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Modelling Land Use in Rural New Zealand

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Abstract

New Zealand rural land is dominated by four major uses – dairy farming, sheep and beef farming, plantation forestry, and unproductive scrub. Using national time series data we look at how each of these land uses has responded to changing economic returns, as measured by relevant commodity prices, over the period from 1974 to 2008. We do this by developing a dynamic econometric model which relates rural land use to economic factors. We follow the literature on the estimation of dynamic singular equation systems. We adopt this framework to look at land use choices. Our coefficients provide preliminary estimates of the responsiveness of different types of rural land to changing economic returns. They are used to compare different carbon price scenarios.

JEL codes

Q15, Q24

Keywords

Land use change, New Zealand, National, time series

1. Introduction

Rural land use is a major determinant of economic and environmental outcomes in New Zealand. In 2010 around 5 per cent of New Zealand's GDP was due to agricultural, or forestry production[1], both of which use rural land as a key input. On the environmental side, agricultural production is a large source of Greenhouse Gas (GHG) emissions while forestry is an emissions sink. Despite this there is little research investigating the economic determinants of rural land use in New Zealand.

New Zealand rural land is dominated by four major uses – dairy farming, sheep and beef farming, plantation forestry, and unproductive scrub. Using national time series data we look at how each of these land uses has responded to changing economic returns, as measured by relevant commodity prices, over the period from 1974 to 2008. We do this by developing a dynamic econometric model which relates rural land use to economic factors. We follow the literature on the estimation of dynamic singular equation systems (Anderson and Blundell (1982), (1983)). Singular equation systems have often been estimated to model consumer expenditure patterns – expenditure and savings always add up to income. We adopt this framework to look at land use choices – the sum of rural land in each use always adds up the total amount of rural land.

Our coefficients provide preliminary estimates of the responsiveness of different types of rural land to changing economic returns. In other work, we use these estimates to look at different carbon price scenarios. The small quantity of data is a potential problem for our research. However our results seem sensible and have an intuitive interpretation. Long-run own-price elasticities are typically positive while cross-price elasticities are typically negative. In the short-run there seems to be a split between productive and non-productive land uses, with all types of productive rural land use increasing with increases in any commodity prices, and non-productive rural land decreasing with increases in any commodity prices.

The rest of this paper is structured as follows. In section 2 we develop a theoretical model of land use choice at a parcel level, and show what this implies for aggregate land use. Section 3 describes our data and looks at summary statistics and graphs. Cointegration tests are reported in section 4. In section 5 we present our econometric methodology. Section 6 contains estimation results, including our tests of dynamic simplifications. Section 7 presents a baseline land use scenario until 2050. In section 8 we conclude.

[1] This number was calculated using data from Statistics New Zealand that can be accessed at www.stats.govt.nz/infoshare/

2. Theoretical framework

2.1. Individual land use choices

We solve a dynamic land allocation problem. Our model follows the models of Stavins and Jaffe (1990) and Parks (1995) closely. Consider a land manager who has a fixed quantity of land denoted by A making a plan for her land at time $t = 0$. She takes the proportion of her total land in each of k uses at the initial period, denoted by a_{i0} where $i = 1, \ldots, k$, as given (this would be the case if she had only just become the land manager, or she were reconsidering her land use choices in which case her old choices are then given). She chooses non-land inputs (which we have supressed for clarity – the results are qualitatively unchanged) and the amount of land to transfer between each use, $z_{ijt}\ \forall\ \boldsymbol{i \neq j}$, to solve the following problem:

$$\max_{\{z_{ijt}\}_{i\neq j}} \int_0^\infty \left(\sum_{i=1}^{k} \pi_i(a_{it}) - \sum_{i=1}^{k} \sum_{j\neq i}^{k} C_{ij}(z_{ijt}) \right) e^{\delta t} \mathrm{d}t, \tag{1}$$

subject to

$$A = \sum_{i=1}^{k} a_{it}, \qquad \forall\, t \tag{2}$$

$$a_{it} \geq 0, \qquad \forall\ i, t \tag{3}$$

$$\dot{a}_{it} = \sum_{j\neq i}^{k} z_{ijt} - \sum_{j\neq i}^{k} z_{jit}, \qquad \forall\, i, t \tag{4}$$

$$z_{ijt} \geq 0, \qquad \forall\, i, j, t \tag{5}$$

$$a_{io} \text{ a given constant}, \qquad \forall i.$$

Expression (1) gives the net present value for any set of decisions about land conversions. $\boldsymbol{\pi_i(a_{it})}$ and $\boldsymbol{C_{ij}(z_{ijt})}$ are both increasing functions of their arguments. We assume that land managers are able to borrow to fund conversions and such debt is repayed over the lifetime of the investments - this is included in the function $\boldsymbol{C_{ij}(z_{ijt})}$. Constraint (2) says that in every time period $\boldsymbol{t}$ total land $\boldsymbol{A}$, which is assumed to be constant over time, is equal to the sum of all land used for production $\boldsymbol{a_{it}}$ - this means we are assuming that conversion, $\boldsymbol{z_{ijt}}$, is instantaneous. Constraint (3) ensures the amount of land in each use is nonnegative. Constraint (4) is the law of motion which determines how the land use shares, $\boldsymbol{a_{it}}$, evolve over time. The change in the amount of land in use $\boldsymbol{i}$ is equal to the sum of all land transfered into use $\boldsymbol{i}$ minus the sum of all land transferred out of use $\boldsymbol{i}$. Constraint (5) is a nonnegativity constraint which ensures the $\boldsymbol{z_{ijt}}$

have the interpretation as the amount of land moving from use $\boldsymbol{j}$ to use $\boldsymbol{i}$ - this clearly cannot be negative even though net land transfer between use $\boldsymbol{i}$ and use $\boldsymbol{j}$ can be negative.

The current value Hamiltonian for this model is given by

$$\boldsymbol{H} = \left(\sum_{i=1}^{k} \boldsymbol{\pi}_i(\boldsymbol{a}_{it}) - \sum_{i=1}^{k} \sum_{j \neq i}^{k} \boldsymbol{C}_{ij}(\boldsymbol{z}_{ijt}) \right) + \sum_{i=1}^{k} \boldsymbol{\lambda}_{it} \left(\sum_{j \neq i}^{k} \boldsymbol{z}_{ijt} - \sum_{i \neq j}^{k} \boldsymbol{z}_{jit} \right). \quad (6)$$

The first order conditions are

$$\frac{\partial \boldsymbol{H}}{\partial \boldsymbol{z}_{ijt}} = -\boldsymbol{C}'_{ij}(\boldsymbol{z}_{ijt}) + \boldsymbol{\lambda}_{it} - \boldsymbol{\lambda}_{jt} = \boldsymbol{0}. \quad (7)$$

$$\frac{\partial \boldsymbol{H}}{\partial \boldsymbol{a}_{jt}} = \boldsymbol{\pi}'_j(\boldsymbol{a}_{jt}) = -(\dot{\boldsymbol{\lambda}}_{jt} - \boldsymbol{\delta}\boldsymbol{\lambda}_{jt}). \quad (8)$$

To confirm the $-\boldsymbol{\lambda}_{jt}$ in (7) term simlpy expand constraint (4) before differentiating. Condition (7) determines optimal conversion and by setting it to zero we are implicitly assuming an interior solution. While corner solutions are likely to be important for individual land managers we use data on national time series in which corner solutions are irrelevant.

Multiplying (7) by δ and substituting $\delta\lambda_{it}$ from (**8**) gives

$$\boldsymbol{\delta}(\boldsymbol{\lambda}_{it} - \boldsymbol{C}'_{ij}(\boldsymbol{z}_{ijt})) = \boldsymbol{\pi}'_j(\boldsymbol{a}_{jt}) + \dot{\boldsymbol{\lambda}}_{jt}. \quad (9)$$

We see that at an optimum the marginal benefit (net of annualised conversion costs) of an extra hectare in the new use i, given by $\delta(\lambda_{it} - C'_{ij}(z_{ijt}))$, must equal the marginal cost of an extra hectare in the original use j, given by the direct marginal profit of an extra hectare in the old use $\pi'_j(a_{jt})$, plus future gains to returns in the old use $\dot{\lambda}_{jt}$. This result is very similar to Parks (1995) where $\dot{\lambda}_{jt}$ is interpreted as capital gains. All land with returns that exceed a threshold will be put into the new use and this happens at every threshhold.

Importantly this model predicts instantaneous land use change. In practice land use change can be slow. Stavins and Jaffe (1990) suggest forest age distribution, liquidity constraints, uncertainty about the permanence of price movements, and decision-making inertia as possible reasons for slow land use adjustment. When we specify our econometric model later we will include dynamics to allow for slow land use change.

2.2. Aggregation

The model above implies that all parcels of a given quality with the same prospects for capital gains should have the same land use. In this work we use national time series data. Land use differs across New Zealand. Stavins and Jaffe (1990) suggest two reasons for heterogeneous land use in aggregate land areas; firstly land use may be adjusting towards a steady state; secondly there is unobservable heterogeneity in land and farmers.

An important question is how we can make predictions about land use at the national level from our parcel level model. This is a classic case of the aggregation problem faced by econometricians. Stavins and Jaffe (1990) first answered this question for county level data. They assumed a distribution of land quality and showed how changes in flood protection projects affected land quality and hence land use. In our work we are interested in the effect of economic returns on land use choices. We don't model the distribution of land quality as changing, but only have in mind that as economic returns change, the amount of land that should be allocated to different uses will change. Suppose the price of the good associated with land use i increased. Because profit includes revenue this will increase the right-hand side of (9). Then because $C_{ij}(z_{ijt})$ is increasing the optimal level of z_{ijt} would fall – i.e., if the price associated with use i increased then the amount of land converted from use i to use j would fall. Similar dynamics apply to $\dot{\lambda}_{it}$ as well as things that might affect the function $C_{ij}(z_{ijt})$.

3. Data

3.1. Data sources

We need two main types of data: data on the area of land in each rural use, and data on economic variables which we expect to be associated with land use. Our data comes from a variety of sources.

3.1.1. Land area data

Rural land use data for New Zealand has been collected in various ways in recent history. Statistics New Zealand (SNZ) conducted the Agricultural Production Census for the years 1974 to 1987, 1990, 1994, 2002, and 2007. They also conducted sample surveys for the years 1988, 1989, 1991 to 1993, 1995, 1996, 1999, 2003 to 2006, and 2008[2]. Unfortunately SNZ did not collect land area data at even the national level for 1997, 1998, 2000, or 2001. However the Meat and Wool Economic Service used their own surveys to construct national level data designed to be consistent with SNZ's Agricultural Production Statistics data for 2000 and 2001. They estimated national land use areas in 1997 and 1998 using linear interpolation. Thus, using these sources as well as land area data published by SNZ in 1972 and 1973 provides us with a time series of observations on rural land areas.

[2] The survey that was conducted in 1999 had a different population base and so we did not use it.

This time series does not distinguish between farm land used for dairy production as opposed to sheep and beef meat production. Because dairy production and sheep and beef meat production are very different in terms of their economic and environmental effects we want to model these separately. For the years 1980 to 1996, 2000, 2001, and 2002, Meat and Wool separated pasture land in to dairy land, sheep and beef land, and other pastoral land, at the national level by using data on average farm size and total farm numbers. We split pasture in the remaining periods between dairy and sheep and beef land by extrapolating based on animal numbers.

Data on the land area in plantation forestry is mostly available from the SNZ – however the period from 1997 to 2001 is again an exception. The National Exotic Forestry Description (NEFD) has data on the amount of new land converted into plantation forestry as well as the amount of land deforested over this period. Thus we combine plantation forestry area data on levels from SNZ in 1996 and 2002, with data on changes from NEFD between 1997 and 2001 to estimate the amount of land in plantation forestry between 1997 and 2001.

We estimate the area of scrub land as the residual of total rural land less the amount of land used for grazing animals, for plantation forests, or for horticulture. The amount of land in rural uses has changed over the passed few decades. Among other things, this is due to increases in urban land and changes in conservation land. We expect changes in the total amount of rural land to be primarily driven by factors other than economic returns in rural uses. We define a new category, other land, which measures these exogenous changes in rural land relative to 1974.

$$\text{other\_land}_t = \text{total\_rural\_land}_{1974} - \text{total\_rural\_land}_t$$

Thus when $\text{other\_land}_t > 0$ we have $\text{total\_rural\_land}_t < \text{total\_rural\_land}_{1974}$. Thus if other_land_t is increasing then $\text{total\_rural\_land}_t$ is decreasing. We end up with a time series on the area of New Zealand land in each of the four major rural uses – dairy farming, sheep and beef farming, plantation forestry, and scrub, and a measure of the changes in total rural land.

3.1.2. Commodity prices

SNZ published data on the volume and value of agricultural exports in all years for which we have land use data. This allows us to back out the export price in cents per kilogram for each agricultural product of interest. Importantly, much agricultural production was subsidised until 1990. We increase our prices over the period of subsidisation by weighting factors, documented by Anderson (2007), which reflect the proportion of farm profits due to government assistance. This gives us a time series of effective prices faced by farmers by land use for the period 1972 to 2008. For dairy and forestry land the raw prices we use are the export price in cents per kilogram of milk solids, and cents per cubic metre of wood. For sheep-beef we use a composite price which is the weighted average of the price in cents per kilogram for sheep meat, beef meat, and wool, where we weight by volume sold.

3.1.3. Other macroeconomic indicators

SNZ also collects data on Gross Domestic Product measured in various ways. The Reserve Bank of New Zealand (RBNZ) has data on the interest rate of 5 year bonds as well as exchange rates. These macroeconomic variables could be important for land use decisions and hence we try several specifications including them in different combinations. However, because we only have 35 time observations and we estimate both short and long run effects we quickly lose degrees of freedom. In our preferred specification we only include nominal interest rates. We present results for several specifications in our appendix.

3.2. Summary statistics

In this section we present summary statistics for our data. Land data is presented as shares of total rural New Zealand land in 1974. Price data is presented as $\log(\text{real\_price}_t)$, where we used the RBNZ's CPI with base year 2008. Our data is annual and spans the period from 1974 to 2008 inclusive, giving us 35 yearly observations on 4 land uses of interest. Table 1 presents means and standard deviations for data used in our analysis.

Table 1: Summary statistics

Variable	Mean	Std. Dev.	Min	Max
dairy share	0.09	0.02	0.07	0.12
sheep-beef share	0.70	0.06	0.57	0.76
forestry share	0.08	0.02	0.03	0.11
scrub share	0.13	0.03	0.09	0.18
other share	0.01	0.05	-0.04	0.12
log(dairy price)	6.29	0.20	5.85	6.77
log(sheep-beef price)	6.55	0.25	6.16	7.00
log(forestry price)	9.65	0.24	9.09	10.13
interest rate	9.33	3.67	5.41	18.47

Several things are worth noting. Firstly sheep beef land accounts for the majority of land use throughout the series – at it's peak sheep beef land accounted for 76 per cent of rural New Zealand land (as a percentage of total rural land in 1974). The change in rural New Zealand land relative to 1974 has fluctuated, as shown by the fact that the share of other land has been both positive and negative over the period. The mean reported for price variables is the mean of the logs rather than the log of the mean.

3.3. Graphs of time series

In this section we present graphs of our data to get a feel for their time series properties. Figure 1 shows the share of land in each of the four major rural uses between 1974 and 2008. Sheep-beef farming has historically dominated rural land use, however since the mid 1990s it has fallen from above 70 per cent to less than 60 per cent of rural land. The remaining three land uses have historically made up a much smaller percentage of rural New Zealand land. However from around the mid 1990s they have all had a roughly equal share of rural New Zealand land of about 10 per cent.

Figure 1: Share of rural land by use, 1974-2008

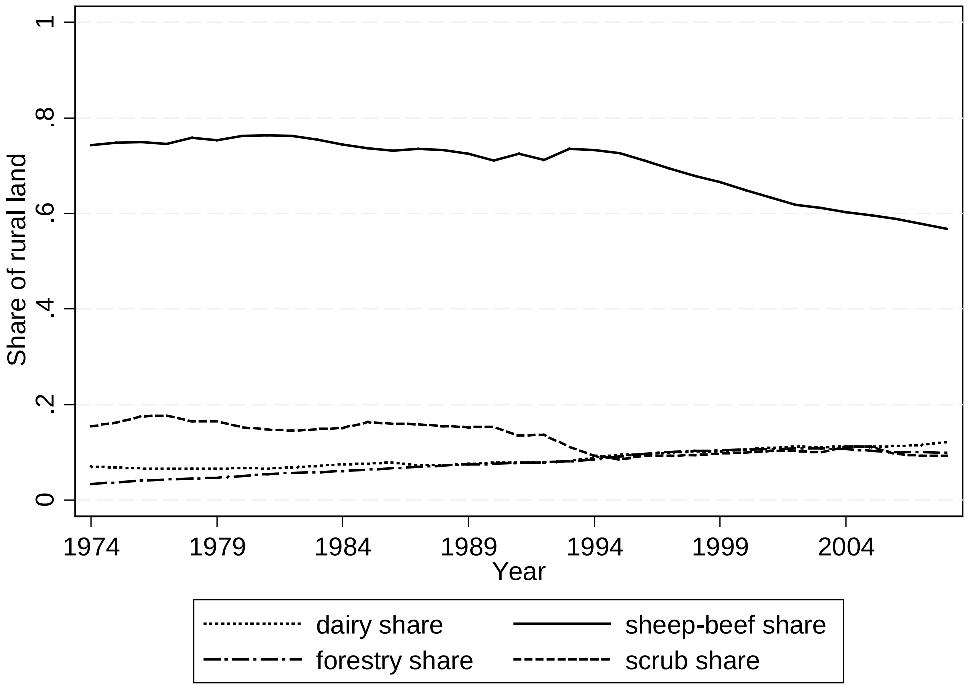


Figure 2 graphs the log of the producer subsidy equivalent real prices corresponding to our three land uses. From the graph, relative prices have stayed more or less constant throughout the period. The sharp increase in wood prices in 1994 shows up clearly.

Figure 2: Real prices of agricultural products, 1974-2008

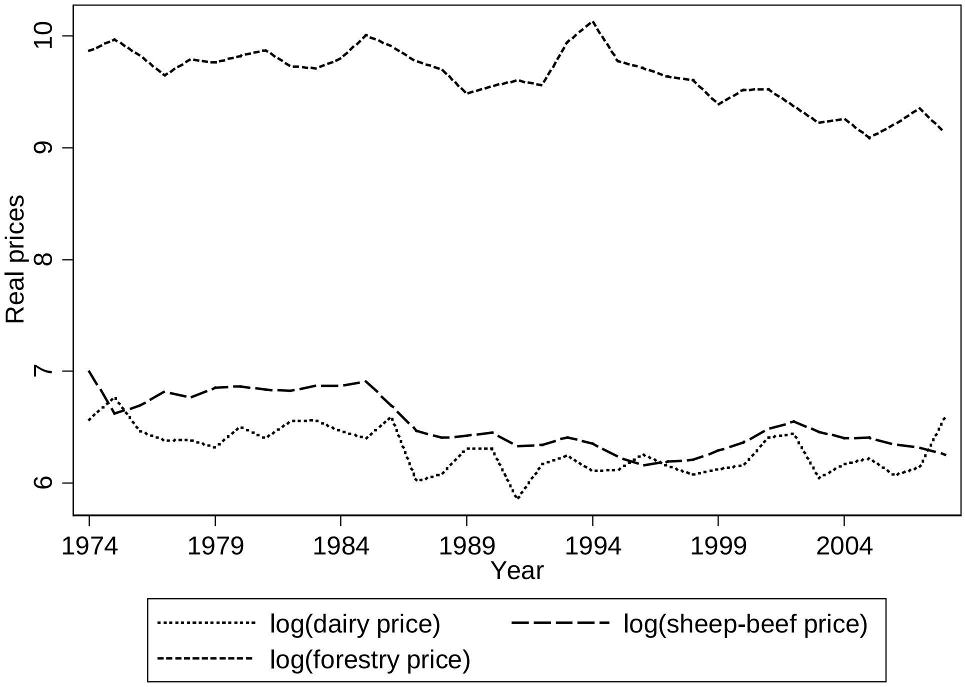
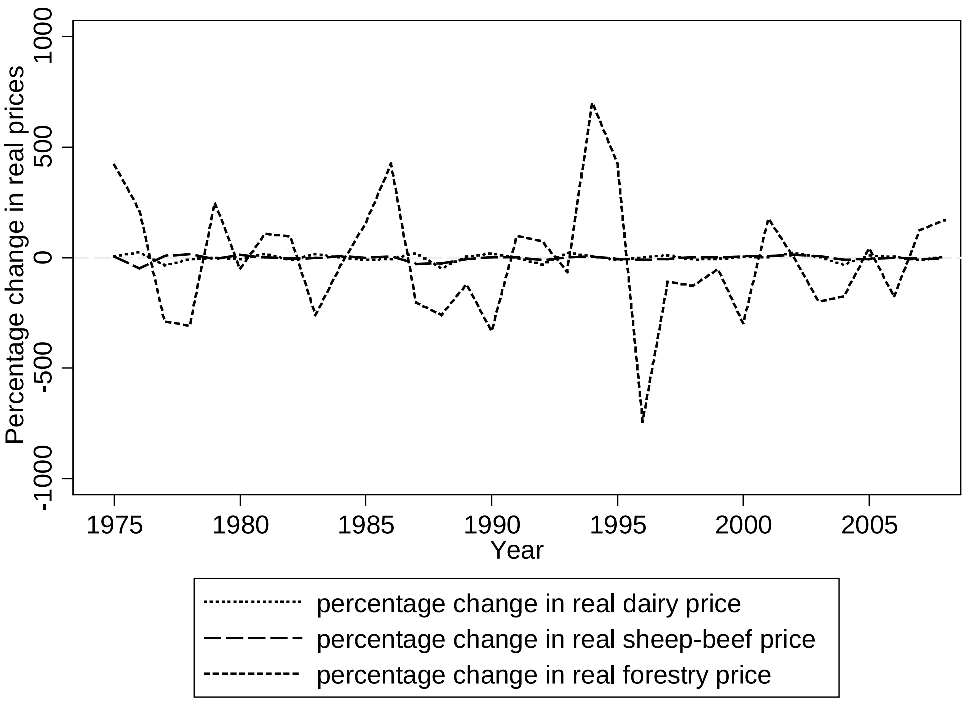


Figure 3 graphs the percentage change in the level of real producer subsidy equivalent prices. The export price per cubic metre of wood product is far more volatile than either the dairy export price or the sheep-beef export price.

Figure 3: Percentage change in real prices, 1975-2008



3.4. Unit root tests

In this section we look at whether our land share, and price series are individually stationary or not. Table 2 reports the test statistics for several Dickey-Fuller unit root tests as well as the 5 per cent critical values.[3] The first two columns present test statistics for unit roots in levels, where column (2) allows for a deterministic trend but column (1) does not. Columns (3) and (4) present test statistics for first differences and column (4) allows for a trend while column (3) does not.

For each test the null hypothesis is that the univariate sequence contains a unit root. The alternative hypothesis is that the series is stationary. We reject the null hypothesis if the test statistic is smaller (more negative) that the critical value. Thus looking at the series as levels we see that we cannot reject the null hypothesis of a unit root for any of the series except the forestry share and the log(dairy price). From figure 1 it is clear that most of the land use time series have reasonably strong trends over the period for which we have data. When we allow for such trends we can only reject the null of a unit root in the series for log(dairy price).

Table 2: Unit root tests

	Levels		First differences	
	(1)	(2)	(3)	(4)
dairy share	1.44	-2.61	-3.87	-4.33
sheep-beef share	2.14	-1.29	-4.56	-5.75
forestry share	-3.03	1.97	-1.68	-2.37
scrub share	-0.57	-1.98	-4.54	-4.49
other share	3.15	-2.01	-3.34	-5.73
log(dairy price)	-3.16	-4.43	-7.88	-7.76
log(sheep-beef price)	-1.63	-1.93	-5.64	-5.56
log(forestry price)	-1.68	-3.09	-5.63	-5.60
interest rate	-1.33	-2.41	-4.76	-4.94
critical value 5%	-2.98	-3.56	-2.98	-3.56

While most of the series have unit roots in their levels, we can reject the null of unit roots in favour of stationarity when we take first differences. Apart from the first difference in the forestry share, all other differenced series have test statistics considerably more negative than the critical values. Thus our series, with the possible exception of the forestry share, all appear to be I(1).

[3] More sophisticated tests for unit roots exist. For our data they all yield qualitatively similar results, with very few changes in rejection of the null hypothesis.

4. Cointegration tests

Given our time series appear to be I(1) it is natural to wonder whether some combination of them are I(0). I.e., are there cointegrating factors amongst our time series which we could think of us representing equilibrium tendencies? In particular we assume for each land use there exists a long run equilibrium relationship of the form

$$s_{it} = \alpha_i + \sum_{j=1}^{3} \gamma_{ij} \log(p_{jt}) + \beta_{i1} i_t + \beta_{i2} s_{ot} + \nu_{it} \quad (10)$$

where s_{it} is the share of land in use i at time t, p_{jt} is the price of the j-th commodity at time $t-1$[4], i_t is the nominal 5 year interest rate, s_{ot} is the share of other land, ν_{it} is ther error term, and α_i, γ_{ij}, β_{i1}, and β_{i2} are parameteres to be estimated.

We then test for cointegration by using panel unit root tests on the residuals from regressions estimating the long run structure of our model, ignoring dynamic properties. We use two panel unit root tests. One test is based on Choi (2001) and requires only $T \to \infty$ asymptotics. The null hypothesis is that the residuals of all equations have unit roots, and the alternative is that at least one equation is stationary. This does not test cointegration directly but uses appropriate asymptotics – if we cannot reject the null hypothesis this would be evidence against cointegration. The second test is based on Hadri (2000). It requires $T \to \infty$ and then $N \to \infty$. Given we are only interested in four land uses this may not be appropriate. On the other hand the hypotheses are appropriate. Under the null the residuals of all equations are stationary, while under the alternative at least one has a unit root. These tests are both designed as unit root tests (with differing null hypotheses) and we have made no adjustment to the p-values to reflect that we are testing cointegration and multiple regressors in the first stage when we calculate the residuals. However we hope these tests are indicative of whether it is reasonable to think cointegration holds. Given three rural land shares and the amount of other land the fourth land use is completely determined. Thus we implement these tests using residuals obtained by estimating (10) by OLS for dairy, sheep-beef, and forestry land shares. We implement the above two tests on the demeaned residuals using no lags, one lag or two lags. Using the first method we reject the null hypothesis that all residual series have unit roots at the 5 or 10 per cent level for any lags. Using the second method we fail to reject the null that all residual series are stationary at even the 10 per cent level using any of the above number of lags.[5]

[4] Because land use decisions depend on expected future profitability under different uses lagged prices are often used to account for expectations formation – see footnote 5 of Miller and Plantinga (1999)

[5] We used information from the Stata user manual – [xt] xtunitroot throughout this section.

5. Econometric methodology

We want to estimate the relationship between land use and commodity prices. I.e., how does land use change at the national level as commodity prices change. It is useful to think in terms of an allocation problem. Given current and expected economic returns over land uses what is the best allocation of a particular parcel of land. Aggregating up to the national level we want to know what share of rural land will be in each use given expected returns. This leads us naturally to consider land use as a system of share equations. The share of land in each rural use depends on the expected returns of land under each use. When the set of uses considered is exhaustive and mutually exclusive such a system of equations is necessarily singular. With four rural land uses (five if you include exogenous other land) we can always exactly infer the share of land in the fourth use given the shares in the other three uses.

Dynamic considerations play an important role in our econometric specification. Land use decisions now impact future options and profitability because of conversion costs for example. This means that responses to economic conditions may have dynamic effects[6]. Anderson and Blundell (1982) developed a methodology for incorporating general dynamics in singular system estimation. Their method attractively nests several dynamic simplifications allowing researchers to test whether a static model really is rejected by the data. Anderson and Blundell (1983) is a good example of estimating such a general dynamic singular system. Ng (1995) looks at cointegration within the Almost Ideal Demand System framework of the Deaton and Muellbauer (1980), originally a static singular system of equations.

Given the long run cointegrating relationship established in the previous section we specify our general dynamic model as

$$\Delta \boldsymbol{s_t} = \boldsymbol{A}\Delta\widetilde{\boldsymbol{x}}_{\boldsymbol{t}} - \boldsymbol{B}(\boldsymbol{s_{t-1}} - \boldsymbol{\Pi x_{t-1}}) + \boldsymbol{\varepsilon_t} \qquad (11)$$

where, as analogues to Anderson and Blundell (1983), $\Delta \boldsymbol{s}_t$ is a vector of the changes in each land use between time t and time $t-1$, $\boldsymbol{x}_{t-1}$ is a vector containing the variables that go into the long run equation above at time $t-1$, and $\widetilde{\boldsymbol{x}}_t$ is the same as $\boldsymbol{x}_t$ with the constant removed (so it is a vector that is shorter than $\boldsymbol{x}_t$ by one element). $\boldsymbol{\Pi x}_t$ specifies the long run structure exactly as in (10), and $\boldsymbol{B}$ combines adjustment coefficients. It is important to note that

[6] In consumer expenditure modelling, perhaps the major application of share equation systems, static models were often found to reject fundamental properties of consumer theory. Appropriate allowance for dynamics substantially reduced rejection rates. This would be consistent with habit formation, for example. In a land use setting dynamics are arguably even more important.

the individual adjustment coefficients are not identified (we cannot recover them from $\boldsymbol{B}$ which only contains combinations of them), however all aspects of the long run structure are identified.

Because this system of equations is singular, estimation requires us to omit one of the land shares. We estimate the system by iterated nonlinear generalised least squares using Stata. Theses estimates converge to the standard maximum likelihood estimates, which have the desirable property of being invariant to the land share omitted (even when restrictions are imposed on the model).

6. Results

In this section we present results from our econometric estimation. Firstly we estimate our general dynamic framework. Following that we test against several popular dynamic simplifications. In the general specification we find that most of the long run responsiveness of land shares to price changes are as expected. Own price elasticities are positive and cross price elasticities are negative. Short run responsiveness tells a different story. Almost all productive land shares increase when any prices increase, and the share of land in unproductive scrub decreases as any prices increase. This suggests that there may be other factors driving the short run side of land use changes that we are not accounting for. Finally, it is important to note that most of our coefficients lack statistical significance. This is not surprising given we have little and noisy data.

6.1. Estimation of the general dynamic model

We estimate the general dynamic model in equation (10) using feasible iterated generalised least squares. Our results are presented in Table 3. For the i-th land share α_i is the estimated long run constant, γ_{ij} is the estimated long run coefficient of the j-th price, β_{i1} is the long run effect of exogenous changes in other land, and β_{i2} is the long run effect of interest rates. a_{ij} is the short run effect of the j-th price for $j \in \{1, 2, 3\}$, the short run effect of changes in other land for $j = 4$, and the short run effect of interest rates for $j = 5$. b_{ij} represent the composite adjustment factors – recall that individual adjustment factors are not identified.

Standard errors are presented in parentheses. These are too small in finite samples. However given the amount of data we are working with there are relatively few statistically significant estimates in any case. We have not implemented finite sample corrections.

Table 3: General dynamic model coefficient estimates[7]

land use i	α_i	γ_{i1}	γ_{i2}	γ_{i3}	β_{i1}	β_{i2}	a_{i1}	a_{i2}	a_{i3}	a_{i4}	a_{i5}	b_{i1}	b_{i2}	b_{i3}
dairy	-0.471	0.001	-0.050	0.092	0.279*	0.001	0.001	0.007***	0.006***	0.038	0.000***	0.633***	-0.046	-0.313***
	(0.606)	(0.032)	(0.035)	(0.075)	(0.170)	(0.001)	(0.002)	(0.003)	(0.002)	(0.051)	(0.000)	(0.135)	(0.030)	(0.063)
sheep-beef	1.766*	-0.033	0.126**	-0.176	-1.129***	-0.004**	0.001	0.020*	0.013	-0.586***	-0.002***	1.011*	0.398***	-0.039
	(0.997)	(0.053)	(0.058)	(0.124)	(0.279)	(0.002)	(0.009)	(0.012)	(0.010)	(0.223)	(0.001)	(0.586)	(0.131)	(0.273)
forestry	-1.009	-0.001	-0.109	0.191	0.051	0.002	0.001	0.000	0.005***	-0.063**	0.000	0.011	-0.048***	-0.020
	(1.445)	(0.076)	(0.085)	(0.180)	(0.405)	(0.003)	(0.001)	(0.001)	(0.001)	(0.027)	(0.000)	(0.070)	(0.016)	(0.033)
scrub	0.714	0.034	0.033	-0.107	-0.202	0.002	-0.004	-0.027	-0.024	-0.389	0.001	-1.655	-0.304	0.372
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Standard errors in parentheses

* significant at the 10 per cent level, ** significant at the 5 per cent level, *** significant at the 1 per cent level (no finite-sample correction used)

Table 4: Testing dynamic simplifications

	(1)	(2)	(3)	(4)
D.F.	15	15	9	9
LR stat	43.7*	37.9*	210.6*	216.3*
CV 0.05	25.0	25.0	16.9	16.9
CV 0.01	30.6	30.6	21.7	21.7

* significant at the 1 per cent level

[7] We had to correct an overly restrictive identification constraint in terms of the number of observations and the number of coefficients to estimate in the Stata 11 base ado file nlsur. In essence nlsur did not account for the fact that we had multiple equations. The correction only required changing two lines of code.

Looking at the long run price responsiveness we see that most shares are estimated to increase as their own commodity price increases but to decrease as competing commodity prices increase. There are three exceptions, which from the point of view of simulating scenarios are important: the dairy share is positively associated with forestry prices; the scrub share is positively associated with dairy prices; the scrub share is positively associated with sheep-beef prices. The dairy share, forestry price, association is something that comes through strongly in the data. We do not think this represents a causal relationship. However we are not sure why these two time series historically have happened to have a high degree of linear co-movement – not that the land shares on the left hand side are already differenced. The scrub share, commodity price relationships are also unusual. These exceptions should remind us that we are not estimating causal relationships, and thus we must use judgement and care when producing scenarios based on New Zealand's national land use data.

The short run price relationships are also interesting. The change in land share for all productive uses is estimated to increases as any commodity price increases (in fact the forestry share has a negative coefficient if it is shown to 4 decimal places). All changes in commodity prices are estimated to have negative coefficients in the scrub share equation. Thus there appears to be a split in the short run between productive and unproductive use. This could suggest an important omitted variable, such as GDP, or exchange rates, which could be important in allowing changing land use in the short run – perhaps due to facilitating access to credit. However we report results including real GDP and the UK exchange rate both separately and together in the appendix and our results do not change qualitatively[8].

6.2. Testing dynamic simplifications

The dynamic specification of our model is likely to be important because land use choices now affect future land use profitability. Several simpler dynamic structures are nested in our general model and can be implemented by appropriate coefficient restraints. In particular Anderson and Blundell (1982), (1983) showed the coefficient restrictions necessary to collapse the general model to either an AR(1) model, a partial adjustment model, or a static model. Consider equation (10): if each $a_{ij} = \pi_{ij}$ for all i and j then we get the AR(1) model; if each $a_{ij} = \sum_{k=1}^{3} b_{ik} \pi_{kj}$ we get the partial adjustment model; from either the AR(1) model or the partial adjustment model we can get the static model by constraining $b_{ij} = \delta_{ij}$ where δ_{ij} is the kronecker delta.

[8] Exchange rate data is obtained from the Reserve Bank of New Zealand's website – the Trade Weighted Index does not extend back as far as our data series, so we use the UK exchange rate.

We test each of these dynamic simplifications in turn using likelihood ratio tests. Our results are presented in Table 4. The D.F. row reports the number of coefficient constraints necessary to implement the nested model. The LR stat row reports the likelihood ratio statistic for the test. CV 0.05 and CV 0.01 report the $\chi^2_{D.F.}$ critical value for D.F. degrees of freedom at the 5 per cent and 1 per cent levels respectively. Column (1) reports the test for the general model against the AR(1) model; column (2) gives results for the general model against the partial adjustment model. The static model is tested against the AR(1) model and the partial adjustment model in columns (3) and (4). All simplifications can be rejected at the 1 per cent level. The most general model we consider, which allows the disequilibrium in dairy, sheep-beef, and forestry to affect all land use changes is always preferred in our data.

7. Baseline scenario

In this section we present a baseline scenario for land use until 2050. For this scenario we use the price projections used in MAF's Pastoral Supply Response Model until 2015 (using lagged prices as our predictors these have effects until 2016). From 2015 onward we assume constant real prices. We also assume that nominal interest rates and the share of land that is not in any of the four major rural uses stays constant at its 2008 level going into the future. Under these assumptions our baseline scenario is shown in Figure 4.

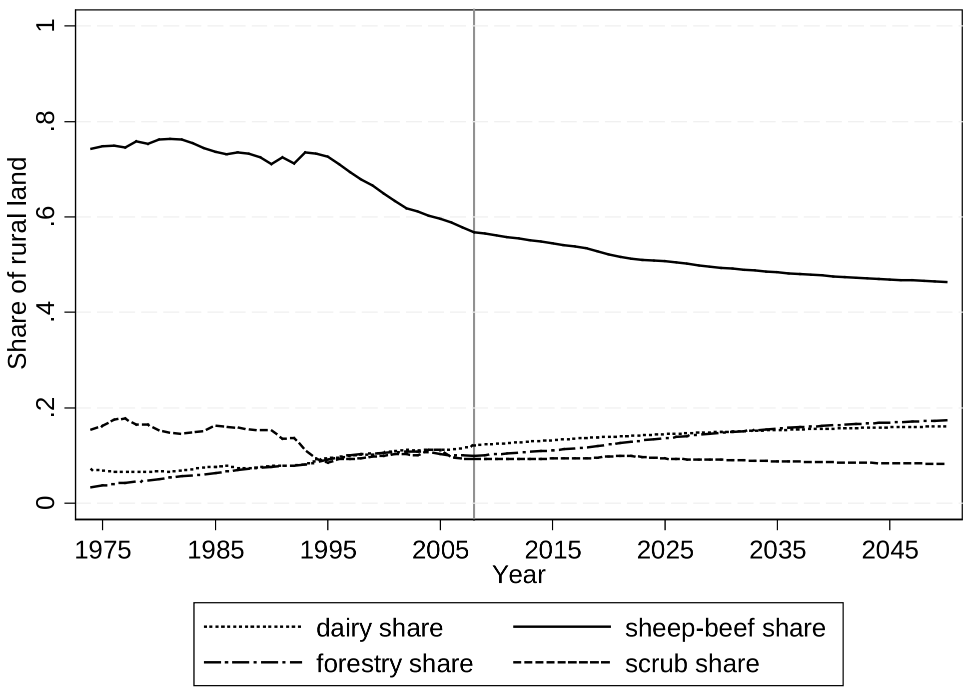


Figure 4: Baseline scenario, 2009-2050

The vertical grey line separates the graph into two sections. The left side shows observed land share data from 1974-2008. The right hand side shows our baseline projections when there is no NZ ETS. We have smoothed the dynamics in the first 10 years – there was some fluctuation as changing projected prices affected long run equilibrium levels. The two important aspects of the baseline scenario are its overall trends, and its dynamics. These are both driven by changes in projected prices, because these are the only predictors which vary between 2009 and 2050. In particular the real dairy price projections increase from 635 to 937 cents per kilogram of milk solids, the sheep-beef price projections increase from 533 to 549 cents per kilogram, while the forestry price increases from 11970 to 19288 cents per cubic metre of wood. Until 2016 these price projections result in relative price changes – however from 2017 onwards all relative prices are stable.

The change in projected forestry prices dominates the other changes in terms of its magnitude. Thus, because the long run forestry share increases with the forestry price, and the long run sheep-beef and scrub shares fall with forestry prices it is not surprising that the long run trend is for increasing forestry and decreasing sheep-beef and scrub. The long run dairy trend should be assessed with care. In particular our estimates show that the dairy share responds positively to increases in forestry prices. We do not think that this represents a causal effect – however the correlation appears strongly in historic New Zealand land use data. This responsiveness results in the dairy share increasing more in the baseline than it would if it were only being driven by increases in the dairy price projections.

Our current baseline has rather volatile short run dynamics. These mainly show up in the sheep-beef and scrub shares which have the quickest aggregate responses to disequilibrium effect.[9] These are due to swings in relative commodity prices over the period in which price projections are variable. Once relative commodity prices projections settle down these dynamics no longer have an important role.

8. Conclusion

This paper has estimated the relationships between New Zealand's main rural land uses and their associated export prices using national time series data. We have a short time series and so it is not surprising that many of our coefficient estimates are not statistically significant.

In the short run we estimate that most productive land uses are positively associated with relevant prices, while unproductive scrub is negatively associated with relevant prices. In the long

[9] Recall that the individual adjustment factors are not identified.

run all land shares were estimated as being positively associated with the price of their own products and most were estimated to have a negative relationship with the price of products from other land uses.

Theoretically we think that dynamic considerations should be important for land use choices. This hypothesis is reinforced by the data. Likelihood ratio tests overwhelmingly reject the static models in favour of the simple dynamic AR(1) and partial adjustment models. Furthermore both of these models are rejected at the 1 per cent level compared to our more general model.

For simulation work there are further limitations that should be kept in mind. We have time series data from before the implementation of the NZ ETS. Our estimates of land use responsiveness to economic returns are based on this data and we have not allowed for structural change – in particular the ETS itself may represent a structural change. Furthermore simulations based on our parameter estimates must explicitly incorporate the structure of expectations of future returns. Because of conversion costs land use may not respond to changes in economic returns that are perceived as purely transitory.

This work represents are first step in estimating how rural land use responds to economic factors in New Zealand. Further work will continue to explore the relationship between rural land use and economic returns using panel data provided by Statistics New Zealand at a Territorial Local Authority level, as well as satellite and land use panel data in 1996, 2002, and 2008. This collection of work will help estimate the impact of policy that aims to achieve environmental outcomes by changing land use through affecting economic incentives.

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Appendix A

In this appendix we present two sets of estimation results that include separately GDP and the UK exchange rate. Inclusion of GDP and the UK exchange rate together yields qualitatively similar results.

Our motivation for including these explanatory variables is the interesting short run coefficients in our preferred specification. In particular almost all shares responded positively to increases in any price. One possible explanation for this result could be that planned conversions are undertaken when the economy is doing well and land managers are not so credit constrained. The results from these specifications are presented in Table 5 and Table 6.

Both sets of coefficient estimates are similar to each other, and to our preferred specification reported in Table 3. Importantly the split between short run productive and unproductive land use responses to commodity prices is still apparent. Thus, so far, we are unable to explain what is driving our estimated short run coefficients. This will be of interest in future research on land use using other data sets.

Table 5: General dynamic model with GDP included

land use i	α_i	γ_{i1}	γ_{i2}	γ_{i3}	β_{i1}	β_{i2}	β_{i3}	a_{i1}	a_{i2}	a_{i3}	a_{i4}	a_{i5}	a_{i6}	b_{i1}	b_{i2}	b_{i3}
dairy	-0.504	0.000	-0.009	0.067	0.066	0.000	0.004	0.001	0.006	0.006	0.016	0.000	0.003	0.556	-0.060	-0.264
	0.587	0.017	0.031	0.070	0.259	0.001	0.002	0.002	0.004	0.002	0.054	0.000	0.001	0.132	0.029	0.072
sheep-beef	2.386	-0.026	0.095	-0.223	-1.201	-0.005	-0.003	0.002	0.039	0.011	-0.770	-0.002	-0.002	0.863	0.374	0.257
	1.849	0.055	0.097	0.221	0.815	0.005	0.008	0.008	0.017	0.009	0.241	0.001	0.006	0.588	0.130	0.321
forestry	-1.464	-0.008	-0.022	0.179	-0.257	0.000	0.009	0.001	0.000	0.005	-0.059	0.000	-0.001	0.029	-0.044	-0.030
	1.786	0.053	0.094	0.213	0.787	0.005	0.008	0.001	0.002	0.001	0.030	0.000	0.001	0.073	0.016	0.040
scrub	0.582	0.033	-0.083	0.111	-0.457	0.004	-0.001	-0.002	-0.033	-0.010	-0.187	0.002	0.005	-0.335	-0.390	-0.491
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Standard errors in parentheses
* significant at the 10 per cent level, ** significant at the 5 per cent level, *** significant at the 1 per cent level (no finite-sample correction used)

Table 6: General dynamic model with UK exchange rates included

land use i	α_i	γ_{i1}	γ_{i2}	γ_{i3}	β_{i1}	β_{i2}	β_{i3}	a_{i1}	a_{i2}	a_{i3}	a_{i4}	a_{i5}	a_{i6}	b_{i1}	b_{i2}	b_{i3}
dairy	-0.284	0.001	-0.045	0.070	0.236	0.001	-0.016	0.001	0.009	0.007	0.018	0.000	0.006	0.702	-0.038	-0.400
	0.440	0.026	0.038	0.059	0.169	0.001	0.062	0.002	0.003	0.002	0.050	0.000	0.008	0.133	0.029	0.077
sheep-beef	1.534	-0.033	0.123	-0.150	-1.062	-0.004	0.014	0.001	0.015	0.011	-0.547	-0.001	0.030	0.890	0.370	0.041
	0.787	0.047	0.067	0.106	0.303	0.003	0.111	0.008	0.012	0.010	0.221	0.001	0.035	0.591	0.129	0.340
forestry	-0.487	0.000	-0.085	0.121	-0.005	0.001	-0.069	0.001	-0.001	0.004	-0.061	0.000	0.003	0.008	-0.049	-0.022
	0.895	0.054	0.077	0.121	0.344	0.003	0.126	0.001	0.001	0.001	0.027	0.000	0.004	0.072	0.016	0.042
scrub	0.237	0.035	-0.083	0.098	-0.169	0.004	0.038	0.000	-0.005	-0.008	-0.410	0.001	-0.027	-0.197	-0.359	-0.419
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Standard errors in parentheses
* significant at the 10 per cent level, ** significant at the 5 per cent level, *** significant at the 1 per cent level (no finite-sample correction used)