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CHAPTER 12

Optimal Taxation for the Reduction of Nitrogen Surplus in Dutch Dairy Farms, 1975–1989

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12.1 INTRODUCTION

Rapid increases in livestock production in the Netherlands have changed manure from a valuable input into a mere waste. This is especially true for the specialised pig and poultry farms. But dairy farms also apply manure to land in such large quantities that huge amounts of minerals, such as nitrogen and phosphate, have leached into the environment, causing serious environmental problems. Since the introduction of the milk quota system in 1984 in the EC the adverse environmental effects from the dairy sector are decreasing. However the intensity of production is still high, resulting in high levels of use of purchased feed and fertiliser.

Since 1984 the Dutch government has formulated policy measures to reduce the harmful effects of the production and application of manure. For the dairy farming sector the measures that have been taken by the government amount to the preventing of any increase in the number of animals, the introduction of maximum application levels of manure, the obligation to remove the manure surplus from the farm, and to apply the manure in such a way that the ammonia emission is drastically reduced.

Recently, economic instruments like levies on feed and on mineral surpluses have been considered by the Dutch government. As demonstrated by Baumol and Oates (1988), economic instruments can in theory achieve policy targets, such as emission levels, at lower total resource costs than uniform regulation. The farmer can then choose how he will react to the levy. He can pay the levy, he can reduce the number of animals, he can adapt the feed to influence the nutrient content of the manure, he can build pig houses with a low emission of ammonia, he can spread the manure in a low emission way, he can grow crops that take up large amounts of nutrients from the soil, he can apply manure at such a time that leaching is minimised, etc. Levies permit flexibility in the amount of pollution reduction achieved by each farmer, allowing polluters with low abatement costs per emitted unit to reduce emissions to a greater degree than polluters with high abatement costs per emitted unit.

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To implement a system with levies on nitrogen and phosphate surpluses, a mineral account has to be kept by the farmer. This requires a complete registration of all inputs (feed, fertiliser, manure, piglets, etc.) and outputs (meat, manure, crops, eggs, etc.) from which the surpluses can be calculated. Imposition of a levy on inputs (e.g. feed, fertiliser) or outputs may be much easier to implement than a levy on the surpluses but has the disadvantage that parts of the input that are not harmful to the environment are also levied. However, by the introduction of threshold values for inputs the "polluter pays" principle can roughly be obtained.

In this chapter the effects of a levy on feed and a levy on the nitrogen surplus at farm level are studied using an econometric approach, applied to data from Dutch dairy farms over the period 1975–89. To this end two bad outputs are included in the production model: nitrogen from animal excretion and nitrogen from fertiliser. Also the restriction on the output of milk in a subperiod of the data, due to the imposition of milk quota, is taken into account. Using duality theory, the optimising behaviour of farmers constrained by technology is represented by a short-run profit function. The bad outputs and the restricted output are treated as quasi-fixed in this function. The consequences of levies are derived, assuming optimal use of the bad outputs in the long term.

In section 12.2 we describe the Dutch dairy sector, the manure problem which the sector faces, and the manure policy of the government. In section 12.3 we put the behaviour of the dairy farmers into a general theoretical framework. The data we use for estimation and simulation purposes are subsequently described in section 12.4. The embedding of the model into a stochastic framework is treated in section 12.5.1. The estimation results are presented in section 12.5.2. Simulating the behaviour of the dairy farms with the aid of these estimation results is the next step, presented in section 12.6. Finally, in section 12.7 the main findings of this chapter are summarised.

12.2 THE DUTCH DAIRY SECTOR AND THE MANURE PROBLEM

Milk production takes place on more than 40 000 farms in the Netherlands. The majority of these farms specialise in dairy farming. In 1992, 1.8 million dairy cows were kept, so that the average size of a Dutch farm is about 45 cows. In 1984 milk quotas were introduced, not allowing a farmer to sell more milk than he sold in the year 1983. Since 1984 the number of dairy cows in the Netherlands has been reduced by more than 20%. This is the result of increasing milk production per cow and a decreasing volume of the milk quota.

The Dutch dairy sector has a rather intensive character. In the first part of the 1980s almost two cows per hectare of feedcrops and grassland were kept, besides 1.5 young stock. Since the introduction of the milk quota, the intensity of production has been considerably reduced, but is still rather high, resulting in relatively high levels of input and output. The butterfat content of the milk production per cow increased between 1970 and 1990 by 2% per year (CBS/LEI-DLO, *Landbouwcijfers*). The factors behind this production growth per cow are, among others, the breeding policy, higher levels of concentrate use, higher levels of fertiliser use, better grassland management and the switch to cubicle houses. Table 12.1 gives an overview of the growth in the use of two important inputs in the production process, concentrates and nitrogen fertiliser.

Table 12.1 Use of concentrates (kg per dairy cow) on large dairy farms on sandy soils and use of nitrogen fertiliser (kg per hectare of grassland) on dairy farms

Year	Concentrates	Nitrogen fertiliser
1965	1.055	159
1970	1.220	200
1975	1.900	256
1980	2.160	320
1985	2.335	343
1990	2.140	294

Sources: LEI, *Bedrijfsuitkomsten in de Landbouw* (various issues), CBS/LEI-DLO, *Landbouwcijfers* (various issues).

Both the use of concentrates per dairy cow and the use of nitrogen fertiliser doubled in a period of 25 years. Since the introduction of the milk quota there has been a tendency for a lower use of inputs per cow and per hectare. Due to a reduction in the number of cows per hectare, the use of concentrates per hectare has decreased by one-third.

The relatively large number of cows per hectare implies a large production of manure per hectare. Together with the high level of fertiliser use this leads to the application of large amounts of phosphate and nitrogen to the soil. Part of the phosphate and nitrogen is taken up by the plants, but a large part of these nutrients is lost to the environment. Despite the declining trend in the use of inputs in the production process of the dairy sector, the surpluses of nitrogen and phosphate that are lost to the environment are still too high. In 1990 the average nitrogen surplus (supply in the form of inputs minus removal in the form of outputs) on specialised dairy farms was about 400 kg of nitrogen per hectare (Poppe et al. 1994). The phosphate surplus was about 30 kg of phosphate per hectare. Only 20% of the nitrogen and only 40% of the phosphate that is supplied to the farm – mainly in the form of fertiliser and concentrates – is taken up by the crops.

Figure 12.1 gives an illustration of the flows of nitrogen through a farm and of the corresponding losses to the environment.

In the upper part of Figure 12.1 the animal production part of the farm is depicted. In the lower part the plant production part is shown. An amount of 194 kg nitrogen per hectare enters the farm in the form of purchased feed. Together with the 311 kg nitrogen per hectare that is included in the feed (mainly grass) produced on the farm, this is fed to the cows. Only 95 kg of nitrogen is transformed into animal products (milk, meat). The rest is excreted by the cows as manure. A small part of the manure vanishes into the air after transformation into ammonia. The remaining part (372 kg nitrogen per hectare) is applied to the crops (grass and maize). Together with the 307 kg of nitrogen in the form of chemical fertiliser and the deposition from the air of 49 kg, the total load of nitrogen amounts to 728 kg of nitrogen per hectare. From this amount 324 kg is taken up by the crops. The remaining 404 kg is lost to the environment, either to the air or to the soil and the ground and surface water.

Table 12.2 presents the nutrient flows in the form of a so-called nutrient balance or mineral balance at farm level.

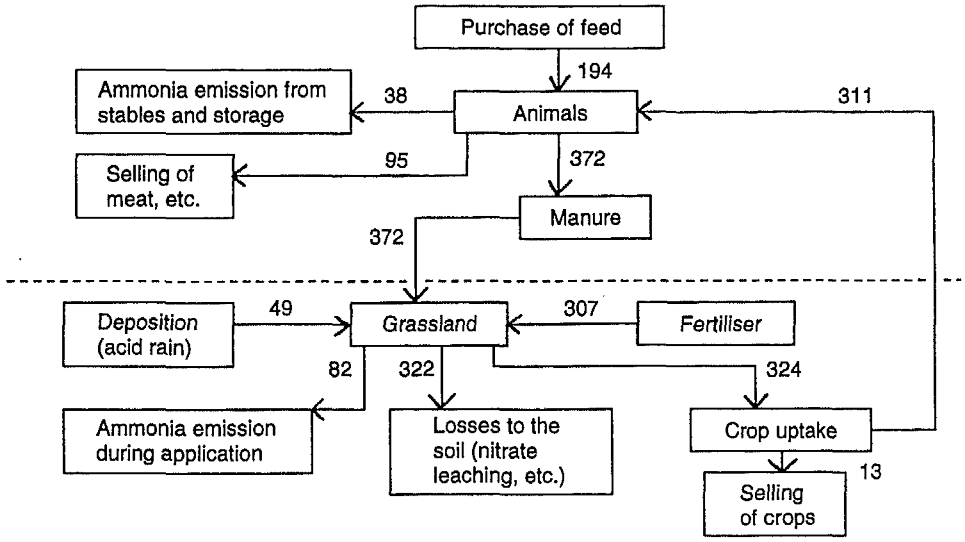

Figure 12.1 Average nitrogen flows on specialised dairy farms in the province of Gelderland in 1988 (kg nitrogen per hectare). Source: Van der Veen et al. (1993)

Table 12.2 Average nitrogen balance on specialised dairy farms in the province of Gelderland in 1988 (kg nitrogen per hectare)

Inputs		Outputs	
Purchased feed	194	Milk, meat	95
Chemical fertiliser	307	Marketed crops	13
Deposition (acid rain)	49	Surplus	442
Total	550		550

Source: Van der Veen et al. (1993).

The excess supply of nutrients to the soil causes large environmental problems. Nitrate and phosphate leaching from the soil affect the quality of the groundwater negatively. The emission of ammonia (NH_3) from stables and from manure spreading leads to acidification.

Since about 1985 the Dutch government has been working on the formulation and implementation of policies that lead to a reduction in the emission of nutrients from agriculture to the environment. One of the first measures that were taken was the fixing of the size of the livestock at farm level at 1986 levels. Furthermore, the application levels of phosphate from manure have been regulated. In four phases the maximum amount of phosphate per hectare that a farmer is allowed to apply to his crops, will be brought back to the level at which the application levels are in equilibrium with crop extraction (Table 12.3).

A farm with a surplus of phosphate can transport it to other farms or export it. A lot of intensive livestock farmers have large surpluses because they have only a small piece of land. Among the dairy farmers there are only a small fraction who have to

Table 12.3 Maximum application levels of phosphate by crop (kg per hectare)

Crop	Year			
	1986	1991	1995	2000*
Arable crops	125	125	110	65
Grass	250	200	150	85
Fodder maize	350	250	110	65

* Crop extraction levels (estimates); the exact levels still have to be decided on.

Source: LNV (1993).

remove manure from the farm. A dairy cow produces 41 kg of phosphate a year. This means that only for farms with a very large number of cows per hectare is the phosphate legislation restrictive.

With the tightening of the phosphate norms in the near future (65 kg per hectare for arable land and 85 kg per hectare for grassland), more dairy farms will be confronted with the norms. When a farmer has to transport a part of the manure to other (arable) farmers, he incurs costs for transport and for the acceptance of the manure by the other farmer. The removal of the manure of one cow will cost about 400 guilders. This is a large amount of money compared to the average labour return per dairy cow which amounted to some 500 or 800 guilders in the period 1970–90 (LEI, *Bedrijfsuitkomsten in de Landbouw* (BUL), various issues).

In 1994 at the national level there is still room for extra application of manure, given the present standards. But not every farmer with a phosphate "shortage" is willing to accept the manure from surplus farms, even if he is paid for it. Towards the year 2000 when phosphate from chemical fertilisers is also taken into account in the legal standards and when the standards become tighter, other solutions should be found for the surpluses of phosphate. A reduction in the size of the livestock, adaptation of the mineral content of the feed, and processing and exporting of manure are some possibilities.

At the moment there are no restrictions on the amount of nitrogen per hectare that is supplied to crops. However, there are some legal restrictions with respect to the period and the way in which the manure is spread, and to the storage of manure. These restrictions are directed at the reduction of the emission of ammonia and the leaching of nitrate. They came into effect in the second half of the 1980s and led to an improvement in the uptake by the crop of the nutrients that are available in the manure. However, the application level of nitrogen fertiliser is not yet bound to a maximum level. As can be seen from Table 12.1 most farmers have already reduced the application of nitrogen fertiliser, partly because of the effect of the milk quota and partly because of the improved effectiveness of the nitrogen in the manure.

Whereas in the 1980s the emphasis in government policy was on physical regulation (e.g. application standards), gradually more economic instruments (e.g. levies on surpluses) have been taken into consideration. The Dutch government prepared legislation for the introduction of levies on mineral surpluses in the second half of the 1990s. Farmers are now obliged to keep mineral accounts at farm levels, comparable with fiscal accounts. A farmer will thus have more flexibility to choose his own way of reducing mineral surpluses. The amount of the levy will determine to what extent changes in the production process will be made. A balance will be sought between the extra costs of paying the levy and the extra costs (or lower revenues) that result from realising smaller mineral surpluses.

Because a lot of effort is needed to prevent fraud with mineral accounts, an alternative may be the introduction of levies on feed or fertiliser. But it is expected that relatively large levies are needed because the costs of feed and fertiliser are only a small part of the total input costs. More than 50% of the total costs (more than 13 000 guilders per hectare) are related to the (quasi) fixed production factors, labour, machinery, land and buildings. The purchases of feed are about 2000 guilders per hectare. The costs of fertiliser are about 500 guilders per hectare, that is less than 5% of the total costs. The revenues in the dairy sector (more than 11 000 guilders per hectare in 1990) consist for some 75–80% of the revenues from milk. The sale of cattle and (fodder) crops constitute the remaining part.

12.3 THEORY

The theoretical framework of this chapter is the neoclassical production theory. This theory is very well known (e.g. Varian 1992). Also the inclusion of restricted outputs is standard (e.g. Moschini 1988; Helming et al. 1993). Attention will be focused on a rather new element: the incorporation of a bad output in the production theory (see also Fontein et al. 1994).

It is assumed that the objective of the farm family is the maximisation of short-run profit and that the farm family is a price-taker in the output and variable input markets. The following notation is used for quantities and prices of inputs and outputs. For the *inputs*, we distinguish between variable inputs (quantities x, prices p) and fixed inputs (quantities z). The state of technology is included in z in order to simplify the notation. For the *outputs*, we distinguish between one unrestricted output (quantity q_1, price p_1), restricted outputs (quantities q_0, prices p_0) and bad outputs (quantities s).

Without loss of generality we set $p_1 = 1$, that is, all prices and values are relative to the price of the unrestricted output. The farms are thus in static equilibrium with respect to the unrestricted output q_1 and the variable inputs x. This equilibrium depends, of course, on the level of the fixed inputs z and the restricted outputs q_0. The production function for the unrestricted output q_1 will depend not only on all inputs (x and z) and restricted outputs q_0, but will also include the quantity of waste discharged (the bad outputs s). This is standard in the theory of environmental economics, see e.g. Baumol and Oates (1988).

Profit, normalised by the unrestricted output price, is maximised by the farmer, subject to a production technology governing the relationship between variable inputs, fixed inputs, restricted outputs, bad outputs and unrestricted output. Thus

$$\pi(p, z, q_0, s) = \max_{q_1,x} (q_1 - p'x) \tag{1}$$

subject to

$$q_1 = q_1(x, z, q_0, s) \tag{2}$$

where π is the profit function normalised by the unrestricted output price.

According to duality theory, the optimising behaviour of farmers constrained by technology can equivalently be represented by the profit function π, given in equation (1). If the profit function satisfies certain regularity conditions, it is dual to the production function and its parameters contain sufficient information to describe the farm's production technology at profit-maximising points in the set of production possibilities. Testable conditions of regularity are: the profit function is decreasing in the price of the inputs; increasing in the price of the output; convex in all prices; linearly homogeneous in prices; increasing in the fixed inputs; decreasing and concave in the restricted outputs; and increasing and concave in the bad outputs. The profit function is normalised by the price of the unrestricted output, to ensure that the resulting function is homogeneous of degree zero in prices.

For the empirical analysis, a flexible functional form is used for the profit function, in this case, the quadratic (Lau 1978). The advantages of the quadratic functional form are: (i) it has a Hessian of constants so that the curvature property of convexity in prices and concavity in bad outputs can be tested globally; (ii) explicit forms can be obtained for the demand functions for the variable inputs, the supply function for the farm outputs, and the supply functions for the bad outputs; and (iii) negative profits are allowed. The normalised profit function is written as

$$\pi = \alpha_0 + \alpha'p + \beta'z + \gamma's + \varepsilon'q_0 + \tfrac{1}{2}p'Ap + \tfrac{1}{2}z'Bz + \tfrac{1}{2}s'Cs + \tfrac{1}{2}q_0'Dq_0 + p'Ez + p'Fs + p'Gq_0 + z'Hs + z'Kq_0 + s'Lq_0 \qquad (3)$$

where α_0 is a parameter; α, β, γ, ε are vectors of parameters; A, B, C, D, E, F, G, H, K, L are matrices of parameters, and A, B, C and D are symmetric.

Demand functions for the variable inputs can be obtained by differentiating the profit function with respect to the normalised prices p (Hotelling's lemma):

$$x = -\,\partial\pi/\partial p = -\,\alpha - Ap - Ez - Fs - Gq_0 \qquad (4)$$

The unrestricted output supply function is, using the definition of the normalised profit ($\pi = q_1 - p'x$),

$$q_1 = \alpha_0 + \beta'z + \gamma's + \varepsilon'q_0 - \tfrac{1}{2}p'Ap + \tfrac{1}{2}z'Bz + \tfrac{1}{2}s'Cs + \tfrac{1}{2}q_0'Dq_0 + z'Hs + z'Kq_0 + s'Lq_0 \qquad (5)$$

It is possible that the "restricted outputs" are restricted only in a subperiod of the data. This happens in our case where the "restricted output" is milk. In the period when the "restricted outputs" q_0 are, in fact, not restricted, we define total profit as

$$\pi^* = \pi + p_0'q_0 \qquad (6)$$

Then, setting marginal total profit with respect to q_0 equal to zero, we obtain

$$0 = \partial\pi^*/\partial q_0 = \partial\pi/\partial q_0 + p_0 = \varepsilon + Dq_0 + G'p + K'z + L's + p_0 \qquad (7)$$

from which supply functions for q_0 are obtained as

$$q_0 = - D^{-1} [p_0 + \varepsilon + G'p + K'z + L's] \tag{8}$$

The model then consists of equations (3)–(5) and, for the subperiod that milk is not restricted, (8).

The consequences of a levy on the variable inputs in the short run can be calculated straightforwardly by using equations (3)–(5). In the short run it is assumed that the quantities of the bad outputs are fixed. In the long run it is assumed that the quantities of the bad outputs are variable, while the quantities of the fixed inputs remain fixed. The distinction between short-run and long-run responses is thus drawn on the basis of changes in the bad outputs. The bad outputs cannot be altered instantaneously and are in a way to be considered as intermediate between an unrestricted and a restricted output. To the policy-makers only the long-run responses are of interest. Using the profit function (equation (3)) we derive the shadow prices of the bad outputs as

$$r = \partial\pi/\partial s = \gamma + F'p + H'z + Lq_0 + Cs \tag{9}$$

where r is a vector of shadow prices of the bad outputs. The relation between the shadow price of the bad output and the bad output itself is negative, because of the assumption that the profit function is concave in the bad output. The relation is linear because of the assumed quadratic form of the profit function.

Using equation (9) the consequences of a levy on a bad output in the long run can be calculated. This is illustrated graphically by Figure 12.2. Assume for example that the actual situation for a farm is given by point A. The amount of the bad output is equal to s_1 and the related shadow price is equal to r_1. Assume that from an environmental point of view a quantity of waste discharged equal to s_3 is just acceptable. The related shadow price at point B is r_3. The surplus of the bad output on the farm is equal to $s_1 - s_3$. Now, we analyse a levy of $r_2 - r_1$ on the bad output. When the farmer decides to stay at point A, he will not be confronted by a decrease in the profit but he has to pay levies equal to $(r_2 - r_1)*(s_1 - s_3)$. The sum of his profit loss and the paid levies at point A are equal to the area AJID. When the farmer decides to reduce production of the bad output according to the environmentally acceptable standard, he moves from point A to point B. His profit will decrease by the area ABD, but he is not due to pay levies. We take into account that the costs to produce the bad output will also decline (area ADFH). The sum of his profit loss and the paid levies at point B are equal to area ABD. When the farmer is a profit maximiser he will decrease the amount of the bad output in the long run by $s_1 - s_2$. At point C the shadow price of the bad output is equal to the levy plus the shadow price in the original situation. His profit loss is equal to area ACE. He also has to pay levies $(r_2 - r_1)*(s_2 - s_3)$. The sum of his profit loss and the paid levies are equal to area ACID. As can be seen from Figure 12.2, the sum of the profit loss and the paid levies are lowest at point C. Because of this change in the bad output, the demand for the variable inputs and the supply of the output will also change, see equations (4) and (5).

The consequences of a levy on the variable inputs in the long run can also be calculated. The same line of reasoning is used as in the literature when a quasi-fixed input is involved, see e.g. Brown and Christensen (1981). A levy on the variable inputs

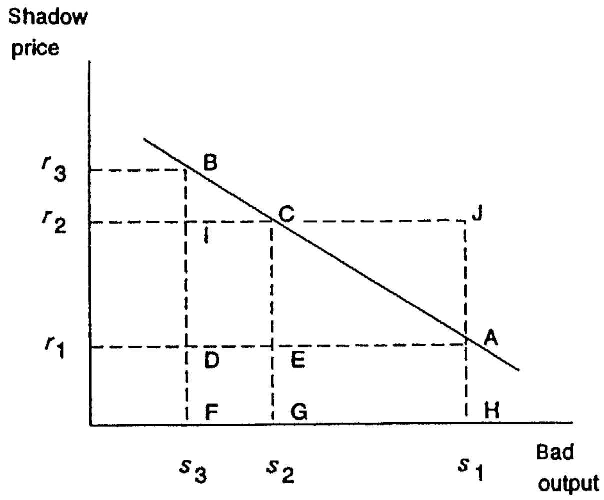

Figure 12.2 The relation between the shadow price and the bad output

results in a price change in the variable inputs. The effects of this price change on the bad outputs can be calculated by rewriting equation (9) as

$$s = C^{-1}(r - \gamma - F'p - H'z - Lq_0) \tag{10}$$

The change in the bad outputs results in a change in the variable inputs, see equation (4).

The effects of a levy on the variable inputs and the bad outputs can be calculated by simulations of the model. However, to get an insight into the working of the model, elasticities can also be used. We will calculate short-run price elasticities, long-run price elasticities, and shadow prices with respect to the fixed inputs, the restricted outputs and the bad outputs.

The short-run (SR) responses of the variable inputs are given by

$$(\partial x/\partial p)_{sr} = -A \tag{11}$$

The short-run responses of the farm output are given by

$$(\partial q_1/\partial p)_{sr} = -Ap \tag{12}$$

The shadow prices of the fixed inputs and the restricted outputs are calculated straightforwardly using the profit function:

$$\partial\pi/\partial z = \beta + E'p + Bz + Hs + Kq_0 \tag{13}$$

$$\partial\pi/\partial q_0 = \varepsilon + Dq_0 + G'p + K'z + L's \tag{14}$$

The long-run (LR) responses of the variable inputs and the bad outputs can be calculated from equations (4) and (10):

$$(\partial x/\partial p)_{\mathrm{lr}} = (\partial x/\partial p)_{\mathrm{sr}} + (\partial x/\partial s)_{\mathrm{sr}}\,(\partial s/\partial p)_{\mathrm{lr}} = -A + FC^{-1}F' \tag{15}$$

$$(\partial s/\partial p)_{\mathrm{lr}} = -C^{-1}F' \tag{16}$$

$$(\partial x/\partial r)_{\mathrm{lr}} = (\partial x/\partial s)_{\mathrm{sr}}\,(\partial s/\partial r)_{\mathrm{lr}} = -F\,C^{-1} \tag{17}$$

$$(\partial s/\partial r)_{\mathrm{lr}} = C^{-1} \tag{18}$$

12.4 DATA

This study is based on data of Dutch farms obtained by the *Landbouw Economisch Instituut* (Agricultural Economics Research Institute (LEI-DLO)). This institute collects yearly data on about 1000 farms. These farmers are allowed to take part for up to seven years in a rotating panel, though some exit earlier. So the survey is an unbalanced panel. Furthermore, only farms over a certain size (measured in standard value added) are included. As a threshold value we took half the size per labourer on large efficient farms. Despite the fact that in this way almost one-third of the farmers are excluded, only 5–10% of agricultural production is left out.

The data used span the period 1975–89 and consist of about 15 000 observations. Of these observations 1% was corrected in one way or another. There were some observations where only quantities but no values were recorded. In this case the missing values were estimated based on an average price for that kind of farm and the relevant year. Observations with negative quantities which clearly should be positive or observations with obvious errors caused by erroneous data entry were deleted from the sample. Furthermore, as this study deals with dairy farms, only farms are selected from the survey for which over two-thirds of the standardised value added contributes to this specific sector. This results in data on 7392 dairy farms for estimation purposes.

Two variable inputs (feed and other inputs) and one variable output are included in the profit function. Prices of these are determined by calculation of a Törnqvist index (Deaton and Muellbauer 1980) from recorded quantities and product specific prices. The Törnqvist index for farm F, P_{F}, is defined as

$$\log(P_{\mathrm{F}}) = \sum_{\mathrm{k}} \tfrac{1}{2}(w_{\mathrm{kF}}^{1} + w_{\mathrm{k}}^{0})\,\log(p_{\mathrm{k}}^{1}/p_{\mathrm{k}}^{0})$$

with w_{kF}^{1} and w_{k}^{0} the budget share of good k with price p_{k}^{1} and p_{k}^{0} in the period of interest and the reference period respectively. The share w_{k}^{0} is an average over the reference period. The resulting indices P_{F} are averaged to obtain one index P. The product-specific prices are obtained from the Dutch Central Bureau of Statistics (CBS) [CBS/LEI-DLO].

The variable input feed consists of feed for cattle (both power feed and roughage), feed for fattening pigs, feed for breeding sows, feed for laying hens, feed for broilers and feed for fattening calves. Of these only bought feed is considered, not feed produced by the farmer himself. Feed for cattle is by far the most important of these. Almost 80% of the value of the input is accounted for by this feed, the remainder consists almost entirely of feed for pigs.

The variable inputs of energy, hired labour, pesticides, the cost of the prevention and cure of diseases, a category of non-specified costs, and the cost of inputs for crop growth (except fertiliser) are collected into one category: other inputs. The main components of this group are non-specified costs (50%), hired labour (35%) and the prevention and cure of diseases (10%).

The variable output consists of cows, calves, fattening calves, sows, pigs for fattening, pigs for consumption, laying hens, broilers, horses, sheep, eggs, the output of crop growth and a remaining group of non-specified revenues. Except for eggs, prices of animal output are obtained from our data, not from CBS data. The prices of the output eggs and the output of crop growth are obtained from the CBS. Again a few components dominate – cows and calves (50%), and pigs for fattening (over 25%). The output of crop growth is the next largest with a contribution of only 5%. We will sometimes refer to the variable output as meat.

Profit is determined by the difference in the value of the above-mentioned variable output and the variable inputs. Of course normalisations by the price of the variable output are carried out in our calculations as described in section 12.3. Note that the revenues of milk are not included in this definition of profit because milk is a restricted output for reasons mentioned in section 12.2.

As for the inclusion of the bad output(s) several possibilities arise. Though both nitrogen and phosphorus (among other constituents) are bad outputs, the composition of manure is rather constant over time. In other words the nitrogen and phosphorous content of manure are highly correlated. Here only the nitrogen content is chosen to be included as a bad output in order to avoid collinearity problems in the estimation process. The same holds for fertiliser. We included only the nitrogen content of fertiliser, and not the phosphorous content. Note that we treat nitrogen in fertiliser as a fixed input. We do this because application of fertiliser is partly determined by habits formed by the farmer. Its use is thus not completely optimised and a treatment as a variable input can lead to its own price elasticities with a wrong sign, see also section 12.5.2.

The fixed inputs are labour, machinery and buildings, and land. Labour is taken in years, land in hectares. For machinery and buildings a Törnqvist index is calculated, based on separate price indices for buildings and machinery obtained from the CBS (CBS/LEI-DLO). A quantity is then determined and implemented as the fixed input by division of the value by the Törnqvist index. A technology change is allowed for by the inclusion of a time variable. This time variable is the year minus 1975 and is treated in the equations as if it were a fixed input. Milk is a restricted output, taken in litres.

The calculated Törnqvist indices for the variable inputs, variable output, milk and the fixed input buildings and machinery are tabulated in Table 12.4. A steady increase in the price of buildings and machinery has occurred over time. The price of feed, though varying over time, is in 1989 equal to the level of 1975. Other inputs, the output and milk have all become more expensive.

Table 12.4 Törnqvist price indices for the variable input feed and other inputs, the variable output and the fixed input buildings and machinery. In addition the price of milk is included. All are presented over the time period 1975–89

Year	Input feed	Other inputs	Output	Milk (fl/l)	Buildings and machinery
1975	1.00	1.00	1.00	0.54	1.00
1976	1.12	1.10	1.00	0.57	1.07
1977	1.13	1.16	1.03	0.62	1.14
1978	1.00	1.21	1.05	0.62	1.20
1979	1.11	1.26	1.05	0.63	1.28
1980	1.19	1.36	1.05	0.64	1.40
1981	1.25	1.43	1.13	0.72	1.49
1982	1.26	1.54	1.17	0.74	1.56
1983	1.32	1.64	1.18	0.77	1.58
1984	1.34	1.69	1.13	0.75	1.60
1985	1.20	1.71	1.15	0.76	1.63
1986	1.09	1.70	1.10	0.77	1.66
1987	0.94	1.68	1.06	0.79	1.71
1988	0.96	1.70	1.15	0.84	1.76
1989	1.00	1.71	1.21	0.84	1.79

Table 12.5 Mean and standard deviation of variables of interest

	Mean	Standard deviation
Nitrogen, animal (kg)	6580	3820
Nitrogen, fertiliser (kg)	6990	5300
Labour (years)	1.55	0.58
Buildings/index (fl)	175 000	129 000
Milk (l)	260 000	175 000
Land (hectare)	25.0	13.9
Normalised profit (fl)	–46 700	49 900
Value feed (fl)	78 300	65 900
Value other inputs (fl)	36 900	32 900
Value outputs (fl)	63 500	59 900

A summary of sample means of variables of interest are presented in Table 12.5. These means are weighted by the relative importance of the individual farms as calculated by the LEI. It appears that the average farm applies about 540 kg nitrogen per hectare to the soil in the form of nitrogen contained in fertiliser and manure, which is about double the amount that is taken up by the crops (see section 12.2). Also note that the mean profit is negative due to the fact that revenues of milk are not included in this figure.

12.5 ESTIMATION

12.5.1 Estimation theory

The model we wish to use for estimation is given by equations (3)–(5) and (8). Embedding these equations in a stochastic framework, we obtain:

normalised profit:

$$\prod_{it} = \alpha_0 + \alpha' p_{it} + \beta' z_{it} + \gamma' s_{it} + \varepsilon_0 q_{0,it} + \tfrac{1}{2} p_{it}' A p_{it} + \tfrac{1}{2} z_{it}' B z_{it} + \tfrac{1}{2} s_{it}' C s_{it} + \tfrac{1}{2} \delta_0 q_{0,it}^2 + p_{it}' E z_{it} + p_{it}' F s_{it} + z_{it}' H s_{it} + q_{0,it} (\lambda' p_{it} + \mu' z_{it} + \upsilon' s_{it}) + u_{it}^{(1)} \quad (19)$$

demand for variable inputs (feed and "other inputs"):

$$x_{it} = -\alpha - Ap_{it} - Ez_{it} - Fs_{it} - q_{0,it}\,\lambda + u_{it}^{(2)} \quad (20)$$

unrestricted output (meat) supply:

$$q_{1,it} = \alpha_0 + \beta' z_{it} + \gamma' s_{it} + \varepsilon_0 q_{0,it} - \tfrac{1}{2} p_{it}' A p_{it} + \tfrac{1}{2} z_{it}' B z_{it} + \tfrac{1}{2} s_{it}' C s_{it} + \tfrac{1}{2} \delta_0 q_{0,it}^2 + z_{it}' H s_{it} + q_{0,it} (\mu' z_{it} + \upsilon' s_{it}) + u_{it}^{(3)} \quad (21)$$

"restricted output" (milk) supply:

$$q_{0,it} = \begin{cases} -(1/\delta_0)(p_{0,it} + \varepsilon_0 + \lambda' p_{it} + \mu' z_{it} + \upsilon' s_{it}) + u_{it}^{(4)} & \text{(period I)} \\ q^*_{0,it} + u_{it}^{(4)} & \text{(period II)} \end{cases} \quad (22)$$

The double subscript *it* refers to farm *i* in year *t*. There are 15 years of observations, 1975–89. The data form a rotating panel where each farm is represented in the sample for a maximum period of seven years (some farms much shorter). The total number of farms in the sample over the whole period is 7392 and these are treated as independent observations.

Our estimation problem is complicated by the fact that a milk quota was instituted by Dutch law in April 1984. This implies that during the first period of nine years ("period I") the production of milk was not restricted, while during the second period of six years ("period II") milk should be treated as a restricted output. Thus equation (22) consists of two parts, one for each period. In period I (no quota) we used the supply functions derived in equation (8), while in period II (quota restriction) we set

$$q_{0,it} = q^*_{0,it} + \text{random error}$$

where $q^*_{0,it}$ denotes the applicable milk quota for farm *i* in year *t*. In practice, we do not observe $q^*_{0,it}$. However, it would be irrational for farmers not to produce the maximum quantity of milk. Hence, we put $q^*_0 = q_0$ in period II.

The other variables have the following meaning and dimensions:

Π = profit, normalised by the price of meat (the unrestricted output)

p = (p_1, p_2) = price of variable inputs, normalised by the price of meat:
- p_1 = feed
- p_2 = other inputs

$z =$ (z_1, z_2, z_3, z_4) = fixed inputs:
z_1 = human labour (years)
z_2 = buildings and machinery normalised by its price index
z_3 = land (ha)
z_4 = time (years, 1975 = 0)

$s =$ (s_1, s_2) = bad outputs:
s_1 = nitrogen (animal excretion, kg)
s_2 = nitrogen (fertiliser, kg)

$x =$ (x_1, x_2) = variable inputs:
x_1 = feed
x_2 = other inputs

q_1 = unrestricted output (meat)
q_0 = "restricted output" (milk)
p_0 = price of milk (when applicable), normalised by the price of meat

The matrices A, B and C are symmetric. In addition, we assume that the 2×2 matrix C is diagonal. Taking these restrictions into account, there are 54 structural parameters to be estimated. Regarding the stochastic structure, we assume that the observations are uncorrelated, but that the four equations are correlated, that is,

$$\text{var}[(u_{it}^{(1)}, u_{it}^{(2)\prime}, u_{it}^{(3)}, u_{it}^{(4)})'] = \sum$$

The covariance matrix $\sum$ is of dimension 5 (not 4), thus adding another 15 parameters. This brings the total number of unknown parameters to 69.

Equations (19)–(22) form a system of nonlinear (because of (22)) simultaneous equations and are estimated, in essence, by nonlinear 3SLS. As instruments we used not only all exogenous variables (which would lead to standard 3SLS estimates), but also θ_t times the exogenous variables and $\theta_t q_0$, where θ_t is a dummy variable, taking the value 0 in period I and the value 1 in period II.

12.5.2 Estimation results

The estimates of the parameters of the model are presented in Table 12.6. The R^2 of the profit function is 0.71; the R^2 of the demand function for feed is 0.80; the R^2 of the demand function for other variable inputs is 0.68; the R^2 of the supply function of the unrestricted output is 0.57; and the R^2 of the supply function of milk is 0.92. Nine of the 54 parameters are not significant at the 5% level. However, care should be taken not to base far-reaching conclusions on the significance of parameters. The profit function is nonlinear in variables, so that one cannot generally associate a parameter with a particular variable, as in a linear model. More information is provided by price elasticities of input and output and shadow prices of bad outputs and fixed inputs. The correlations between the equations (Table 12.7) are caused either by the effects that are common to all farmers but vary across years (like the weather) or by omitted, farm-specific variables (like the personal skills of a farmer or the quality of land). We

Table 12.6 Parameter estimates of the normalised profit function, the demand functions for feed and other input, the supply functions of the output and milk

Parameter	Estimate	"T" ratio
α_0	$20.1 * 10^3$	5.35
α_1	$-52.3 * 10^3$	-13.9
α_2	$-14.4 * 10^3$	-5.14
β_1	$10.4 * 10^3$	4.48
β_2	0.102	6.75
β_3	-944	-6.77
β_4	999	2.17
γ_1	24.2	37.4
γ_2	0.258	0.63
ε_0	-0.426	-24.8
A_{11}	$43.7 * 10^3$	13.28
A_{12}	$5.30 * 10^3$	2.65
A_{22}	$21.0 * 10^3$	7.20
B_{11}	$-1.72 * 10^3$	-5.08
B_{12}	$-47.9 * 10^{-3}$	-6.51
B_{13}	-202	-2.32
B_{14}	-360	-1.83
B_{22}	$-0.349 * 10^{-6}$	-5.85
B_{23}	$-2.05 * 10^{-3}$	-3.63
B_{24}	$-2.10 * 10^{-3}$	-1.8
B_{33}	-4.59	-1.20
B_{34}	47.3	4.12
B_{44}	-85.5	-1.76
C_{11}	$-0.529 * 10^{-3}$	-20.4
C_{22}	$-28.5 * 10^{-6}$	-0.67
δ_0	$2.10 * 10^{-6}$	20.3
E_{11}	$-3.77 * 10^3$	-6.75
E_{21}	$-16.0 * 10^{-3}$	-4.38
E_{31}	$1.77 * 10^3$	48.8
E_{41}	108	0.83
E_{12}	$-4.30 * 10^3$	-13.5
E_{22}	$6.75 * 10^{-3}$	3.21
E_{32}	-390	-18.3
E_{42}	-998	-7.41
F_{11}	-12.6	-88.2
F_{12}	-3.23	-12.0
F_{21}	2.54	23.7
F_{22}	-0.573	-9.57
H_{11}	2.06	6.21
H_{12}	$45.3 * 10^{-6}$	17.7
H_{13}	0.155	8.80
H_{14}	-0.320	-7.35
H_{21}	0.219	0.93
H_{22}	$3.57 * 10^{-6}$	2.58
H_{23}	$40.2 * 10^{-3}$	3.98
H_{24}	-0.151	-4.70
λ_1	$-97.1 * 10^{-3}$	-17.6
λ_2	$-36.3 * 10^{-3}$	-13.5
μ_1	$0.829 * 10^{-3}$	0.09
μ_2	$-0.782 * 10^{-6}$	-10.4
μ_3	$-2.82 * 10^{-3}$	-4.57
μ_4	$13.5 * 10^{-3}$	9.97
υ_1	$-46.5 * 10^{-6}$	-17.5
υ_2	$-3.25 * 10^{-6}$	-2.31

Table 12.7 Correlations of residuals of equations (19)–(22)

Equation	(19) profit	(20) feed	(20) other inputs	(21) meat	(22) milk
(19) profit	1.0000	−0.3084	−0.3805	0.4363	0.1969
(20) feed	−0.3084	1.0000	0.1423	0.5692	0.0543
(20) other inputs	−0.3805	0.1423	1.0000	0.3163	−0.0873
(21) meat	0.4363	0.5692	0.3163	1.0000	0.1718
(22) milk	0.1969	0.0543	−0.0873	0.1718	1.0000

will illustrate both cases and comment on the sign of the correlations. First, a year with high temperature and low rainfall causes a relatively low profit in combination with a relatively high level of purchased feed and other inputs and relatively low outputs. This leads to a negative correlation between equation (19) on the one hand and equation (20) on the other. Between equation (19) on the one hand and (21) and (22) on the other there is a positive relation. This is in accordance with Table 12.6. Second, high quality of land and labour causes a high profit in combination with a relatively low level of purchased inputs and relatively high outputs, also in accordance with our estimated correlations.

Before calculating the elasticities and shadow prices it is important to test the basic assumption underlying the methodology used in this study, that is that farmers are profit maximisers. Results of testing the assumption of monotonicity are displayed in Table 12.8. This table shows that the data are relatively well behaved in relation to the theory, with the exception that there are some doubts with respect to the monotonicity condition of labour. According to Table 12.6 the normalised short-run profit function is convex in the normalised prices and concave in the bad outputs. The assumption of short-run profit maximisation behaviour is, therefore, not rejected by the data.

The short-run price elasticities of feed, other inputs and the meat output were calculated using equations (9) and (10), see Table 12.9. The shadow prices of the bad outputs and the fixed inputs were calculated using equations (11) and (12). The variances of these elasticities are calculated by a bootstrapping technique.

As can be concluded from Table 12.9, the price elasticity of the demand for feed is −0.39. Feed and other inputs are complements. The elasticity of feed with respect to the price of meat is the opposite of the sum of the price elasticities with respect to the inputs because the input demand functions, and also the output supply function, are homogeneous of degree zero in prices.

The price elasticities of Table 12.9 are high compared to other studies (Elhorst 1990; Helming et al. 1993; Thijssen 1992). A possible reason for this difference is that in these other studies differences between the quality of labour and land across farms is taken into account by including fixed effects. We therefore also estimated a model with fixed effects. This model, however, results in a negative long-term relation between the level of fertiliser and the price of fertiliser. This unrealistic result is probably caused by the fact that models estimated by fixed effects are more sensitive to measurement errors. Fertiliser is a small input and therefore difficult to handle in our model. We also estimated a model where we assume that fertiliser is a variable input. Once again this results in a positive price elasticity of fertiliser.

The shadow price of the nitrogen content in manure for the average dairy farm is 6.49 guilders, see Table 12.10. This means that the short-run profit (that is, the

Table 12.8 Percentage of farms that fulfil the monotonicity conditions

Derivative of profit by:	% that fulfil monotonicity condition
Price feed	99.3
Price of other inputs	99.8
Output price	99.7
Labour	52.5
Buildings	84.8
Nitrogen (animal)	90.0
Nitrogen (fertiliser)	99.3
Land	96.6

Table 12.9 Short-term price elasticities for the average dairy farm, period 1987–89 (standard errors in brackets)

	Price of feed	Price of other inputs	Price of meat
Feed	−0.39 (0.03)	−0.08 (0.03)	0.47 (0.03)
Other inputs	−0.12 (0.04)	−0.80 (0.11)	0.92 (0.10)
Meat	−0.29 (0.03)	−0.38 (0.04)	0.67 (0.06)

Table 12.10 Shadow prices for the average dairy farm, period 1987–89 (standard errors in brackets)

	Shadow price
Nitrogen (animal)	6.49 (0.29)
Nitrogen (fertiliser)	0.79 (0.23)
Human labour per year	−3320 (1520)
Capital per guilder	0.028 (0.009)
Milk (l)	−0.41 (0.01)
Land per hectare	459 (85)

difference between revenues and costs of the variable inputs, see equation (1)) rises by 6.49 guilders when the nitrogen content of manure increases by 1 kg. This is caused by the relation between cows and the nitrogen content in manure: an increase of the nitrogen content in manure implies an increase in cows. On average a cow produces 130 kg of nitrogen a year. So, an increase of one cow results in an increase of about 1000 guilders of the short-run profits.

The shadow price of nitrogen in fertiliser for the average dairy farm is 0.79 guilders. This is lower than the price of nitrogen in fertiliser, which is about 1 guilder. This indicates that fertiliser was overused on dairy farms in this period.

Because of the quota on milk there is a surplus of labour on dairy farms, leading to a negative shadow price for labour. The shadow price of capital is the profit which can be used to pay the capital interest and depreciation costs. The result for capital is reasonable. The rent of land without the quota of milk is low. The shadow price of milk is calculated using equation (3). To obtain the shadow price of the quota equation (6) should be used. The resulting nominal shadow price of the quota in 1988/

Table 12.11 Long-term price elasticities for the average dairy farm, period 1987–89 (standard errors in brackets)

	Price of feed	Price of nitrogen
Feed	−5.0 (2.5)	0.4 (0.7)
Nitrogen (animal)	−2.0 (0.1)	−0.5 (0.1)
Nitrogen (fertiliser)	7.6 (11)	−2.8 (3.5)

89 was 0.43 guilders per kilogram for the average farm. This equals the lease price of the quota observed in the Netherlands in the same period.

Finally, long-term price elasticities were calculated using equations (15)–(18). The price elasticity of feed rises considerably in comparison to the short-term elasticity, see Table 12.11. The positive relation between the price of feed and the demand for fertiliser indicates the large substitution possibilities between purchased feed and fertiliser. The standard error is very high, this indicates once again the problems which we have in handling the input fertiliser.

A rise in the price of nitrogen reduces the amount of cows and the amount of fertiliser, but because of the substitution possibilities between fertiliser and feed, the demand for feed rises. The long-term elasticities with respect to the shadow price of nitrogen give an indication of the effects of a levy on the nitrogen surplus. This levy is further investigated in the next section.

12.6 SIMULATIONS

12.6.1 Method of simulation

As pointed out in section 12.3, the effect of a levy on feed or nitrogen on the output of nitrogen can be calculated with the aid of equation (8). In the simulations presented below equation (8) is used in differential form, i.e. the change in the produced amount of nitrogen Δs is calculated from the effect of a levy on feed of magnitude Δp, or a levy on nitrogen of magnitude Δr. This results in

$$\Delta s = C^{-1} (\Delta r - E'\Delta p) \tag{23}$$

with $\Delta r = 0$ or $\Delta p = 0$ in the case of a levy on feed or nitrogen respectively. In the case of a levy on nitrogen the levy is taken equal (per kg) for both nitrogen excretion and fertiliser. However, the levy is only applied to the amount of nitrogen which exceeds the uptake of nitrogen by the crops. In our simulations this limit is set to 300 kg/ha. As was shown in section 12.2, this is a reasonable estimate for specialised dairy farms in the present situation. However, with lower levels of nitrogen – for example because of the introduction of a levy – the nitrogen uptake of the crops will also be lower. This effect has not been taken into account in the simulations. The environmentally acceptable application level will be somewhat higher than the 300 kg we assumed. A small amount of losses to the environment need not be very harmful. An agricultural practice without losses seems even impossible. By neglecting the 50 kg of nitrogen that comes from deposition (acid rain) we implicitly assumed a levy-free surplus of 50 kg/ha. Thus, the levy paid equals ($\sum s - z_3$ * 300 kg/ha) times the levy per kilogram of nitrogen, with

$\sum s$ the amount of nitrogen excretion plus fertiliser after the levy is applied. Three cases can occur:

(1) If the original amount of nitrogen is below the threshold value, Δs is set to zero. No levy is paid in this case. This is an uncommon situation.
(2) If the levy causes the amount of nitrogen to drop from above to below the threshold value, Δs of both components (animal excretion and fertiliser) are adjusted by the same factor in such a way that the output of nitrogen after the levy equals the threshold value. In this case no levy is paid. This situation becomes the more common the higher a levy per kilogram excess nitrogen is imposed.
(3) If both the original amount of nitrogen and the amount after the levy is applied lie above the threshold value, Δs is calculated correctly by equation (23). The levy paid is equal to the amount of kilograms of nitrogen above the threshold value times the levy per kilogram. This is the most common situation.

Every farmer can avoid the levy by transporting the manure away to other farms. There is no way in which we can model this effect with the available data. Transportation, however, is costly and it will become even more so if farmers are less willing to accept the manure of others because in that case manure has to be transported over larger distances. Furthermore, as long as the imposed levy does not exceed the cost of transportation of about 3 guilders per kilogram of nitrogen no transportation will take place anyway.

Also, if a very high levy on feed is applied, Δs as calculated by equation (23) could become so large that it causes one or both of the nitrogen components to become negative. If this occurs Δs of this component is adjusted such that s of this component is zero after the levy on feed. Avoiding this levy in a way other than by buying less or different feed is impossible. In the case where he buys less he may grow more feed of his own. This is a problem if the farmer uses a lot of polluting fertilisers in doing so. We will return to this possibility in the next subsections.

Once Δp or Δr are set and Δs and s after the levy is applied are calculated for every farm by means of equation (23), the profit and the amount of inputs and outputs can be calculated from equations (3)–(5) both before and after a levy is applied. In case of a levy on nitrate the profit still has to be lowered by the levy paid, as the cost of this levy is not included in equation (3). Furthermore, in our simulations we added the revenues of milk to the profit of equation (3) in order to obtain an income concept which is relevant to the farmer. All simulations presented in the next sections are carried out in this way. Of course, in these simulations use has been made of the estimated coefficients presented in Table 12.6. Also the fixed inputs, prices and the amount of nitrogen are taken to be the same as in the estimation process except for the obvious cases of the price of feed after a levy on feed and the amount of nitrogen after a levy.

After the simulations, means of the relative change of the profit (including the revenues of milk) and the amount of nitrogen due to the levy are taken. These are weighted by the relative importance of the individual farms as calculated by the LEI, in order to obtain figures that are a more general reflection of the environmental impact of the nationwide institution of a levy on feed or nitrogen.

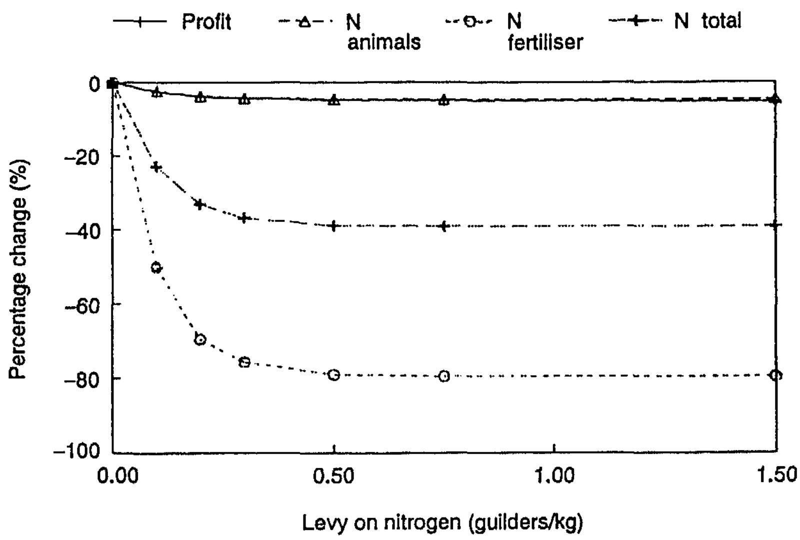

Figure 12.3 Influence of a levy on the surplus of nitrogen

12.6.2 Simulation results

12.6.2.1 Levy on the surplus of nitrogen

In Figure 12.3 we plotted the results of our simulations of a levy on the nitrogen surplus. These simulation results are long-term effects, because in our model we assumed the amount of nitrogen to be fixed in the short term. The percentage change of nitrogen caused by a levy on nitrogen reaches a saturation level at around 0.5 guilder/kg. At this point a decrease in the total amount of nitrogen of over 40% is obtained. This saturation effect can be explained as follows. From Table 12.5 it appears that the average dairy farm uses about 6600 kg of nitrogen contained in fertiliser and produces an almost equal amount of nitrogen contained in manure. This results in an average of 13 500 kg nitrogen per farm. If we combine this figure with the average amount of land of a dairy farm, which is 25 ha, we obtain 540 kg/ha. As a levy on the nitrogen surplus has no further effect once the total amount of nitrogen drops to 300 kg/ha, this rough estimate sets an upper limit to the percentage change of the nitrogen production to about 44%. This can be compared to the observed saturation level of around 40% in our simulations. The main difference is that the simulations were carried out over the period 1987–89, and Table 12.5 contains data averaged over the entire data set (1975–89).

It is also clear from Figure 12.3 that the percentage change in the amount of nitrogen in fertiliser is much larger (about 80%) than that in manure (about 5%). This is because a 1 kg reduction of nitrogen in manure is much more costly than the same reduction in fertiliser. As pointed out earlier, in many cases too much fertiliser is used, the shadow price of fertiliser is lower than the market price. Because of this fact the reduction in the application of fertiliser in the case of a levy on the nitrogen surplus is very strong. Due to the linear character of our simulation model this strong reaction does not diminish at high levels of the levy. This is a shortcoming of our simulation

12.6.2.3 Refunding

We also investigated different scenarios of refunding the revenues of the levy to the farmers. In these simulations we assumed the farmers react the same, irrespective of getting the refund or not. We studied a refund proportional to the amount of land, proportional to the amount of labour and an equal refund per farm. As most farms are very similar with respect to the amount of land and labour, it turned out that there are few differences between these scenarios. This holds for both a levy on feed and a levy on the surplus of nitrogen.

12.7 CONCLUSIONS AND CAVEATS

In this chapter an econometric model of the Dutch dairy sector is presented. The estimated model describes Dutch dairy farmers' decisions about short-run profit, demand for feed and other variable inputs, meat supply, and milk supply in the unrestricted period. The description seems to be appropriate, because the underlying theoretical assumptions are not rejected by the data, and the sign of elasticity estimates are correct. Short-term price elasticities of supply and feed demand are smaller than one. This is not surprising because of the assumption that the size of the livestock and the use of fertiliser is kept fixed in the short term. However, the elasticities are high in comparison to studies which use a fixed effects model. The estimated profit function is used for calculating shadow prices of the quasi-fixed and fixed inputs. The results are reasonable, especially for milk and the bad outputs. The shadow price of nitrogen is lower than the market price, indicating the overuse of fertiliser in this period.

Using this model and assuming optimal use of the bad outputs (nitrogen from animal excretion and from fertiliser), long-term elasticities are calculated. These turn out to be substantial. The long-term feed price elasticity of the demand of feed is –5. The long-term feed price elasticities of nitrogen are –2 for animal excretion and +7.6 for fertiliser, the latter reflecting the substitution possibility of purchased feed by feed produced on the farmer's own land. The long-term nitrogen price elasticities are 0.4, –0.5 and –2.8 for feed, nitrogen (animal) and nitrogen (fertiliser), respectively. The first also reflects the substitution possibilities with respect to feed. The standard errors of the estimated elasticities are very high, indicating the problems which we have in handling the input fertiliser.

The model is used to assess the impact of levies that are meant to reduce mineral surpluses in the Netherlands. Two types of levy are taken into consideration:

- A levy on feed
- A levy on the nitrogen surplus at farm level

The nitrogen surplus at farm level is defined as the sum of the total excretion of nitrogen by animals and the amount of nitrogen contained in fertiliser minus the amount of nitrogen taken up by crops (300 kg/ha).

A reduction in the nitrogen excretion by 40% can be realised with a levy of over 0.50 guilders per kilogram on the nitrogen surplus, mainly caused by a reduction in the use of fertiliser. A levy on feed leads to an increase in the nitrogen surplus.

Of course the results of this chapter must be interpreted against the background of the formulated model. The model assumes that the only way a farmer can respond to levies is by adapting the number of animals, the amount of fertiliser and the amount of variable inputs (feed and other inputs). The response of the farmer mainly comes down to a change in the mix of purchased feed and his own production of feed. Possible adaptations in the feed composition (feed with less nitrogen) are not taken into account. In the past there was no incentive for farmers to use alternative feed, so there are no historical data available. Also the use of buildings with low levels of ammonia emission are not taken into consideration.

The definition of the nitrogen surplus deserves some attention. It is assumed that an amount of 300 kg nitrogen per hectare is exempt from the levy. This 300 kg is a rough indication of the uptake of nitrogen by the crop. It is still in discussion how much more than the crop uptake will be free from levy, because a certain amount of nitrogen loss is inevitable. Another problem is that the intention of the Dutch government is to levy only the manure that stays on the farm. Farmers can transport the manure to other farmers who can apply the manure in an environmentally acceptable way. Transportation, however, is costly and will probably not take place.

Then there is the connected problem of the dependence between the size of the levy and the size of the transportation costs. With a levy of 0.50 guilders nitrogen excretion is reduced by 40%, which means that the manure surplus at the national level is reduced enormously. The opportunity to transport manure at low cost will then increase, and the effect of the levy will be weaker than calculated.

A related point is that the effect of the decrease in the size of the livestock on the price of the output is neglected. Incorporation of this effect would lead to a smaller reduction of profits. In fact we made the tacit assumption that output prices are determined by factors outside our model. This assumption is justified only in the case where international competition (in the milk market) is strong or prices are set by EU policy, which is valid to a high degree for the Netherlands as a member of the European Union.

As a final caveat we mention that our study assumes that all existing farms continue production. In practice some farms will stop production totally, selling their milk quota to others.

In spite of these caveats the main conclusions of our study hold: To reduce the nitrogen surplus in Dutch dairy farms a levy on feed is not an appropriate instrument, because the use of fertiliser increases. A more promising instrument is a levy on the nitrogen surplus. This levy leads to a considerable reduction in the use of fertiliser. The related profit losses and the decrease in the nitrogen from animal excretion are small.

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