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 1974-2008. 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. Furthermore, our coefficients suggest that land use responds very slowly to changing economic returns, as measured by relevant commodity prices.

JEL codes

Q15, Q24

Keywords

Land use, New Zealand, time series

1 Introduction

Rural land use is a major determinant of economic and environmental outcomes in New Zealand. Policies aimed at altering land use, by changing the incentives that land managers face, must confront the fact that land use change is not instantaneous. In an American context, Hornbeck (2009) finds that land use change is very slow, despite large shifts in relative productivities, and presumably profits, after an environmental catastrophe. In this paper we estimate a model of dynamic model of land use change. We find that in New Zealand it can take many years before the full land-use impact of changes economic returns is realised.

In 1973 exports of New Zealand agricultural commodities to the U.K. fell sharply, as it joined the European Economic Community. In 1986 New Zealand saw the removal of large subsidies to sheep meat, beef meat, and wool production. Figure 1 shows composite sheep-beef prices and New Zealand's sheep-beef land share from 1973-2008.[1] There are very large drops in the composite sheep-beef price in both 1973 and in 1986. Despite this, the share of land used for sheep-beef farming stays relatively stable, and then begins a steep decline in the mid 1990s.

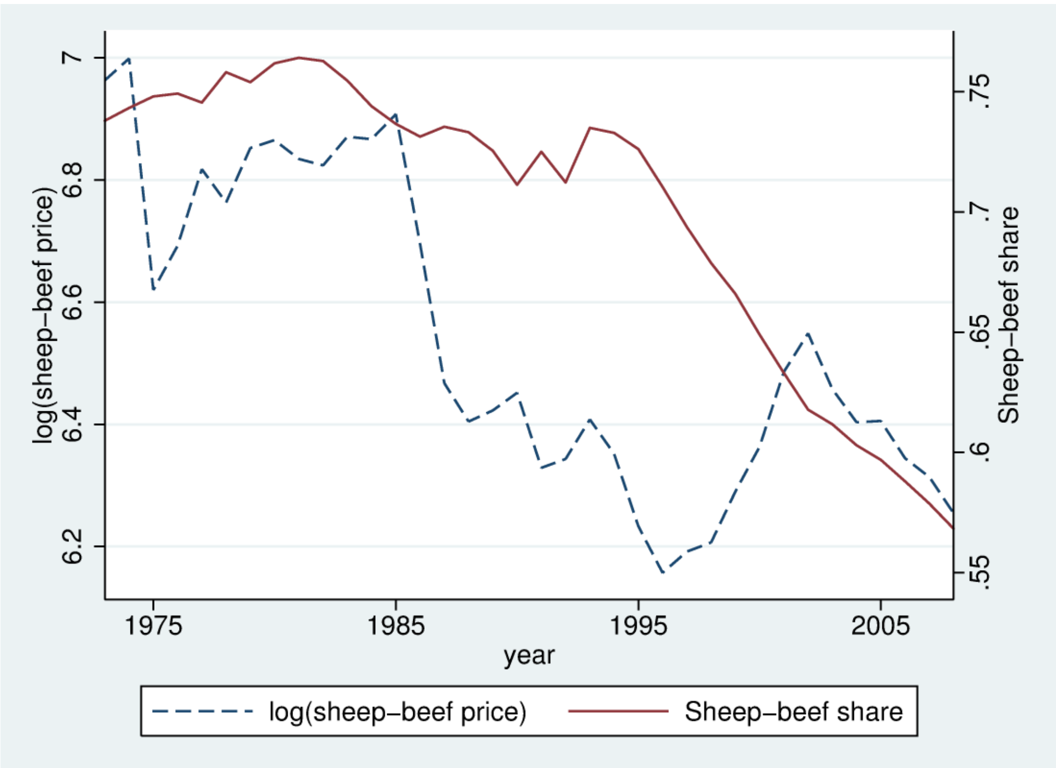

Figure 1: Sheep-beef land use and prices, 1974-2008

[1] Because sheep and beef are often grazed on the same land we cannot separate the two land uses. We use a weighted average of several commodity prices relevant to sheep and beef farming explained below.

There are many things going on throughout this period. However this graph is suggestive of the fact that large changes in economic profits need not be followed by instantaneous responses in land use. Land use responses can be considerably delayed, and they can be gradual. Furthermore, our econometric dynamic model of land use yields estimates that suggest land use responds very slowly to changes in economic returns.

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 2005. 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), Anderson and Blundell (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.

A major advantage of estimating the responsiveness of rural land use to economic returns in New Zealand is that, due to its small size, export prices are credibly exogenous. Thus while revenue and production costs, through the choice of output, are likely to be endogenous, prices are not. Furthermore, large cuts to agricultural supports in 1986[2] provide an extra source of credibly exogenous variation in agricultural returns.

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 the land use implications of different carbon price scenarios. The small quantity of available 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.

A key finding of our paper is that modelled land use only very gradually moves to a long run equilibrium after being shocked by a persistent change in relevant commodity prices. This

[2] McDermott et al. 2008.

finding is consistent with Hornbeck (2009). (What is the policy implication? Keep in mind that the speed of adjustment to equilibrium and the magnitude of the impact are not the same.) However, an econometric investigation into the major causes of gradual land use adjustment was outside the scope of our data and is left to future work.

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. In section 4 we present our econometric methodology. Section 5 contains estimation results, including our tests of dynamic simplifications. Section 6 looks at land use responses to permanent increases in relevant commodity prices. It shows that, under the coefficients we estimate, land use adjustment is slow. In section 7 we conclude.

2 Theoretical framework

Our model is close to the one presented in Parks (1995). In this model, rural land use change is driven by people looking to maximise the net present value of benefits from rural production. Suppose a land manager makes land use decisions for L hectares of land of where L is sufficiently small that its land quality q is homogeneous.[3] Suppose A_t hectares are used for agriculture and the remaining land is used for forestry F_t. The price for agricultural output is $p_{a,t}$ and the price for forestry output is $p_{f,t}$. The rent per hectare of land in agriculture is $\pi_a(p_{a,t};\ q)$, and the rent per hectare of land in forestry is $\pi_f(p_{f,t};\ q)$. At every point in time, the land manager can choose net conversion from agriculture to forestry f_t.[4] Net conversion forestry is constrained to be in $f_{MIN,t} \leq f_t \leq f_{MAX,t}$. Net conversion costs, per hectare, are given by C_t.[5] The land manager is assumed to be a price taker.

The problem faced by the land manager is to choose land conversion to maximise the net present value of benefits $\int_{t=0}^{\infty}\left(\pi_a\left(p_{a,t}, q\right)A_t + \pi_f\left(p_{f,t}, q\right)F_t - C_t f_t\right)e^{-rt}dt$, subject to the constraint that total land is L. Following Parks 1995 we translate the problem into one with a current-valued Hamiltonian and derive the first-order conditions for optimal land use

[3] We depart from Parks 1995 by considering a parcel of homogeneous quality. However most of the analysis can be carried through unchanged. As in Lichtenberg 1988 we could assume that land quality can be summarised as a continuous index on [0, 1]. However, as will be discussed below, we will not explicitly make use of land quality measures in this national level analysis.

[4] By interpreting f_t as net conversion and allowing it to be negative, we make another departure from Parks 1995 by allowing conversion both in and out of forestry.

[5] This implicitly assumes that conversion costs per hectare are the same for conversion into and away from forestry. The same qualitative results can be derived regardless, and this is cleaner.

conversion. Optimal land use conversion depends on the sign of the expression $r(\lambda_{F,t} - C_{f,t}) - \partial\pi_a(p_{a,t}, q)/\partial A_t + \dot{\lambda}_{A,t}$. If this expression is positive, then net conversion into forestry should occur as rapidly as possible. That is $f_t = f_{MAX,t}$. If it is negative, then net conversion away from forestry should occur as quickly as possible; $f_t = f_{MIN,t}$. Finally, if the expression equal zero, then the land manager is indifferent towards conversion. This is the result is very similar to Parks (1995).

This model has two important predictions for guiding our investigation of the responsiveness of land use to changes in economic returns. Following Parks 1995, we interpret $r(\lambda_{F,t} - C_{f,t})$ as the annualised land value of forestry. Thus an increase in agricultural prices will increase the annualised land value of forestry. This will decrease the amount of land in agriculture and increase the amount of land in forestry.[6] Decreases in agricultural prices have the opposite effect, and a symmetrical result applies to forestry prices. Secondly, because of our constraint on the maximal rate of conversion, land use change must be gradual.[7] Even a large change in relative economic returns from rural production, such as the removal of agricultural subsidies in 1986, will only have a gradual effect on land use in this model. Gradual land use change is essentially an assumption of the model; however we discuss its justification further below.

This result is derived for land of a given quality. Different quality land will result in different available rents π_a and π_f and hence different optimal ratios for agriculture and forestry. At a national level, observed land use is the result of aggregating the land use decisions of a multitude of land managers. Stavins and Jaffe (1990) made an important contribution to the land use literature by showing how econometricians could deal with this aggregation problem. They assumed a distribution of land qualities. They showed that flood protection projects that altered the distribution of land qualities could induce private land owners to deforest wetlands. However, their model also deals with the case where the distribution of land quality is constant and changes in economic variables alter the thresholds at which conversion should take place. This is the case in an analysis of land use at the national level, where as a first approximation the distribution of land quality is constant.

[6] To see this, note that for marginal land $r(\lambda_{F,t} - C_{f,t}) = \frac{\partial\pi_a(p_{a,t},q)}{\partial A_t} + \dot{\lambda}_{A,t}$. By assumption $\pi_a(p_{a,t}, q)$ is increasing in $p_{a,t}$ and $\frac{\partial\pi_a(p_{a,t},q)}{\partial A_t}$ is always increases if $p_{a,t}$ increases. Thus an increase in agricultural prices results in marginal forest land will convert to dairy. This will occur until the forest land value in the remaining forest land is high enough that it is not worth converting even at the new higher agricultural prices.

[7] Here we are assuming that the maximal conversion rate binds, at least sometime.

We have imposed a maximum rate of conversion for each land use. This can be interpreted as an analytical simplification of the idea that conversion costs are convex or decline over time, Hornbeck (2009). Conversion costs could decrease over time as people learn about opportunities for land use conversion, or as the land manager changes (the new manager may have different skills or preferences). Declining conversion costs are important as they provide us with a way to interpret very slow land use adjustment. Our current work, as well as that of Hornbeck (2009), documents very slow land use adjustment in response to changes in potential economic returns. However, evaluating the mechanisms that are the most important causes of slow land use change is left for future work.

3 Data

We need two main types of data: data on the area of land in each rural use, and data on economic variables that we expect to be associated with land use.

3.1 Land area data

We use national level land area data from Statistics New Zealand (SNZ) and Meat and Wool Economic Service (MWES), now known as Beef and Lamb. SNZ provides data on New Zealand's total rural land area, as well as the land area in pasture,[8] plantation forestry, and horticulture.[9] We use SNZ data for the periods from 1972-1996 and 2002-2008. SNZ did not collect data in 1997, 1998, 2000, or 2001. Furthermore the 1999 survey used a different population base to other years and so we exclude it. We interpolate the plantation forestry area for these years. We do this as follows. We find the net change in forestry over the period. We then find a second source of data on national level plantation forestry area; the National Exotic Forestry Description reports. From this data source, we calculate the annual proportions of the total change in forest area between 1996 and 2002. We use these proportions to allocate the total change in the SNZ data.

The MWES data covers the period 1980-2008, including the period 1997-2001, when SNZ did not collect land area data). Importantly, MWES splits pasture between dairy land, sheep-beef land, and other agricultural land. We extrapolate the dairy area series back to 1972. In particular, we regress the dairy area from 1980-2008 on time, total dairy cattle numbers, from

[8] On www.stats.govt.nz/infoshare this is the grazing area, or the sum of grassland, lucerne, tussock, and danthonia (sometimes the grazing area is reported, and sometimes only the other categories are reported, but whenever they all are recorded the sum of the other categories is equal to the grazing area).
[9] The population which is sampled has changed over time. Prior to 1994 it included all business recorded on SNZ's Business Directory engaged in horticulture, cropping, livestock farming, or exotic forestry operations. From 1994 to 1996 only GST registered businesses were included. Currently all businesses involved in agricultural, horticultural, or forestry production are included.

SNZ, and an interaction of time and cattle numbers, this will capture changes in stocking rates over time. We then estimate the change in dairy area from year to year using the coefficients from this regression and data on dairy cattle numbers back to 1972. This enables us to extrapolate the dairy land area back to 1972. We use the remaining pasture land as our measure of sheep-beef land.[10]

This gives us land area data for three of the four major rural New Zealand land uses. We define scrub, the last major use, to be the difference between the total rural land area and the land area in pasture, plantation forestry, or horticulture.[11] Finally, the total amount of rural land in New Zealand has been typically shrinking over the period we study. We calculate all land use shares relative to total rural land in 1974. We then define the area of other land in any year to be the difference between total rural land in 1974 and the sum of land in rural uses in the same year.

3.2 Commodity price and export unit value data

We use two main sources of data on commodity prices and export unit values. SNZ overseas merchandise trade data provides information on the value, in New Zealand Dollars (NZD), and volume of exports for beef meat, sheep meat, wool, and logs.[12] We use this data to calculate export unit values for sheep meat, beef meat, wool, and logs. Land Improvement Corporation (LIC) data is used for milk solid prices.

New Zealand has a history of strong agricultural assistance. Anderson et al. (2007) estimates positive levels of support provided for sheep meat, beef meat, wool, and dairy until 1990. We want our export unit values and prices to be an exogenous measure of the economic return to each productive rural land use. If we ignored agricultural assistance then our export unit values and prices could not be expected to give a good measure of relative economic returns across land uses, or across time. Thus we use the Anderson et al. (2007) estimates to adjust our export unit values and prices for the relevant period.

Finally, because we only have 35 years of data, and we want to estimate a dynamic model, which requires lagged variables to enter our estimating equation, we are severely restricted in terms of our degrees of freedom. To address this problem, we make a composite sheep-beef export unit value, which allows us to avoid entering sheep meat, beef meat, and wool export unit

[10] This includes land used for deer and goat farming. However the relevant areas are trivially small.

[11] Horticultural area must be interpolated for 1972-1982 and 1997-2001. We use simple regressions of the area in horticulture on time.

[12] These series are available from www.stats.govt.nz/infoshare from 1989 July to 2008 June. Our beef meat data corresponds to HS codes HS0201-HS0202. Sheep meat data is from HS020410-HS020443. Wool data is from HS5101. The log data for export unit values are from the Ministry of Agriculture and Fisheries (MAF); recent data can be found at http://www.maf.govt.nz/news-resources/statistics-forecasting/forestry/annual-forestry-export-statistics.aspx. We use the series for logs and poles.

values, as well as their lags, into our regressions separately. Our composite export unit value in any year is simply the average of the individual export values, weighted by export volume in the same year.

3.3 Time series graphs

In this section we present graphs of our data to get a better feel for their time series properties. Figure 2 shows the share of land in each of the four major rural uses between 1973 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 dairy and forestry land shares have been consistently rising since the 1980s. By the mid 2000s each of these uses accounted for about 10 per cent of New Zealand's rural land. The scrub land share has been relatively stable over time, except for a noticeable drop around 1993. Increases in the share of other land represent decreases in the overall level of rural New Zealand land relative to 1974.

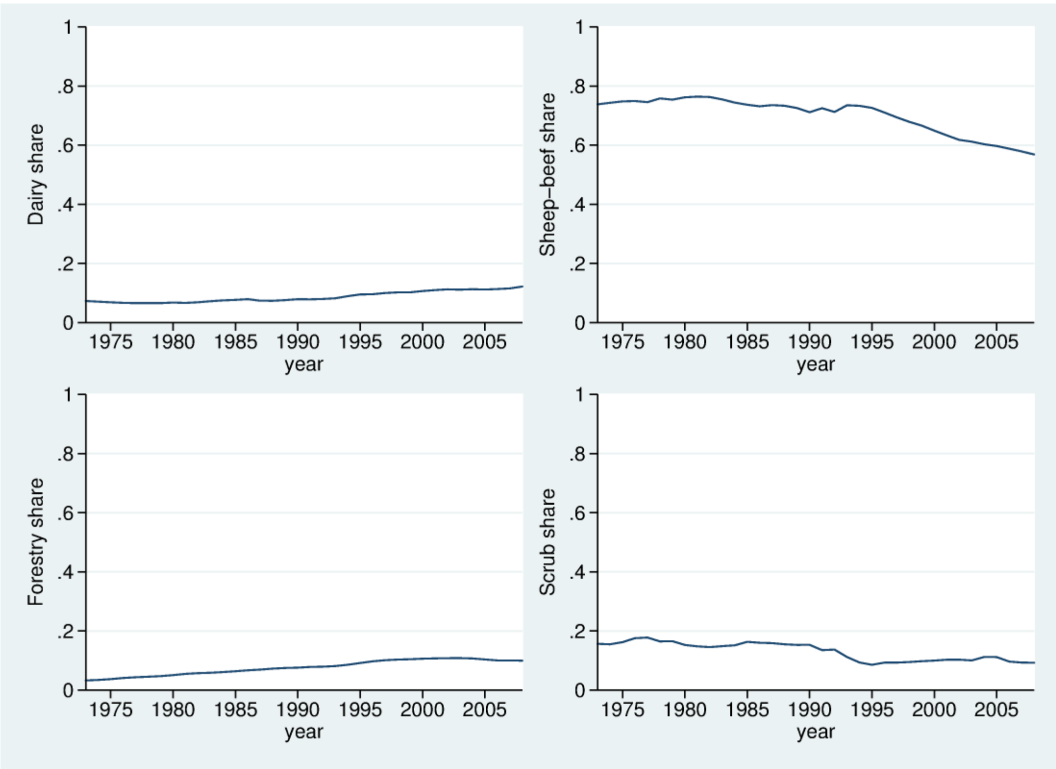

Figure 2: Share of rural land by use, 1973-2008

Figure 3 shows real dairy, sheep-beef composite, and log prices. To present them together, the prices have been standardised to have mean 0 and standard deviation 1. Between 1985 and 1987 both the dairy price and the sheep-beef composite price fell substantially.

Forestry prices experience large increases in 1994. Dairy prices increased a lot in 2008 and subsequently, although not in this graph, they returned to previous levels.

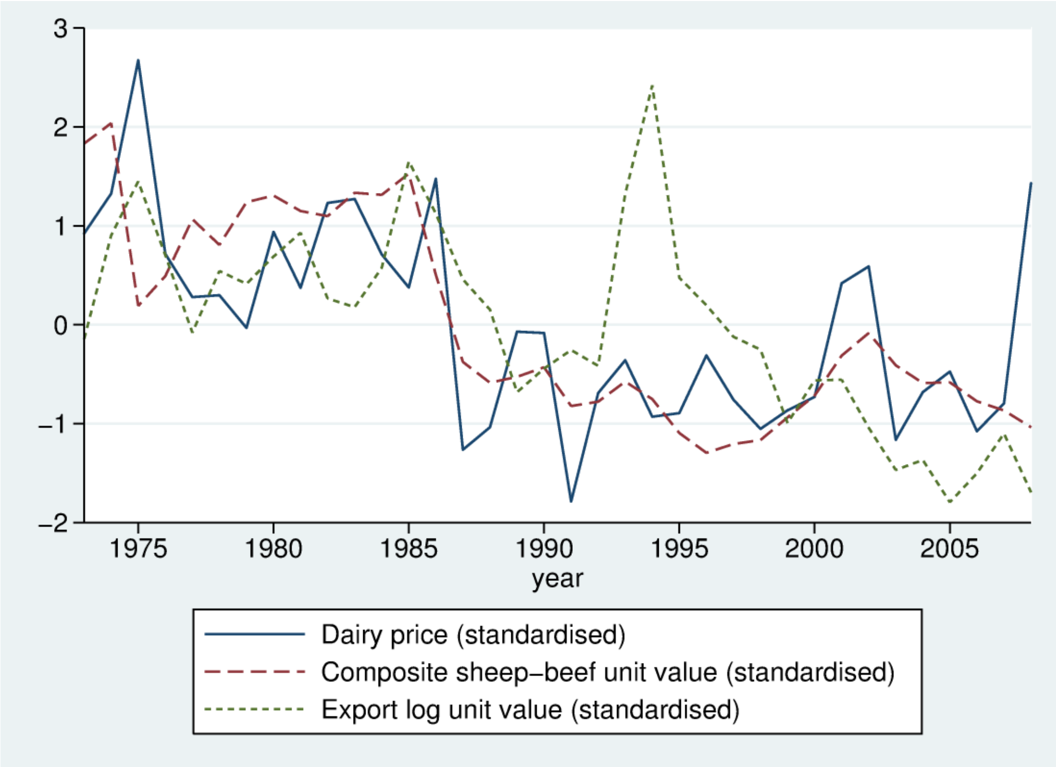

Figure 3: Real prices (standardised), 1973-2008

Notes. Each series has been standardised to have mean zero and unit variance. The graph demonstrates the large drop prices, accounting for government supports, that occurred around 1986.

4 Econometric methodology

4.1 Unit root tests

In this section we look at whether each of our land share and price time series are stationary. Table 1 reports the test statistics for several Dickey-Fuller unit root tests as well as the relevant 5 per cent critical values.[13] Columns (1) and (2) present evidence on the stationarity of each series in levels. Column (2) allows for a deterministic trend but column (1) does not. Columns (3) and (4) present evidence on the stationarity of the first difference of each series. Column (4) allows for a trend while column (3) does not.

For each test the null hypothesis is that the univariate sequence is nonstationary. The alternative hypothesis is that the series is stationary. We reject the null hypothesis if the test statistic is smaller, i.e., more negative, that the critical value. Column (1) and column (2) provide

[13] 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.

evidence that our series are nonstationary in levels. In column (1) we marginally reject nonstationarity for both the forestry share and the log(dairy price) series. However, Figure 1 shows that our land share time series are dominated by rather large trends. In column (2) we allow for trends in our time series. In this case, we can only reject nonstationarity for the log(dairy price) series.

Table 1: Unit root tests

	Levels		First differences	
	(1)	(2)	(3)	(4)
dairy share	0.843	-2.656	-3.901	-3.968
sheep-beef share	1.942	-1.022	-4.420	-5.550
forestry share	-2.265	1.415	-0.659	-1.167
scrub share	-0.806	-1.623	-4.249	-4.175
other share	2.240	-2.804	-3.235	-5.647
log(dairy price)	-3.077	-4.225	-7.476	-7.346
log(sheep-beef price)	-1.638	-1.766	-5.341	-5.294
log(forestry price)	-1.639	-2.846	-5.374	-5.465
interest rate	-1.292	-2.264	-4.513	-4.761
critical value 5%	-2.98	-3.56	-2.98	-3.56

Notes. This table reports test statistics for Dickey-Fuller unit root tests on each univariate time series used in our analysis. The sample period is 1974-2005, which is the same sample period that we use for our final analysis. Each cell reports a separate test statistics; the row identifies the dependent variable and the column identifies the specific test. Columns 2 and 4 allow for trends, while columns 1 and 3 do not.

Although our series appear to be nonstationary in levels, we can reject the null nonstationarity 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, for the rest of this paper we proceed under the assumption that our series are indeed I(1).

4.2 Cointegration tests

Given our time series are I(1) it is natural to ask 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

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

where s_{it} is the share of land in use i at time t, p_{jt} is the price (we demean, after taking logs) of the j-th commodity at time $t-1$,[14] i_t is the nominal 5 year interest rate, s_{ot} is the share of other land, v_{it} is ther error term, and α_i, γ_{ij}, β_{i1}, and β_{i2} are parameters to be estimated. The results from this estimating this equation by OLS are shown in Table 2 below.

Table 2: Auxiliary long-run model for cointegration tests

	dairy	sheep-beef	forestry	Scrub
dairy price	0.002	-0.015	-0.002	0.016
	(0.004)	(0.009)	(0.007)	(0.010)
sheep-beef price	-0.019***	0.027***	-0.054***	0.046***
	(0.003)	(0.008)	(0.006)	(0.010)
forestry-price	0.013***	0.030***	0.012**	-0.056 ***
	(0.004)	(0.009)	(0.006)	(0.010)
other land share	0.520***	-1.480***	0.608 ***	-0.647 ***
	(0.028)	(0.070)	(0.049)	(0.077)
interest rates	0.001***	-0.004***	0.003***	0.000
	(0.000)	(0.001)	(0.000)	(0.000)
constant	0.073**	0.747***	0.049 ***	0.131***
	(0.002)	(0.005)	(0.003)	(0.006)

Notes. Standard errors are in parentheses. Each column reports the coefficient from estimating a single equation model by OLS. The dependent variable is the column title. Each row reports coefficients for the relevant regressor. Commodity price variables are demeaned, after taking logs. The sample period is 1974-2005, which is the same sample period that we use for our final analysis. * / ** / *** significant at the 10 / 5 / 1 per cent level respectively.

Using the residuals from these regressions, we test for cointegration. We use two panel unit root tests.[15] One test is based on Choi (2001) and requires only $T \rightarrow \infty$ asymptotics. The null hypothesis is that the residuals of all equations are nonstationary, and the alternative hypothesis is that at least one equation is stationary. This does not test cointegration directly, but it 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 $T \rightarrow \infty$ and then $N \rightarrow \infty$. Given we are only interested in four land uses this may not be appropriate. On the other hand the null hypothesis is appropriate. Under the null hypothesis the residuals of all equations are stationary, while under the alternative hypothesis the residuals of at least one of the equations are nonstationary. These tests are both unit root tests. Although we are testing cointegration, and we have used multiple regressors in the first stage regression used to calculate

[14] Because land use decisions depend on expected future profitability under different uses, lagged prices are often used to account for expectations formation; for example, see footnote 5 of Miller and Plantinga 1999.
[15] We used information from the [xt] xtunitroot section of the Stata's User Manual throughout this section.

the residuals, we have made no adjustment to the p-values. However these tests are indicative of cointegration.

We implement these tests using residuals obtained by estimating (1). Because the fourth use is completely determined given the other three rural land shares and the amount of other land, we omit one series in these panel unit root tests. We demean the residuals and run separate specifications with no lags, one lag or two lags. Using the Choi's method we reject the null hypothesis that all residual series have nonstationary at the 5 or 10 per cent level for any lags; the results of this test do not rule out cointegration. Using Hadri's method we fail to reject the null hypothesis that all residual series are stationary at even the 10 per cent level using any of the above number of lags; this is also consistent with cointegration. We take this as evidence that our variables are cointegrated and that there is a cointegrating factor which means the system represents a long run equilibrium relationship. As such, we proceed to develop a dynamic econometric model, which has a structure that closely resembles an error correction model.

4.3 Dynamic specification

We want to estimate the relationship between land use and commodity prices. In particular, using national level time series data, we want to see how land use changes at the as commodity prices change. In terms of the theoretical framework outlined above, we can think of each land owner varying her allocation of land to each uses to maximise her profit. In a stochastic world the land owner must form expectations about future returns under each land use. At a national level, the land area in each rural use is the result of aggregating these individual profit maximising decisions. These land areas can also be expressed as shares of total rural land. The share of land in each use depends on the expected returns to rural production in each use. When the set of uses considered is exhaustive and mutually exclusive, such a system of equations is necessarily singular. We have four rural land uses; five if you include exogenous other land. Thus given three of the rural land shares we can perfectly infer the fourth.

Dynamic considerations play an important role in our econometric specification. Land use decisions made now impact future options and profitability; for example, because of conversion costs. This means that responses to economic conditions may have dynamic effects.[16]

[16] In consumer expenditure modelling, the major field for the estimation 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. 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), which was originally a static singular system of equations. Our model is a singular system of equations representing land use, and we use a dynamic model paying attention to cointegration.

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.

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

$$\Delta \boldsymbol{s_t} = \boldsymbol{A}\Delta \widetilde{\boldsymbol{x}}_{\boldsymbol{t}} - \boldsymbol{B}(\boldsymbol{s_{t-1}} - \boldsymbol{\Pi x_{t-1}}) + \boldsymbol{\varepsilon_t} \qquad (2)$$

where, as analogues to Anderson and Blundell (1982),[17] $\Delta \boldsymbol{s_t}$ is a 4 by 1 vector of the changes in each land use between time t and time $t-1$, $\boldsymbol{x_{t-1}}$ is a 4 by 1 matrix containing the variables that go into the long run equation above at time $t-1$, and $\widetilde{\boldsymbol{x}}_{\boldsymbol{t}}$ is the same as $\boldsymbol{x_t}$ with the column for the constant removed. $\boldsymbol{\Pi x_t}$ specifies the long run structure and $\boldsymbol{B}$ is a 4 by 3 matrix that contains combinations of adjustment coefficients. It is important to note that the adjustment coefficients are not individually identified. I.e., we cannot recover them from $\boldsymbol{B}$ which only contains combinations of them; for details see Anderson and Blundell (1982). 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. These 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.

5 Results

In this section we present results from our econometric estimation. Firstly we report estimates for 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 responses 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

[17] Note that in Anderson and Blundell (1983) equation (9) on page 399 has a mistake. There is an n superscript missing on $\boldsymbol{w_{t-1}}$. This is corrected in Table II on page 400. As it stands, equation (9) requires multiplication of non-conformable matrices.

most of our coefficients lack statistical significance. This is not surprising given we have little and noisy data.

5.1 Estimation of the general dynamic model

We estimate the general dynamic model in equation (2) 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 (we demean the price series, after taking logs), 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 again 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.

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; the dairy share is positively associated with forestry prices, the scrub share is positively associated with dairy prices, and 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. The scrub share, commodity price relationships are also unusual. While these estimates have unusual signs none of them are estimated as differing from zero at conventional levels of statistical significance. It may be the case that we simply lack enough data to get good estimates of the causal relationships of interest, and thus if we had more data, these results would not occur.

The short-run price relationships are also interesting. The change in land share for all productive uses is estimated to increase as any commodity price increases. 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 also suggests there could be an important omitted variable from our estimating equation

Table 3: General dynamic model coefficient estimates[18]

Change in land use i	Constant	log(lagged dairy price)	log(lagged sheep-beef price)	log(lagged forestry price)	Lagged other land	Lagged interest rates	Change in log(dairy price)	Change in log(sheep-beef price)	Change in log(forestry price)	Change in other land	Change in interest rates	B_{i1}	B_{i2}	B_{i3}
Dairy	0.080***	0.007	-0.053**	0.063	0.495***	0.002***	0.000	0.008**	0.006**	0.018	0.000	0.545***	-0.042	-0.331***
	(0.012)	(0.015)	(0.026)	(0.049)	(0.093)	(0.001)	(0.002)	(0.003)	(0.002)	(0.070)	(0.000)	(0.135)	(0.034)	(0.067)
Sheep-beef	0.719***	-0.041*	0.106	-0.099	-1.478***	-0.006***	0.004	0.029**	0.021***	-1.151***	-0.002**	1.198*	0.417***	-0.111
	(0.020)	(0.024)	(0.042)	(0.079)	(0.151)	(0.001)	(0.009)	(0.014)	(0.001)	(0.284)	(0.001)	(0.614)	(0.137)	(0.273)
Forestry	0.062***	0.013	-0.102*	0.102	0.578***	0.004***	0.001	0.000	0.005***	-0.087**	0.000	0.060	-0.048***	-0.016
	(0.025)	(0.030)	(0.053)	(0.101)	(0.192)	(0.002)	(0.001)	(0.001)	(0.001)	(0.035)	(0.000)	(0.076)	(0.017)	(0.034)
Scrub	0.139	0.020	0.050	-0.067	-0.586	0.001	-0.006	-0.037	-0.032	0.220	0.002	-1.803	-0.327	0.459
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Notes. Standard errors are in parentheses. The coefficients are the result of estimating a dynamic singular equation system following Anderson and Blundell (1982). The system contains four equations and hence has four dependent variables; dairy, sheep-beef, forestry, and scrub land-shares, which each have a separate row in the table. The sample period is 1974-2005. We lose the first observation due to differencing, and we exclude 2006-2008, because people were already responding to the planned Emissions Trading Scheme. All commodity price variables are demeaned, after taking logs. Each column reports the coefficients for a separate regressor. The lagged variables correspond to the long-run structure, while the differenced variables correspond to the short-run structure. The $\boldsymbol{B_{ij}}$ coefficients correspond to combinations of adjustment parameters that are not separately identified; see Anderson and Blundell (1982). * / ** / *** significant at the 10 / 5 / 1 per cent level respectively (no finite-sample correction used). The coefficients in the scrub equation are backed-out from the adding up constraints. We omit their standard errors, (-).

[18] The Stata 11 base ado file nlsur did not use the correct number of observations when deciding whether or not the estimation was feasible. We fixed this by changing two lines its code.

Our advantage for estimating the causal response of land uses to changes in economic returns is that, due to New Zealand's small size, export price changes are credibly exogenous and because New Zealand exports nearly all of its agricultural and forestry products these are theain driver of economic returns. This removes a large source of potential reverse causation. On the other hand, the unusual results highlighted above suggest that biases in estimation may still be important. In particular, we are only capturing one source of the variation in economic returns; omission of other important variables that affect economic returns and hence land use choices could be an important source of bias in our estimates.

5.2 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) 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(2). If $a_{ij} = \pi_{ij}$ for all i and j, then we get the AR(1) model. If each $a_{ij} = \sum_{k=1}^{3} b_{ik}\, \pi_{kj}$, then 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.

Table 4: Testing dynamic simplifications

	AR(1)	PA	Static	Static
Degrees of freedom	15	15	9	9
Likelihood-ratio statistic	50.2*	42.3*	148.7*	156.6*
Critical value 1%	30.6	30.6	21.7	21.7

Notes. The table reports the results of likelihood-ratio tests of dynamic simplifications. Column 1 compares the dynamic model in Table 3 with an AR(1) model. Column 2 compares the model in Table 3 with a partial adjustment model. Columns 3 and 4 compare the AR(1) and partial adjustment models respectively with a static model.

We test each of these dynamic simplifications in turn using likelihood ratio tests. Our results are presented in Table 4. 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 respectively 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.

6 Land use responses to a permanent price change

We run a series of simulations to look at the effect of commodity prices on land use; in particular we are interested in the speed of adjustment. Firstly, we hold all regressors fixed at their 2005 levels and calculate the paths of each land-use share into the future. Secondly, we increase one log(commodity price) by one standard deviation, hold it there for all time, and calculate the associated paths for land-use shares. We take the difference between the paths with a permanent increase in a single commodity price and the paths with all regressors fixed at their 2005 levels. These are our estimates of the land use responses to a permanent change in a commodity price. In this section we present the own-price responses for the sheep-beef share and the forestry share.

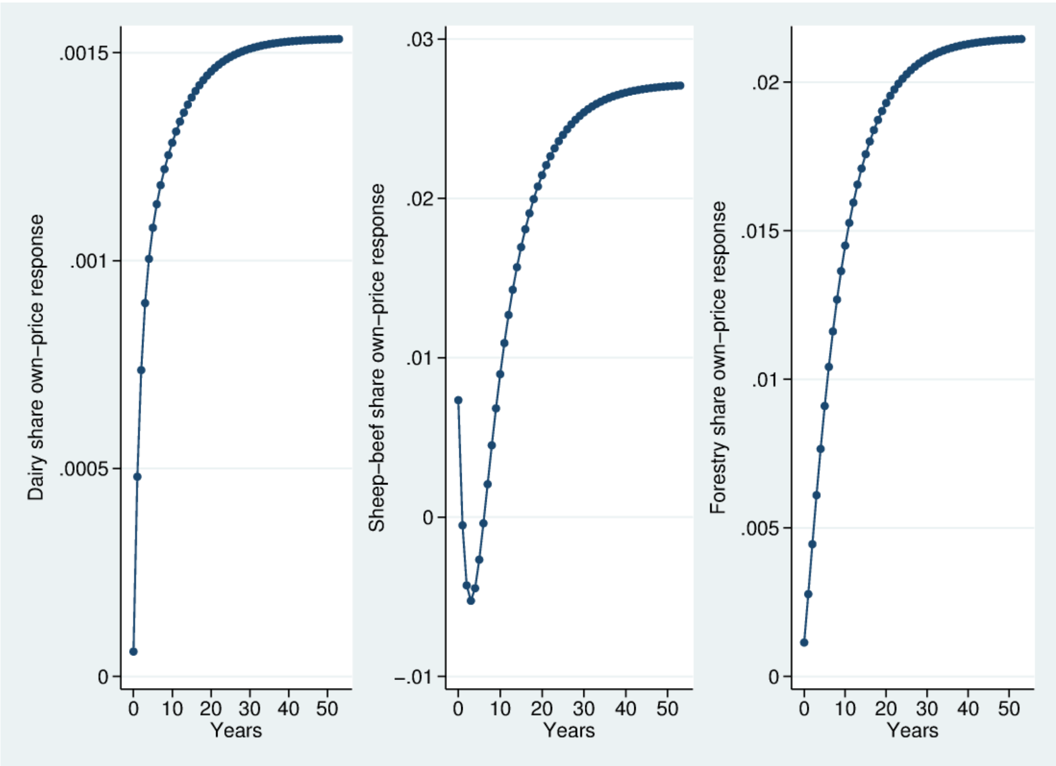

Figure 4: Land share responses to 1 std. dev. permanent own-price increase

Notes. Each panel plots the response to a land share when its own log(commodity price) is increased by 1 standard deviation. The response is calculated from two different scenarios. In the first scenario we hold all regressors constant at their 2005 levels and project land shares using the coefficients reported in Table 3. The second scenario is the same as the first, except we increase the own log(commodity price) by 1 standard deviation, calculated for the years 1974-2005. The response is the difference between the second scenario and the first one.

Figure 4 presents the land share response to an own-price increase of one standard deviation for each land use; scrub does not have a price so it is not shown.[19] Dairy and forestry land-use shares respond similarly in face of a permanent increase in their own price. They both have a positive short-run impact, which is followed by a gradual approach towards equilibrium. The dairy share increases by half of its eventual 50 year impact in 3 years. It takes 4 more years, for a total of 7 years, for the dairy share to reach three-quarters of its 50 year impact. The forestry response is even more gradual. It takes 7 years for the forestry share to increase by half of its 50 year impact, and it takes more than 12 years for it to reach three-quarters of its 50 year impact.

The sheep-beef land-use response has an immediate short-run increase, followed by a noticeable dip, and then it returns to its equilibrium path. This highlights the fact that the land use shares are very interdependent because of the adding up constraint. In particular, the scrub share increases in the long-run in response to an increase in the sheep-beef price. This happens relatively quickly, and sheep-beef ends up temporarily decreasing to satisfy the adding up constraint; dairy and forestry shares are always falling in response to an increase in sheep-beef prices.

This phenomenon of gradual adjustment is typical of all the land share responses.[20] We can compare the speed of our land use adjustment to recent work by Hornbeck (2009). He looked at the impact of topsoil lost during the Dust Bowl catastrophe during the 1930s, which continued until 1938. He found evidence that crop productivity decreased relative to pasture, and that wheat productivity decreased relative to hay. However he didn't find evidence of statistically significant reductions in the crop land share until the period 1950s and statistically significant decreases in the wheat land share did not occur until the 1970s.[21] On the face of things it seems like Hornbeck (2009) finds much slower land use change than we do. We suggest a possible way to reconcile these two results. Firstly, in Hornbeck (2009) crop productivity falls more than pasture productivity immediately. And while the reduction in the crop land share is not statistically significant until the 1950s, the estimated effect on the crop land share is always negative. Thus Hornbeck is estimating negative coefficients on the crop land share immediately after the Dust Bowl event; however these effects are not statistically significant. It could be the case that land use is gradually adjusting; however the net change is just not large enough to be

[19] Most of the land share adjustments are sensible. However, 4 of the 12 land share responses go in the wrong direction. A further two have unusual short-run dynamics, which are related to disequilibrium effects in other land shares.

[20] Recall that disequilibrium in any land share will increase the annual adjustments of all land shares.

[21] We are referring to panels A and B of Table 3 in Hornbeck (2009).

detected until more than 10 years after the shock. This would not be inconsistent with our estimates.

7 Conclusion

In this paper we estimated the relationships between New Zealand's main rural land uses and their associated export prices using national time series data. Despite the length of our time series, most of our coefficients are consistent with standard economic theory. 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-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.

Interestingly, our coefficient estimates imply that land use adjusts slowly in response to changes in economic returns as measured by commodity prices. We estimate that it takes at least 6 years for land shares to get to 66 per cent of their 50 year adjustment in response to a 1 standard deviation change in the log of their own commodity price. This is consistent with results from Hornbeck 2009, which showed that land use change can occur very slowly. If land use response to climate change policy is equally slow then it will be important to account for this in any evaluation of the impact of the policy, on either greenhouse gas emissions or the social outcomes of such policy.

The short length of our time series was problematic for our study. Also, we only account for changes in economic returns through output prices. Thus many of our coefficients are estimated imprecisely. Furthermore, some of the point estimates are unconvincing. In particular, the short-run coefficients imply that all productive land shares expand in response to increases in any commodity price. Future work using more data, and potentially accounting for other avenues of economic returns may be able to yield more precise coefficient estimates.

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