	9,650
Taranaki	325	34,300	-39,300	3,325	1,350
Manawatu-Wanganui	2,275	53,250	-93,500	20,250	17,725
Wellington	1,425	9,775	-23,900	7,600	5,100
West Coast	175	9,750	-13,325	1,525	1,875
Canterbury	-3,300	53,575	-80,850	15,225	15,350
Otago	625	25,275	-50,375	11,525	12,950
Southland	3,450	28,950	-36,575	500	3,675
Tasman	1,075	1,675	-4,750	850	1,150
Nelson	50	0	-100	25	25
Marlborough	625	1,750	-11,025	4,750	3,900
Region missing	0	175	-350	100	75
Total change	21,250	360,800	-595,000	120,650	92,300
Percentage change	5.40	21.33	-9.37	7.85	6.94

The final two rows show changes at the national level. Percentages are relative to the 2012 basemap.

Figure 8. Simulated land-use transitions by 2065: initial (left) and final (right) land use

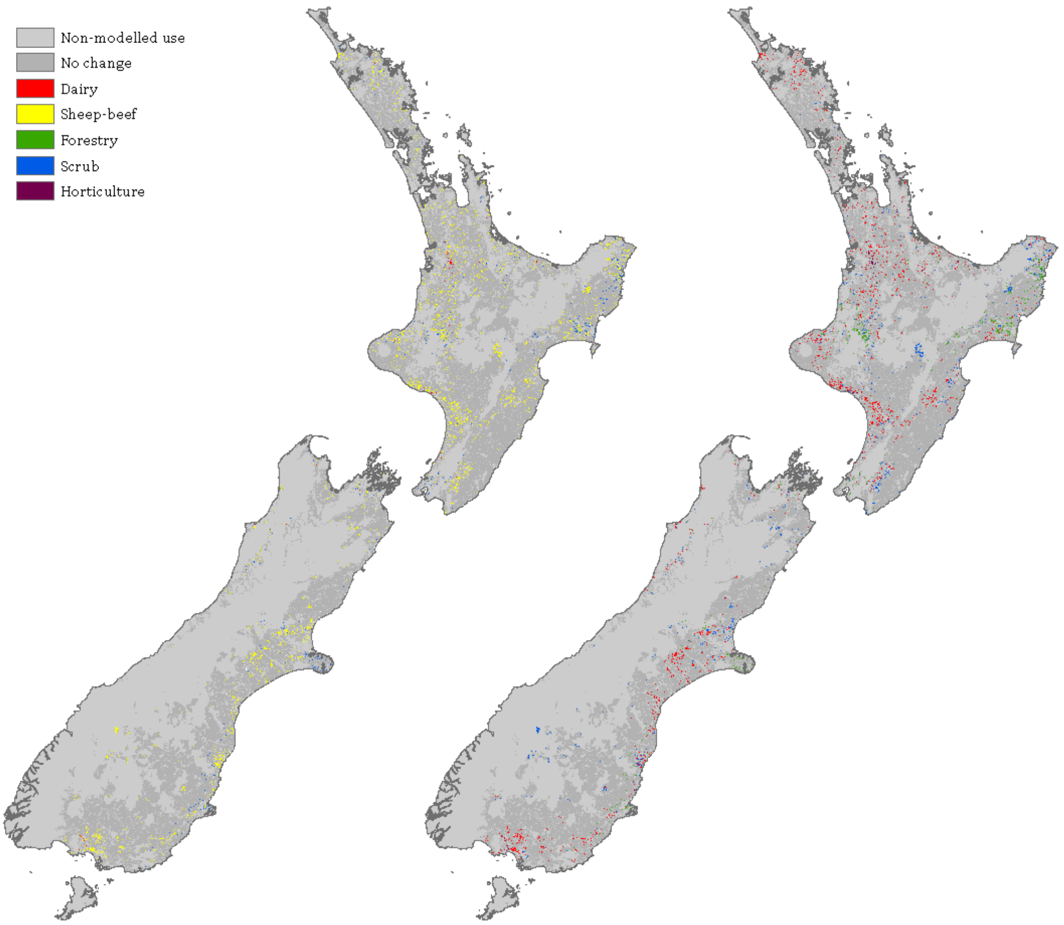
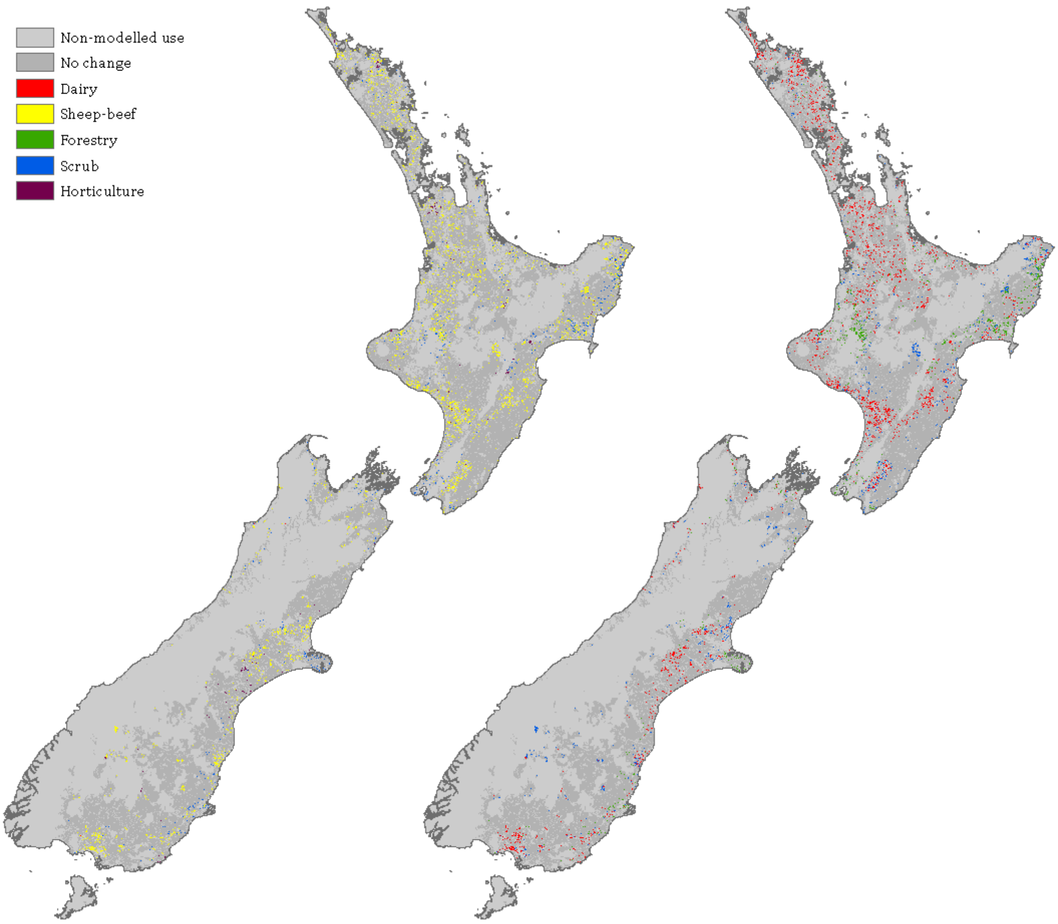


Table 5. Simulated land-use change in response to pasture yield changes by 2100 (hectares)

Region	Horticulture	Dairy	Sheep-beef	Forestry	Scrub
Northland	-4,625	91,600	-90,275	5,225	-1,925
Auckland	-1,575	25,950	-26,150	1,850	-75
Waikato	-7,625	122,550	-141,050	18,950	7,175
Bay of Plenty	-1,925	21,300	-24,450	4,450	625
Gisborne	-1,300	17,950	-51,275	31,950	2,675
Hawkes Bay	-2,750	38,900	-76,950	30,375	10,425
Taranaki	-1,875	35,975	-39,850	5,250	500
Manawatu-Wanganui	-2,925	79,375	-127,625	35,600	15,575
Wellington	-1,300	19,425	-38,025	13,650	6,250
West Coast	50	8,900	-12,350	1,625	1,775
Canterbury	-11,300	59,800	-81,250	18,050	14,700
Otago	-3,100	30,800	-58,075	16,500	13,875
Southland	275	32,250	-39,450	3,375	3,550
Tasman	150	4,275	-9,525	3,475	1,625
Nelson	0	75	-350	225	50
Marlborough	-25	4,000	-17,350	8,425	4,950
Region missing	0	325	-525	150	50
Total change	-39,850	593,450	-834,525	199,125	81,800
Percentage change	-10.13	35.09	-13.14	12.96	6.15

The final two rows show changes at the national level. Percentages are relative to the 2012 basemap.

Figure 9. Simulated land-use transitions by 2100: initial (left) and final (right) land use



6 Conclusion

In this paper, I estimate a multinomial discrete choice model of land use that includes explanatory variables for potential net primary productivity in dairy and sheep-beef pastures. The estimated marginal effects suggest that, as expected, higher dairy yields increase the probability of dairy use and decrease the probability of sheep-beef use, and vice versa. To the extent that pasture yields are correlated with yields in horticulture or forestry, the effects of these will also be captured in the estimates. The model's in-sample predictions fit observed patterns in the distribution of land uses at a regional scale relatively well.

Combined with projections of pasture yields under a simulated future climate, the model generates predictions for the size of the land-use response to climate change. This model forms the foundation of the Yield Change Module of LURNZ. In addition to enabling simulations of overall land-use change under different climate scenarios, the Yield Change Module also has the ability to model land-use change spatially. The spatial allocation embedded in the module also draws on estimation results from the land-use choice model. The module can run in standalone mode, in which case it applies simulated land-use responses to the basemap, or in various combinations with the other modules of LURNZ.

I apply the Yield Change Module to perform mid-century and end-of-century simulations of land use under RCP 8.5, the climate future with the highest level of greenhouse gas emissions. Compared to the end of the century, pasture production under this RCP is characterised by generally lower mid-century yields. Even in areas where initial yield trends are negative, these trends tend to reverse over the longer time horizon. In this illustrative application, I ignore economic drivers of land-use change.

Simulations over both time horizons suggest an overall increase in dairy, forestry and scrub areas, and a decrease in sheep-beef area. Horticulture area expands in the mid-century runs, but contracts in the end of the century runs. In both absolute and relative terms, the two pastoral land uses experience the largest response to climate-driven changes in pasture production. Dairy area increases by nearly 600,000 hectares and sheep-beef area falls by over 800,000 hectares by the end of the century – these changes are not out of the ordinary when compared to the rate of historical land-use change in New Zealand. Qualitatively, the spatial pattern of simulated land-use change is consistent with that identified in previous research.

Over the next century, economic drivers are expected to have a larger effect on land use than climate change itself. Nonetheless, the simulations highlight that land use may continue to intensify as a result of a changing climate (under RCP 8.5). This would put further pressure on New Zealand's water resources and could contribute to further increases in the country's atmospheric greenhouse gas emissions.

There are two important caveats to the results in this paper. First, not being able to account for irrigation in the model may cause me to underestimate the size of the land-use response to yield changes. Second, the results are based on changes in mean climate only. Climate variability, which is expected to increase under RCP 8.5, could potentially also have a large impact on yields and consequently on rural land use and economic outcomes.

References

Anastasiadis, Simon, Suzi Kerr, Wei Zhang, Corey Allan, and William Power. 2014. "Land Use in Rural New Zealand: Spatial Land Use, Land-Use Change, and Model Validation." Motu Working Paper 14–07. Wellington, New Zealand: Motu Economic and Public Policy Research.

Daigneault, Adam, Sandy Elliot, Suzie Greenhalgh, Suzi Kerr, Edmond Lou, Leah Murphy, and Levente Timar. Forthcoming. "Modelling the Potential Impact of New Zealand's Freshwater Reforms on Land-Based Greenhouse Gas Emissions." Wellington, New Zealand: Ministry for Primary Industries.

Keller, E. D. 2016. Personal communication.

Keller, E. D., and W. T. Baisden. Forthcoming. "Climate Change Impacts on New Zealand Pasture Production in 2100 under Four Representative Concentration Pathways." GNS Science.

Keller, E. D., W. T. Baisden, L. Timar, B. Mullan, and A. Clark. 2014. "Grassland Production under Global Change Scenarios for New Zealand Pastoral Agriculture." *Geoscientific Model Development* 7 (5): 2359–91.

Kerr, Suzi, Simon Anastasiadis, Alex Olssen, William Power, Levente Timar, and Wei Zhang. 2012. "Spatial and Temporal Responses to an Emissions Trading Scheme Covering Agriculture and Forestry: Simulation Results from New Zealand." *Forests*: 1133–56.

Ministry for the Environment. 2016. "Climate Change Projections for New Zealand: Atmospheric Projections Based on Simulations Undertaken for the IPCC 5th Assessment." Wellington, New Zealand: Ministry for the Environment.

Timar, Levente. 2011. "Rural Land Use and Land Tenure in New Zealand." Motu Working Paper 11–13. Wellington, New Zealand: Motu Economic and Public Policy Research.

Train, Kenneth E. 2009. *Discrete Choice Methods with Simulation*. Cambridge University Press.

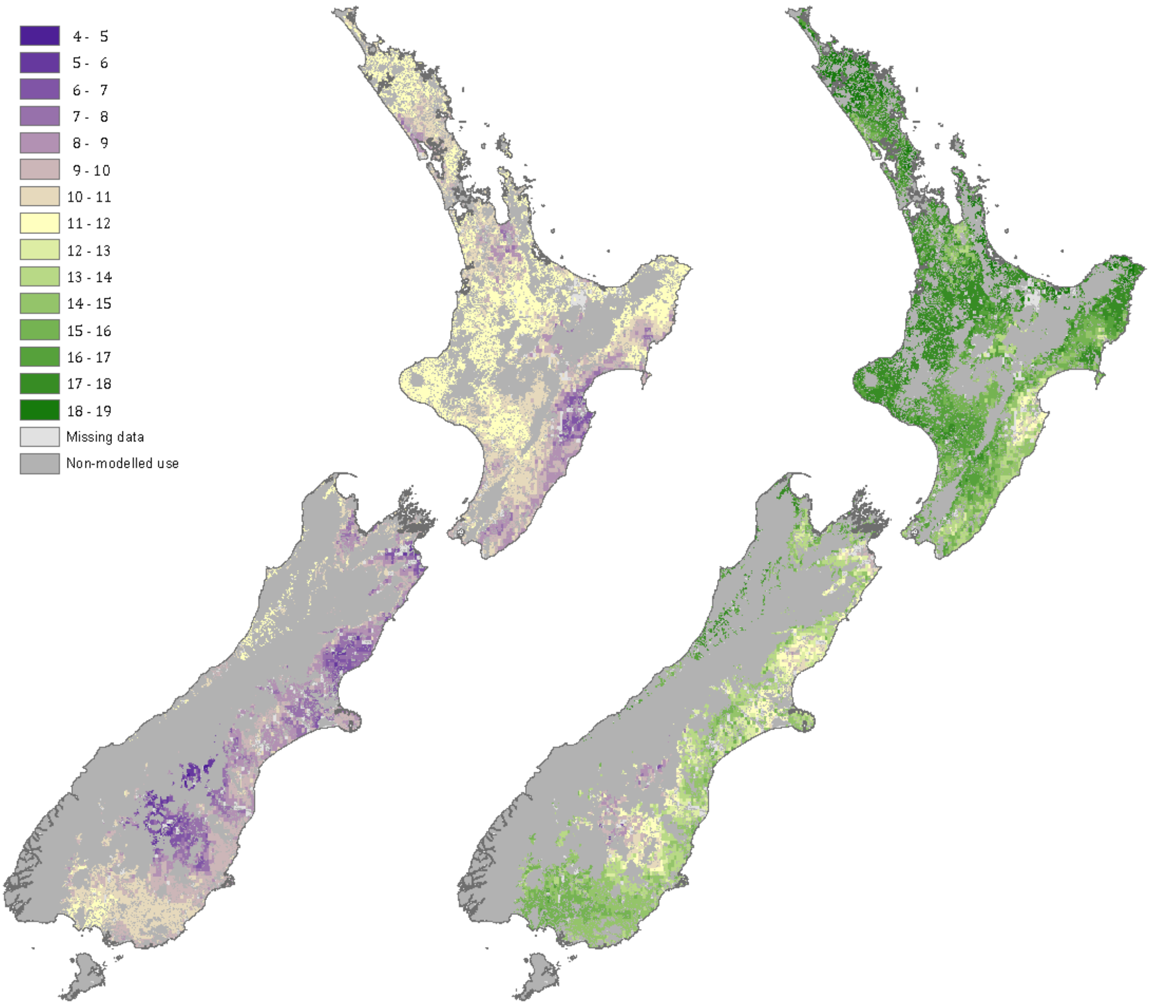
Appendix

Appendix Table 1. Parameter estimates from the multinomial logit land-use choice model

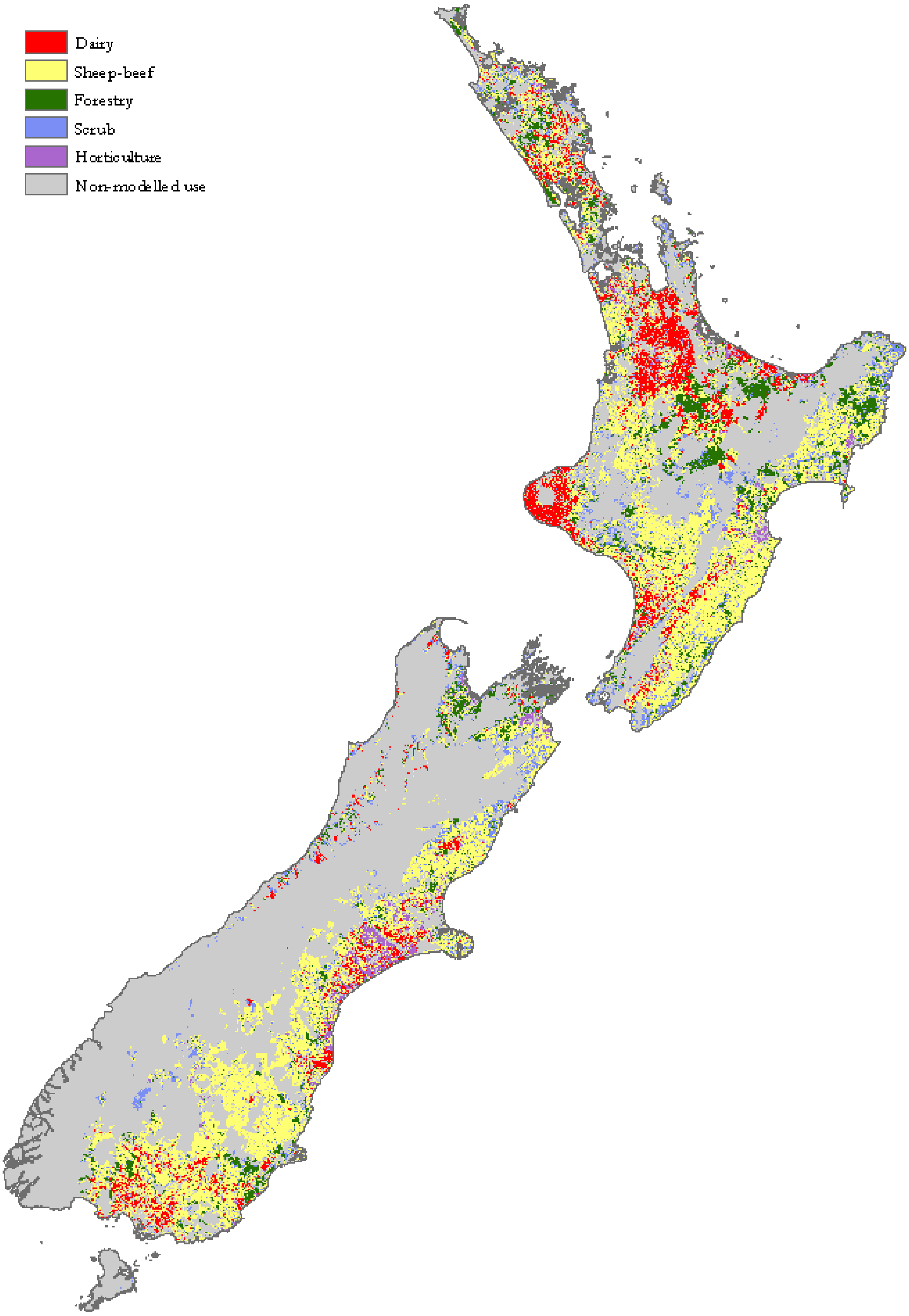
Variable	Horticulture	Dairy	Sheep-beef	Forestry
Distance to port	-0.147**	-0.092**	-0.046**	-0.078**
	(0.003)	(0.002)	(0.001)	(0.001)
Distance to town	-0.387**	-0.231**	0.014**	0.014**
	(0.009)	(0.004)	(0.001)	(0.002)
Maori tenure	-1.173**	-1.960**	-1.277**	-0.431**
	(0.081)	(0.044)	(0.022)	(0.023)
Slope	-0.087**	-0.681**	-0.067**	-0.065**
	(0.024)	(0.018)	(0.005)	(0.007)
LUC class	-0.339**	-0.142**	-0.248**	-0.545**
	(0.070)	(0.055)	(0.042)	(0.052)
Dairy yield	1.012**	0.914**	-0.193**	-0.452**
	(0.064)	(0.050)	(0.046)	(0.055)
Sheep-beef yield	-1.614**	-0.942**	0.137*	0.494**
	(0.093)	(0.074)	(0.068)	(0.080)
Dairy yield x slope	-0.042**	0.017**	-0.007**	0.010**
	(0.006)	(0.003)	(0.001)	(0.002)
Dairy yield x LUC class	-0.121**	-0.105**	-0.013	0.056**
	(0.018)	(0.011)	(0.009)	(0.010)
Sheep-beef yield x slope	0.055**	0.016**	0.010**	-0.014**
	(0.009)	(0.005)	(0.002)	(0.002)
Sheep-beef yield x LUC class	0.135**	0.122**	0.009	-0.036*
	(0.026)	(0.016)	(0.013)	(0.015)
Constant	6.860**	1.796**	6.646**	4.062**
	(0.293)	(0.263)	(0.235)	(0.281)

Scrub coefficients are normalised to zero and hence not displayed. Standard errors are shown in parentheses. Stars indicate statistical significance at the 1% (**) and at the 5% (*) level.

Appendix Figure 1. Baseline sheep-beef (left) and dairy (right) pasture yields in tonnes of dry matter per hectare annually



Appendix Figure 2. The land-use basemap of 2012



Recent Motu Working Papers

All papers in the Motu Working Paper Series are available on our website www.motu.nz, or by contacting us on info@motu.org.nz or +64 4 939 4250.

16-14 Chappell, Nathan and Adam B Jaffe. 2016. "Intangible Investment and Firm Performance."

16-13 Kerr, Suzi and Judd Ormsby. 2016. "The New Zealand Emissions Trading Scheme de-link from Kyoto: impacts on banking and prices."

16-12 Carver, Tom and Arthur Grimes. 2016. "Income or consumption: which better predicts subjective wellbeing?"

16-11 Apatov, Eyal and Arthur Grimes. 2016. "Higher education institutions and regional growth: The case of New Zealand.

16-10 Chappell, Nathan and Isabelle Sin. 2016. "The Effect of Trial Periods in Employment on Firm Hiring Behaviour" (also known as Treasury Working Paper 16/03)

16-09 Timar, Levente. 2016. "Does money grow on trees? Mitigation under climate policy in a heterogeneous sheep-beef sector"

16-08 Jaffe, Adam, Trinh Le and Nathan Chappell. 2016. "Productivity distribution and drivers of productivity growth in the construction industry."

16-07 Fabling, Richard, Arthur Grimes and Levente Timar. 2016. "Labour market dynamics following a regional disaster."

16-06 Leining, Catherine and Suzi Kerr. 2016. "Lessons Learned from the New Zealand Emissions Trading Scheme."

16-05 Grimes, Arthur, Judd Omsby, Anna Robinson, Siu Yuat Wong. 2016. "Subjective wellbeing impacts of national and subnational fiscal policies."

16-04 Ryan Greenaway-McGrevy, Arthur Grimes, Mark Holmes. 2016. "Two Countries, Sixteen Cities, Five Thousand Kilometres: How Many Housing Markets?"

16-03 Fabling, Richard and Lynda Sanderson. 2016. "A Rough Guide to New Zealand's Longitudinal Business Database (2nd edition)."

16-02 MacCulloch, Robert. 2016 "Can "happiness data" help evaluate economic policies?"

16-01 Gørgens, Tue and Dean Hyslop. 2016. "The specification of dynamic discrete-time two-state panel data models"

15-20 Maré David C., Ruth M. Pinkerton and Jacques Poot. 2015. "Residential Assimilation of Immigrants: A Cohort Approach."

15-19 Timar, Levente, Arthur Grimes and Richard Fabling. 2015. "Before a Fall: Impacts of Earthquake Regulation and Building Codes on the Commercial Market"

15-18 Maré David C., Dean R. Hyslop and Richard Fabling. 2015. "Firm Productivity Growth and Skill."

15-17 Fabling, Richard and David C. Maré. 2015. "Addressing the absence of hours information in linked employer-employee data."

15-16 Thirkettle, Matt and Suzi Kerr. 2015. "Predicting harvestability of existing *Pinus radiata* stands: 2013-2030 projections of stumpage profits from pre-90 and post-89 forests"

15-15 Fabling, Richard and David C. Maré. 2015. "Production function estimation using New Zealand's Longitudinal Business Database."

15-14 Grimes, Arthur, Robert MacCulloch and Fraser McKay. 2015. "Indigenous Belief in a Just World: New Zealand Maori and other Ethnicities Compared."

15-13 Apatov, Eyal, Richard Fabling, Adam Jaffe, Michele Morris and Matt Thirkettle. 2015. "Agricultural Productivity in New Zealand: First estimates from the Longitudinal Business Database."

Motu