Effects of nitrogen input and nitrogen surplus taxes in Dutch agriculture

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Effets d'une taxation des engrais et des excédents azotés dans l'agriculture néerlandaise

Résumé – Dans cet article, un modèle régionalisé d'équilibre partiel, comparatif statique, de programmation mathématique est développé pour analyser les effets des taxes sur l'utilisation des intrants azotés dans l'agriculture néerlandaise. Les résultats sont exprimés en termes de marge brute, d'utilisation du sol, de composition du cheptel et d'excédent azoté au niveau du sol. Points forts et faiblesses du modèle sont discutés. Ses points forts reposent sur la cohérence entre les niveaux régional, national et sectoriel et sur la possibilité de modéliser les flux d'engrais et le marché des produits intermédiaires de manière détaillée. Les points faibles portent sur le niveau d'agrégation et le nombre restreint de possibilités de substitutions au niveau des activités. En première analyse, les résultats soulignent l'importance des ajustements réalisés dans le secteur agricole suite aux programmes d'actions et réglementations mis en place en fonction d'objectifs environnementaux. A moins de comprendre le mécanisme de ces ajustements, les résultats des politiques initiées demeurent a priori incertains. En seconde analyse, il ressort que les taxes portant directement sur la pollution environnementale sont plus efficaces que les taxes portant sur l'utilisation des intrants ayant une chaîne causale plus longue entre l'application et l'impact environnemental.

Mots-clés : fourrages concentrés, engrais minéraux, excédents azotés, marchés, modèles sectoriels

Effects of nitrogen input and nitrogen surplus taxes in Dutch agriculture

Summary – In this paper a partial equilibrium, regionalised, comparative static, mathematical programming model of the Dutch agricultural sector is developed to analyse the effects of taxes on nitrogen input use and nitrogen surpluses in Dutch agriculture. The focus of this paper is on effects of taxes on nitrogen surpluses at the soil level, gross margin from agriculture, land use and livestock composition. Strong and weak points of the model are discussed. Strong points are its consistency at regional, national and sector level and the possibility to model manure flows and markets for intermediates in detail. Weak points are the level of aggregation and the restricted number of substitution possibilities at the activity level. As a result elasticities of input demand are quite low.

Environmental policies effect different components of the Dutch agricultural sector simultaneously. Therefore the effects of nitrogen input and nitrogen surplus taxes on environmental targets are very uncertain.

Key-words : feed concentrates, mineral fertilisers, nitrogen surpluses, markets, sector models

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IN the Netherlands livestock production is concentrated in the sandy regions in the south and east. Crop production is concentrated in the clayey regions in the north and south-west of the Netherlands. Production in both cattle farming and the intensive livestock industry is largely based on concentrates imported from abroad at relatively low prices compared to prices for EU produced feed grains. As a result excess amounts of manure are produced at livestock holdings according to prevailing legislation (Brouwer and Van Berkum, 1998). Part of livestock manure is used at the own holding and excess amounts are transported to neighbouring holdings with a lower stocking density. Alternatively, excess amounts of manure may also be exported to surrounding countries or may be processed in factories. Part of livestock manure is also transported to other regions. However, the costs involved in such transport are substantially higher than the costs involved in using the manure within the region. Furthermore, arable crop production is based to a large extent on purchased mineral fertiliser because of the relatively low prices for mineral fertilisers.

The manure and mineral surpluses at livestock farms are major issues of environmental concern in the Netherlands. It is believed that the combination of relative prices for variable inputs and outputs have contributed to this externality problem. Economic instruments as taxes or levies can be used to internalise the externality problem into farmers behaviour. In Pirttijärvi (1998) an overview of the theory of externalities is given.

The Dutch government has already decided to use mineral bookkeeping systems at farm level as the central part of the manure legislation. As from 1998 holdings with more than 2.5 LU/ha will be confronted with a mineral bookkeeping system. This system will apply to all agricultural holdings by the year 2002. Under this new policy farmers are charged a levy if their so-called acceptable losses of nitrogen and phosphate exceed certain emission standards. Standards on acceptable nutrient losses and levies are set until 2008/10 (Brouwer and Van Berkum, 1998).

This paper results from a study for the OECD about the impacts of taxes and subsidies on the use of inputs in agriculture (Helming and Brouwer, 1997). One of the objectives of that study was to compare the effectiveness of a tax on nitrogen surpluses with the effectiveness of a tax on nitrogen consumed by agriculture through fertiliser and feed concentrates. The effectiveness of alternative economic policies to achieve less intensive production systems in agriculture in the Netherlands was investigated as a case study.

The Dutch government has already decided what instruments will be used to achieve environmental targets related to manure and ammonia emission from agriculture. Therefore this paper is not an *ex ante* investigation of the possible effects of this policy switch for the Dutch agricultural sector. The first aim of this paper is to give insights into the wisdom of a tax on nitrogen surpluses compared to a tax on nitrogen used by mineral fertilisers and feed concentrates. This may be helpful for policymakers in other countries and regions where governments are still in the process of defining manure policies. Furthermore the paper contributes to the existing literature from a methodological point of view. This is explained below.

Most studies with respect to the cost efficiency of alternative environmental policies have been carried out at the farm level (Berentsen and Giesen, 1994 and 1995; Oude Lansink and Peerlings, 1997). Farm models have the advantage of very detailed analyses at the farm level. However, an important shortcoming is that market behaviour is lacking. As a reaction to a levy on mineral surpluses or an emission tax, dairy farmers might decrease the nitrogen use on grassland and increase the purchase of silage maize (Berentsen and Giesen, 1995). This might be the optimal solution at the farm level when prices for fodder crops are fixed. At the more aggregate level the income losses are likely to be underestimated because of changes in market prices through changes in aggregate demand and supply. Livestock holdings with excess manure might increase the transportation of manure to other farms in order to reduce mineral surpluses at the farm level. Again with fixed manure prices the income losses are likely to be underestimated. The complexity of the problem increases when markets for fodder crops and animal manure interact. In equilibrium changes in prices for animal manure could affect the optimal nitrogen use on grassland, optimal yield levels of grassland and total land use. As a result of the changes in supply, market prices for fodder crops are affected as well.

When evaluating manure policies, markets for intermediates as fodder crops and manure should be included into the modelling concept simultaneously to take into account possible inelastic demand and inelastic supply. As stated by Taylor and Howitt (1993) more aggregate modelling concepts are called for when the policy switch will significantly shift aggregate supply and demand and thus significantly affect market prices and quantities. This is likely to be the case with an input tax or an emission tax that is meant to influence farmers behaviour.

The quantitave analysis provided in this report is based on the Dutch Regionalised Agricultural Model (DRAM), which is a partial equilibrium, regionalised, comparative static, mathematical programming model of the Dutch agricultural sector. DRAM allows for some endogenous price effects and substitution of cropping activities. Regional and national balances are used to model interregional manure flows, manure markets and markets for fodder crops simultaneously. Several options to reduce mineral surpluses are included in the model. First, reducing the use of mineral fertilisers and animal manure by substitution between crops and changes in mineral levels per hectare grassland. Second, minimising the production of animal manure by substitution between animals and changes in excretion levels per milking cow. Third, interregional transportation of animal manure. And fourth export of animal manure.

In this paper the model is used to compare the effects and cost efficiency of the following environmental policies to reduce mineral surpluses :

– a tax on nitrogen in feed concentrates ;
– a tax on nitrogen in mineral fertilisers ;
– a tax on nitrogen in feed concentrates and mineral fertilisers ;
– a tax on 'gross' nitrogen surpluses including a levy free zone.

The paper is organized as follows. In the first section we start with a general description of the model used for the policy simulations. The markets for fodder crops and animal manure and the calculation of the mineral surpluses are discussed in more detail. The second section describes some important data. The third section presents the effects of the different taxes on livestock, land use, income, nitrogen surpluses and cost efficiency. Special attention will be given to regional effects on nitrogen surpluses. We end this paper with discussion.

MODEL DESCRIPTION

In this paper the Dutch Regionalized Agricultural Model is used for the analysis of demand and supply responses and market price responses to taxes on inputs and emission produced in the Dutch agricultural sector. DRAM takes into account regional and national balances of intermediates and substitution of cropping activities. The modelling approach is more or less comparable with that taken in other national sector models (Horner *et al.*, 1992 ; Lankoski and Lehtonen, 1998). A mathematical representation of the model can be found in appendix 1. In the following we first give a general description of the model. Then we concentrate on intermediate balances. This is done because changes in demand and supply of intermediates and resulting changes in intermediate prices to a large extent influence the effects of economic policies.

General overview

A schematic presentation of the model is given in figure 1. The model assumes that farmers act so as to maximise farm profit subject to technical and market restrictions. The sector model includes 22 agricultural products marketed outside the agricultural sector and 3 intermediates (roughage from fodder crops, young stock and manure) produced and consumed inside the sector. The model distinguishes between fourteen regions. Seven regions have clayey soil, five regions have sandy soil and two regions have peaty soil. Each region is treated like a large, more or less mixed farm. Data for the technical and economic parameters per activity per region are taken from the Dutch Farm Accountancy Data Network (FADN). Parameters per activity are combined with the Dutch agricultural census to aggregate to the sector level. The model's base period describes the actual situation with respect to regional and national prices and quantities over the period 1990/1991 – 1992/1993.

The model is built around a set of linear regional supply and demand functions. Agricultural products can be divided between products traded between farms (intermediate products) and other products (sales). In this paper the domestic and export demand for sales is assumed to be perfectly elastic.

The model includes 15 marketable products belonging to the arable sector : cereals, pulses, sugar beets, fodder beets, ware potatoes, seed potatoes, starch potatoes, onions, other arable products, flower bulbs, four types of vegetables in the open and non-food commodities. It is assumed that these products represent total arable production in the Netherlands. Fruit and horticulture under glass are not included in the analysis. This is because interaction between these sectors and other agricultural sectors is limited.

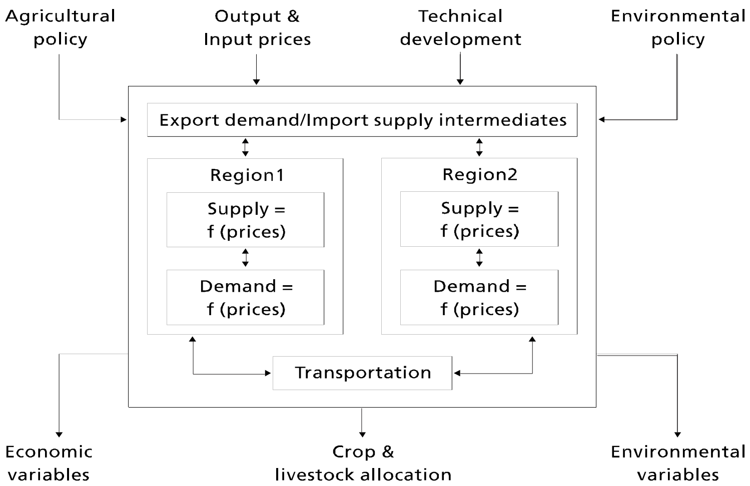
Marketable outputs in the cattle farming sector are milk and beef. Beef represents all outputs from grazing livestock, including male bovines, heifers and suckling cows. In the roughage sector grass, silage and fodder maize is produced. These are used as intermediates in the cattle farming sector. Finally, four marketable outputs (pig meat, poultry meat, eggs and veal) are distinguished in the intensive livestock sector.

We assume perfectly elastic supply of purchased inputs.

Regional balances of intermediates consist of roughage, young stock, minerals and manure. Intermediate balances equate regional production, international trade and interregional imports and exports with regional demand for intermediates. (Shadow) prices for land and quotas are derived from restrictions on regional availability.

An important aspect of the model are the assumptions on production technology. Production technologies are specified as constant proportional (Leontief) production functions. The model includes seven types of dairy cows. Per type of dairy cow the combinations of milk production per cow with nitrogen (N) level per hectare of grassland, concentrate levels per cow and cow numbers per hectare of grassland are fixed (table 1). For example, under the same milk production per cow, concentrate levels per dairy cow can be different because the level of nitrogen per hectare of grassland can be different. Furthermore, the model includes two alternative technologies for beef production.

Figure 1. Schematic representation of DRAM



The objective function

In the model's objective function the total national profit in the agricultural sector is maximised subject to technical restrictions and the restriction that demand equals supply in every regional market. It is assumed that interactions between regions result from profit maximising behaviour of the producers taking advantage of regional price differences (Takayama and Judge, 1971; Labys *et al.*, 1989). Profits are defined as the revenues (including net exports of intermediates) minus total variable costs.

Total variable costs per activity are split into a linear part and a quadratic part. The linear part consists of costs for inorganic fertilisers, use of animal manure and transportation costs of intermediates. The quadratic part consists of purchased feed, pesticides, remaining fertilisers, services, seed and planting materials, energy, hired labour and by-products (as a negative input). The cost involved in a given activity in a region is assumed to increase in the regional level of that activity. The parameters of these quadratic activity-based functions are based on exogenous prices and quantities of purchased inputs per activity per unity and shadow values for actual regional activity levels. These shadow values are obtained from an initial model run with activities (areas, livestock number and techniques) restricted to actual, observed figures. This approach is called Positive Mathematical Programming (PMP) and calibrates the model exactly to the actual, observed figures without any loss of flexibility. The PMP approach thus combines some of the advantages of the mathematical programming and econometric approaches. More detailed information on PMP is given in Howitt (1995) and Horner *et al*. (1992).

Intermediate balances

A general overview of the intermediate balances is given in annex I. In this subsection we will discuss the balances for fodder crops and animal manure in more detail.

Markets for fodder crops

The model allows for various technologies for the production of milk and beef. It includes various feed balances for internally provided fodders e.g. grass silage for a certain type of dairy cow. It is assumed that fodder crops are not transported between regions. Regional supply exceeds regional demand for every type of fodder crop and production technology. Regional balances between the feed requirements of the dairy cows and the beef cattle per type and the corresponding supply from fodder crops per type are given as:

$$\sum_{i=1}^{2} \rho_{iftr} X_{itr} - \sum_{i=3}^{4} \theta_{iftr} X_{itr} \leq 0 \quad [\pi_{ftr}] \tag{1}$$

where i = 1 for milking cows, including youngstock, i = 2 for beef cattle, i = 3 for grassland and i = 4 for maize; f = 1 for grass for grazing, f = 2 for grass silage and f = 3 for maize; t = 1..9, alternative technologies; r = 1..14, regions.

ρ_{iltr} is the demand coefficient from sub sector i and technology t for fodder crop f in region r (kg dm per unity), θ_{iltr} is the productivity coefficient from sub sector i and technology t for for fodder crop f in region r (kg dm per unity) and X_{itr} is agricultural activity from sector i and technology t in region r (in ha or average number of animals). π_{ftr} denotes the dual variable or the shadow price for fodder crop f from subsector i and technology t in region r (Dfl per kg dm).

The regional price for fodder crops (W_{gr} in Dfl per kg dm) can be calculated as:

$$W_{gr} = \left(\sum_{ift} \pi_{ftr} \rho_{iftr} X_{itr}\right) / \left(\sum_{ift} \rho_{iftr} X_{itr}\right) \tag{2}$$

Manure markets

In this subsection we show how shadow prices for animal manure and minerals that originates from animal manure are calculated [(1)]. Demand for minerals from animal manure per crop per region is calculated as the difference between the total uptake of minerals by crops plus the export demand for minerals minus the use of minerals from inorganic fertilisers. This can be written as:

$$DM_{sr} = UPTAKE_{sr} + EXPORT_{sr} - MINF_{sr} \qquad (3)$$

where $s = 1$ for nitrogen and $s = 2$ for phosphorous; DM_{sr} is the demand for mineral s from animal manure in region r (kg), $UPTAKE_{sr}$ is the total uptake of mineral s by crops harvested in region r (kg), $EXPORT_{sr}$ is the export of mineral s from region r (kg), $MINF_{sr}$ is the use of mineral s from inorganic fertilisers in region r (kg). The uptake of minerals per hectare is different for every individual crop. This means that the total uptake of minerals is a function of the area allocation to the crops.

The supply of minerals s from animal manure in region r (SM_{sr}) is calculated as:

$$SM_{sr} = \theta_{sr}\, ANIMAL_r - \sum_{r'} TMREG_{srr'} + \sum_{r'} TMREG_{sr'r} \qquad (4)$$

where θ_{sr} is the net supply of mineral s in animal manure in region r before application to the soil (kg per animal per year), $ANIMAL_r$ is the number of animals in region r, $TMREG_{srr'}$ is the interregional transportation of mineral s from region r to region r' (kg), $TMREG_{sr'r}$ is the interregional transportation of mineral s from region r' to region r (kg). The net supply of minerals in animal manure before application to the soil equals the total supply of minerals in animal manure minus the losses of nitrogen as ammonia from the stable and during storage.

Through regional transportation of animal manure the minerals production from animal manure might differ from minerals supply from animal manure. To make sure that the fixed relationship between nitrogen and phosphorous in animal manure is respected the following equation is added to the model:

$$SM_{nr} = \sum_{p} SM_{pr}\, \theta_{nr} \big/ \theta_{pr} \qquad (5)$$

where $n = 1$ for nitrogen and $p = 1$ for phosphorous. Manure contains organic and mineral nitrogen (Berentsen and Giesen, 1995). The model assumes that part of the mineral nitrogen is emitted as ammonia while applying manure to the land or when cows are grazing. Furthermore, a fixed amount (including organic nitrogen) is added to the soil balance.

[(1)] For reasons of convenience we describe the regional demand and supply of minerals from animal manure assuming only one animal, one crop and one technology.

The crops can use the rest. These corrections result in a fixed coefficient representing regional mineral losses to the air and soil balance (ν_{sr}). The regional manure balance for mineral s is written as:

$$(1 - \nu_{sr})\, SM_{sr} - DM_{sr} - EXCESS_{sr} = 0 \qquad [\mu_{sr}] \tag{6}$$

where $EXCESS_{sr}$ is the excess supply of mineral s in region r (kg). It is assumed that excess supply is added to the soil balance. The symbol in square brackets represents the shadow price for mineral s in region r (Dfl per kg).

The regional supply of animal manure in volume terms, m^3, determines the regional application costs and the regional transportation costs of animal manure. The regional supply of animal manure in m^3 (AM_{mr}) can be calculated as:

$$AM_{mr} = \delta_{mr}\, ANIMAL_r - \sum_{nr'} TMREG_{nrr'}\, (\delta_{mr}/\theta_{nr}) + \sum_{nr'} TMREG_{nr'r}\, (\delta_{mr'}/\theta_{nr'}) \tag{7}$$

where δ_{mr} is the excretion of manure per animal per year per region r (m^3 per animal per year).

Finally, regional prices for animal manure in Dfl per m^3 (W_{mr}), excluding transportation and application costs, can be calculated from the regional shadow prices for minerals from animal manure:

$$W_{mr} = \sum_{s} \mu_{sr}\, (1 - \nu_{sr})\, SM_{sr} / AM_{mr} \tag{8}$$

Mineral balances

In Pirttijärvi (1998) an extensive discussion of the use of mineral balance calculations or nutrient balance calculations (NBC) as an information tool or as a policy tool is given. The basic principle underlying mineral balance calculations is a comparison between the minerals entering a system and the minerals leaving a system at certain observations points. There are different methods to calculate mineral balances (Pirttijärvi, 1998). In this paper the surface balance method is used. The surface balance is calculated as the difference between the minerals entering into and exiting from the soil surface. The model accounts for minerals used in mineral fertilisers and animal manure. From the output side the uptake of minerals by the harvested crops are accounted for. The gross surface balance is obtained by subtracting the mineral inputs from the mineral outputs. The regional gross surface balance can be written as:

$$GMINBAL_{sr} = SM_{sr} - DM_{sr} \tag{9}$$

where $GMINBAL_{sr}$ is called the gross regional surplus of mineral s (kg), including losses to the air while applying manure to the land and losses to the soil balance.

The net surface balance can be written as:

$$NMINBAL_{sr} = SM_{sr} - DM_{sr} - NEMIS_{sr} \quad (10)$$

where $NMINBAL_{sr}$ is called the regional mineral surpluses *s* at soil level (kg) and $NEMIS_{sr}$ are the minerals emitted to the air while applying manure to the land (kg). Because the net surface balance corrects for both emission of ammonia from the stable and from application to the soil, this method reveals the problem of nitrogen losses to watercourses more clearly than the gross surface balance method (Pirttijärvi, 1998).

DATA AND SOFTWARE

Prices and quantities in the model are yearly averages for the period 1990/1991 – 1992/1993. A three year average is used to correct for occasional events and to obtain a benchmark data set. Main data sources are the Dutch Agricultural Census, the Dutch Farm Accountancy Data Network (FADN), results from dairy farm models and specific findings in the literature. The Dutch Agricultural Census is used to obtain regional cropping plans and livestock numbers. The FADN is a stratified random sample of some 1000 farms representing about 95 percent of the production and some 65 percent of the farms and contains very detailed data.

The following figures are taken for each crop activity from the FADN (on a hectare base): yields, revenue, variable costs, minimum nitrogen fertilization and use of nitrogen from animal manure. With respect to the regional use of phosphorus on arable land normative guidelines are used.

Milk production per dairy cow, minimum nitrogen levels per hectare of grassland, feeding ration per dairy cow (grass, maize and concentrates) and manure and minerals excretion per dairy cow are highly correlated (Berentsen and Giesen 1995; Mandersloot, 1992). The model uses data and results from dairy farm models on milk production to define different types of dairy cows (Mandersloot, 1992). Results are presented in table 1.

Fodder crops are also used to feed heifers and male bovine (table 2). The model uses fixed input/output relationships for heifers, male bovines, pigs and poultry. Data with respect to the use of feed concentrates, the average nitrogen content of feed concentrates and the corresponding nitrogen excretion per animal type are presented in table 2.

Transportation costs of animal manure are taken from Luesink (1993). The values of emission coefficients of housing systems and manure application systems are taken from Oudendag (1993). The model uses fixed efficiency coefficients of the minerals in the animal manure in accordance with normative guidelines. These coefficients differ between regions according to soil types. The minerals uptake by crops is taken from Berghs and Hotsma (1993).

The parameters of the quadratic costs functions are estimated using priors on supply elasticities. It is assumed that the supply elasticities do not exceed 2 for any output. This number has been obtained from Bob MacGregor of Agriculture and Agri-Food Canada.

DRAM was built using the GAMS (General Algebraic Modelling System) mathematical programming software (Brooke *et al.*, 1992). The model is solved using the non-linear solver MINOS 5.3.

Table 1. Some important characteristics per type of dairy cow per year in the base period 1990/1991 – 1992/1993

Technique	Milk production (kg/ dairy cow)	Minimum nitrogen level per hectare of grassland	Dairy cows per hectare of fodder crops	Feed concentrates (kg/ dairy cow)	Nitrogen content of feed concentrates (gr/kg)	Nitrogen excretion (kg N/ dairy cow)	Nitrogen content in feed concentrates per kilogram milk (gr/kg)
LMHNGS	6,000	382	1.72	1,915.2	26.2	175.1	8.36
LMMNVG	6,000	337	1.45	2,166.2	26.2	181.8	9.46
MMMNGS	7,000	337	1.58	2,297.3	32.3	173.2	10.6
MMMNVG	7,000	337	1.37	2,612.1	32.3	179.2	12.05
MMHNVG	7,000	382	1.45	2,386.3	32.3	211.4	11.01
HMLNGS	8,000	257	1.36	2,623.7	38.4	162.3	12.59
HMLNVG	8,000	257	1.21	2,876.3	38.4	185.5	13.81

LMHNGS: Low milk production per cow, high nitrogen level per hectare grassland, land partly used for the production of maize.

LMMNVG: Low milk production per cow, average nitrogen level per hectare grassland, all land used as grassland.

MMMNGS: Average milk production per cow, average nitrogen level per hectare grassland, land partly used for the production of maize.

MMMNVG: Average milk production per cow, average nitrogen level per hectare grassland, all land used as grassland.

MMHNVG: Average milk production per cow, high nitrogen level per hectare grassland, all land used as grassland.

HMLNGS: High milk production per cow, low nitrogen level per hectare grassland, land partly used for the production of maize.

HMLNVG: High milk production per cow, low nitrogen level per hectare grassland, all land used as grassland.

Sources: Mandersloot, 1992; Van Eerdt (ed.), 1994 a; LEI-DLO

Table 2. Some important characteristics per animal type per year in the base period 1990/1991 –1992/1993

Animal type	Beef cattle per hectare of fodder crop	Feed concentrates (kg N/animal type)	Nitrogen content (gr N/kg)	Nitrogen in feed concentrates per animal type (kg N)	Nitrogen excretion (kg N/animal type)
Male bovine	9.5	852	34.3	29.2	40
Heifers	2.3	132	26.2	3.46	60
Finishing pigs	*n.a.*	756	26.9	20.33	14.9
Sows	*n.a.*	1.664	34.6	57.57	35.7
Laying hens	*n.a.*	42.1	36.7	1.51	1
Slaughter chicken	*n.a.*	30.7	35.6	1.09	0.58

n.a. not applicable
Sources: LEI-DLO; Van Eerdt (ed.) 1993, 1994a, 1994b.

RESULTS

The effects of four types of taxes are explored in this report: a tax on nitrogen used by fertilisers, a tax on nitrogen in feed concentrates, a tax on both nitrogen used by fertilisers and feed concentrates and a tax on gross nitrogen surpluses. The tax on nitrogen evaluated in this report equals Dfl 5,00 per kg N. With respect to the tax on the nitrogen surpluses a threshold level or levy-free zone of 200 kilogram nitrogen surplus per hectare grassland and 150 kilogram nitrogen surplus per hectare arable land is assumed. A levy only needs to be paid in case nitrogen surpluses exceed the levy-free zone. The assumption on levy free zones is taken from policy proposals of national government for the year 2005 (MLNV, 1995).

A tax on nitrogen used by feed concentrates

In table 3 the first column present model results for some selected variables for the base period 1990/1991 – 1992/1993. The negative price for animal manure means that there exists an income transfer from the users of animal manure to the producers of animal manure, excluding transportation and application costs. The next column shows the effects of a tax on nitrogen used by feed concentrates in percentage differences from the base period. A Dfl 5,00 tax on nitrogen used by feed concentrates reduces the use of nitrogen in feed concentrates by about 13 percent and the production of animal manure by 8 percent. The decrease in the production of animal manure leads to an increase in the (shadow) price for animal manure. The decrease in manure production in regions with high livestock densities and excess amounts of manure is partly offset by a sharp decrease in interregional transportation of animal manure and an increase in the use of nitrogen from mineral fertilisers. Annex II gives a detailed overview of these effects for the sandy region in the south of the Netherlands. Results for this region are presented in more detail because it includes the most severe manure surplus areas in the Netherlands. Because of changes in total demand for fodder crops, the (shadow) price for fodder crops decreases slightly. The change in demand is caused by changes in the beef livestock (table 4). A very small increase in demand for fodder crops from dairy cows is more than offset by decreasing demand from beef cattle.

The impact of the tax on nitrogen used by feed concentrates on land use is given in table 5. The land allocated to grassland decreases because of the decreasing beef livestock. As a sum of an increase in demand from dairy cows and a decrease in demand for beef cattle, the land allocated to maize is unaffected. As a result of the decline in land used for fodder crops, the area allocated to arable crops increases.

The tax on nitrogen used by feed concentrates has a large impact on the intensive livestock sector (table 4). It leads to a decrease of production in the intensive livestock sector of about 20 percent.

Table 6 shows the effects of the tax on nitrogen used by feed concentrates on tax payments, gross margins and nitrogen surpluses at soil level. It is assumed that the tax payments are returned to the agricultural sector, without influencing the (optimal) model solution. The net income effect (changes in gross margins minus changes in tax payments) equals minus 124 mln Dfl or about 1 percent. The nitrogen surpluses at soil level decreases by approximately 28 mln kg N or 7 percent.

A tax on nitrogen used by mineral fertilisers

A Dfl 5,00 tax on nitrogen used by mineral fertilisers decreases the use of mineral fertilisers by about 18 percent and increases the use of nitrogen in feed concentrates by about 7 percent. The production of animal manure decreases by about 10 percent. The sharp increase in the (shadow)price for animal manure is explained by the decrease in production, mainly in the dairy sector and an increase in demand for animal manure. This increase in demand can be explained by the substitution of nitrogen used by mineral fertilisers by nitrogen from animal manure. The tax on nitrogen used by mineral fertilisers has a limited impact on manure transportation from regions with high livestock densities to other regions. Through changes in supply of fodder crops the price for fodder crops increases by about 20 percent.

The increase in the use of nitrogen in feed concentrates results from a technology switch in the dairy sector from mainly “MMMNGS” to “HMLNGS” (table 1) and an increase in the number of pigs and poultry. The technology switch reduces the number of dairy cows needed to fully produce the national milk quota. The pig and poultry sector gain from higher prices for animal manure (table 4).

Table 3. Effects of taxes on quantities
and prices of purchased inputs and intermediates (Dfl 5,– per kg N tax on nitrogen in)

	Base scenario	Feed concentrates	Mineral fertilisers	Feed concentrates and mineral fertilisers	'Gross' nitrogen surpluses
		Percentage change compared to base scenario			
Quantities					
Feed concentrates (mln kg N)	477	-13.3	+6.7	-11.4	-4.2
Mineral fertilisers (mln kg N)	374	+2.0	-18.1	-4,7	-6,9
Manure transportation (mln kg N)	37.6	-59.3	-7.2	-60.4	-35.4
Animal manure (mln kg)	604	-8.1	-10.3	-10.8	-11.9
Prices					
Fodder crops (Dfl/kg dm)	0.41	-3.9	+19.5	+12.0	-13.9
Manure (Dfl/m^3)	- 0.75	15.1	903	1,032	-3,442

Table 5 shows that the area of fodder crops is hardly affected. The decline in demand due to the drop in the number of animals in the cattle farming sector (beef cattle and dairy cows) is offset by a decrease in production per hectare of grassland through a decreasing use of nitrogen on grassland. With the same acreage allocated to fodder crops, total supply will go down and prices for fodder crops will go up.

With higher fertilisation costs the land allocated to potato crops decreases in favour of other arable crops. The tax on nitrogen used by mineral fertilisers has a negative net income effect of about 250 mln Dfl or 1.9 percent (table 6). The nitrogen surpluses at soil level decrease by approximately 44 mln kg N or 10.8 percent.

Table 4. Effects of taxes on livestock composition (Dfl 5,– per kg N tax on nitrogen in)

	Base scenario	Feed concentrates	Mineral fertilisers	Feed concentrates and mineral fertilisers	'Gross' nitrogen surpluses
	1000 animals	Percentage change compared to base scenario			
Dairy cows	1.6	0	-12,5	-2,1	-12,5
Beef cattle	1.1	-9,1	-9,9	-9,9	-9,9
Meat calves	0.62	-9,7	-4,8	-8,1	-3,2
Finishing pigs	7.1	-19,7	1,4	-16,9	-9,9
Sows	1.28	-18,8	0	-16,4	-8,6
Poultry [a]	76.6	- 19,3	5,7	-19,3	-15,4

[a] Excluding laying hens younger than 18 weeks.

Table 5. Effects of taxes on land use (Dfl 5,– per kg N tax on nitrogen in)

	Base scenario	Feed concentrates	Mineral fertilisers	Feed concentrates and mineral fertilisers	'Gross' nitrogen surpluses
	1000 ha	Percentage change compared to base scenario			
Fodder crops					
Grass	1,077	-2.4	-0.6	-4.0	-0.4
Maize	207	0	3.3	4.3	0.5
Total	1,284	-2.0	0.1	-2.6	-0.2
Arable land					
Cereals	188	4.3	0.5	4.8	0
Potato	161	3.1	-8.9	-4.3	4.3
Other	281	4.6	4.3	11.4	-1.4
Total	630	4.1	-0.2	5.4	0.5

A tax on nitrogen used by feed concentrates and mineral fertilisers

The effects of combined taxes on nitrogen used by feed concentrates and mineral fertilisers are complex. The use of nitrogen in feed concentrates decreases by about 11 percent. Nitrogen used by mineral fertilisers decrease by about 5 percent. This relatively small reduction is explained by the increases in prices for fodder crops. The tax on nitrogen used by feed concentrates stimulates the substitution towards the use of nitrogen from fodder crops, with higher prices for fodder crops as a result. Because prices for fodder crops are relatively high, the optimal nitrogen level and dry matter production on grassland is relatively high. Together with the relatively high prices for nitrogen from animal manure, this explains the limited impact of the tax on nitrogen used by mineral fertilisers.

The price for animal manure increases through the substitution between nitrogen from mineral fertilisers and nitrogen from animal manure and through the decrease in the production of animal manure. The latter results from adjustments in the cattle farming and intensive livestock sector, necessary to counteract the increasing costs for feed concentrates (table 4). The decrease in manure production in the manure exporting regions is partly offset by a sharp decrease in manure transportation.

With high fertilisation costs the allocation of land is shifted from grassland and potato crops towards maize, cereals and other arable crops.

Because of the increasing prices for both feed concentrates and mineral fertilisers the economic adjustment possibilities are very limited.

With high tax payments, the net income effect is relatively small: minus Dfl 192 mln or 1.5 percent. The nitrogen surpluses at soil level decrease by about 37 mln kg N or 9 percent. This is also relatively small compared to a tax on nitrogen used by feed concentrates or a tax on nitrogen used by mineral fertilisers only.

Table 6. Effects of taxes on tax payments (budget), gross margins from agriculture and N-surplus at soil level (Dfl 5,– per kg N tax on nitrogen in)

	Base scenario	Feed concentrates	Mineral fertilisers	Feed concentrates and mineral fertilisers	'Gross' nitrogen surpluses
Tax payments (mln Dfl)	-	2,070	1,530	3,900	469
Gross margins (mln Dfl)	12,828	10,634	11,045	8,736	12,135
Net income effect (mln Dfl)	-	-124	-253	-192	-224
Nitrogen surpluses at soil level (mln kg N)	407	379	363	370	361

A tax on 'gross' nitrogen surpluses

The fourth policy that has been evaluated is a tax on 'gross' nitrogen surpluses. The levy free zone is 200 kg N per hectare of grassland and 150 kg N per hectare of arable land. Table 3 shows that under this policy the use of nitrogen in feed concentrates decreases by about 4 percent, nitrogen used by mineral fertilisers decreases by about 7 percent and the production of animal manure decreases by about 12 percent. The tax on 'gross' nitrogen surpluses is directly included in the shadow price for animal manure. The positive price for animal manure can be seen as an income transfer from the producers of animal manure to the users of animal manure. As a result of this change in income transfer the number of animals and the transportation of animal manure from the exporting regions reduce sharply (table 3, table 4).

Contrary to a tax on nitrogen used by mineral fertilisers, the price for fodder crops decreases under a tax on 'gross' nitrogen surpluses. This can be explained as follows. Because fertilisation costs are relatively low, the dry matter production per ha of grassland is relatively high. Area allocated to fodder crops is also relatively unaffected (table 5). Because demand for fodder crops decreases and supply of fodder crops remains almost unaffected prices for fodder crops will be lower.

The area allocation over the crops is affected by the changes in fertilisation costs. Table 5 show that the area allocated to potato crops increase and the area allocated to grassland and other arable crops decrease.

The tax on 'gross' nitrogen surpluses has a negative income effect of about Dfl 224 mln or 1.7 percent. The nitrogen surpluses at soil level decrease by about 46 mln kg N or about 11 percent.

Cost-efficiency

Analyses of the cost-efficiency of the policy instruments were conducted under alternative tax rates. Impacts on net income and nitrogen surpluses at soil level where used to estimate the parameters of a linear upward sloping marginal social costs (MSC) of pollution function. As mentioned by Pirttijärvi (1998) the positive slope of the curve is logical, as the costs of pollution reduction per unit will increase when abatement levels increase. Only a small range of pollution abatement levels is analysed to stay as close as possible to the initial situation. Results are presented in table 7. At the abatement levels presented, a tax on 'gross' nitrogen surpluses is more cost-efficient than the other policies considered. The tax on 'gross' nitrogen surpluses has the advantage of including a levy-free zone, while taxes on inputs also include the inputs not lost to the environment. A remark was made by one of the reviewers that for monitoring reasons, non-linear taxes on inputs are impossible, while it is possible to use such a device on an observable measure. A tax on nitrogen from mineral fertilisers comes second and compares favourably to a tax on nitrogen used by feed concentrates. Following Dabbert *et al.* (1997) a tax on nitrogen used by feed concentrates is relatively less efficient because there are more interfering variables and the causal chain between nitrogen in feed concentrates and the environmental indicators is longer. At low abatement levels a combined tax on nitrogen used by both feed concentrates and mineral fertilisers is more cost efficient than a tax on nitrogen used by feed concentrates only. This changes at higher abatement levels because of the limited adjustment possibilities, with both prices for animal manure and fodder crops increasing.

Table 7. Effects of taxes abatement cost at different abatement levels (Dfl/kg N) (Dfl 5,– per kg N tax on nitrogen in)

Abatement	Feed concentrates	Mineral fertilisers	Feed concentrates and mineral fertilisers	'Gross' nitrogen surpluses
5 %	3.4	2.7	2.7	2.2
10 %	6.0	5.3	5.7	4.3
15 %	8.5	8.0	8.7	6.5

Regional effects

Table 8 shows the effects of alternative economic instruments on regional nitrogen surpluses at soil level. The manure and minerals surpluses in the Netherlands are concentrated in the sandy regions in the south, east and middle of the Netherlands. From table 8 it can be seen that taxation of nitrogen used by mineral fertilisers or a tax on 'gross' nitrogen surpluses have more impact on nitrogen surpluses at soil level than taxation of nitrogen used by feed concentrates. This can be explained by changes in the production of minerals from animal manure and changes in regional transportation of animal manure. When less nitrogen is transported from the surplus areas to other regions the nitrogen surpluses at soil level in the surplus areas might go up. Even under a decrease in the regional production of minerals from animal manure.

Table 8. Effects of taxes on regional nitrogen surpluses at soil level (mln kg N) (Dfl 5,– per kg N tax on nitrogen in)

	Base scenario	Feed concentrates	Mineral fertilisers	Feed concentrates and mineral fertilisers	'Gross' nitrogen surpluses
	Mln kg N	Percentage change compared to base scenario			
Sandy regions:					
South	87.2	-0.2	-8.1	0.8	-6.1
East	67.9	-6.2	-9.0	-4.4	-17.1
Middle	28.6	-2.1	-8.7	-1.4	-10.5
Total sandy regions	183.7	-2.7	-8.5	-1.5	-10.8
Other regions	224.1	-10.1	-12.6	-16.0	-12.1
Total Netherlands	407.8	-6.8	-10.8	-9.4	-11.5

For the sandy regions as a whole a tax on nitrogen surpluses seems to be more effective than a tax on nitrogen used by mineral fertilisers, although results are to some extent ambiguous in this respect. The conclusion that a tax on nitrogen surpluses leads producers with high nitrogen surpluses to lower the nitrogen surpluses more than producers with small nitrogen surpluses was more clearly found at the farm level for individual arable farmers (Oude Lansink and Peerlings, 1997). Therefore these authors conclude that from an environmental perspective a tax on nitrogen surpluses should be preferred above a tax on nitrogen from mineral fertilisers.

Other environmental indicators

The effects of alternative nitrogen policies on other environmental indicators should be taken into account as well when assessing the environmental gains. Taxation of 'gross' nitrogen surpluses reduces the emission of ammonia more than a tax on mineral fertilisers (Annex II). Model results show that a tax on 'gross' nitrogen surpluses goes together with a larger decrease in phosphorous surpluses in the sandy regions of the Netherlands than a tax on nitrogen in mineral fertilisers. The explanation for this is the general decrease of animal manure production in the sandy regions under a tax on 'gross' nitrogen surpluses. We find opposite results in the case of the use of pesticides. This can be explained by the decrease in the area allocated to potato crops under a tax on nitrogen in mineral fertilisers. Another argument in favour of the latter policy could be that high monitoring costs arising from the calculation of the nitrogen surpluses are avoided.

DISCUSSION

Some disadvantages of the model that is used in this paper should be noted. First, substitution possibilities at the activity level are limited compared to other studies at the farm level (Berentsen and Giesen, 1994, Oude Lansink and Peerlings, 1997). Only for grassland and milking cows different output levels per hectare and per head as a function of nitrogen input are included (table 1). This means that changes in input demand and output supply only originate from substitution between outputs. As a result demand elasticities are low compared to those found by other studies (Burrel, 1989; Dijk, Hoogeveen and de Haan, 1995).

Second, market prices are taken as given. In other words we assume that the price elasticities of supply of marketable inputs and outputs are infinite. This applies for example if the domestic price equals the world market price and domestic developments do not influence the world market price. This is the so-called small country assumption. If price elasticities are somewhere between zero and infinity however, then there is scope for a price decrease or increase due to a drop in national demand or supply as a result of the tax. As an example, with a price elasticity of supply between zero and infinity, the important changes in demand for feed concentrates due to a high tax on nitrogen from feed concentrates could affect market prices for feed concentrates. This is not included in the analysis.

Another point of discussion is the limited relevance of the regional nitrogen surpluses at soil level. Nitrogen surpluses at the soil level is a local problem, therefore the distribution of the nitrogen surpluses is as important as the total surplus itself [(2)]. Lankoski and Lehtonen (1998) apply the same type of model and argue that the regional aggregate nutrient balances given by the sector model should be complemented by farm level analysis to deal with this problem. They also argue that the sector model yields the first approximation of the regional level impacts on the environment. It takes into account the market behaviour and many dynamic factors that are lacking from static farm level models (Lankoski and Lehtonen, 1998).

Other caveats are related to the assumptions with respect to the uniformity of production possibilities and profit maximizing behaviour over

[(2)] I would like to thank one of the reviewers for stressing this point.

all farms (the aggregation bias) and the time dimension of the adjustments. Since DRAM is a comparative static model the time-path towards completion of the adjustments is unknown.

Notwithstanding the shortcomings of the model, it is shown that taxation of environmentally relevant inputs will affect market prices for intermediates. These price changes should be included into farm models to fully assess the impact of taxes on farm income.

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APPENDIX 1

Mathematical representation of DRAM

Objective function

$$max\ Z = \sum_i \sum_j \sum_r P_{ijr}\, Q^d_{ijr} - \sum_i \sum_t \sum_r \left(\kappa_{itr} + \kappa^1_{itr}\, X_{itr} + 0.5\ \kappa^2_{itr}\, X_{itr}\, X_{itr}\right)$$

$$+ \sum_i \sum_l \sum_r \left(\upsilon_{il} - \varsigma_{ilr}\right) E_{ilr} - \sum_i \sum_l \sum_r \left(\tau_{il} + \varsigma_{ilr}\right) M_{ilr} - \sum_i \sum_l \sum_r \sum_{r'} \varsigma_{ilrr'}\, T_{ilrr'}$$

Commodity balances

$$Q^d_{ijr} - Q^s_{ijr} = Q^d_{ijr} - \sum \gamma_{ijtr}\, X_{itr} \qquad all\ j,r$$

Intermediate balances

$$N^d_{lr} - N^s_{lr} = \sum_{i=1}^{m} \sum_t \rho_{iltr}\, X_{itr} - \sum_{i=m+1}^{n} \sum_t \theta_{iltr}\, X_{itr}$$

$$- \sum_i M_{ilr} + \sum_i E_{ilr} - \sum_i \sum_{r'} T_{ilr'r} + \sum_i \sum_{r'} T_{ilrr'} \leq 0 \qquad all\ l,r$$

Trade balances

$$\sum_i \sum_r E_{ilr} \leq e_l \qquad all\ l$$

$$\sum_i \sum_r M_{ilr} \leq m_l \qquad all\ l$$

Primary input balances

$$\sum_i \sum_t \delta_{iktr}\, X_{itr} \leq B_{kr} \qquad all\ k,r$$

Variables

Q^d_{ijr} = Demand of sector i and output j in region r
Q^s_{ijr} = Supply of sector i and output j in region r
X_{itr} = Agricultural activity in sector i with technology t in region r
N^d_{lr} = Demand of intermediate l in region r
N^s_{lr} = Supply of intermediate l in region r
M_{ilr} = Import of sector i intermediate l in region r
E_{ilr} = Export of sector i intermediate l in region r
$T_{ilr'r}$ = Transport of sector i intermediate l from r' to r
$T_{ilrr'}$ = Transport of sector i intermediate l from r to r'

Coefficients

P_{ijr} = Price in sector i of output j in region r

κ_{itr}, κ^{1}_{itr}, κ^{2}_{itr} = PMP coefficients of the quadratic cost function for sector i and technology t in region r

υ_{il} = Unit export price in sector i of intermediate l

τ_{il} = Unit import price in sector i of intermediate l

$\varsigma_{ilrr'}$ = Unit transportation costs in sector i of intermediate l from region r to region r'

ς_{ilr} = Unit transportation costs in sector i of intermediate l from region r to the national border

γ_{ijtr} = Productivity coefficient in sector i and technology t for output j in region r

θ_{iltr} = Productivity coefficient in sector i and technology t for intermediate l in region r

ρ_{iltr} = Demand coefficient in sector i and technology t for intermediate l in region r

e_l = Export demand for intermediate l

m_l = Import demand for intermediate l

B_{kr} = Factor availability k in region r

δ_{iktr} = Factor requirement coefficient k in sector i and technology t in region r

APPENDIX 2

Effects of taxes on nitrogen in feed concentrates, mineral fertilisers, both nitrogen in feed concentrates and mineral fertilisers and 'gross' nitrogen surpluses (Dfl 5,-) on nitrogen surpluses at soil level in the sandy region in the south of the Netherlands, other regions and total Netherlands (mln kg N)

	Base scenario			Taxes on nitrogen in feed concentrates		
Nitrogen balance	Southern sandy region	Other regions	Total	Southern sandy region	Other regions	Total
Production by animals	179.4	424.3	603.7	156.2	398.7	554.9
Emission as ammonia	32	71.1	103.1	28.3	64.9	93.2
Mineral fertilisers	48.8	326.1	374.9	47.9	334.3	382.2
Supply	196.2	679.3	875.5	175.8	668.1	843.9
Regional transport	32	-32	0	12.8	-12.8	0
Foreign export	11.6	0	11.6	11.6		11.6
Uptake by crops	65.4	390.7	456.1	64.5	387.8	452.3
Demand	109	358.7	467.7	88.9	375	463.9
Nitrogen surpluses at soil level	87.2	320.6	407.8	86.9	293.1	380

	Taxes on nitrogen in mineral fertilisers			Taxes on nitrogen in feed concentrates and Mineral fertilisers		
Nitrogen balance	Southern sandy region	Other regions	Total	Southern sandy region	Other regions	Total
Production by animals	169.5	372.2	541.7	158.1	377.5	535.6
Emission as ammonia	30.7	61.4	92.1	28.8	60.2	89
Mineral fertilisers	39.2	268	307.2	47.6	307.6	355.2
Supply	178	578.8	756.8	176.9	624.9	801.8
Regional transport	30.4	-30.4	0	13.1	-13.1	0
Foreign export	11.6		11.6	11.6		11.6
Uptake by crops	56	325.6	381.6	64.4	356.5	420.9
Demand	98	295.2	393.2	89.1	343.4	432.5
Nitrogen surpluses at soil level	80	283.6	363.6	87.8	281.5	369.3

	Taxes on 'Gross' nitrogen surpluses		
Nitrogen balance	Southern sandy region	Other regions	Total
Production by animals	153.7	377.9	531.6
Emission as ammonia	28.5	62	90.5
Mineral fertilisers	40.2	307.9	348.1
Supply	165.4	623.8	789.2
Regional transport	19.1	-19.1	0
Foreign export	8.8	8.2	17
Uptake by crops	55.7	355.7	411.4
Demand	83.6	344.8	428.4
Nitrogen surpluses at soil level	81.8	279	360.8