Towards Analysis of Sustainable Export-Oriented Agriculture: Exploring Land-use Data and CGE Modelling in New Zealand*

by

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Prepared for the
Eleventh Annual Conference on Global Economic Analysis

Helsinki, Finland
12-14 June 2008.

* We gratefully acknowledge valuable contributions from Peter Newsome, Oscar Montes de Oca Munguia and Roger Parfitt (Landcare Research, New Zealand) and Suzi Kerr at Motu, Wellington. We are also grateful for funding support from the FRST/Pastoral 21 Work Programme: Delivering Environmental Solutions for Sustainable Productivity Outcomes for New Zealand's Pastoral Industries, and the Massey University Research Foundation (MURF) Grant 07/0079.
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Abstract

Despite New Zealand's continuing development, agriculture remains a major sector of the economy, and the vast majority of farm and food production is exported. The accelerating intensification of farming in New Zealand over recent decades raises concern over the current sustainability of New Zealand farming, and whether it can remain so in the future. Livestock's impact on the environment, especially water availability and pollution and GHG emissions, is an important domestic policy issue in New Zealand given its high share of economy-wide emissions. It has also become a trade policy issue with the growing trend for foreign buyers and policy makers to place emphasis on 'green' and environmentally-friendly livestock production. Therefore there is an imperative for New Zealand to work towards sustainable export-oriented agricultural production. The paper compares official GHG emissions data for New Zealand with those in the GTAP database and notes some major discrepancies. We next explain why we do not use the GTAP AEZ data for New Zealand, but instead adopt a New Zealand-specific system of land environment classification. From these data, we derive values to substitute for the GTAP AEZ data. We modify the standard GTAP model to incorporate several land classes, and run two illustrative simulations. Further research plans are presented.

1. Introduction

Despite New Zealand's continuing development, agriculture remains a major sector of the economy. Farming's contribution to gross domestic product was 5.6% in 1993 and by 2005 and fallen only to 5.1%. When the manufacture of food and beverages is added to farm production, the combined share of national GDP declined over the same period from 11.3% to 10.3%. New Zealand's population is only a little over 4 million, and the vast majority of farm and food production is exported. Of the country's total merchandise exports, the contribution of raw and processed agricultural products remained around 55% between 2002 and 2007. When total forestry products are added, the combined share of total exports reaches 67%.

New Zealand's farming has been intensifying for the last 100 years. A new intensification phase occurred following the deregulation of agriculture in the mid-1980s, and the rate of intensification has accelerated further over the last decade. For example between 1990 and 2005, the total area of farmland has declined by 15%, the number of dairy cows has increased by 50% (although total livestock units declined by 6.6%), and total use of nitrogenous and phosphatic fertilisers (on a nutrient basis) has risen by 590% and 186% respectively. The accelerating intensification over recent decades raises concern over the current sustainability of New Zealand farming, and whether it can remain so in the future (MacLeod and Moller 2006).

Livestock farming's potential to cause environmental degradation worldwide is now well documented (Steinfeld et al. 2006) and includes land degradation, deforestation, climate change and air pollution, water shortage and pollution and loss of biodiversity. Livestock's impact on the environment, especially water availability and pollution and GHG emissions, is an important domestic policy issue in New Zealand since livestock farming accounts for around two-thirds of the value of farm output. It has also become a trade policy issue with the growing trend for foreign buyers and policy makers to place emphasis on 'green' and environmentally-friendly livestock production. Since livestock and their manufactured products contributes around 70% of the country's total agricultural and food exports, failure to adequately respond to foreign market trends poses a trade risk to the country. Therefore there is an imperative for New Zealand to work towards sustainable export-oriented agricultural production. To that end, government has proposed an emissions trading scheme.

2. Agriculture's Impact on the New Zealand Environment

2.1 New Zealand's greenhouse gas emissions

Under its obligation to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, New Zealand is required to keep an annual inventory of human induced emissions and removals of greenhouse gases (GHGs). The Ministry for the Environment (MfE) collates this GHG Inventory, which is submitted each year to the UNFCCC with a 2-year lag in data. CO_2 (carbon dioxide), CH_4, N_2O, HFCs (hydrofluorocarbons), PFCs (perfluorocarbons) and SF_6 (sulphur hexafluoride) are reported in total emissions, which are converted to CO_2 equivalents (CO_2-e) using global warming potentials (GWPs).[1] Recent trends are shown in Figure

[1] A GWP is the relative warming effect of a unit mass of the gas compared with the same mass of CO_2 over a specific period.

1. While 14 percent of global GHG emissions come from agriculture, New Zealand is unusual among developed countries with almost half of the country's emissions being generated by the agricultural sector (Figure 2). The other main contributor to New Zealand's GHG emissions is the energy sector, which was responsible for 43.4 percent of total emissions in 2005. New Zealand has a significant sink for GHGs in its land use, land-use change and forestry (LULUCF) sector, removing 31.8 percent of the country's GHG emissions in 2005 (Ministry for the Environment (MfE) 2007).[2]

New Zealand ratified the Kyoto Protocol in December 2002, with the target to reduce GHG emissions to 1990 levels. It seems a distant target when by 2005 New Zealand's overall GHG emissions had increased by 24.7 percent. The energy sector reported the greatest increase with emissions up 42 percent from 1990. While emissions from agriculture had increased by 15.2 percent, the dairy sector alone had increased emissions 70.5 percent above 1990 figures. The waste sector (which contributes only 2.4 percent of the country's GHG emissions) reported a 25.9 percent fall in emissions below the 1990 baseline. Net removals of GHG emissions by the LULUCF sector were 29.1 percent above net removals in 1990 (MfE 2007).

It should be noted that GHG inventories include a wide range of emission estimates and this is particularly so for New Zealand where a large proportion of the GHG emissions are not point source emissions but are from agriculture, and in terms of uncertainty, removals from forest land are also significant. The calculated uncertainty for New Zealand's total inventory of emissions and removals for 2005 was ±16.9 percent and ±20.7 percent for emissions (excluding removals). The high uncertainty is a consequence of the uncertainty in calculation of CH_4 emissions from enteric fermentation in domestic livestock, N_2O emissions from agricultural soils and removals of CO_2 from forest land (MfE 2007).

2.1.1 GHG emissions from New Zealand agriculture: Comparisons with GTAP data

The agriculture sector, which includes pastoral and arable farming and horticulture is responsible for 48.5 percent of New Zealand's total GHG emissions. Almost all of New Zealand's agricultural emissions are methane (CH_4) emissions from ruminant livestock (also swine and horses) and nitrous oxide (N_2O) emissions from animal excreta and nitrogenous fertiliser use.[3] CH_4 emissions as a by-product of enteric fermentation in domestic livestock accounted for 63.9 percent of the country's agricultural emissions in 2005, up 9.6 percent from 1990 levels. As stated earlier, CH_4 emissions from the dairy sector had increased 70.5 percent from 1990, but this had been partially offset by the reduction in methane emissions from sheep production by 18.2 percent, and also from other animals (Ministry for the Environment (MfE) 2007).

CH_4 emissions result from enteric fermentation and manure management from livestock and are reported separately for dairy cattle (including dairy heifers, where the information is available), non-dairy cattle, sheep, goats, horses, swine, poultry (manure management only) and deer (refer to Appendix Table 2). These CH_4 emissions are aggregated into the three relevant GTAP sectors (relevant GTAP agricultural sectors are defined in Appendix Table 1) and are shown in Table 1

[2] The inventory analysis is conducted both excluding and including the LULUCF category.
[3] Non-CO_2 emissions only are reported in the agricultural sector.

alongside the CH_4 emissions given for New Zealand in the global GTAP database. [4] There are some large discrepancies between the two data source that we will have to address, with the GTAP data consistently under-estimating emissions from cattle and over-estimating those from milk production and other animals.

Table 1: CH_4 emissions (Gg) from New Zealand agriculture

	Sector	1990		1995		2000		2005	
		GTAP	NZ GHG	GTAP	NZ GHG	GTAP	NZ GHG	GTAP	NZ GHG
9	ctl	615.24	808.71	592.69	774.62	584.11	763.57		741.22
10	oap	148.99	9.71	143.53	10.67	141.46	10.06		10.52
11	rmk	727.91	248.10	701.23	304.54	691.09	368.34		422.51
	Total	1492.14	1066.52	1437.45	1089.83	1416.66	1141.97		1174.25

Source: GTAP CO2 emission database (May 2006) and non-CO2 database (March 2003) and New Zealand's GHG Inventory 1990-2005.
Note: In the 2002 Agricultural census (Statistics New Zealand) cattle, sheep, deer, pigs, goats and horses comprise 99.96% of livestock in New Zealand. Since mules, assess, camels and llamas make up only 0.04% of livestock, emissions for these animals are not estimated.

N_2O emissions from New Zealand agriculture are a result of manure management, pasture, range and paddock manure, direct soils emissions, indirect emissions and field burning of cereal crop residues (see Appendix Table 3). Direct soils emissions refers to nitrogen input to soils from the application of synthetic fertilisers and from manure applied to soils, nitrogen fixed by nitrogen-fixing crops, nitrogen in crop residues returned to soils and also emissions from soils where histols[5] have been cultivated. N_2O emissions also occur as a result of nitrogen excretion from livestock grazing on pasture, range and paddock, and finally indirect emissions occur from volatised nitrogen from fertilisers and animal manure, and nitrogen that is lost through leaching and runoff from these sources. In order to attribute the N_2O emissions to subsectors of agriculture, some assumptions had to be made. Manure management in New Zealand occurs in both dairy and swine production, however, the quantity of manure management for swine is negligible in comparison to that from dairy production so it can safely be approximated to zero. Direct soils emissions from animal manure applied to soils are also attributed to dairy production. Direct soils emissions from synthetic fertilisers are attributed to the vegetables and fruit sector, while those from the nitrogen-fixing crops and crop residue are attributed to arable and other crops. It is further assumed that land cultivated from histols is for pasture and that the much greater quantity of indirect emissions is from livestock than from synthetic fertiliser. Therefore emissions from cultivation of histols, pasture, range and paddock manure and indirect emissions have been split proportionally over dairy cattle (53.3 percent) and other livestock (46.7 percent). The result of the assignment

[4] While CH_4 emissions are recorded as a result of the prescribed burning of savannas and field burning of agricultural (cereal) residues (see Table 3), these are negligible in comparison to the emissions from livestock, so for this reason they have not been included in Table 1.
[5] Histols are marshes and peat bogs.

of N_2O emissions to the agricultural subsectors is presented in Table 2 alongside the N_2O emissions given for New Zealand in the global GTAP non-CO2 database. As with CH_4, there exist large discrepancies between the GTAP data and those recorded in New Zealand's statistics. The GTAP data consistently over-estimates N_2O emissions for the cropping sectors but grossly under-estimates emissions for cattle and milk production.

Table 2: N_2O emissions (Gg) from New Zealand agriculture

Sector	1990		1995		2000		2005	
	GTAP	NZ GHG	GTAP	NZ GHG	GTAP	NZ GHG	GTAP	NZ GHG
v_f	22.96	0.81	23.32	2.02	23.87	2.85		4.85
arable+other crops	13.84	0.24	14.06	0.25	14.39	0.26		0.10
ctl	0.14	14.46	0.16	14.93	0.19	15.80		16.55
oap	0.03	0	0.04	0	0.05	0		0
rmk	0.16	17.00	0.20	17.63	0.22	18.75		19.71
Total	37.13	32.51	37.78	34.83	38.71	37.66		41.21

Source: GTAP CO2 and non-CO2 databases and New Zealand's GHG Inventory 1990-2005.

2.1.2 Land use, land-use change and forestry (LULUCF) GHG removals:

The LULUCF sector is important for New Zealand, removing 31.8 percent of the country's GHG emissions in 2005. The bulk of stored carbon is primarily stored in the forest biomass. Natural forest is in a relatively steady state, therefore changes in the size of this sink are primarily a result of variations in planting rates and the impact of harvest regimes in production forestry. National forest survey data and computer modelling of the planted forest estate are used to assess the changes in planted forest stocks, and changes in land area of grassland, cropland, wetland, settlements and other land is obtained from Land Cover Databases 1 and 2 (mapped in 1997 and 2002). Changes observed between 1997 and 2002 are then used to extrapolate data for all other years (MfE 2007).[6]

The land cover categories in the New Zealand GHG inventory are forestland, cropland, grassland (which includes both pasture and shrubland), wetlands (which is only noted when land is converted to wetlands with the removal of biomass to flood the land), settlements, other land (land not included in the preceding categories, so alpine, rock etc) and other (which is not land but lime application (in terms of CO_2 emissions) which is not included in agriculture). The GTAP land cover categories used for New Zealand are forest, savannah grassland, cropland, pastureland, and built-up land. The emissions and removals of CO_2 from the different land categories in the LULUCF sector are presented in Table 3. There is also a small quantity of CH_4 emissions (84.9 CO_2 equivalent (Gg) in 2005) and 8.62 CO_2 equivalent (Gg) of N_2O

[6] The Land Use and Carbon Analysis System has been created to improve the level of reporting for the LULUCF sector in the future.

emissions from the sector with just over half of each gas from forest land and the remainder from grassland.

Table 3: Removals/emissions of CO_2 equivalent (Gg) from LULUCF

	1990	1995	2000	2005
Forest Land	-19,754.89	-16,038.76	-21,278.22	-25,513.17
Cropland	-506.69	-550.84	-594.99	-639.14
Grassland	706.91	706.91	706.91	706.91
Wetlands	0.72	0.72	0.72	0.72
Settlements	97.16	97.16	97.16	97.16
Other Land	26.74	30.82	34.9	38.98
Other	346.42	506.9	681.8	714.21
Net emissions	-19,083.63	-15,247.09	-20,351.72	-24,594.33

Source: New Zealand's GHG Inventory 1990-2005

2.2 Livestock and nutrient pollution

Because of livestock's dominance of New Zealand agriculture, water quality issues due to pollution from nutrients such as nitrogen and phosphorus is largely a livestock issue. Much of the water used by livestock returns to the environment in the form of manure and waste water. Livestock excreta contains quantities of nutrients (such as nitrogen and phosphorus), drug residues, heavy metals and pathogens. These can pose serious threats to the environment and human health should they get into water or accumulate in the soil. High concentrations of nutrients in water can lead to accelerated eutrophication and resulting algal blooms and algal toxins, undesirable flavour and odour and excessive bacterial growth, and may pose a public health hazard (Steinfeld et al. 2006). Problems due to nitrogen excretion from livestock, especially dairy cattle, have become a major concern in New Zealand with increased N concentrations in surface and ground waters. In the Waikato region 17% groundwater samples had nitrate-N concentrations exceeding the WHO limit, some lakes in the Rotorua region have algal blooms and N concentrations are increasing in Lake Taupo, New Zealand's largest lake (Parfitt et al. 2006). The impacts of recent intensification of farming are yet to be observed since it may take 40 years for nutrients to flow through groundwater to lakes, but trends in water quality are already generally downward.

Major inputs of nitrogen to New Zealand agriculture (Table 4) include that through biological N fixation (BNF) and fertilisers. New Zealand is one of the few temperate countries where much farm production depends on BNF through white clover in pastures that are grazed year-round. In recent years, however, use of N fertilisers has grown rapidly – total application in 2005 was 351Gg of N compared with 156Gg in 1995. Much of this increase is accounted for by increased use on pastures used for intensive dairying. Livestock manure is the other major N input, and nearly all from pastoral livestock. The major N output is in pasture consumed by livestock. Between 1990 and 2005 the average N loss at farms increased from 31 kg/ha to 46 kg/ha. Phosporus inputs and outputs of New Zealand agriculture are shown in Table 5. Major input sources are fertiliser and animal manure, while forage (pasture) consumption is the major output. Trends in the N and P balances are given in Figure 3. Since 1985 the N balance has increased at the average rate of 2.6% per year and that of phosphorus by twice that rate. Since 1999 the growth in the P balance has been similar to its longer term average rate, but that for N almost doubled to 5% per year.

Table 4. Nitrogen Inputs and Outputs to New Zealand Agriculture ('000 tonnes)

Description	1990	1995	2000	2005
NITROGEN INPUTS	1,856,710	2,022,931	2,106,330	2,343,584
Fertilisers	59,265	151,263	189,096	350,320
Net Input of Manure	1,267,667	1,354,023	1,433,690	1,539,192
-Pigs & poultry	8,182	10,031	11,447	12,920
-Pastoral Livestock	1,259,486	1,343,992	1,422,243	1,526,272
Other Nitrogen Inputs[a]	529,778	517,644	483,544	454,072
NITROGEN OUTPUTS	1,455,096	1,552,357	1,642,968	1,757,811
Total Harvested Crops	23,863	25,094	26,782	23,411
Total Forage	1,431,234	1,527,264	1,616,185	1,734,400
BALANCE (Inputs minus Outputs)	401,613	470,573	463,363	585,774
Nitrogen Balance (kg/ha farmland)	31	37	37	46

Source: Dr Roger Parfitt (personal communication).
a. Primarily biological nitrogen fixation.

Table 5. Phosphorus Inputs and Outputs to New Zealand Agriculture ('000 tonnes)

Description	1985	1990	1995	2000	2004
PHOSPHORUS INPUTS	296,576	254,208	319,760	333,844	385,260
Fertilisers	146,100	109,824	170,016	177,320	204,160
Net Input of Manure	146,408	140,518	145,944	152,772	177,359
-Pigs & poultry	2,875	2,679	3,222	3,562	3,970
-Pastoral livestock	143,533	137,839	142,722	149,210	173,389
Other Phosphorus Inputs[a]	4,068	3,867	3,800	3,752	3,740
PHOSPHORUS OUTPUTS	183,618	175,829	182,208	190,521	220,152
Total Harvested Crops	4,202	3,530	3,806	4,008	3,416
Total Forage	179,416	172,298	178,402	186,513	216,736
BALANCE (Inputs minus Outputs)	112,957	78,379	137,552	143,323	165,108
Phosphorus Balance (kg/ha farmland)	8.6	6.0	10.7	11.3	13.1

Source: Dr Roger Parfitt (personal communication).
a. Mainly atmospheric deposition.

3. CGE Modelling of New Zealand Agriculture's Environmental Impacts

3.1 Background

Since much of New Zealand's farm output is eventually sold in foreign markets, analyses of the future development of this sector in New Zealand, and consequent environmental impacts is best conducted within a global setting. For the same reasons, analyses of New Zealand's policy responses to environmental developments must also be conducted within a global framework since such policies may impact on New Zealand agriculture's international competitiveness and export performance.

Our first experience in using a global cge model for environmental analysis used the standard GTAP model (Rae and Strutt 2001). This focussed on nitrogen pollution from livestock farming and used gross nitrogen production from livestock effluent as a proxy for the nitrogen surplus. The modelled projections indicated that multilateral trade reforms could have positive impacts on the global environment and that structural change is of much greater consequence than trade reform as a driver of environmental damage. This analysis was further developed in a subsequent publication (Rae and Strutt 2007). First, nitrogen balance data from the OECD were used in place of gross nitrogen production from livestock, which also allowed nitrogen surpluses from non-livestock farming to be included. Second, the standard GTAP model was modified through incorporation of additional substitution relationships. Agro-chemicals were allowed to substitute for land in crop production, purchased feeds to substitute for land in livestock production, and substitution was also permitted among individual feedstuffs in livestock production. This allowed us to model the impacts of trade liberalisation on the intensity of agro-chemical use in agriculture which we used as an additional environmental indicator. We also incorporated milk and sugar quotas since these sectors can be important contributors to environmental damage, through nitrogen surpluses in the case of milk production and fertiliser in the case of sugar. The study found that assumed Doha Round reforms could bring about a small improvement in nitrogen balances in the OECD, that cropping becomes less intensive in chemicals in West Europe and developed Asia but more intensive in other OECD countries.

3.2 Improving land-use modelling

Land quality and value play an important role in determining how landowners allocate land among uses and hence the greenhouse gas and nutrient emissions that result from the various land types and use activities. While the standard GTAP model recognises a single land type, recent GTAP research has developed a land use and land cover database to permit a much more refined characterisation of the potential for shifting land use among cropping, livestock and forestry activities (Lee et al. 2005; Ramankutty et al. 2007). When combined with the GTAP greenhouse gas databases the potential exists to better assess the role of land use change on greenhouse gas mitigation strategies and as a factor in greenhouse gas abatement.

3.2.1 Agroecological zones and GTAP land use data

The GTAP land use database is built on the agroecological zoning (AEZ) research of FAO and IIASA (Fischer et al. 2002). AEZ refers to the segmentation of a parcel of land into smaller units according to agroecological characteristics such as moisture and temperature regimes and length of the growing period. In this way the heterogeneity of land is taken into account. Thus in the model competition for land within a given AEZ across uses is constrained to include only activities that have been observed to take place in that zone. If two land uses do not appear in the same AEZ, then they will not compete in that land market.

Our initial step was to examine the AEZ data for New Zealand and attempt to check it if necessary against data from national land use sources. [7] Six of the 18 AEZs are defined for New Zealand agriculture and forestry, with AEZ11 and AEZ12 being dominant. Given the importance of pasture for livestock farming in New Zealand, we checked the way in which land used by these pastoral activities was distributed across AEZs.[8] The SAGE database was the original source of total land areas, but 'pastoral' land was not divided into that used by the various pastoral livestock activities, such as sheep farming, beef raising or milk production. As a result, we found that in the GTAP land-use database for New Zealand the distributions of the market value (VFM) of pasture land used in the ruminant cattle ('ctl') and milk ('rmk') GTAP sectors were identical (Figure 4). The distributions of sheep & cattle, and dairy land over AEZ 11 and 12 might in fact be rather similar, since those zones cover practically all of the North Island and the coastal areas of the South Island (Figure 5). However these two land uses would not maintain a similar relativity in AEZ16, which is defined as a boreal zone and is primarily the South Island high country where sheep farming is the dominant pastoral farming activity. This problem with the AEZ data may not be such an issue in countries where pastoral agriculture is much less important than in New Zealand.

To improve on the land allocations in the AEZ database, we required suitable geographic definitions of the various AEZs as defined for New Zealand. Despite our best efforts, Figure 5 was the best information our enquiries could uncover, clearly unsuitable to match geographic regions with the AEZs. We then approached relevant scientists in New Zealand to learn whether they could recreate the AEZ definitions at a regional level for New Zealand. We learned during these discussions that the AEZ concept was not currently used in New Zealand, but that an alternative land environment database had been recently constructed. Had we continued with the AEZ concept, not only would we be using questionable data, but we would also run the risk of being marginalised in New Zealand debates over land use since we would be using an unfamiliar land definition making communication difficult, which could hinder efforts to partake in collaborative research with other New Zealand scientists. We therefore decided to replace the AEZ data with that derived from New Zealand's own land environment classification.

3.2.2 Land Environments of New Zealand and Land Use

The land environments of New Zealand (LENZ) classification was developed by a large team of scientists including several from Landcare Research, one of New Zealand's Crown Research Institutes, and the Ministry for the Environment (Leathwick et al. 2003). LENZ is a classification of New Zealand's landscapes using a comprehensive set of climate, landform and soil variables. Although these variables were primarily selected for their role in driving geographic variation in indigenous ecosystems, they also have wide application for land use management in agriculture, horticulture and forestry since the variables that influence indigenous systems also

[7] We used the GTAP Land Use Data, Release 2.0, October 30, 2007.
[8] GTAP Land use database, Release 2.0, October 2007.

strongly constrain the productivity of crop species. LENZ is presented at four levels of detail containing 20, 100, 200 or 500 environments – we use the first level of 20 environments. A total of 15 variables were used to define the environments, including annual and winter minimum temperatures, annual and winter solar radiation, monthly water balance, soil slope and drainage, and chemical composition of the soil. Unlike AEZ, it does not explicitly incorporate the length of the growing season (degree days) although total degree days can easily be calculated from the underlying data.

Within each of the 20 environments, data were available on the total area of land and the distribution of that land over geographic regions in New Zealand. From other New Zealand sources we obtained land use data (essentially horticulture, other cropping, sheep, beef and deer farming, dairying and production forestry) by the same geographic regions. Overlaying these two databases (LENZ and land use) the total area of land, by land use classification, was obtained for each of the environments .
It is of interest to observe how the share of land used in some farm activity within any environment, varies across environments. Figures 6 and 7 present such information for sheep, beef and deer farming, and for dairy farming. Each point in the graphs represents a particular environment. Dairy production tends to occur in environments with mean annual temperatures between 10-15^{0}C, and on relatively flat land. Some sheep and beef production occurs under similar environments, but is also found in cooler and steeper environments.

To use these data within GTAP, the land area data by farm activity and environment has to be converted to rental values. On the assumption that land rentals are proportional to land values, we obtained official land valuations per hectare by land use and the same geographical regions (77 Territorial Authorities) that were used above.[9] These were then applied to the land use by environment data.
Figure 5 shows how the total valuation of pasture land used in sheep, beef and deer production, and that used for dairying, are distributed across the land environments. Unlike Figure 4 (the GTAP AEZ data), these distributions are quite different. While environment F (Central hill country) is important for both farm activities, environment A (Northern Lowlands) is relatively more important for dairy, while the reverse holds for environments D (Northern Hill Country) and Q (Southeastern Hill Country and Mountains).

4. Modifications to the Standard GTAP model and Databases

4.1 Database modifications

Our new land use data is to substitute for the AEZ values for New Zealand in the GTAP land use database. We omit environments S and T since they support very little agricultural land use – this leaves us with 18 classes, conveniently the same as the number of AEZ classes. Care must be exercised to ensure that various balance conditions in the original GTAP database (such as the sectoral zero profit conditions) are not disturbed by this data substitution. In the GTAP Land Use Data, AEZ values are given for three variables: EVOA, EVFA and VFM. Our new data must therefore replace the AEZ values in each of these variables for New Zealand. In order to

[9] We gratefully acknowledge that these valuation data were provided through the FRST-funded Motu project ‘Integrated Economics of Climate Change’.

maintain balance conditions in the GTAP database, we adjusted our new land value data in the following way. This procedure is followed for each of the above GTAP variables.

Let $aez_{k,j,NZ}$ be the original AEZ data in the GTAP land use database, for AEZ class k in sector j in New Zealand,

and let $lv_{k,j,NZ}$ be our new land value data for the New Zealand land environment k in sector j.

The $lv_{k,j,NZ}$ data for New Zealand are adjusted by a constant so that the summation of that data over all environments and sectors, is identical to a similar summation of the $aez_{k,j,NZ}$:

$$aez^{*}_{k,j,NZ} = lv_{k,j,NZ} \quad * \quad [\sum_k \sum_j aez_{k,j,NZ} \quad / \quad \sum_k \sum_j lv_{k,j,NZ}]$$

Now $\sum_k \sum_j aez_{k,j,NZ} = \sum_k \sum_j aez^{*}{}_{k,j,NZ}$

but for any sector j, $\sum_k aez_{k,j,NZ} \neq \sum_k aez^{*}{}_{k,j,NZ}$

We took the decision to distribute the differences implied in the above equation, for any given sector, across the values for that sector's non-land endowments, in proportion to the values of those non-land endowments. Illustrating this for the GTAP variable VFM we have:

$$VFM^{*}{}_{i,j,NZ} = VFM_{i,j,NZ} + [SHR_{i,j,NZ} * (\sum_k aez_{k,j,NZ} - \sum_k aez^{*}{}_{k,j,NZ})]$$

where $SHR_{i,j,NZ}$ is the share of the i^{th} non-land endowment in the total of VFM summed over all non-land endowments in sector j and
$VFM^{*}{}_{i,j,NZ}$ is the adjusted value for this variable.

4.2 Model modifications

A number of modifications to the standard GTAP model are made to accommodate the AEZ data. In particular, we adapt the standard GTAP production functions to now include different land types, as shown in Figure 9. A new nested Constant Elasticity of Substitution (CES) function is introduced for the different land types and following the work of Golub, Hertel and Sohngen (2008), we set the elasticity of substitution among different land types in production to 20. This relatively high elasticity of substitution should cause the return to land across AEZs, but within a given use, to move closely together (Golub, Hertel and Sohngen 2008). Land mobility is constrained using a Constant Elasticity of Transformation (CET) frontier, following the treatment of sluggishly mobile factors of production in the standard GTAP model (Hertel 1997). The larger the absolute value of the CET parameter, the more mobile land; the closer to zero, the more unresponsive are changes in land use in response to changes in relative returns to land from different activities (Golub, Hertel and Sohngen 2008).[10]

5. Exploratory Simulations

Two exploratory simulations are undertaken to examine the impact of including multiple sub-types of land in the model. In particular, we project an aggregation of the version 6 GTAP database from its benchmark 2001 through to 2010. We then repeat this projection using the modified version of the GTAP model and database that incorporates different land-types.

Given the exploratory nature of this initial set of simulations, we focus only on a limited selection of results for New Zealand. In particular, we compare changes in sectoral output and changes in land-use and prices, first using the standard version of GTAP then using the modified version of the model including the 18 land environments.

Figure 10 presents the projected changes in New Zealand's sectoral output from 2001 to 2010 using the standard version of the GTAP model with results using our modified model and database. There are significant differences in results for the two simulations. Most striking is the case of the forestry sector, which is projected to experience significantly higher increases in output in the modified version of the model. In the standard GTAP database, there is no allocation of land value to the forestry sector, therefore no possibility that land may transfer into this sector. However, in the modified version of GTAP, land is allocated to the forestry sector and can move between sectors in response to changing incentives. For other sectors, the directions and magnitudes of output changes are somewhat similar in both simulations. The main exceptions appear to be bovine products, where output is projected to increase in the first simulation but decline when the modified model is used and also the cattle&wool sector, where projected increases in output are significantly dampened in the second simulation.

Now we turn to changes in the price and quantity of land used by each sector. Table 6 presents results for projected changes in the price and quantity of land used in the standard GTAP model, with only one land type. Figures 11 and 12 show these same results for the modified version of the model, now with 18 land environments available. In the original results, market price increases for land in each sector range from 63 percent to 221 percent. This range is much wider using the modified model, with particularly large increases in the price of land in the forestry sector. Shifts of land into the forestry sector are also striking in the second simulation, with land tending to shift out of the raw milk and cattle&wool sectors. These results are very preliminary and require further investigation, including sensitivity analysis of the key parameters determining land use shifts.

[10] We initially assume a CET parameter of -1, reflecting the imperfectly mobile or sluggish movement of different land types between alternative activities.

Table 6 Changes in the price and quantity of land for each land-using sector to 2010, standard GTAP model and database (%)

	Market price of land	Quantity of land used
Veg_Fruit	177.9	0.3
OtherCrops	221.8	16.1
RawMilk	151.4	-9.3
Cattle_Wool	198.3	7.6

6. Concluding Remarks and Future Directions

This work is at a preliminary stage and further modifications to the modelling of land use will be made in subsequent versions of this paper, including further research into how substitution of land between agriculture in general and forestry might best be modelled. Other future directions for this work include the following: update the New Zealand I-O tables in the GTAP database to reflect our new land valuations by sector; add additional farm input substitutions into the model; recognise environment-specific production functions so as to allow the I-O structure of dairy, sheep and beef production to change across some environments; and the land-environmental database may be useful in estimating how regional distribution of land uses might change with climate change. We will also undertake sensitivity analysis to see how robust our results are when key parameters and assumptions change.

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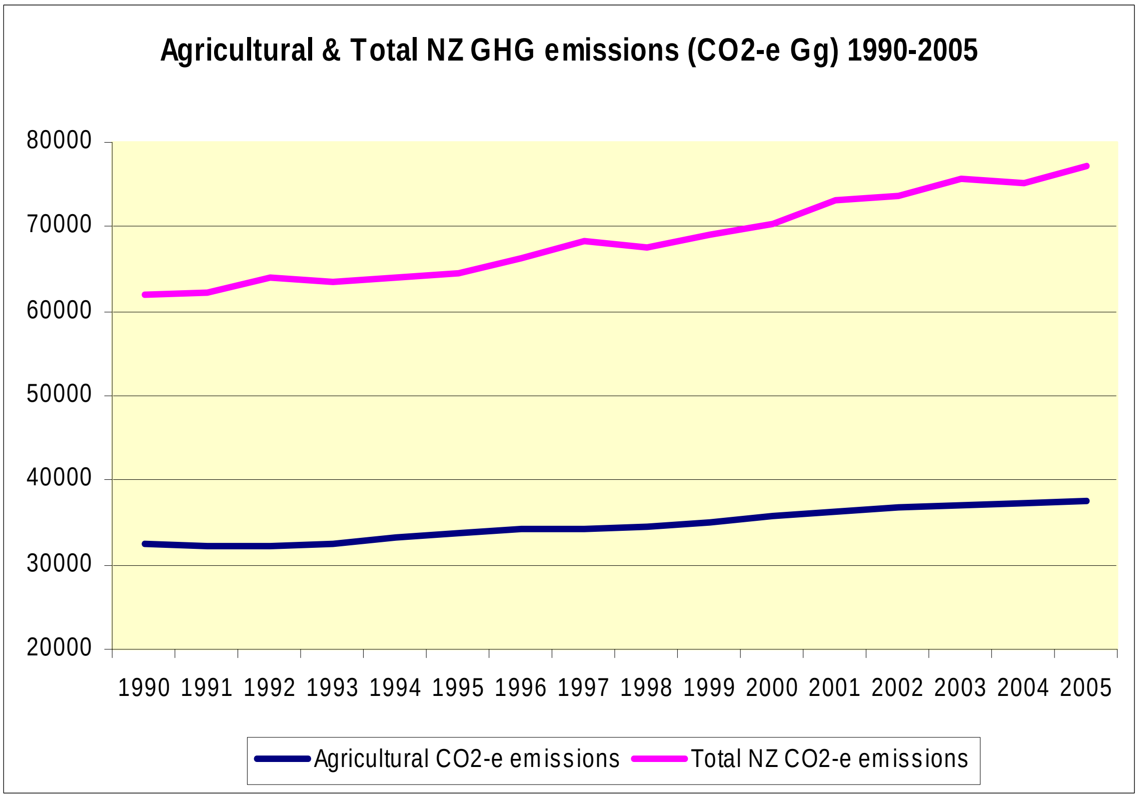


Figure 1

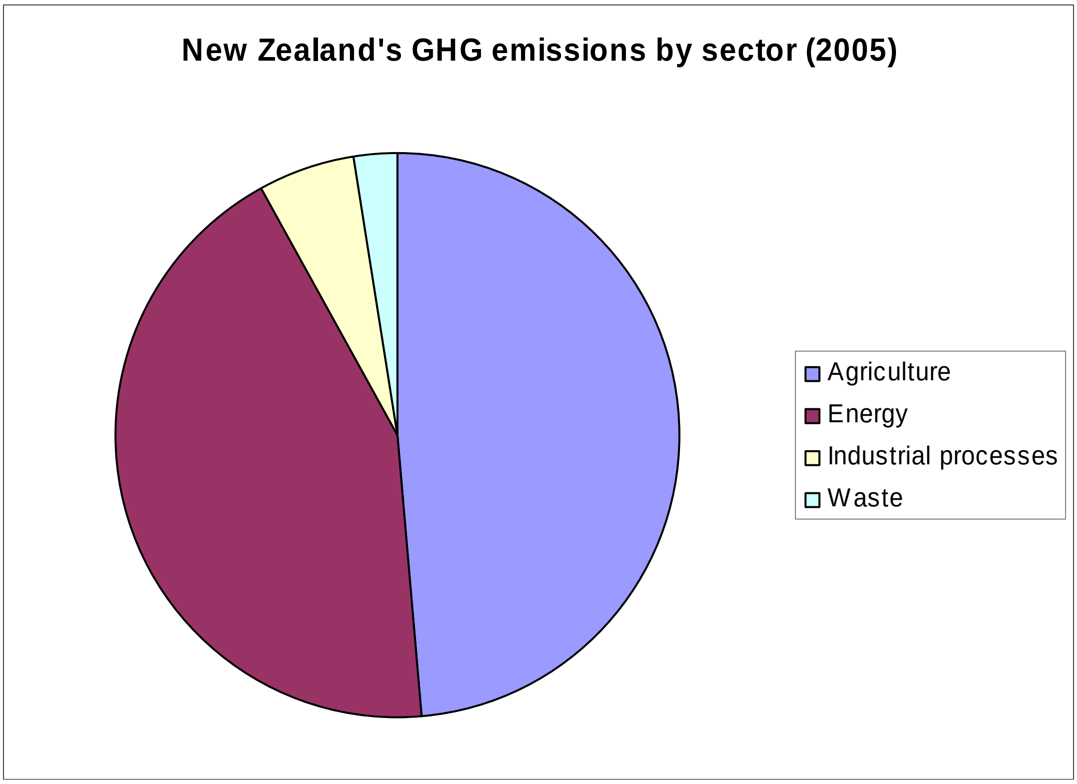
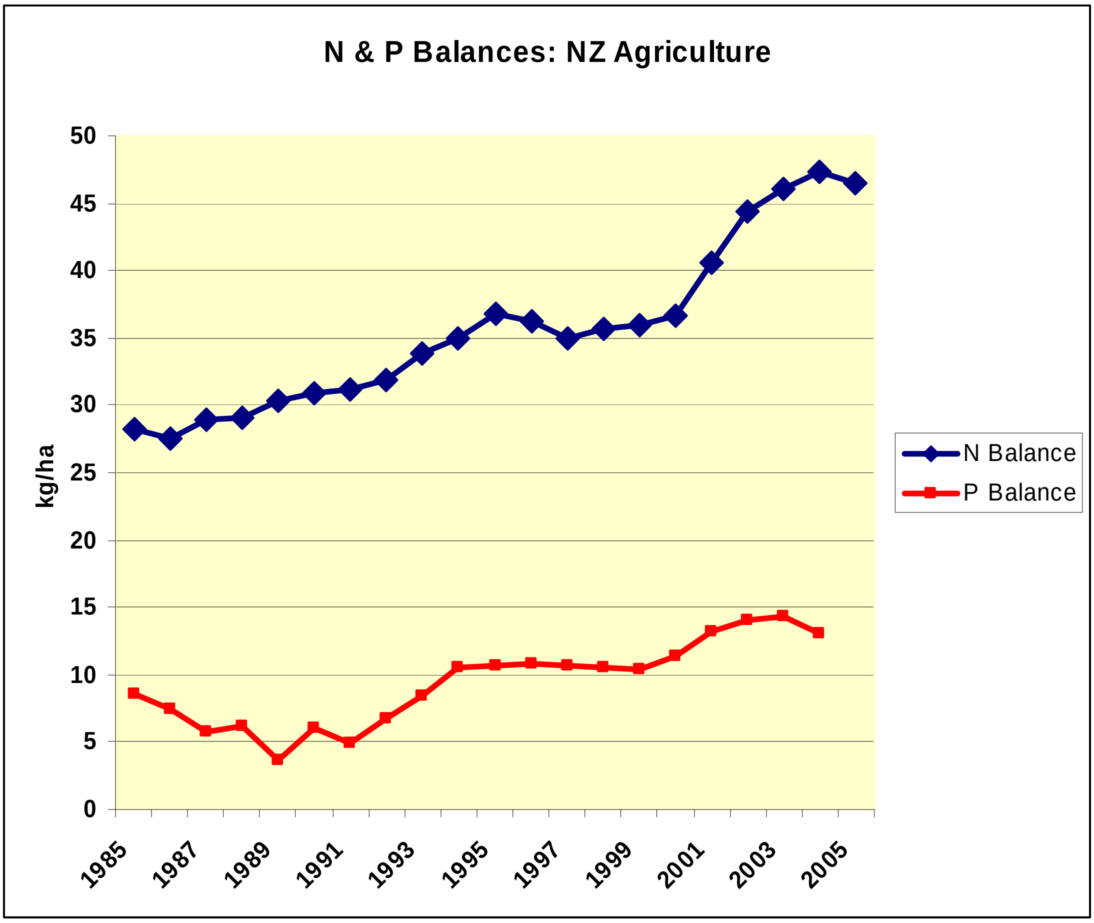
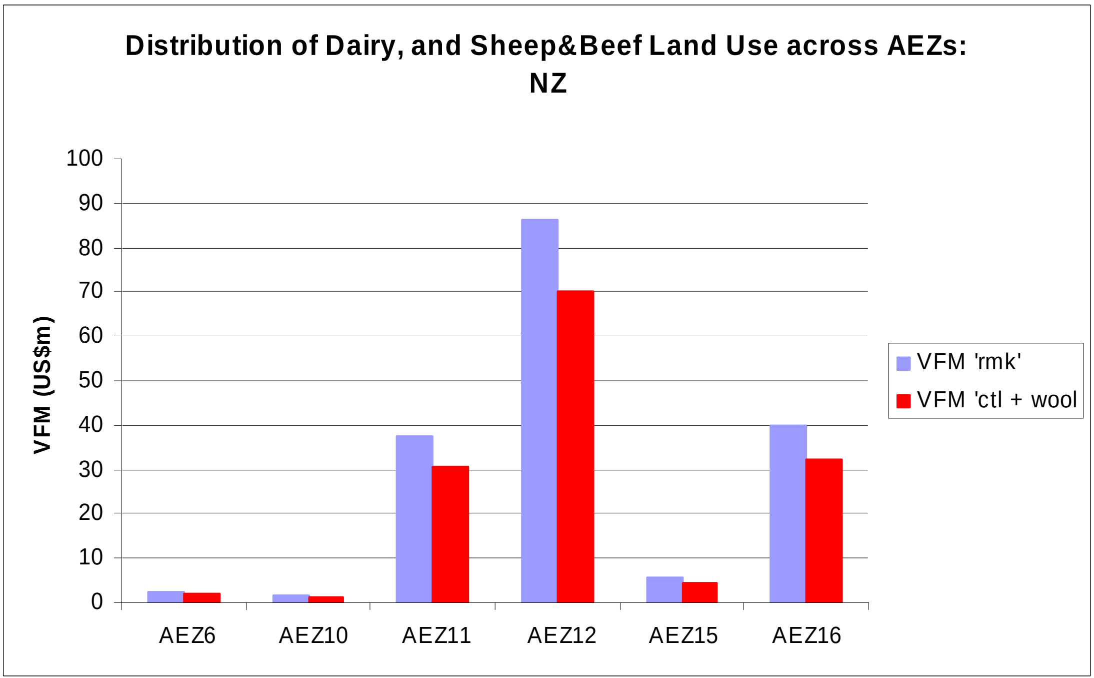


Figure 2



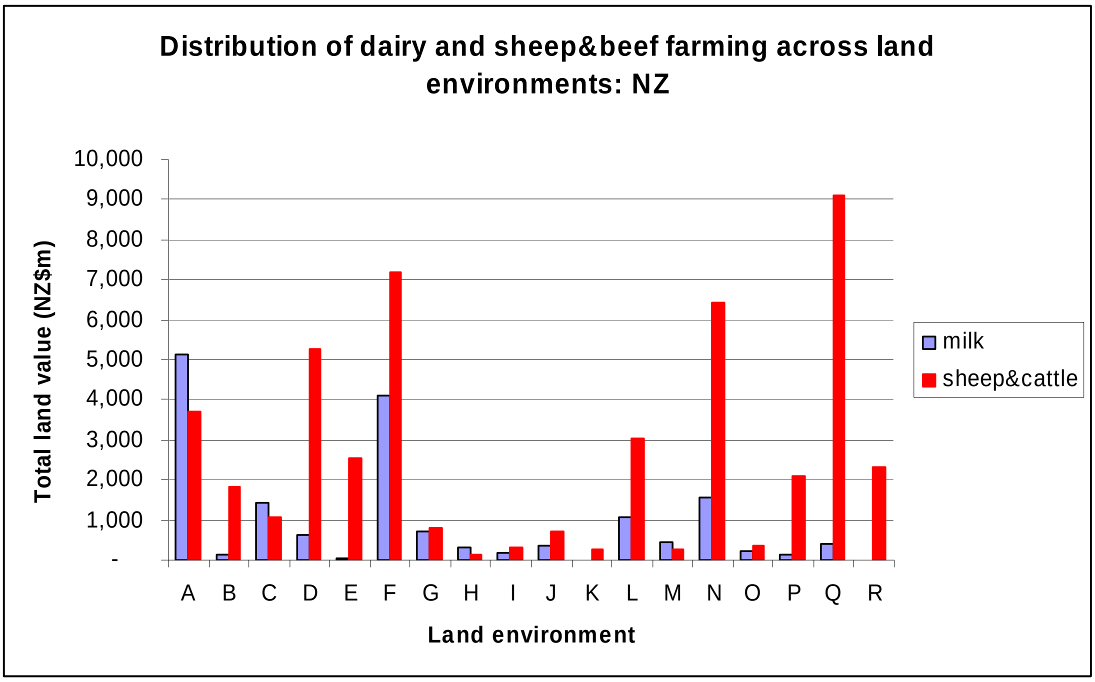
Source: Roger Parfitt, Landcare Research.

Figure 3.



Source: GTAP land use database, Release 2.0

Figure 4.



Sources: Landcare Research, MOTU

Figure 5

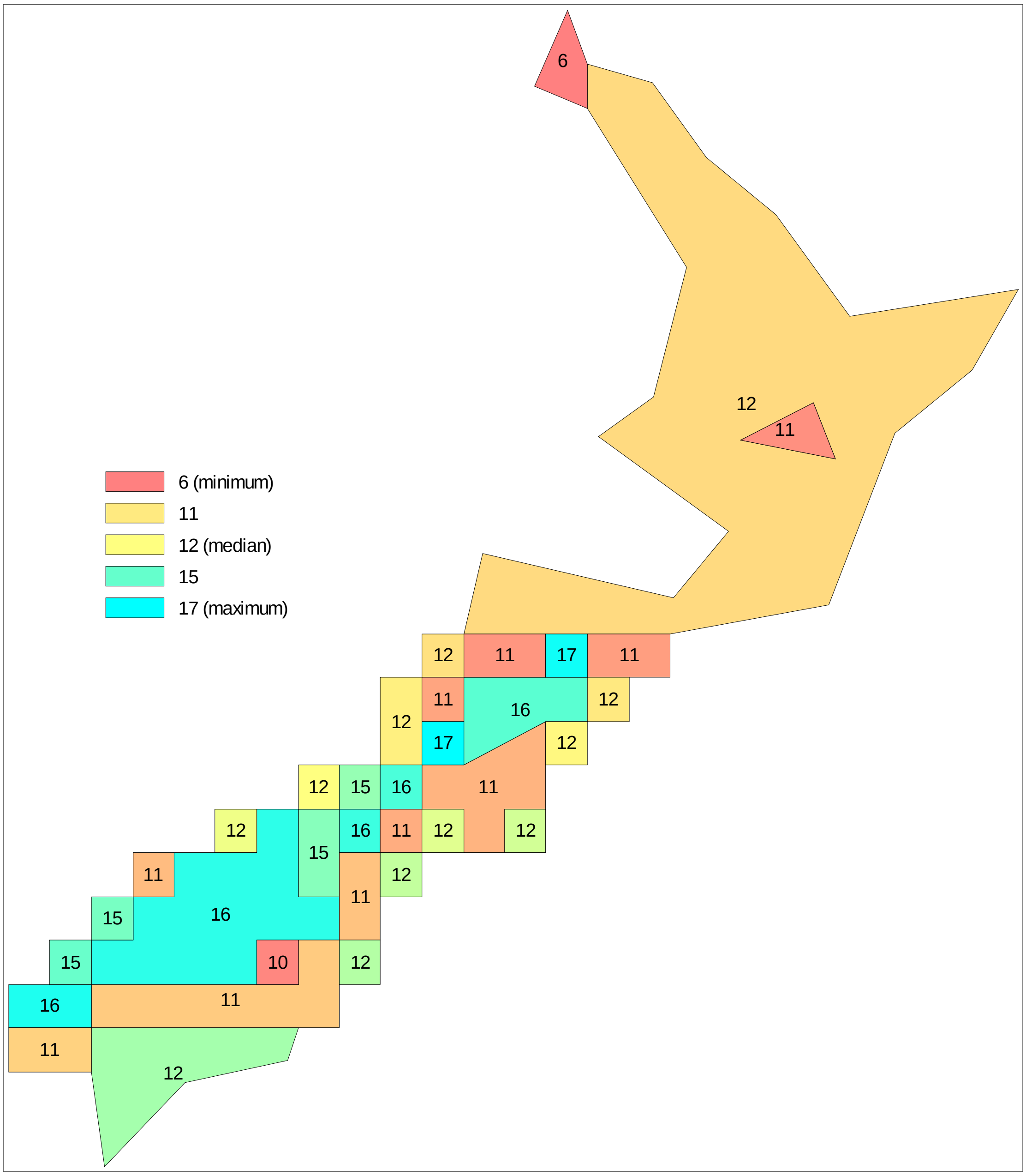


Figure 6. Definition of the GTAP AEZ: New Zealand

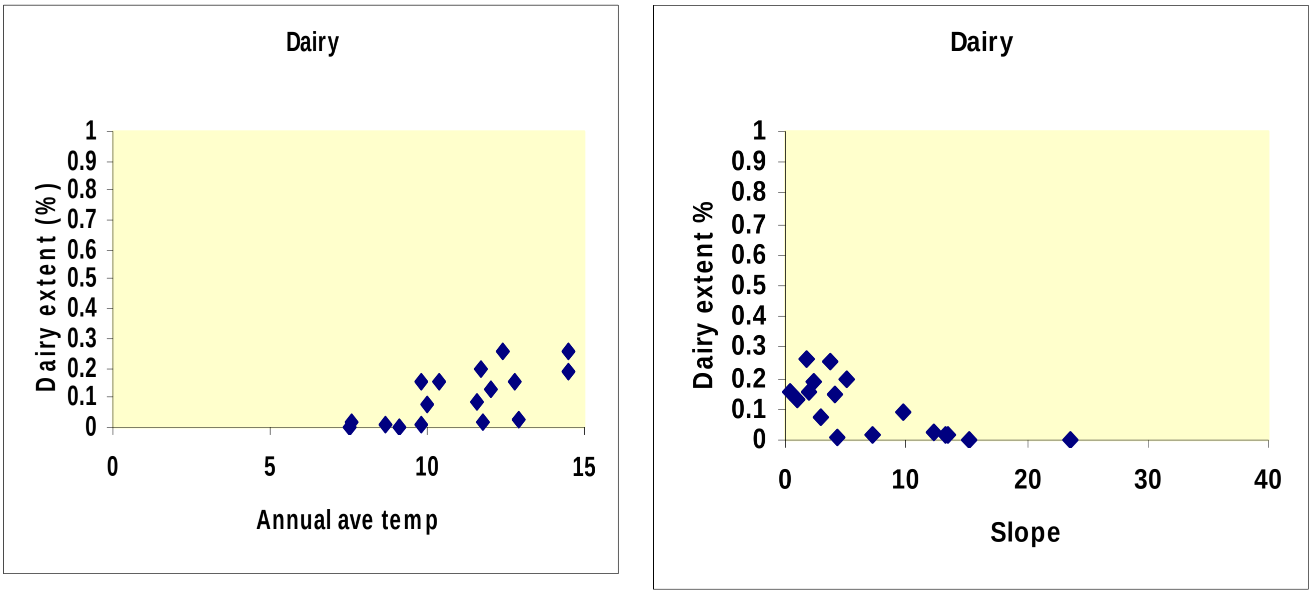


Figure 7. Relationships Between Annual Average Temperature and Slope and Extent of Dairy Pasture: Level I Environments

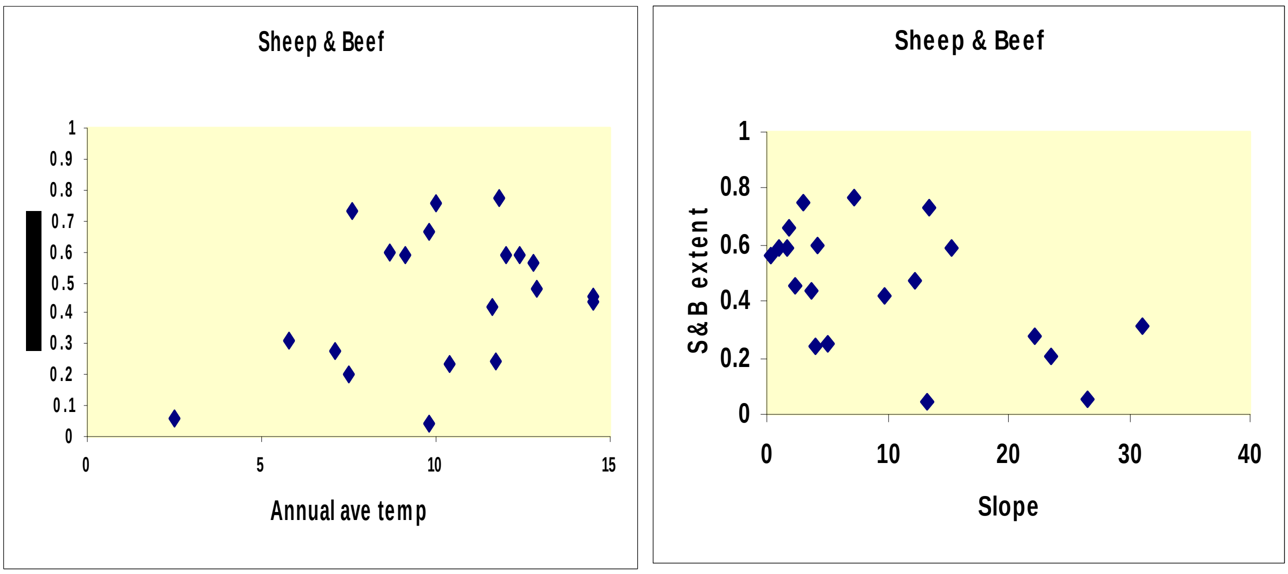


Figure 8. Relationships Between Annual Average Temperature and Slope and Extent of Sheep & Beef Cattle Pasture: Level I Environments

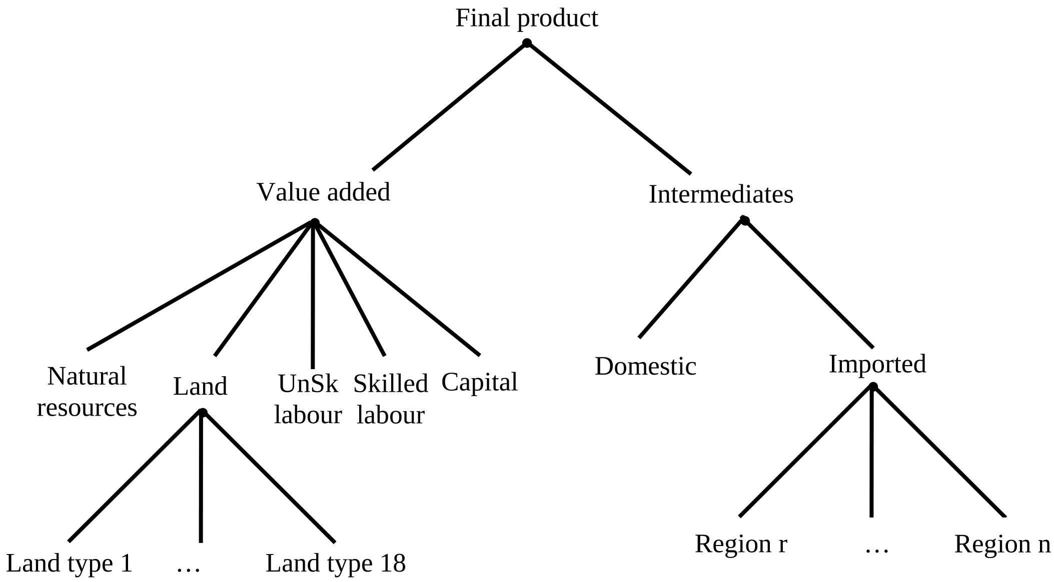


Figure 9 Production structure in the modified version of GTAP

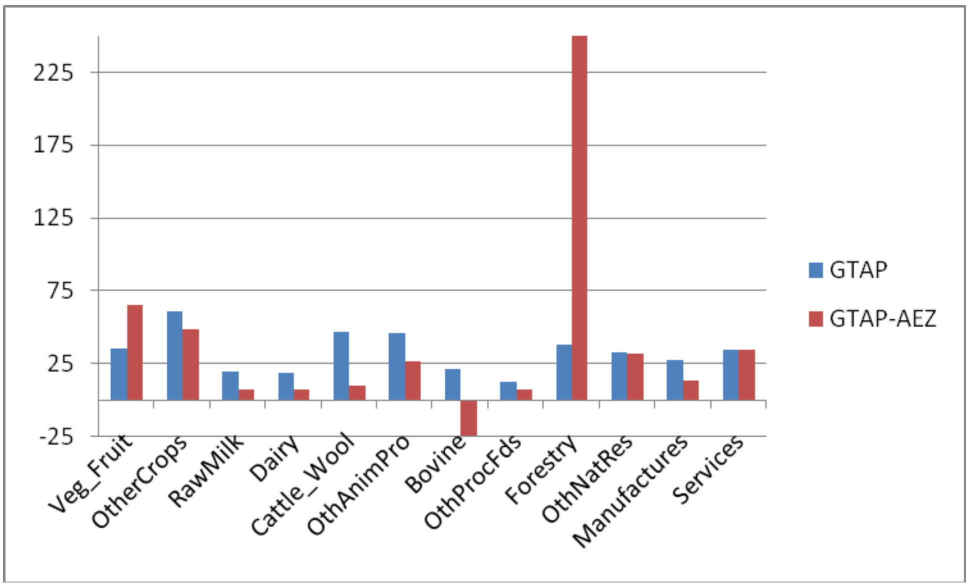


Figure 10 Projected changes in NZ sectoral output to 2010 (%)

Figure 11 Changes in the quantity of land used by each sector in New Zealand to 2010, modified GTAP model and database (%)

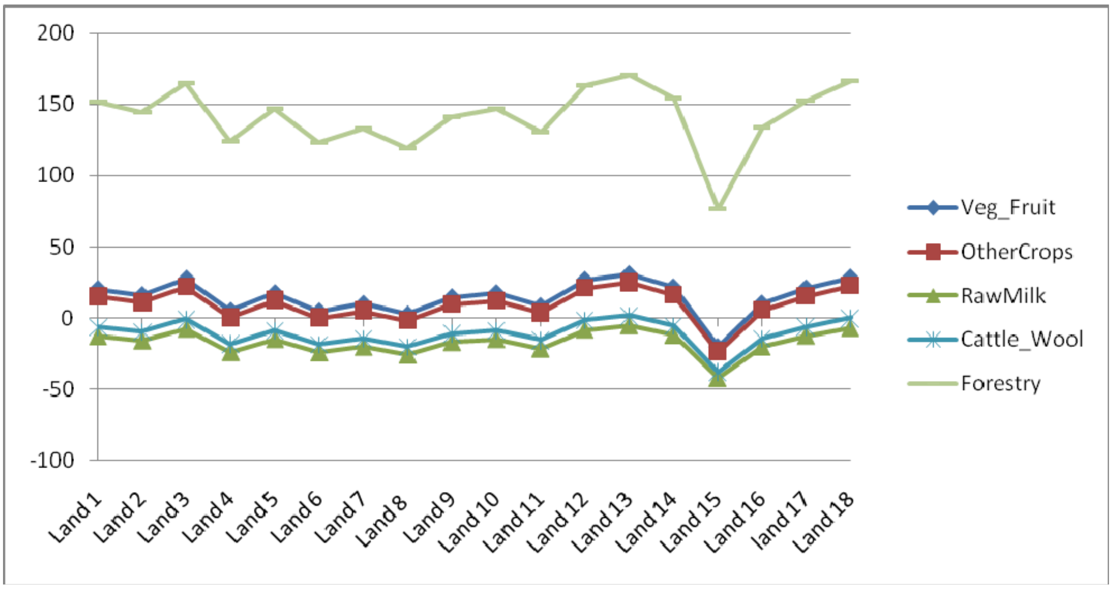
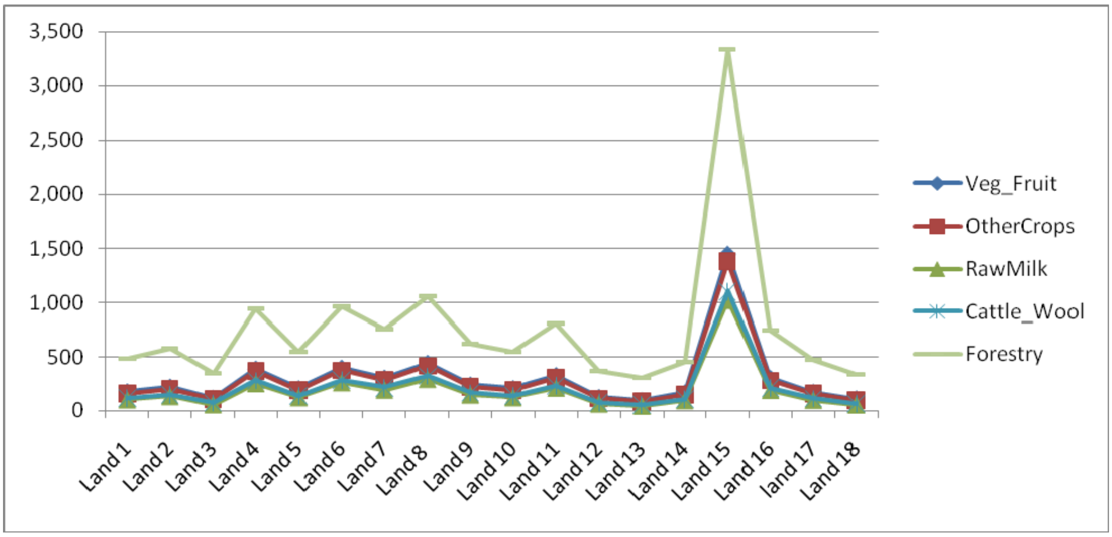


Figure 12 Changes in the price of land used by each sector in New Zealand to 2010, modified GTAP model and database (%)



Appendix Table 1: Relevant GTAP sectors:

GSC2 Number	Code	CPC Code	Description
2	wht	0111	Wheat and meslin
3	gro	0112	Maize (corn)
		0115	Barley
		0116	Rye, oats
		0119	Other cereals
4	v_f	012	Vegetables
		013	Fruit and nuts
5	osd	014	Oil seeds and oleaginous fruit
6	c_b	018	Plants used for sugar manufacturing
7	pfb	0192	Raw vegetable materials used in textiles
8	ocr	015	Live plants; cut flowers and flower buds; flower seeds and fruit seeds; vegetable seeds
		016	Beverage and spice crops
		017	Unmanufactured tobacco
		0191	Cereal straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets; swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets
		0193	Plants and parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes
		0194	Sugar beet seed and seeds of forage plants
		0199	Other raw vegetable materials
9	ctl	0211	Bovine cattle, sheep and goats, horses, asses, mules, and hinnies, live
		0299	Bovine semen
10	oap	0212	Swine, poultry and other animals, live
		0292	Eggs, in shell, fresh, preserved or cooked
		0293	Natural honey
		0294	Snails, live, fresh, chilled, frozen, dried, salted or in brine, except sea snails; frogs' legs, fresh, chilled or frozen
		0295	Edible products of animal origin n.e.c.
		0297	Hides, skins and furskins, raw
		0298	Insect waxes and spermaceti, whether or not refined or coloured
11	rmk	0291	Raw milk

CPC Central Product Classification - developed by the Statistical Office of the United Nations.
Source: Rose & Lee *forthcoming*

Appendix Table 2: CH_4 emissions (Gg) from New Zealand agriculture

Source of CH_4	enteric ferment.	manure mgt	1990 total	enteric ferment.	manure mgt	1995 total	enteric ferment.	manure mgt	2000 total	enteric ferment.	manure mgt	2005 total
Dairy cattle	237.72	10.38	248.1	292.36	12.18	304.54	353.6	14.74	368.34	405.24	17.27	422.51
Non-dairy cattle	235.48	2.87	238.35	271.42	3.29	274.71	256.64	3.12	259.76	255.03	3.11	258.14
Sheep	535.17	5.22	540.39	466.51	4.57	471.08	459.38	4.51	463.89	438.02	4.33	442.35
Goats	9.23	0.18	9.41	2.54	0.05	2.59	1.58	0.03	1.61	1.08	0.02	1.1
Horses	1.69	0.2	1.89	1.22	0.14	1.36	1.32	0.15	1.47	1.39	0.16	1.55
Swine	0.61	8.09	8.7	0.64	8.52	9.16	0.55	7.28	7.83	0.54	7.14	7.68
Poultry		1.01	1.01		1.51	1.51		2.23	2.23		2.84	2.84
Deer	18.5	0.17	18.67	24.66	0.22	24.88	36.51	0.33	36.84	37.74	0.34	38.08
Prescribed burning savannas			0.13			0.07			0.04			0.04
Field burning (cereals)			0.89			0.96			1.02			0.51

Source: New Zealand's GHG Inventory 1990-2005

Appendix Table 3: N_2O emissions (Gg) from New Zealand agriculture

Source of N_2O	**1990**	**1995**	**2000**	**2005**
Total from Agriculture	32.51	34.83	37.66	41.21
Manure management (all Dairy)	0.12	0.15	0.18	0.2
Direct soils emissions (total)	1.53	2.83	3.76	5.69
synthetic fertilisers	0.81	2.02	2.85	4.85
animal manure applied to soils (Dairy)	0.37	0.45	0.54	0.62
N-fixing crops	0.08	0.08	0.08	0.06
crop residue	0.14	0.15	0.16	0.03
cultivation of Histols	0.13	0.13	0.13	0.13
Pasture, range & paddock manure	22.12	22.54	23.69	24.39
Indirect emissions (total)	8.72	9.29	10.01	10.92
atmospheric deposition	4.61	4.85	5.19	5.57
nitrogen leaching & runoff	4.11	4.44	4.82	5.35
Field burning crop residues (cereal)	0.02	0.02	0.02	0.01

Source: New Zealand's GHG Inventory 1990-2005