LINCOLN TRADE AND ENVIRONMENT MODEL-ENVIRONMENTAL MODULES:

GROUNDWATER NITRATE POLLUTION

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1. Brief overview

Dairy farming can 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.

Based on these considerations, the LTEM was extended to quantify the linkages between dairy sector and groundwater nitrate contamination by modifying the main model structure to include an environmental sub-module/environmental damage function[1]. 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, various countries 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 which measured groundwater nitrate contamination based on the applied nitrogen fertilizer and used feed concentrates. The link between the first and second extensions was added by endogenizing the nitrogen fertilizer market and intermediate demand for feed products.

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

2. Environmental focus and approach used to link environment and trade

Table 1: Environmental focus and linking environment and trade

Environmental Focus:	-nitrogen fertilizer usage -feed concentrate usage -groundwater nitrate contamination
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. Changes in basic behavioral specifics

Domestic supply

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 it 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.

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

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

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

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

4. Environmental sub-module

Model extensions

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

First, the major dairy producing trading blocs were each sub-divided into regions 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 as well as the nitrogen fertilizer and feed concentrates use. The divisions are introduced to 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.

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 4 (Bidwell, 1999). Basically, 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[2].

$$GNCa = \frac{(\chi_0 + \chi_1 Na + \chi_2 ka - \chi_3 qsa)}{W} \qquad 4$$

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)

Whilst the quantity of concentrate feed (*ka*) used in dairy production in each region was generated endogenously by the existing LTEM structure[3], use of nitrogenous fertiliser (*N/ha*) in different regions was endogenized in the LTEM by estimating the conditional input demand

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

function for nitrogen fertilizer, equation 5. 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 quantity supplied of raw milk per hectare in region a (qsa_i)[4]. 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. The variable qsa_i was included as a shift factor which proxies the technological changes in the production process and/or irregular effects that effect supplied amount of raw milk (Burrell, 1989). The coefficients β_{i1} and β_{i2} show the elasticity of fertilizer demand in region *a* with respect to a change in raw milk supply in region *a* and relative prices. 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.

$$Na = \beta_0 (qsa_i)^{\beta_{i1}} \left(\frac{pc_k}{pc_N} \right)^{\beta_{i2}} ; \quad \beta_{i1} > 0 , \ \beta_{i2} > 0 \qquad 5$$

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

References

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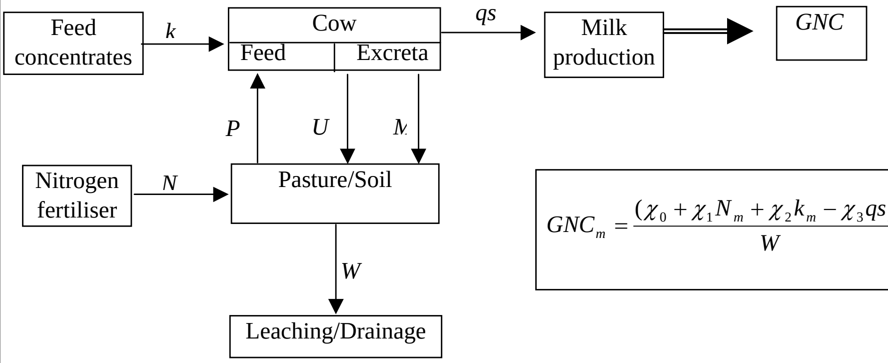
Appendix

Chart 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).

Chart 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). $N_q = c_5 qs$
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).