Modelling Nitrogen Fertiliser Demand in New Zealand

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Abstract

In New Zealand, the demand for nitrogen fertiliser has increased markedly since the early 1980s. Potentially, this trend has significant environmental and climate change implications. While many factors could contribute to this trend, little work has been done to examine the drivers of increased use of nitrogen fertiliser in New Zealand. In this paper, we review the international literature and discuss a theoretical framework for modelling fertiliser demand. Using a national data set, we develop an empirical cointegration model for New Zealand. The results suggest that, in the long run, nitrogen fertiliser use is elastic (2.3) to output prices and unit elastic to its own price.

Introduction

Nitrogen makes up about 78 percent of the atmosphere, however this pool is almost all in gaseous form, which few organisms can use. Nitrogen gas is converted into usable, reactive forms, through both natural and industrial processes. Globally, about 75 percent of the 165 teragrams of reactive nitrogen produced each year is related in some way to agriculture, and the remaining 25 percent results from the combustion of fossil fuels and from industrial uses of nitrogen (Galloway *et al*. 2003). Reactive nitrogen cascades through different environmental compartments, changing form with diverse effects.

High levels of reactive nitrogen compounds such as nitrates, ammonia, and nitrogen oxides now threaten the environment on many scales and the problem will become worse, especially in rapidly developing parts of the world.

On the positive side, higher agricultural production over the past century—driven almost entirely by fertilizers that contain nitrogen—has made it possible to feed growing numbers of

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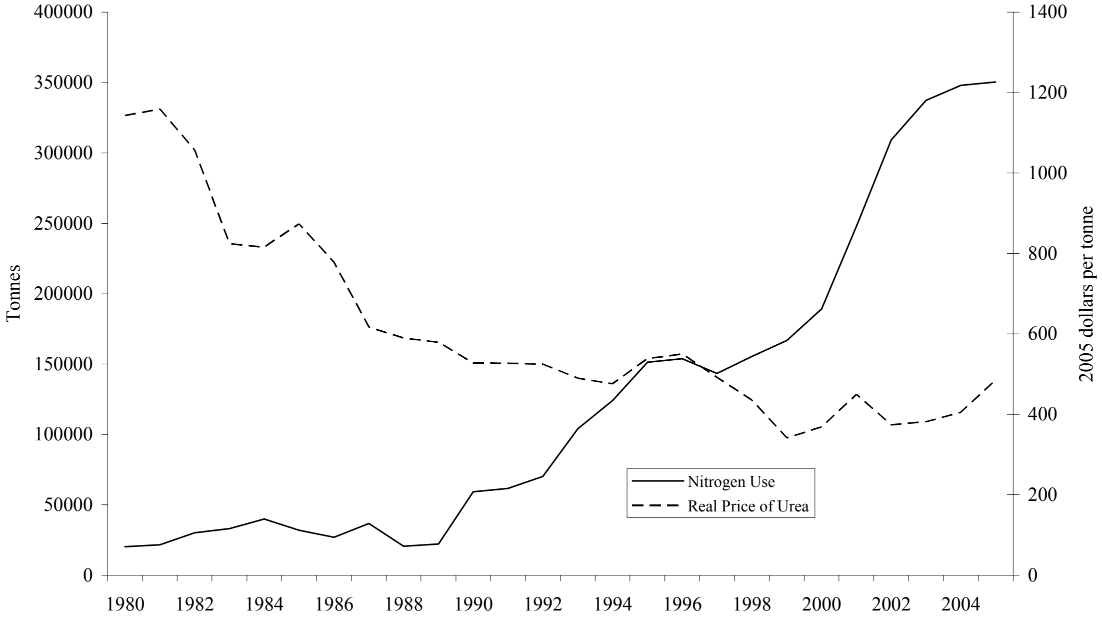
animals and humans. Forty percent of the world's population would not be alive but for this massive alteration of the natural nitrogen cycle (Smil 2001). Globally, food production uses 110 teragrams of reactive nitrogen every year, most of which is generated when components of natural gas are made to react with atmospheric nitrogen. The manufacture of fertilizer accounts for 5 percent of global natural gas consumption.

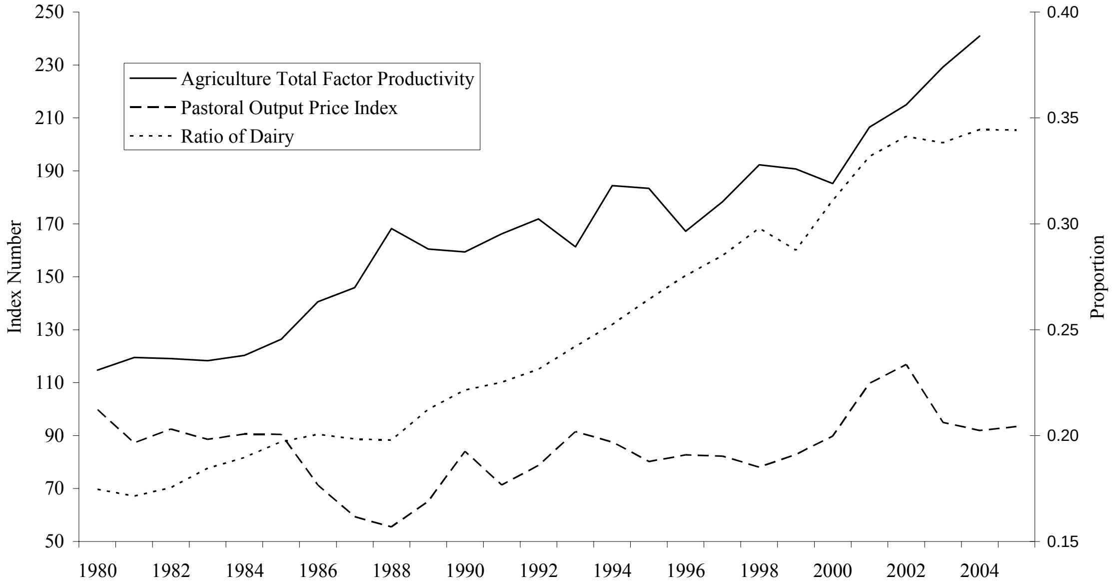
Nitrogen fertiliser is used in intensive agricultural production systems and impacts on water quality as well as generating greenhouse gas emissions. In New Zealand, direct nitrous oxide emissions from nitrogen fertiliser made up 3 percent of total greenhouse gas emissions in 2004. Water quality is also affected by nitrogen discharged from farming activities and has caused increasing concerns. (PCE Report, 2005) For example, it is believed that pastoral farming contributes almost 40 percent of all nitrogen flows into Lake Taupo, New Zealand's largest lake. (Environment Waikato, 2005).

Figure 1: Nitrogen Use and Real Price of Urea



There is worldwide interest in modelling the use of nitrogen fertiliser and in polices that curb the negative externalities associated with nitrogen's use. In Europe, much of the focus has been on the use of a nitrogen tax or cutting producer subsidies (Mergos and Stoforos, 1997; Rayner and Cooper, 1994; Burrell, 1989). Due to the nature of such policies, it is important to understand how demand for nitrogen fertiliser varies in response to its price and relative to other input and output prices. In New Zealand, there has been significant effort to encourage the efficient management of nitrogen fertiliser use. However, there is also a need to understand the drivers of nitrogen fertiliser demand, as this provides insights into nitrogen fertiliser management policies, and the impact of nitrogen fertiliser use on future greenhouse gas emissions.

Figure 2: Total Factor Productivity, Real Output Prices and the Ratio of Stock Units in Dairy to Total Stock Units



In New Zealand, nitrogen fertiliser is used primarily to boost forage production for grazing ruminants. The extra feed is either grazed *in site* or is conserved for subsquent feeding to animals. This is unlike most other animal systems, where nitrogen fertiliser is use to boost crops that are largely feed to housed animals.

Urea is the predominant nitrogen fertiliser type used in New Zealand of which the majority is applied to diary pastures (Statistics NZ, 2005). There has been a trend in recent years to apply more nitrogen on sheep and beef farms in hill country. One driver for increased nitrogen fertiliser use on diary farms is reported to be the clover root weevil (Sitona lepidus), which results reduced nitrogen fixation from clover (NZIER 2005).

The purpose of this paper is to analyse the factors that influence nitrogen fertiliser demand at the aggregate level. The following sections are constructed into two parts. Part I reviews the international literature on modelling nitrogen fertiliser demand and provides insights to the development of a New Zealand specific empirical model. Part II presents the empirical model and discusses the estimation results.

Literature

There have been attempts to model nitrogen demand in a variety of countries, for a number of crop types using a variety of methodologies. Much of this research is of limited value to the New Zealand context due to methodological problems and differences in bio-physically conditions between New Zealand and the other countries studied. To our knowledge this paper is the first to attempt to model the demand for nitrogen fertiliser in New Zealand.

A single equation approach has been used widely in other studies (for example see Burrell (1989) for a literature review on this type of model). This approach assumes that both the input and output markets are perfectly competitive. Typically, a demand function is then estimated using time series of total nitrogen applied or nitrogen per hectare applied with some price variables and often a linear trend. Especially amongst older studies, the time series properties of the data are often ignored. Static regressions of variables in levels with non-stationary data can lead to falsely significant, or spurious, relationships. Burrell (1989), Garcia and Randall (1994) and more recently Bel *et al* (2004) are typical of studies with this problem.

Of the studies that do adequately test for, and deal with non-stationarity in the time series data, two use a ratio of the price for nitrogen over the output price as an exogenous variable (Rayner and Cooper (1994) and Denbaly and Vroomen (1993)). Since output price and the price of nitrogen potentially play quite a different role in determining nitrogen demand, this seems an important limitation.

One paper that does deal with non-stationarity in the time series data and separates the impact of output prices and nitrogen prices is the study of Greek agriculture by Mergos and Stoforos (1997). This study found that for Greece, the long run own price elasticity of nitrogen is -0.81 and the output price elasticity is 1.11. Mergos and Stoforos conclude that in the Greek context of subsidized output prices, the most effective way to reduce nitrogen use is to reduce agricultural support.

Theoretical Framework

The demand for nitrogen fertilizer can be analysed as a standard input demand problem (Varian 1992). In this framework, a representative firm is assumed to maximise profits and is subject to competitive input and output markets. This profit function can be represented as follows; where p is the output price, x is a vector of inputs, w is a vector of input prices and q=f(x) is a production function.

1) $\Pi(p,w) = \max p.f(x) - w.x$

Profit maximisation for this representative firm implies that the marginal revenue generated by each input will be equal to the price of that particular input.

2) $p.\frac{\delta f(x)}{\delta x_i} = w$

From this profit maximisation condition, the optimal input (x^*) demand for any given input is a function of that input's price, all other input prices and the output price.

3) $x^* = f(p, w)$

From the profit maximisation condition (2), demand for an input is expected to be negatively related to its own price, positively related to the output price, negatively related to the price of complimentary inputs and positively related to the price of inputs that are substitutes in the production process.

This analysis assumes that the representative firm's production function is constant through time. When extending this assumption to a New Zealand wide nitrogen demand function, two problems arise.

Firstly, dairy is more nitrogen fertiliser intensive than other pastoral land uses. As dairy herds have replaced sheep and beef as a land use activity, a New Zealand wide agricultural production function has become more nitrogen fertiliser intensive.

Secondly, technical change in agriculture might be non-neutral with respect to nitrogen as some agricultural practices may increase the demand for nitrogen. Examples of this type of technical change include: the introduction of improved grass cultivars that utilize more nitrogen, improved on farm management techniques that improve pasture utilization at the farm level, and improved machinery and trading networks that increase pasture utilization on a larger district level.

Other innovations could have the opposite effect on nitrogen demand. The development of nutrient budgeting models such as OVERSEER^{TM} is one example of this.

As with all international studies of this type, this theoretical framework ultimately rests on an implied agricultural production function. Therefore, New Zealand's particular bio-physical characteristics could potentially have a large impact on the final results. For example, research on the demand for three different types of fertiliser for three different crops in the United States by Roberts and Heady (1982) gives a broad range of price elasticities for the nine different scenarios.

Data and Time Series Properties

The data series used in this paper are from 1980 to 2005 and were obtained from the following sources:

- Nitrogen fertiliser used in New Zealand is that reported in New Zealand's Greenhouse Gas Inventory 1990-2004, with earlier data obtained from the Food and Agriculture Organisation of the United Nation's website.

- Real price of nitrogen fertiliser is represented by urea prices provided by fertiliser companies and deflated by the producer price index.

- Output prices are represented by an index of the price of milk solids, lamb and beef prices deflated by specific producer price indexes and weighted by the share of total stock units devoted to each activity.

- Annual days of soil moisture deficit measurements are weighted by the concentration of dairying across locations, sourced from National Institute of Water and Atmospheric Research and calculated by the Ministry of Agriculture and Forestry.

- The ratio of dairy stock units to total stock units is derived from the Agricultural Production Survey data collected by Statistics New Zealand.

- Total factor productivity (TFP) in agriculture is taken from Lattimore (2006). This is calculated as an index of agricultural outputs over an index of agricultural inputs. Increasing use of nitrogen fertiliser would not, *a priori,* increase total factor productivity although it would most likely cause an increase in measures of partial productivity such as milk solids per cow. The availability of new nitrogen intensive production techniques, such as a new grass cultivar, could cause both an increase in total factor productivity and nitrogen use, as long as the index of outputs increased by a larger proportion than the index of inputs. In this context, TFP is used as a proxy for technical change, assuming that most TFP gain is caused by technical progress.

All the data were then converted into natural logs to interpret the coefficients directly as elasticities.

Stationarity

When analysing time series data, a key assumption underlying ordinary least squares regressions (OLS) is that the time series are stationary. This means the impact of shocks to a stationary time series will not persist into the future.

For example, since one particularly dry year does not mean dryness will be maintained through to the next year, we expect that a time series of days of soil moisture deficit will be stationary. This is fundamentally different from a series such as gross domestic product (GDP) where we do expect an increase in the level of GDP to be maintained into the next year. Here we expect the level of GDP to be non-stationary therefore making it an inappropriate to use in an OLS regression. Using non-stationary variables in OLS regressions often leads to spurious results, which are typified by extremely high t ratios and R-squared statistics.

Statistical tests of non-stationarity are known as unit root tests. In appendix one Phillips-Perron unit root tests were carried out for all the time series used in this paper. These results indicate that all variables, except days of soil moisture deficit, are non-stationary in levels.

Empirical Results

Cointegration Analysis

Since all but one of the time series data used in this paper are non-stationary, it is appropriate to begin building a model of nitrogen demand using cointegration analysis. Non-stationary variables have a cointegrating relationship if a linear combination of those variables is itself stationary. This cointegrating relationship is equivalent to a long run equilibrium relationship. We use Johansen's (1991) procedure that extends Engle and Granger's (1987) work on cointegration into a multi-equation framework.

One advantage of Johansen's framework is its ability to analyze causality between the variables. This can be used to check for the presence of multi-collinearity between the variables, which will appear as an extra relationship between variables. It can also be used to analyze the weak exogeneity status of each of the variables with respect to nitrogen use (for further detailed discussion of the concept of weak exogeneity see Harris and Sollis (2003)).

The first step in implementing Johansen's procedure is to estimate a vector autoregressive (VAR) model in levels. The lag length of the initial VAR model was selected using the both the Hannan–Quinn and Schwarz information criterion, which picked a lag length of one year. A VAR with k lags takes the following form, where X is a vector of all of the (potentially) endogenous variables.

4) $X_t = \mathrm{A}_1 X_{t-1} + \ldots \mathrm{A}_k X_{t-k} + u_t$

Days of soil moisture deficit entered this model as an exogenous variable from the beginning.

The second step is to test for the number of cointegrating relationships using the trace and maximum eigenvalue tests. Non-stationary variables have a cointegrating relationship if a linear combination of these variables results in a stationary series. Table 2 contains the results of trace and maximum eigenvalue cointegration tests conducted with this VAR model. These results indicate that the null hypothesis of no cointegrating relationships was rejected by both tests but the hypothesis of at most one such relationship could not be rejected. These results suggest that there is only one cointegrating relationship amongst these variables.

Table 2: Cointegration Test Results

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	5% Critical Value	Prob.**
None *	0.7904	82.5019	69.8189	0.0035
At most 1	0.6321	46.5651	47.8561	0.0658

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	5% Critical Value	Prob.**
None *	0.7904	35.9368	33.8769	0.0280
At most 1	0.6321	22.9979	27.5843	0.1736

* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

The third step is to estimate a vector error correction (VEC) as follows (Johansen, 1992)

5) $\Delta \mathrm{X}_{\mathrm{t}} = \Gamma \Delta X_{t-1} + \alpha\beta' X_{t-1} + \mu + \varepsilon_t$

For the VEC model the β matrix contains the long-run equilibrium parameters, hence $\beta' X_{t-1}$ comprises the error correction term, which is stationary. The parameters in the α matrix measure the speed at which ΔX_t adjusts to the lagged error correction term. This was estimated with one cointegrating relationship.

The weak exogeneity status of the variables is examined by testing whether the row of the α matrix corresponding to the variable of interest is zero; if so, that variable is considered weakly exogenous with respect to the long run cointegrating parameters. In such cases it is statistically valid to model nitrogen demand conditional upon those variables, hence they may dropped from the left hand side of the system without losing any information (Johansen, 1992). If the real price of urea, the real output price, total factor productivity and the ratio of dairy stock units to total stock units are all found to be weakly exogenous, the appropriate model is a single equation conditional error correction model.

The results from Table 3 confirm that both the urea price, the output price, total factor productivity and the ratio of dairy stock units are each individually and together jointly weakly exogenous to nitrogen use. This result suggests that it is appropriate to use a single equation cointegration approach to model the demand for nitrogen. Since the real price of nitrogen is weakly exogenous to nitrogen demand it is not necessary to model nitrogen supply.

Table 3: VEC Weak Exogeneity Tests

α restrictions	$\chi 2$ test statistic	p-value
Urea Price	3.7998	0.0513
Output Price	0.1684	0.6815
TFP	0.0165	0.8977
Ratio of dairy	0.3060	0.5802
Joint	9.3871	0.0573

The long run coefficients from the estimated VEC model are in Table 4. They are of the expected signs but only the main price variables are statistically significant at the 5 percent level.

Table 4: Long Run Coefficients

	Coefficients	T-Statistic	
Urea Price	-0.9672	2.5954	**
Output Price	2.3361	6.4710	***
Ratio of dairy	1.0475	1.4507	
TFP	1.3166	1.7099	*

***denotes significance at the 1percent level, ** the 5 and *** the 10.

The next step in the modelling process is to estimate a single equation error correction model using the long run coefficients estimated in the VEC. This is done by calculating an error correction term, which is the difference between the actual level of nitrogen used and the long run level of nitrogen implied by these estimated coefficients. This error correction term measures the degree of implied disequilibrium present at that particular time.

Figure 3: Error Correction Term

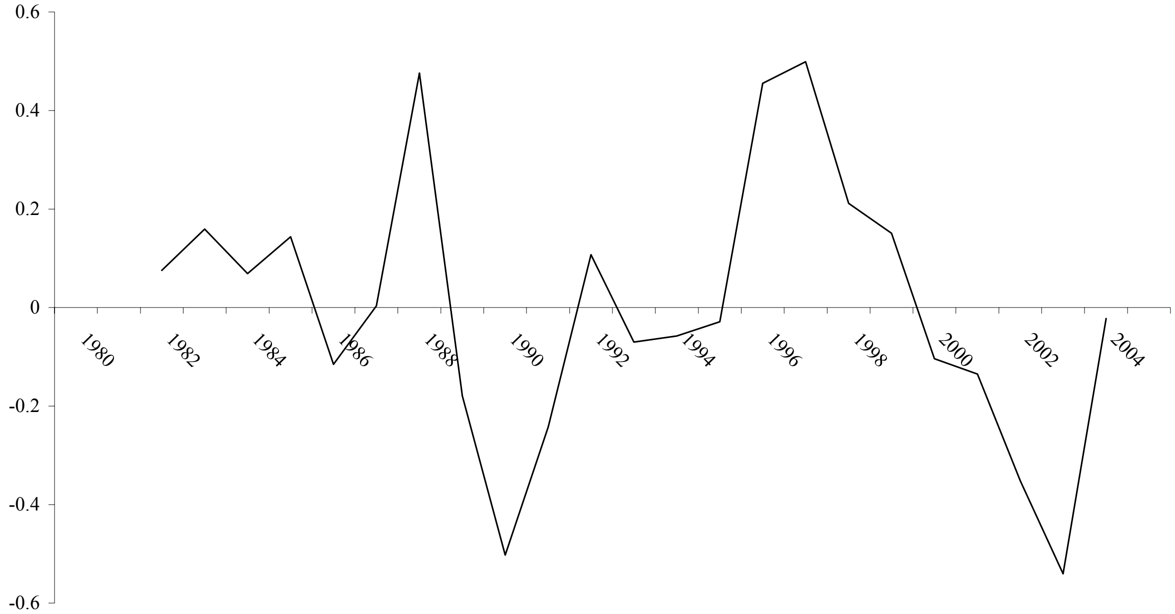


Table 5: Short Run Coefficients

	Elasticity	T-Statistic	
Error Correction Term (t-1)	-0.6991	-2.7733	**
Δ Nitrogen(t-1)	-0.1861	-0.8429	
Δ Urea Price(t-1)	0.2767	0.5451	
Δ Output Price(t-1)	-0.5376	-0.8095	
Δ TFP(t-1)	-1.5937	-1.4967	
Δ Ratio of dairy(t-1)	2.4786	1.1217	
Days of Soil Moisture Deficit	0.1287	0.6047	
Constant	-0.3646	-0.4486	

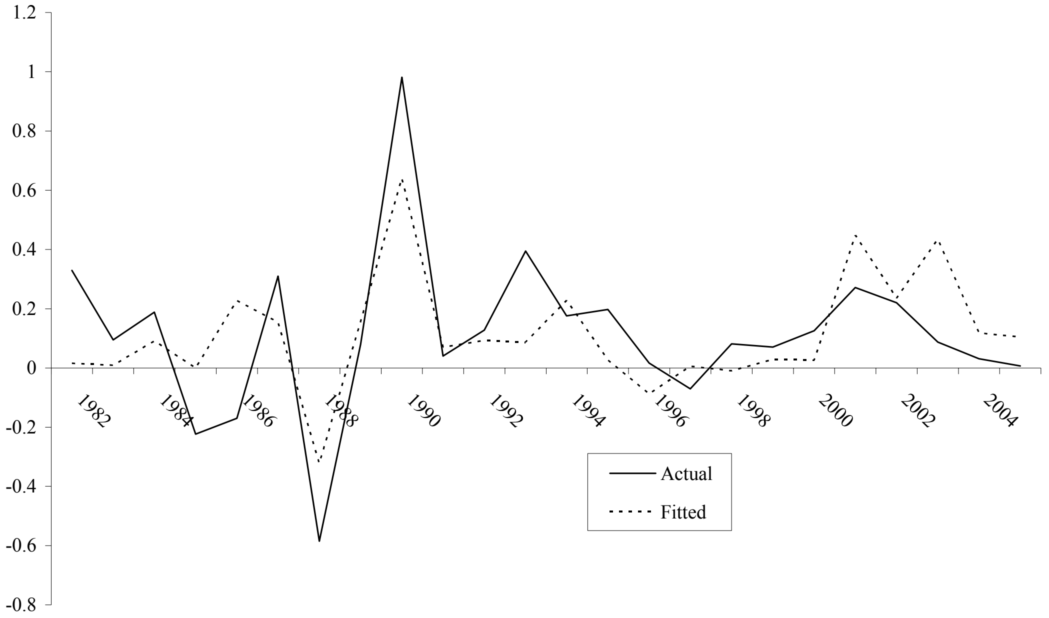
***denotes significance at the 1percent level, ** the 5 and *** the 10.

R^2=0.4941, p(AR)= 0.3552, p(HS)= 0.8272, p(ARCH)= 0.2889

According to the p-values for the LM diagnostic tests for autocorrelation (AR), heteroscedasticity (HS) and autoregressive conditional heteroscedasticity (ARCH) there is no evidence of model specification errors.

In the short run part of the model only the error correction term is significant. The coefficient on the error correction term indicates that 68 percent of last year's disequilibrium is closed in the current year. The adjustment to the implied long run equilibrium value is therefore quite rapid and any changes to prices, productivity or land use are reflected in actual nitrogen fertiliser use quite quickly (97 percent within 3 years).

Figure 4: Actual and Fitted Change in Nitrogen Use



Conclusions

This paper has attempted to construct a model of the demand for nitrogen fertiliser for New Zealand to try to explain the rapid increase in nitrogen use since 1990. Several conclusions can be taken from this:

- Real output prices have a strong influence on nitrogen demand. For instance low output prices in the late 1980s slowed demand considerably and strong output prices in 2001 boosted demand for nitrogen fertiliser.

- The declining real price of urea has been an important factor contributing to the increase in nitrogen demand. Long run own price elasticity is estimated to be 1 (compared to 0.81 for the most comparable international study from Greece (Mergos and Stoforos(1997)).

- Changes in total factor productivity have tended to be non-neutral with respect to nitrogen demand over the study period. This is a historical observation and it does not in principal mean that further increases in total factor productivity would also increase nitrogen demand. Practices that increase the efficiency of nitrogen use could both improve total factor productivity and, everything else being equal, reduce nitrogen demand.

The main limitation of this research is the quantity and resolution of the available data. The statistical tests used to develop this model have low power when applied to small samples. The small sample size also precluded inclusion of other potentially important variables such as cost of capital, cost of labour, cost of alternative feed sources etc. Given the ranges of own price elasticities estimated for different crops and countries in international studies breaking down the demand for nitrogen by sector or by region would provide more useful information, but this data is not available in New Zealand currently.

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Appendix 1: Unit Root Tests

Before estimating a factor demand function for nitrogen, it is necessary to test these time series for their stationarity status since a time series regression model including non-stationary variables often gives spurious results. For this task we used the Phillips–Peron (PP) test which has the null hypothesis of non-stationarity.

Table 1: Non-Stationarity test results

	PP test statistic	p-value
Nitrogen	-1.0758	0.9134
Urea Price	-0.3696	0.9831
Output Price	-2.5512	0.3032
Total Factor Productivity	-2.3382	0.3995
Ratio of Dairy	-2.5392	0.3083
Days of Soil Moisture Deficit	-7.1132	0.0000
Δ Nitrogen	-2.7620	0.0788
Δ Urea Price	-3.8323	0.0081
Δ Output Price	-4.6575	0.0012
Δ Total Factor Productivity	-5.9637	0.0001
Δ Ratio of Dairy	-4.8638	0.0007
Δ Days of Soil Moisture Deficit	-28.3635	0.0001

Here the null hypothesis of non-stationarity could not be rejected for all variables in levels except days of soil moisture deficit. It was rejected at the 5% level for all variables except nitrogen usage which was rejected at the 10% level.

Appendix 2: Data

	Nitrogen Use	Real Price of Urea	Agricultural Total Factor Productivity	Pastoral Output Price Index	Ratio of Dairy	Real Price of Lamb	Real Price of Milk Solids	Real Price of Prime Beef	Dairy Stock Units	Beef Stock Units	Sheep Stock Units	Total Stock Units
1980	20300	1143.16	114.75	99.81	0.1746	1.4538	1.4949	1.5489	18,663	25,383	62,614	106,860
1981	21700	1159.42	119.54	87.21	0.1714	1.2360	1.5200	1.2832	18,402	25,018	63,723	107,339
1982	30150	1056.89	119.08	92.45	0.1755	1.4039	1.6592	1.0500	18,864	23,914	64,454	107,510
1983	33141	824.29	118.35	88.56	0.1846	1.3000	1.6345	1.0675	19,658	22,018	64,474	106,508
1984	40000	815.70	120.32	90.58	0.1897	1.3591	1.6021	1.0670	20,328	22,188	64,172	107,160
1985	32000	873.36	126.43	90.47	0.1970	1.3408	1.6128	1.1102	21,025	22,559	62,554	106,718
1986	27000	778.23	140.52	71.24	0.2007	0.6714	1.8442	1.4055	21,617	23,878	61,476	107,710
1987	36800	617.02	145.91	59.39	0.1984	0.8065	1.1514	0.8678	20,538	23,488	58,585	103,515
1988	20500	589.71	168.19	55.50	0.1979	0.6579	1.2525	0.9132	20,551	23,724	58,432	103,869
1989	22200	579.38	160.49	65.12	0.2124	0.7713	1.7066	0.8133	21,138	22,075	54,822	99,518
1990	59265	527.56	159.40	84.03	0.2216	1.1699	1.8140	0.9771	21,993	22,771	52,633	99,254
1991	61694	526.90	166.24	71.33	0.2252	0.9861	1.2212	1.1762	21,704	22,868	49,602	96,376
1992	70122	524.59	171.84	78.70	0.2313	1.0189	1.6781	1.1262	22,103	23,232	47,803	95,558
1993	104095	490.03	161.30	91.51	0.2421	1.3672	1.7177	1.1190	22,685	22,941	45,821	93,691
1994	124131	475.89	184.45	87.61	0.2524	1.3562	1.4676	1.1649	24,421	25,068	44,958	96,756
1995	151263	538.74	183.35	80.18	0.2644	1.1155	1.5479	1.0755	25,926	25,640	44,279	98,054
1996	153780	550.21	167.15	82.68	0.2756	1.1243	1.8596	0.8372	26,434	24,064	43,210	95,920
1997	143295	491.86	178.33	82.25	0.2849	1.3255	1.6929	0.6084	27,603	24,188	42,690	96,878
1998	155467	435.44	192.29	78.08	0.2980	1.2007	1.5929	0.6530	28,282	22,273	41,876	94,911
1999	166819	341.75	190.77	82.85	0.2876	1.2541	1.6399	0.8337	27,057	22,782	41,744	94,089
2000	189096	369.04	185.26	89.76	0.3110	1.3815	1.6796	0.9610	29,223	22,698	39,379	93,958
2001	248000	449.54	206.52	109.71	0.3318	1.6564	2.0603	1.2084	31,117	23,026	36,906	93,796
2002	309200	373.67	215.00	116.85	0.3413	1.8324	1.9956	1.4378	31,841	21,841	36,687	93,301
2003	337400	381.78	229.15	94.96	0.3383	1.5810	1.3708	1.3894	31,842	22,579	36,723	94,133
2004	348000	405.27	240.93	91.91	0.3445	1.5343	1.6199	0.8932	32,221	21,708	36,498	93,519
2005	350320	485.60		93.45	0.3443	1.5627	1.6978	0.8115	32,365	21,593	37,010	94,015