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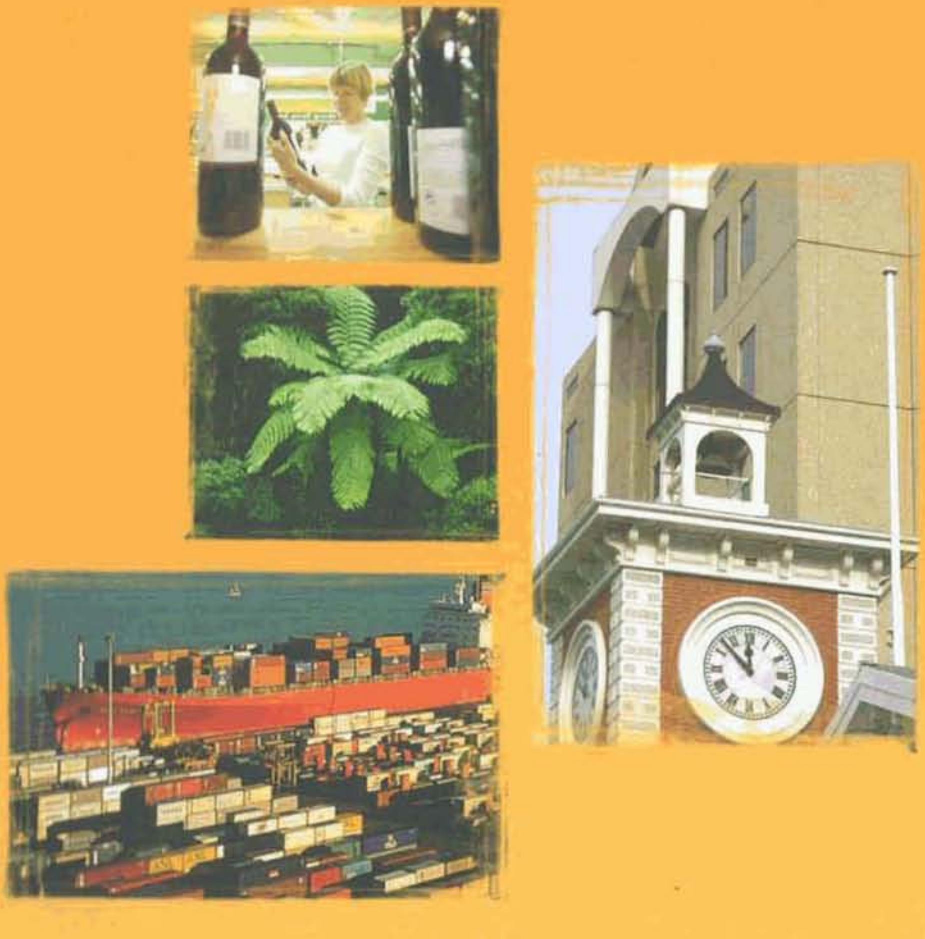

Lincoln Trade and Environment Model (LTEM): Linking Trade and Environment

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Summary

This paper has reviewed the modification of the LTEM to incorporate production systems and their environmental consequences. This means that the impact of changes in trade policy and/or changes in environmental policy on the environment and trade can be assessed.

Chapter 1
Introduction

Agricultural trade liberalisation and its potential environmental consequences are currently a politically emotive topic. Proponents of free trade argue that continued liberalisation will deliver significant economic efficiency, and therefore welfare gains, as global resource allocations shift to better reflect international comparative advantages. Moreover, since much environmental degradation may be attributed to ‘inappropriate’ agricultural activities induced by market distortions, liberalisation may cause production and associated resource use to revert to a more environmentally benign pattern. By contrast, opponents of free trade contend that heterogeneity of environmental characteristics both between and within trading nations means that environmental degradation may increase locally, if not globally. That is, since the assimilative capacity of the environment with respect to agriculture varies spatially, if production patterns relocate geographically then the net change in environmental damage will depend partly upon the relative environmental fragility of the old and new locations. Moreover, rigidities in production structures mean that it is by no means certain that reducing market distortions will necessarily lead to more environmentally or socially benign production patterns in locations currently experiencing degradation (Parikh *et al*., 1988; Abler and Shortle, 1992; Potter, 1998; Redclift *et al*., 1999).

Identifying the relationship between freer agricultural trade and environmental impacts across different trading nations is thus important. However, it is not a trivial task. Representing production and environmental heterogeneity requires careful consideration, not only of the trade flows arising from international market and policy interactions, but also the production structures and constraints underpinning domestic supplies and (localised) environmental susceptibility to changes in both the levels and mixes of outputs generated and inputs used.

Two significant agricultural production related issues in New Zealand (NZ) with regard to their potential effect on environmental degradation are groundwater nitrate contamination and greenhouse gas emissions. Nitrogen and feed concentrate use are considered the main factors affecting nitrate concentration in groundwater. Various combinations of these two factors determine the nitrate contamination in different dairy production systems. Both Nitrogen use and to a lesser extent, feed concentrate use, also affect GHG emissions from agriculture, as do the actual animal numbers.

Groundwater contamination from dairy farming is a serious problem, both in NZ and internationally. It is particularly sensitive to differing production systems, which are often affected by changes in trade policy.

There is a strong link between GHG production and climate change, and international policies, notably the Kyoto Protocol (1997), aim to reduce GHG emissions. NZ agriculture may be particularly affected by mitigation efforts, as 55 percent of NZ GHG emissions come from agriculture.

Under new agreements and mounting international pressure, governments around the world are indicating possible intentions to liberalise their trade policies. Following liberalisation of domestic borders, global production patterns are likely to shift. Countries such as New Zealand, relying heavily on exports of agricultural products, will be affected by these policy changes. Possible outcomes may be changing quantities of production, shifts in production systems and inputs, and as a consequence of the above, changes in environmental effects.

Based on this background, this paper attempts to model different dairy production systems explicitly and to quantify the linkages between agricultural production and groundwater nitrate contamination, as well as greenhouse gas emissions.

Chapter 2
A Brief Overview of the Lincoln Trade and Environment Model (LTEM)

The LTEM is an agricultural multi-country, multi-commodity model which uses a partial equilibrium (PE) framework to quantify and analyse the price, supply, demand and net trade effects of various domestic agricultural and border policy changes. The countries and commodities included in the LTEM are presented in Appendix Table 1 and general characteristics of the framework are given in Table 1 below. The commodities included in the model are treated as homogenous with respect to the country of origin and destination and to physical characteristics of the product. Importers and exporters are assumed to be indifferent about their trading partners. Therefore commodities are perfect substitutes in consumption in international markets. Based on this, the LTEM is a non-spatial model which emphasizes the net trade of commodities in each region.

Table 1
General Characteristics of the LTEM

Model	LTEM
Modelling Approach	Partial equilibrium
Temporal Properties	Comparative static and can also provide short term dynamics (via sequential simulation)
Solution Type	Non-spatial, net trade
Solution Algorithm	Newton's global algorithm
Parameters	Synthetic
Commodity Coverage	19
Country Coverage	18
Behavioural Equations (per commodity, country)	Domestic supply food Domestic demand* feed Stocks processing Producer price Consumer price Trade price
Economic Identity	Net trade

*Type of demand is dependent on the type of product.

The interdependencies between primary and processed products and/or between substitutes are reflected by cross-price elasticities. The policy parameters and/or variables and incorporation of these into the LTEM are explained in Cagatay and Saunders (2003). In general there are six behavioural equations and one economic identity for each commodity under each country in the LTEM framework[1]. Basically, the model works by simulating the commodity based world market clearing price on the domestic quantities and prices, which may or may not be under the effect of policy changes, in each country. Excess domestic supply or demand in each country spills over onto the world market to determine world prices. The world market-clearing price is determined at the level that equilibrates the total excess demand and supply of each commodity in the world market, using a non-linear optimization algorithm.

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[1] More technical information can be found in Cagatay and Saunders (2003).

In linking trade and the environment in various contexts, the LTEM is preferred to an economy-wide general equilibrium (GE) framework, for three main reasons. First of all, the dairy sector behavioural functions are explicitly modelled in the LTEM in order to observe the impact of policy changes on specific dairy products rather than on raw milk only. Although a PE framework uses a “standard approach” to model international trade, explicit modelling of the dairy sector at a disaggregated level is one of the strengths of the LTEM. Secondly, the level of commodity disaggregation that the framework allows makes it possible to perform product and country based policy analysis. At the same time, with this PE framework the problem of data and parameter availability or calibration problems which arise as one of the main problems at this level of disaggregation in GE models is also avoided. Lastly, the differences among raw milk physical production systems in the main dairy markets such as Australia, EU, New Zealand and USA are incorporated into the LTEM by separating the total physical production into three regions and by explicit modelling of the supply response in these regions.

Chapter 3
Linking Trade and Environment: Groundwater Nitrate Contamination

Dairy farming may cause various forms of environmental degradation including a significant contribution to nitrate concentrations in groundwater, both directly, through nitrogenous fertiliser applications on grassland and indirectly, through the nitrogen content of grass and other feeds excreted in manure and urine (Rae, 1999). Different dairy production systems generate different levels of nitrate emissions and different environmental conditions display different capacities to assimilate these (Cameron *et al*., 1998). Since groundwater quality is a policy issue in several countries, there is interest not only in the distribution of economic impacts following trade liberalisation (e.g. output gains and losses) but also in the distribution of nitrate pollution between and within countries.

The dairy sector is currently subject to highly protectionist policies. The policies are complex and include internal production quotas (in the EU and Canada); prohibitive tariffs (in the EU and elsewhere); preferential access under bilateral agreements (EU, Canada, USA) and direct producer subsidies. Consequently, the location of raw milk production and the trade in processed dairy products are widely regarded as likely to change following liberalisation (Tyres and Anderson, 1986). Therefore, nitrate concentrations in groundwater are also likely to change, based on the change in location of raw milk production.

Based on these considerations, the LTEM was extended to quantify the linkages between the dairy sector and groundwater nitrate contamination by modifying the main model structure to include an environmental sub-module/environmental damage function[2].

The LTEM was modified and extended in two directions. First, in order to reflect the differences among raw milk physical production systems in terms of the differences in nitrogen fertilizer and feed concentrates use, the countries Australia, EU, New Zealand and USA were separated into three regions and supply responses in these regions were modelled explicitly. Second, in order to reflect the effect of different production systems on the groundwater quality, an environmental damage function was introduced, measuring groundwater nitrate contamination based on the nitrogen fertilizer applied and feed concentrates used. The link between the first and second extensions was made by endogenizing the nitrogen fertilizer market and intermediate demand for feed products. Table 2 summarizes the environmental and policy focus of this version of the LTEM. The behavioural equations and parameters of the dairy sector and quantification of dairy market policy instruments are introduced in the next section[3]. The relationship measuring groundwater quality and the linkage between the dairy sector and groundwater quality are presented in section 3.2.

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[2] See Ervin (1999) for definition and details of environmental damage functions.

[3] The functional and variable specifications of dairy sector equations for Australia, EU, New Zealand and USA are the same unless otherwise stated.

Table 2
Environmental and Policy Focus of the LTEM

Environmental Focus:	-nitrogen fertilizer usage -feed concentrate usage -groundwater nitrate contamination
Policy Focus:	-domestic agricultural output and input related policies -border measures
Approach Used to Quantify Environment & Trade Link:	-endogenized nitrogen usage through separate fertilizer market linked to agricultural goods -endogenized feed concentrate demand -endogenized groundwater nitrate contamination based on nitrogen and feed concentrate usage

3.1 Behavioural Specifics of the Dairy Sector and Policy Incorporation

Domestic Supply. The dairy sector is modelled as five commodities; raw milk is defined as the farm gate product and is then allocated to the liquid milk, butter, cheese, whole milk powder or skim milk powder markets depending upon their relative prices subject to physical constraints. The domestic supply (*qs*) function for raw milk in region *a* (qsa_i) is shown in equation 1. The total domestic raw milk supply is equal to the sum of supply in regions *a*, *b* and *c*, equation 2. In equation 1, the subscript $_i$ stands for raw milk and $_j$ is used to show substitute commodities such as beef and veal, and $_k$ shows feed products such as wheat, coarse grain and oil meals. The variables *pp* and *pc* represent the producer and consumer price level respectively. Therefore, domestic supply of raw milk is specified as a function of producer price for raw milk, beef, and consumer prices of feed inputs. The own-price elasticity of supply is shown by the exponent α_{ii} and is positive. The cross-price supply elasticity with respect to beef price ($^{\alpha ij}$) and feed products ($^{\alpha ik}$) are negative since raw milk and beef are assumed to be gross substitutes and feed products are the production inputs.

The domestic supply of dairy products (liquid milk, butter, cheese, skim and whole milk powder) is determined based on the raw milk production (qs_i) which reflects the physical constraint on processed dairy production, and producer prices of various dairy products. For example, in equation 3, domestic supply of liquid milk (qs_l) is specified as a function of qs_i, producer price of liquid milk (pp_l) and producer prices of other dairy products (pp_h). The exponentials β_{li}, β_{ll} and β_{lh} show the supply elasticity of liquid milk with respect to raw milk production, producer price of liquid milk and producer prices of other dairy products respectively. The supply side parameter matrix of the dairy sector is provided in Cagatay and Saunders (2003).

$$qsa_i = \alpha_{i0} pp_i^{\alpha_{ii}} \prod_j \prod_k pp_j^{\alpha_{ij}} pc_k^{\alpha_{ik}} \; ; \qquad \alpha_{ii} > 0 \, , \; \alpha_{ij} < 0 \, , \; \alpha_{ik} < 0 \qquad 1$$

$$qs_i = qsa_i + qsb_i + qsc_i \qquad 2$$

$$qs_l = \beta_{l0} qs_i^{\beta_{li}} pp_l^{\beta_{ll}} \prod_h pp_h^{\beta_{lh}} \; ; \qquad \beta_{li} > 0 \, , \; \beta_{ll} > 0 \, , \; \beta_{lh} < 0 \qquad 3$$

$_h$: *butter, cheese, skim and whole milk powder*
$_i$: *raw milk*
$_j$: *beef and veal*
$_k$: *feed crops*
$_l$: *liquid milk*

In order to analyse the effects of raw milk production quota in the EU, the regional supply functions were respecified to include an exogenously determined policy variable that constrains the total domestic production at the maximum quota level, equation 4. The production quota, pq_{mi}, becomes a decision variable in the solution algorithm, which becomes binding if the calculated equilibrium quantity in the mathematical solution procedure is greater than or equal to this quota amount. A mathematical MIN function integrated to the supply equation is used for this purpose. With this method the production quota amount becomes binding if the calculated equilibrium qsa_i is greater than the pq_i and the model is pushed to choose pq_i as the solution value. If the calculated equilibrium qsa_i is less than the pq_i then the model continues with the calculated qsa_i as the solution amount[4].

$$qsa_i = MIN((\alpha_{i0} shf_{qs}{}^{1} pp_i{}^{\alpha_{ii}} \prod_j \prod_k pp_j{}^{\alpha_{ij}} pc_k{}^{\alpha_{ik}}), pq_i) \qquad 4$$

Domestic Demand. As the produced raw milk is consumed and exhausted in various forms of dairy products the domestic demand for raw milk is not modelled in the LTEM, instead the demand for dairy products are modelled endogenously at country level. The aggregate domestic demand relationship for dairy products is given by equation 5[5]. In this equation domestic demand for liquid milk, qd_l is defined as a function of consumer prices of the own (pc_l), substitute and complementary commodities (pc_h), per capita income *(pinc)* and population growth rate *(pop).* The cross-price demand elasticities (δ_{lh}) with respect to prices of other raw milk products are positive as these products are assumed to be gross substitutes with liquid milk. The elasticity of demand with respect to income (δ_{l2}) and population growth (δ_{l3}) is also expected to be positive. The exponents reflect the related elasticities, and the demand side parameter matrix of the dairy sector is provided in Cagatay and Saunders (2003).

$$qd_l = \delta_{l0} shf_{qd}{}^{1} pc_l{}^{\delta_{ll}} pinc^{\delta_{l2}} pop^{\delta_{l3}} \prod_h pc_h{}^{\delta_{lh}} ; \quad \delta_{l1} < 0 ,\ \delta_{l2} > 0 ,\ \delta_{l3} > 0 ,\ \delta_{lh} > 0 \qquad 5$$

Stocks and Net Trade. The main determinant of the stock demand is the transaction motive, which responds to the quantity of production or consumption, rather than speculative motives (equation 6). In the dairy market it is assumed that raw milk is stocked in the form of butter, cheese and skim milk powder (in USA stock for whole milk powder is also allowed). The net trade function for a commodity and country is defined as an economic identity which accounts for the difference between domestic supply and the sum of various demand amounts and stocks. Since it is assumed that all raw milk produced is utilized in the form of processed products, raw milk is not traded (equations 7 and 8).

$$qe_h = \varphi_{h0} qs_h{}^{\varphi_{hh}} ; \qquad \varphi_{hh} > 0 \qquad 6$$

$$qt_l = qs_l - qd_l \qquad 7$$

$$qt_h = qs_h - qd_h - \Delta qe_h \qquad 8$$

Prices. The domestic producer (*pp*) and consumer prices (*pc*) in the LTEM are determined by the trade price (*pt*) of the related commodity and country, border policies (per unit import tariffs/taxes and export subsidies/taxes) that affect domestic prices (*tp* and *tc*) and transportation costs (*tc*), which are assumed to be zero. Equations 9 and 10 present this price transmission mechanism for liquid milk and other dairy products. The trade price of a commodity in a country is determined by the world market price of that commodity, and its

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[4] The variable shf_{qs} and shf_{qd} in equations 4 and 5 proxy the supply and demand side shift factors.

[5] The demand for other dairy products (qd_h) other than liquid milk is specified by using the same functional form and the same behavioral relationships that are in qd_l.

effect on the domestic market is reflected through the price transmission elasticity[6]. Various domestic producer and consumer support and subsidy measures in the dairy market are incorporated in the price transmission mechanism in the form of ad-valorem distortions such as border measures, which form a price wedge between domestic and world prices. These measures include direct payments ($sd_{h,l}$), input subsidies ($si_{h,l}$), general services expenditures ($sg_{h,l}$) and other market subsidy payments ($sm_{h,l}$) to the producers and a consumer market subsidy ($cm_{h,l}$).

$$pp_{h,i} = pt_{h,i} + tp_{h,i} + tc + sd_i + si_i + sg_i + sm_i \tag{9}$$

$$pc_{h,i} = pt_{h,i} + tc_{h,i} + tc + cm_{h,i} \tag{10}$$

The intervention price in the EU dairy market is incorporated in the LTEM in the solution procedure through the mathematical MAX function. In the new producer price function, which is respecified in equation 11, the intervention price, $mp_{h,l}$, becomes a decision variable and becomes binding if the calculated equilibrium $pp_{h,l}$ is less than the $mp_{h,l}$. When $pp_{h,l}$ is less than $mp_{h,l}$ the model is pushed to choose $mp_{h,l}$ as the solution value. If the calculated equilibrium $pp_{h,l}$ is higher than the $mp_{h,l}$ then the model continues with the calculated $pp_{h,l}$ as the solution price level.

$$pp_{h,i} = MAX((pt_{h,i} + tp_{h,i} + tc + sd_i + si_i + sg_i + sm_i), mp_{h,l}); \qquad tc=0 \tag{11}$$

Therefore, the model incorporates all measured subsidies as a price wedge and in the case of the EU, internal production quotas and intervention price policies are modelled explicitly.

3.2 Environmental Sub-Module

Model extensions. In order to incorporate the link between agricultural production, trade and groundwater nitrate concentration (GNC) into the LTEM, two extensions were made.

First, the major dairy producing trading blocs were each sub-divided into regions (defined as in Table 3) to better reflect internal heterogeneity with respect to dairy production systems and environmental conditions. These divisions were based on observed variation in, for example, yields, stocking rates and drainage characteristics (presented in Table 3) as well as the nitrogen fertilizer and feed concentrate use (given in Table 4). The divisions are incorporated into the LTEM through the regional domestic raw milk supply equations. Data on production systems were taken from a number of sources, including farm advisory recommendations, census and survey reports, and field trials.

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[6] The price transmission elasticity is assumed to be 1 for all dairy products in Australia, EU, New Zealand and the USA.

Table 3
Heterogeneity in the Dairy Production System among Regions

Region	**Production per cow (litres)**	**Average stocking rate (per ha)**	**Area (000ha)**	**Average Drainage (mm/yr)**
EU (15) :				
West EU	5310	2.4	3174.8	400
East EU	4680	1.8	6639.6	200
Other EU	4991	2.3	3302.2	300
Australia:				
Victoria	4715	1.0	1267.9	300
NSW	4972	0.5	504.0	300
Rest of Australia	4608	0.5	1046.0	200
USA:	7238			
California	8439	10.0	149.2	200
WI, MI, MN, PA, NY	7182	3.0	1251.2	500
Rest of USA	6770	2.7	1727.8	300
New Zealand:				
Auckland	3278	2.8	494.6	700
South Island	3874	2.6	274.8	350
Rest of NZ	3300	2.0	570.4	400

Secondly, an environmental damage function that measures (in physical units) the effect of different dairy production systems on groundwater nitrates was introduced. In principle, the economic value of damage arising from nitrate contamination, rather than the physical level of contamination, should be addressed. This would allow direct comparison of social costs and benefits associated with dairy production. However, in practice, consensus has yet to be achieved on how to measure such damage, and physical indicators remain the most commonly used measure for policy purposes (Moxey, 1999). Hence, for the purposes of this study, the environmental effect of dairy production was expressed in physical units as in equation 12 (Bidwell, 1999). Essentially, nitrogenous fertiliser (*Na/ha*) and the amount of concentrate feed (*ka*) used in each region (in the equation it is shown for region *a*) both contribute to nitrate emissions, but some of their nitrogen content is removed in milk (qsa_l). The effect of emissions on groundwater concentrations (*GNCa*) depends on the degree of dilution offered by annual drainage (Whitehead, 1995). Parameter values for this equation were obtained from relevant literature and discussions with scientists in the UK and New Zealand[7].

$$GNCa = \frac{(\chi_0 + \chi_1 Na + \chi_2 ka - \chi_3 qsa)}{W} \qquad 12$$

GNCa: average groundwater nitrate concentration in region a ($g/m^3/yr$)
Na: nitrogen use in region a (kg/ha/yr)
ka: feed grain (concentrate) use in region a (kg/ha/yr)
qsa_i: quantity of raw milk produced in region a (l/ha/yr)
W: annual average drainage per year (mm)

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[7] See Bidwell (1999) and Whitehead (1995) for the methodology, parameters and functional form; see Table 3 and 4 for the data and parameters; see Appendix Chart A1 and A2 for the derivation of this equation.

Table 4
Technical Parameters

Country	*Weights Used to Calculate Feed Concentrates Price* *Wheat*	*Coarse Grains*	*Oil Seeds*	*Oil Meals*
Australia	0.34	0.57		0.09
EU (15)	0.24	0.50	0.01	0.25
New Zealand	0.05	0.84	0.01	0.10
USA	0.04	0.80	0.02	0.14
	Weights Used to Calculate Feed Concentrates Usage [1] *Wheat*	*Coarse Grains*	*Oil Seeds*	*Oil Meals*
Australia	0.32	0.31	0.18	0.18
EU (15)	0.26	0.25	0.14	0.14
New Zealand	0.62	0.66	0.59	0.59
USA	0.19	0.19	0.10	0.10
	Weights Used to Calculate Groundwater Nitrate Concetration from Nitrogen and Feed Concentrates Usage and from Raw Milk Production *Nitrogen Fertilizer Usage*	*Feed Concentrates Usage*	*Raw Milk Production*	
Australia				
Victoria	0.028	0.0018	0.00065	
New South Wales	0.028	0.0018	0.00065	
Rest of Australia	0.028	0.0018	0.00065	
EU (15)				
West EU	0.021	0.00144	0.00052	
East EU	0.021	0.00144	0.00052	
Rest of the EU	0.027	0.0018	0.00065	
New Zealand				
Auckland	0.028	0.0018	0.00065	
South of New Zealand	0.028	0.0018	0.00065	
Rest of New Zealand	0.028	0.0018	0.00065	
USA				
California	0.028	0.0018	0.00065	
WI, MI, MN, PA, NY	0.028	0.0018	0.00065	
Rest of USA	0.028	0.0018	0.00065	

[1]: Given as percentage of total feed demand for each feed product in each country.

Whilst the quantity of concentrate feed (ka) used in dairy production in each region was generated endogenously by the existing LTEM structure[8], use of nitrogenous fertiliser (N/ha) in different regions was endogenized in the LTEM by estimating the conditional input demand function for nitrogen fertilizer, equation 13. In this equation, the demand for nitrogen use per hectare, for example in region a (Na), was specified as a function of relative prices of the feed concentrates (pc_k) to the nitrogen (pc_N), and the quantity of raw milk supplied per hectare in region a (qsa_i)[9]. The variable pc_k was calculated as a weighted average of consumer prices of wheat, coarse grains, oil seeds and oil meals. The weights were found by calculating the percentage share of each feed product in total feed use (see Table 4 for the weights). The variable qsa_i was included as a shift factor which proxies the technological changes in the production process and/or irregular effects that affect the amount of raw milk supplied (Burrell, 1989). The coefficients β_{i1} and β_{i2} show the elasticity of fertilizer demand in region a

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[8] That is, since grains are a traded agricultural output included in the basic model, feed use for dairy production is specified in their demand function.

[9] Since raw milk is totally used for producing other dairy products, the nitrogen demand function is specified for raw milk only and not for the other dairy products.

with respect to a change in raw milk supply in region *a* and relative prices (presented in Table 5). The β_{i2} is expected to be positive and an increase in pc_k is expected to result in an increase in nitrogen demand as nitrogen fertilizer and feed concentrates are expected to be gross substitutes.

$$Na = \beta_0 \left(qsa_i\right)^{\beta_{i1}} \left(\frac{pc_k}{pc_N}\right)^{\beta_{i2}} ; \quad \beta_{i1} > 0 , \ \beta_{i2} > 0 \qquad 13$$

Table 5
Input Demand Parameters: Relative Price Elasticity

Country *Input*	*Relative Consumer Price* *Feed Concentrates / Nitrogen*
Nitrogen Fertilizer	
Australia	
Victoria	0.32
New South Wales	0.28
Rest of Australia	0.23
EU (15)	
West EU	0.70
East EU	0.31
Rest of the EU	0.66
New Zealand	
Auckland	0.91
South of New Zealand	0.54
Rest of New Zealand	0.73
USA	
California	0.47
WI, MI, MN, PA, NY	0.41
Rest of USA	0.52

Chapter 4
Linking Trade and Environment: Greenhouse Gas Emissions

Methane (CH_4) and Nitrous Oxide (N_2O) are the two main GHGs produced from agriculture. With the relatively large ruminant animal population in New Zealand, methane production is particularly significant. Because New Zealand has a comparatively small industrial base, that uses predominantly renewable sources for electricity generation, and has a relatively large agricultural sector, the greenhouse gas emissions have an unusually high methane to carbon dioxide ratio among developed countries (Lassey *et al*., 1992, MAF, 2001).

Methane from livestock is produced from two possible sources: the digestion process ("enteric fermentation") and the decomposition of ruminant fecal waste ("manure management") (Lassey et al., 1992). The amount of methane produced depends on the amount of feed intake as well as the type and quality of the feed.

Nitrous oxide (N_2O), although emitted in much smaller quantities than either CH_4 or $CO_{2,}$ is important because of its relative impact in terms of global warming potential[10]. There are a number of sources of this gas arising from agricultural production. The first source is defined as animal waste management systems (AWMS). Six alternative regimes for treating animal manure, (anaerobic lagoon, liquid systems, daily spread, solid storage and drylot, pasture range and paddock, used fuel, other system) are identified in the Intergovernmental Panel on Climate Change (IPCC) guidelines. Emissions from agricultural soils make up a further source of N_2O, which are further divided into three sections - (1) direct emission of N_2O from agricultural soils (2) direct soil emissions of N_2O from animal production, and (3) indirect emissions of N_2O from nitrogen used in agriculture (IPCC Guidelines, 1996). Direct emissions from agricultural soils result from synthetic fertiliser application, the use of animal waste as fertiliser, nitrogen-fixing crops, and crop residues. Direct soil emissions of N_2O from animal production refers to the manure deposited by grazing livestock on pasture range and paddock and left there to decompose. This is the major management regime for animal waste in New Zealand. Indirect emissions result from the atmospheric decomposition of ammonia and nitrogen oxides, and leaching.

Animal numbers and nitrogen use are essentially the main factors behind agricultural GHG production in New Zealand. Various combinations of these 2 factors in different meat and dairy production systems determine the level of GHG emissions from agriculture.

This section examines in more detail the link between agriculture, in particular the livestock sector, and GHG emissions. More specifically, the paper attempts to quantify the relationship between meat production (the focus here is on beef production but the same principles apply to sheepmeat production), different dairy production systems and GHG emissions by incorporating an environmental sub-model into the LTEM. The environmental and policy focus of this version of the LTEM is given in Table 6.

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[10] Methane has a global warming potential (GWP) of 21; Nitrous Oxide has a GWP of 310.

Table 6
Environmental and Policy Focus of the LTEM

Environmental Focus:	-nitrous oxide emissions -methane emissions
Policy Focus:	-domestic agricultural output and input related policies -border measures
Approach Used to Quantify Environment & Trade Link:	-endogenized nitrogen usage through separate fertilizer market linked to agricultural goods -endogenized livestock numbers -endogenized greenhouse gas emissions based on number of animals and nitrogen usage

4.1 Behavioural Specifics of the Dairy and Meat Sector

Domestic Supply. In equation 14 the domestic supply function for beef and veal (qs_b) is presented. Here, subscript $_b$ stands for beef and veal, $_j$ stands for substitute commodities such as sheepmeat, pigmeat, raw milk and/or wool and subscript $_k$ shows feed products such as wheat, coarse grain and oil meals. The variables *pp* and *pc* represent the producer and consumer price level respectively. Therefore, domestic supply of beef and veal was specified as a function of own producer price, producer prices of substitute and complementary products and consumer prices of feed inputs at levels of the variables. The own-price elasticity of supply is shown by the superscript $^{\theta bb}$ and is positive. The cross-price supply elasticity with respect to sheepmeat and other substitutes $^{(\theta bj)}$ and feed products $^{(\theta bk)}$ are negative as beef and sheepmeat are assumed to be gross substitutes and feed products are inputs used for production.

The major dairy producing trading blocs (Australia, EU, New Zealand and USA) were each sub-divided into regions[11] to better reflect internal heterogeneity with respect to dairy production systems and environmental conditions, and to simulate their impact on the nitrous oxide and methane emissions. The domestic supply of the dairy sector was previously presented in equations 1-3 and here these are rewritten in equations 15-17.

$$qs_b = \theta_{b0}\, pp_b^{\theta_{bb}} \prod_j \prod_k pp_j^{\theta_{bj}}\, pc_k^{\theta_{bk}} \; ; \qquad \theta_{bb} > 0,\ \theta_{bj} < 0, \theta_{bk} < 0 \qquad 14$$

$$qsa_i = \alpha_{i0}\, pp_i^{\alpha_{ii}} \prod_j \prod_k pp_j^{\alpha_{ij}}\, pc_k^{\alpha_{ik}} \; ; \qquad \alpha_{ii} > 0,\ \alpha_{ij} < 0,\ \alpha_{ik} < 0 \qquad 15$$

$$qs_i = qsa_i + qsb_i + qsc_i \qquad 16$$

$$qs_l = \beta_{l0}\, qs_i^{\beta_{li}}\, pp_l^{\beta_{ll}} \prod_h pp_h^{\beta_{lh}} \; ; \qquad \beta_{li} > 0,\ \beta_{ll} > 0,\ \beta_{lh} < 0 \qquad 17$$

Animal numbers are of critical importance in determining the CH_4 and N_2O emissions for each country as well as for the supply of meat and dairy industries, as livestock are obviously the major input into their own production. In the LTEM animal numbers in the meat and dairy industries were endogenized using Jarvis's (1974) livestock supply response model. In Jarvis, livestock are considered as both consumption (milk, meat and hides) and capital (productive assets) goods. The fixed supply of animals at any moment creates a trade-off between the amount supplied to consumers and the retention of cattle in the form of investment. Producers are expected to retain livestock as long as their capital value (in production) exceeds their

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[11] See section 3.1.

slaughter value. The cost of raising animals depends on how much the producer decides to feed the animal and on the time he or she fattens them before slaughter. Therefore a representative producer’s problem becomes a profit maximization problem, in which he or she maximizes the difference between the present value of meat produced at slaughter and the cost of raising the animal, equation 18.

$$\pi(\theta) = p(i,\theta)w(i,\theta)e^{-r\theta} - ci\int_{0}^{\theta} e^{-rt}dt \tag{18}$$

$$\frac{\Delta pw}{pw} = r + \frac{ci}{pw}; \qquad \frac{\partial i}{\partial p} > 0, \qquad \frac{\partial \vartheta}{\partial p} > 0 \tag{19}$$

π: profit level
p: price of meat
c: input cost
r: interest rate
θ: slaughter age
i: fixed bundle of daily inputs
w: weight of livestock

The solution of the model in equation 18 provides the optimum input flow and slaughter age, subject to the given prices, costs and interest rates, which maximizes the value of the animal. The first order conditions[12] obtained from the maximization problem provide that the optimal age for slaughter occurs when the growth rate of animal (in terms of meat value) equals the interest rate plus the cost of feeding the animal, that is, when the marginal value product equals marginal cost, equation 19. From the first order conditions, an increase in the price of meat is shown to have an increasing effect on the capital value of breeding animals while at the same time increasing the marginal value product of all inputs. This would make it profitable to hold or fatten the animal longer. In the short-run therefore, the number of animals slaughtered decreases (increases) when the meat/dairy prices increase (decrease) and this decision affects the short and long-run supply of meat and milk[13].

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[12] The derivations are given in Jarvis (1974).

[13] Price elasticities in the short- and long-run have different signs and may change according to the age, sex and type of livestock. Other factors such as weather, interest rate, changes in livestock technology, improved transport and marketing infrastructure, competing agricultural activities also affect short-run and long-run slaughter variation.

Figure 1a: A Temporary Rise in Beef Price in Period 3-4

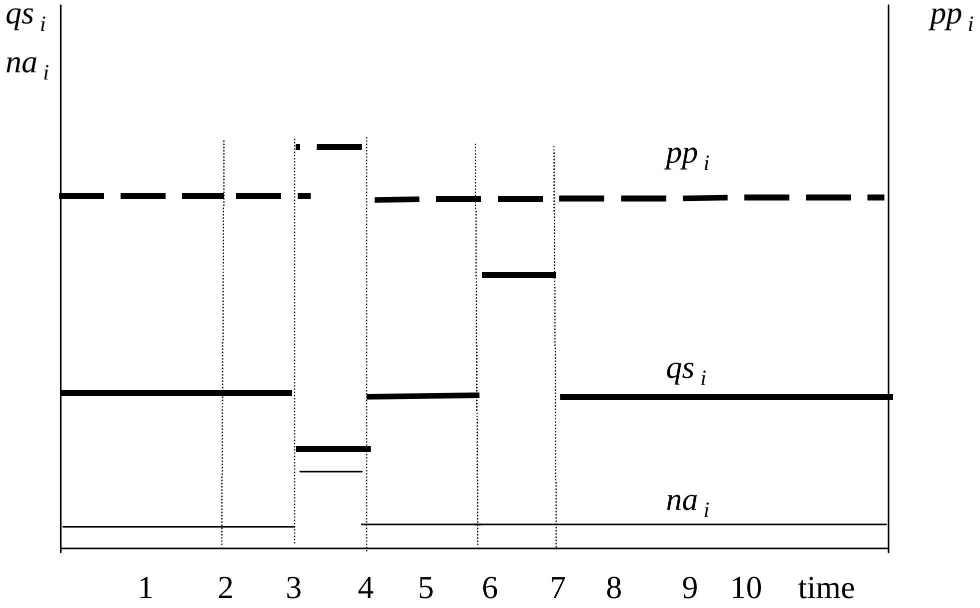
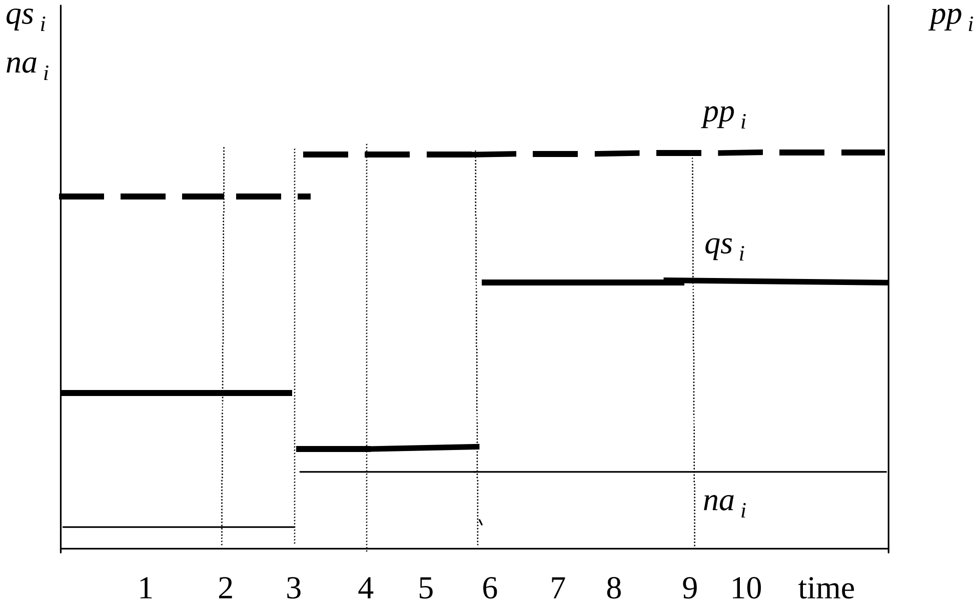


Figure 1b: A Persistent Rise in Beef Price from 3rd Period Onwards



This is also illustrated in Figure 1a and 1b. In Figure 1a the effect of a temporary rise in meat price (2nd Y-axis) in the third period is shown in the number of beef cattle and beef production. While the immediate impact on beef production is negative, as the price rise motivates farmers to retain livestock, it becomes positive in the long-run when the retained livestock becomes productive after the three periods of gestation lag[14]. In Figure 1b, the same interaction is illustrated when the price rise is persistent.

Following Jarvis (1974), the number of animals used for meat and regional dairy production (Na_{ai}) in the LTEM was endogenized by specifying it as a function of various product prices such as; raw milk, beef and veal, sheepmeat, pigmeat and consumer prices of inputs such as; feed concentrates and nitrogen fertilizer, see equation 20. In addition, the supply functions for beef and raw milk are extended to incorporate the number of animals and price of nitrogen fertilizer as explanatory variables, see equations 21 and 22. In these equations the elasticity of

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[14] This is the average lag length for New Zealand and it is shorter for the dairy sector.

raw milk and beef supply with respect to price of nitrogen fertilizer (α_2 and ω_2) is expected to be negative, and with respect to the number of cattle it is expected to be (α_3 and ω_3) positive[15]. Own-price elasticities are expected to be positive in equation 20 and negative in 21 and 22 respectively.

$$Na_{ai} = \chi_0 pp_i^{\chi_1} pc_n^{\chi_2} \prod_j \prod_k pp_j^{\chi_j} pc_k^{\chi_k} \; ; \qquad \chi_1 > 0,\ \chi_2 < 0, \chi_j < 0, \chi_k < 0 \qquad 20$$

$$qs_b = \theta_{b0} pp_b^{\theta_{bb}} pc_n^{\theta_{b2}} Na_{b(t-l)}^{\theta_{b3}} \prod_j \prod_k pp_j^{\theta_{bj}} pc_k^{\theta_{bk}} \; ; \qquad \theta_{1bb} < 0, \theta_{b2} < 0,\ \theta_{bj} < 0, \theta_{bk} < 0 \qquad 21$$

$$\theta_{b3} < 0 \text{ if } l < 3,\ \theta_{b3} > 0 \text{ if } l => 3$$

$$qs_{ai} = \alpha_{i0} pp_i^{\alpha_{i1}} pc_n^{\alpha_{i2}} Na_{ai(t-l)}^{\alpha_{i3}} \prod_j \prod_k pp_j^{\alpha_{ij}} pc_k^{\alpha_{ik}} \; ; \qquad \alpha_{i1} < 0,\ \alpha_{i2} < 0,\ \alpha_{ij} < 0, \alpha_{ik} < 0 \qquad 22$$

$$\alpha_{i3} < 0 \text{ if } l < 2,\ \alpha_{i3} > 0 \text{ if } l => 2$$

Domestic Demand. The domestic demand for beef and veal is given in equation 23. The demand for beef, qd_b, is specified as a function of consumer prices of the own (pc_b), substitute and complementary commodities (pc_j), per capita income *(pinc)* and population growth rate *(pop)*. The exponents reflect the related elasticities. The domestic demand for the dairy sector was explained previously in section 3.1.

$$qd_b = \mu_{b0} pc_b^{\mu_{1b}} pinc^{\mu_{b2}} pop^{\mu_{b3}} \prod_j pc_j^{\mu_{bj}} \; ; \qquad \mu_{b1} < 0,\ \mu_{b2} > 0,\ \mu_{b3} > 0,\ \mu_{bj} > 0 \qquad 23$$

The amount of applied nitrogen fertilizer and feed concentrate used in the production process is not only important because of the impact on supply but also because of the effect on GHG emissions. The demand for feed products (qd_k) in the LTEM is already modelled as intermediate demand by specifying it as a function of consumer prices of the own (pc_k) and substitute feed products (pc_f) and supply amount of raw milk (qs_i) (meat (qs_b)) and substitute products (qs_j) ((qs_h)), equation 24.

In order to endogenize the amount of nitrogen fertilizer used in dairy production in different regions, a conditional input demand function for nitrogen fertilizer is estimated for each region (previously given as equation 13, rewritten here as equation 25). In this equation, the demand for nitrogen use per hectare for example in region $_a$ (N_a), is specified as a function of the relative prices of the feed concentrates (pc_k) to the nitrogen[16] (pc_N) and quantity supplied of raw milk per hectare in region $_a$ (qs_{ai}) (or beef (qs_b) for meat sector)[17].

$$qd_k = \iota_{k0} pc_k^{\iota_{k1}} qs_{it}^{\iota_{k2}} \prod_j \prod_f qs_{jt}^{\iota_{kj}} pc_{ft}^{\iota_{kk}} \; ; \qquad \iota_{k1} < 0,\ \iota_{k2} > 0,\ \iota_{kj} > 0,\ \iota_{kf} > 0 \qquad 24$$

$$Na = \beta_0 (qsa_i)^{\beta_{i1}} \left(\frac{pc_k}{pc_N} \right)^{\beta_{i2}} \; ; \qquad \beta_{i1} > 0,\ \beta_{i2} > 0 \qquad 25$$

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[15] On the average a three year gestation lag is assumed for beef cattle to become productive before slaughtering and a two year lag is assumed for dairy cattle.

[16] Nitrogen price data was obtained from the FAO database (FAOSTAT, 2002) using urea as the closest available fertiliser.

[17] The estimation of nitrogen demand and number of animals for the dairy sector of major markets was carried out using OLS on the log-linear form of the equations. Two major sources of data were used for livestock: the FAO agricultural statistics database (FAOSTAT 2002), and the USDA database (USDA 2002).

The same assumptions and specifications used to model stocks and net trade in section 3.1. are valid in this section also.

4.2 Environmental Sub-Module

To simulate the impact of changing market conditions on production and thus the environment, the factors affecting greenhouse gas emissions have been specified separately and for the purpose of this study, emissions from dairy cattle are taken into account[18]. The principal determinants of gas from this source are livestock numbers, feed intake and type per head (Lassey *et al*., 1992). Most animal waste decomposes aerobically on pasture in New Zealand, resulting in relatively low levels of methane emissions from manure management for this country (MfE, 2000). Lassey *et al*. (1992) also assesses emissions from animal wastes, and from effluent processing plants such as abattoirs and dairy factories to be of relatively minor importance.

The challenge of incorporating methane and nitrous oxide into the LTEM model is to produce an equation (an environmental sub-module) which links all agricultural sources of these greenhouse gases to domestic production, and measures the methane and nitrous oxide emissions in physical terms. Therefore emission factors are crucial in this process, as well as the effect of different production systems, domestic and border policies. The IPCC in its guidelines produces default emission factors for different sources of gases, for a maximum of eight regions of the world[19]. Greenhouse gases (GHG) are incorporated into the model through the equation 15. In this equation *GHG* emissions from raw milk production in region $_a$ is specified as a function of applied nitrogen fertilizer (n_a) and number of animals (Na_a) in region $_a$ which are endogenous to the model. The CH_4 and N_2O emission factors are implicit in the coefficients (ξ, ζ) and values of these coefficients are provided by Clough and Sherlock (2001) (see Appendix Tables A2 and A3 for calculation of coefficients for greenhouse gas production), equation 15. The CH_4 and N_2O emissions from these sources are converted to their CO_2 equivalents by multiplying with their respective weights (21 and 310) to give CO_2 equivalents[20]. The total emission level is equal to the sum of emissions in each region, equation 16.

$$GHG_{amt} = \xi Na_{amt} + \varsigma(n_{at}, Na_{at}) \qquad 15$$

$$GHG_{mt} = GHG_{amt} + GHG_{bmt} + GHG_{cmt} \qquad 16$$

The calculation of coefficients for methane and nitrous oxide production from livestock systems is based on the IPCC methodology for greenhouse gas inventories[21]. Methane and nitrous oxide are separated into their sources. Default emission factors provided by the IPCC are used for the calculation of coefficients in most countries. In the case of nitrous oxide production in New Zealand, the emission factors are based on recent research, and differ from the default IPCC values. For the purposes of the model used in this study, coefficients representing the total methane and nitrous oxide produced from all livestock sources, for each animal type were calculated. Clough & Sherlock (2001) combined the emission factors for the various sources into one coefficient for the production of nitrous oxide and one for the

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[18] In New Zealand, around 57 percent of methane emissions are from sheep and lambs, 27 percent from beef cattle, and 17 percent from dairy cattle (MAF, 2001).

[19] Naturally therefore, these values will vary considerably within each region, and New Zealand, as have many other countries, has carried out in-depth research to provide more accurate emission factors.

[20] The same equation is used to measure nation level emissions from beef and sheep also.

[21] For details on these guidelines, see www.ipcc.org for 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Workbook'

production of methane per animal. A single coefficient for the nitrous oxide emitted from Nitrogen fertilizer was also calculated, constant across animals and countries.

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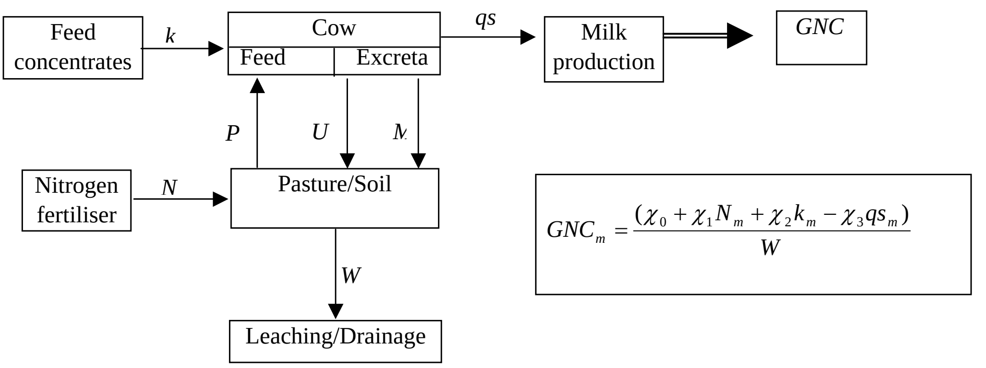
Appendices

Table A1: Country and Commodity Coverage of the LTEM

ID	*Country*	*ID*	
AR	Argentina	WH	Wheat
AU	Australia	CG	Coarse grains
CN	Canada	SU	Sugar (refined)
CZ	Czech Republic	RI	Rice
EU	EU (15)	OS	Oilseeds
HU	Hungary	OL	Oils
JP	Japan	OM	Oilmeal
MX	Mexico	BV	Beef and veal
NI	New Independent States	SH	Sheep meat
NO	Norway	PG	Pig meat
NZ	New Zealand	WL	Wool
PO	Poland	PY	Poultry
SL	Slovakia	EG	Eggs
SW	Switzerland	MK	Raw milk
TU	Turkey	ML	Liquid milk
US	USA	BT	Butter
RW	Rest of World	CH	Cheese
		MW	Whole milk powder
		MS	Skim milk powder

Figure A1: Processes and Mass Flows that Contributes to GNC



$$GNC_m = \frac{(\chi_0 + \chi_1 N_m + \chi_2 k_m - \chi_3 qs_m)}{W}$$

GNC: average groundwater nitrate concentration (g/m^3 /yr)
k: feed grain (concentrate) usage (kg/ha/yr)
$_m$ *: country*
M: nitrogen content of manure
N: nitrogen usage (kg/ha/yr)
P: pasture production (kgDM/ha/y)
qs $_m$ *: quantity of raw milk produced (l/ha/yr)*
U: nitrogen content of urine
W: annual average drainage per year (mm)

Source: Adopted from Bidwell (1999).

Figure A2: Derivation of Groundwater Nitrate Contamination Equation

Assumptions:

The dairy farm is stocked and managed for optimum utilisation of the highly productive pasture, together with any imported feed.

Urine is the primary source of mineral nitrogen for leaching. Manure is shown only for the purpose of calculating the nitrogen content of the urine.

A highly-productive cut pasture (no grazing) is assumed to have negligible leaching losses. Therefore, the formulas represent the formulas represent the incremental leaching due to grazing.

Chart 1 does not show mass balance of nitrogen for the soil and pasture, and other net nitrogen losses to atmosphere are not shown.

Pasture production (P) is related to applied nitrogen fertiliser N by: $P = c_1 + c_2 N$

c_1 is the production of a good rye grass/clover pasture without fertiliser nitrogen

a typical value of c_1 for New Zealand is 13000 kgN/ha/y

a typical value of c_2 for New Zealand is 10 kgDM/kgN

The nitrogen ingested by the cow (N_C) depends on the pasture consumed (P) with nitrogen content c3, and supplemental feed k (as kgDM/ha/y) with nitrogen content c4, so that: $N_C = c_3 P + c_4 k$

a typical value of c_3 for New Zealand is 0.030

a typical value of c_4 for New Zealand is 0.25

The nitrogen removed in the milk (N_{qs}) depends on the milk production (qs) (l/ha/y) and the nitrogen content (kgN/l). $N_{qs} = c_5 qs$

a typical value of c_5 for jersey cows is 0.006 kgN/L

The nitrogen content of dung (N_D) is related only to the dry matter (DM) content of the total feed, irrespective of the nitrogen content of the feed. $N_D = c_6 (P + k)$

a typical value of c_6 is 0.008 kgN/kgDM

The urine of a cow (N_U) contains the nitrogen which is surplus to the requirements for milk production and body maintenance. Therefore, the nitrogen content of the urine is estimated from the nitrogen balance of the cow, on a per hectare basis. By combining N_C, N_{qs}, N_D.

$$N_U = N_C - N_{qs} - N_D$$

if N_C, N_{qs} and N_D. are substituted into N_U:

$$N_U = c_1(c_3 - c_6) + c_2(c_3 - c_6)N + (c_4 - c_6)k - c_5 qs_C$$

Since urine is considered to be the principal source of nitrate leached (W kgN/ha/y) from grazed pasture, it can be estimated from:

$N_L = c_7 N_U$ The coefficient c_7 ddepends on soil type and climatic conditions, and has values up to about 0.45.

a typical value of c_7 is 0.3

The average concentration of nitrate in water draining from the soil is used as a measure of the water quality contributing to the underlying groundwater. If the average annual drainage is W (mm/y), and no account is taken of the proportion of land use, the average nitrate concentration (GNC) (g/m^3) is given by:

$$GNC = \frac{N_L}{W}$$

Source: Adopted from Bidwell (1999).

Table A2: The Calculated Coefficients for Nitrous Oxide for Different Animal Classes*-(tonnes of N_2O per animal per year)

Country	***Animal Class***	***Amount***
New Zealand	Sheep	0.000396
	Beef	0.00244
	Dairy	0.003556
Other countries (based on default values provided by the IPCC)	Sheep	0.00809
	Beef	0.00243
	Dairy	0.003117

*: The coefficient for N_2O emitted from Nitrogen fertilizer is 0.0251 tonnes of N_2O per tonne of fertilizer-N.

Table A3: The Calculated Coefficients for Methane for Different Animal Classes-(tonnes of CH_4 per animal per year)

Animal Class	***Amount***
Sheep	0.01528
Beef	0.00244
Dairy	0.07769