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On Levies to Reduce the Nitrogen Surplus: The Case of Dutch Pig Farms

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Abstract. Pig farms in the Netherlands pay a zero or low price for using the environment. As a consequence, the environment is overused. The Dutch government wants to reduce the emissions of nitrogen and phosphorus. Possible instruments are regulation and levies. In this study a levy on feed and a levy on the nitrogen surplus are investigated, by incorporating a bad output in the production model. The model is estimated using panel data of Dutch pig farms over the period 1975–1989. Levies on nitrogen turn out to be more cost-effective than levies on feed.

Key words. Pollution control, manure problem, nitrogen surplus, bad output, levies

1. Introduction

Since 1984 the Dutch government has formulated policy measures to reduce the harmful effects of the production and application of manure. For the big farming section the measures that have been taken by the government amount to a prohibition to increase the number of animals, the obligation to remove the manure surplus from the farm, to pay a levy of 0.50 guilders for each kg of surplus of phosphate and to apply the manure in such a way that the ammonia emission is drastically reduced.

Another way of tackling the problem of environmental damage caused by the sector is the imposition of a levy on the nitrogen and phosphate *surplus*. 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 moment that leaching is minimized, etc.

To implement a system with levies on nitrogen and phosphate surpluses, a mineral account has to be kept by the farmer. This asks for a complete registration of all inputs (feed, fertilizer, manure, piglets, etc.) and outputs (meat, manure, crops, eggs, etc.) on which basis the surpluses can be calculated.

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Imposition of a levy on inputs (e.g. feed, fertilizer) (or outputs) may be much easier to implement than a levy on the surpluses but has the disadvantage that also parts of the input that are not harmful to the environment are levied. However, by the introduction of threshold values for inputs the 'polluter pays' principle can roughly be obtained.

In this paper the effects of a levy on feed or a levy on the nitrogen surplus at farm level are studied using an econometric approach. To this end a bad output is included in the production model of pig farms. Because historical data on the use of different kinds of feed with different mineral contents are not available, the substitution between different kinds of feed as a result of a levy are not taken into account. Also the use of buildings with low levels of ammonia emission are not taken into consideration. The only way a farmer can react is by adaptation of the size of the farm or by substituting feed for other inputs. The production process, however, does not allow for large substitutions between feed and other inputs, so the main response of the farmer to a levy on feed or on nitrogen production will be a reduction in the output.

In Section 2 we review the Dutch manure problem and government policy. In Section 3 we put the behaviour of the pig farmers into a general theoretical framework. The data we use for estimation and simulation purposes are subsequently described in Section 4. With these data and the embedding of the model into a stochastic framework in Section 5.1 we present estimation results in Section 5.2. Simulating the behaviour of the pig farms with the aid of these estimation results is the next step, presented in Section 6. Finally, in Section 7 the main findings of this paper are summarized.

2. The Dutch Pig Sector and the Manure Problem

2.1. MANURE PROBLEMS AND GOVERNMENT POLICY

The Dutch livestock sector is characterised by a large number of animals per hectare of cultivated land. Some 14 million pigs, 100 million layers and broilers and 1.75 million cows are kept on 2 million hectares. With the growth of the livestock sector in the last two or three decades, the production of manure has increased enormously. This has lead to high levels of application of manure to the soil. Furthermore, high levels of fertilizer per hectare have been applied. This excess supply of minerals to the soil has caused big environmental problems in the form of nitrate leaching, phosphate leaching and denitrification. The emission of ammonia (NH_3) from stables and from manure spreading also contributes to the environmental problems (acidification).

Growing concern on the quality of the soil and the surface water and on the consequences of acidification, have lead the Dutch government to the formulation and implementation of policies to reduce the unfavourable effects on the environment that are linked to agricultural production (Veenendaal and Brouwer, 1991). For phosphate the objective towards the year 2000 is to limit the use to a level that is equal to what crops extract from the soil. For ammonia the emission has to be reduced by 50%–70%, and for nitrate the objective is that the level of fertilization is such that ground and surface water quality levels are met.

Since 1986 the application of phosphate from manure has been regulated. In four phases the standards will become stricter until in 2000 manuring is in balance with crop extraction of phosphate (Table II.1). The standards relate to the farm level and for each kg of phosphate surplus a small levy has to be paid. We expect that the Dutch government will lower the standard relating to 1995 to 110 kg for arable crops and fodder maize and 150 kg for grass.

Table II.1. Maximum application of phosphate by crop (kg per hectare)

Crop	Year			
	1986	1991	1995	2000*
Arable crops	125	125	125	65
Grass	250	200	175	85
Fodder maize	350	250	175	65

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

A lot of farms have a phosphate surplus which has to be transported to other farms or exported. 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 farms with surpluses, even at low cost. In the future when also phosphate from chemical fertilizers is taken into account in the standards and when the standards become tighter, transportation of manure alone will not suffice to solve the problem of the manure surpluses. A reduction of the number of animals, processing and exporting of manure, and changing the mineral content of feed are some alternatives.

Another measure that has been taken by the government is the fixation at farm level of the size of the livestock at 1986 levels. This measure prevents that the manure problem at a national level continues to increase.

With respect to the emission of ammonia to the atmosphere, it is regulated that manure has to be worked into the ground immediately after application instead of spreading it in the traditional way. This measure contains the danger that leaching of nitrate increases. So it has to be accompanied by a reduction in the use of fertilizer.

A measure that is directed to the reduction of nitrate leaching is the prohibition to spread manure during autumn and winter in certain regions where the danger of leaching is large.

Until now the emphasis in the policy of the government is on physical regulation (e.g. application standards), but economic instruments (e.g. levies) are also being considered. The government is preparing legislation for the introduction of levies on mineral surpluses in the second half of the nineties. Mineral accounts at farm level will be the basis of such a levy system. A farmer will then be free to choose his own way of reducing mineral surpluses.

2.2. THE PIG SECTOR

The pig sector is responsible for some 20% of the manure production and for some 25%–30% of the phosphate production in the Netherlands, whereas more than 60% of the phosphate surplus is linked to this sector. The total phosphate production in 1990 was about 230 million kg of which some 70 million kg is excess production with respect to the standards of 1990. More than 60 million kg is transported to other farms and the remaining part is processed and/or exported.

The majority of pigs are kept on farms with a small area of land. Since 1970 the number of farms where pigs were kept, declined from more than 75 000 to less than 30 000 whereas the number of pigs increased from 5.5 million to almost 14 million (half of which are fattening pigs). This means that the number of pigs per farm rose from 70 to 475. Without the 1986 fixation measure the growth would have been ever larger (CBS/LEI-DLO).

Almost 70% of the breeding sows and 55% of the fattening pigs are kept on the almost 10 000 specialized pig farms, a lot of which have less than 10 hectares of land.

A modern pig farm which can be run by one person has a size of 1200 fattening pigs or 120 breeding sows. A fattening pig produces 7.96 kg of phosphate per year whereas a sow produces 20.67 kg per year. (These are the figures that are used by the government to calculate the amount of manure that is allowed to be applied to the soil.) On the basis of the standards that relate to 1991 (Table 1) on a hectare of arable land the manure of only 16 fattening pigs or of 6 sows can be applied. A farmer with 1200 fattening pigs needs at least 38 hectares of fodder maize or 76 hectares of arable land to get rid of all the manure that is produced on the farm. So, a lot of farms will be confronted with government regulations. Besides the regulations that are already effective, regulations with respect to the emission of ammonia will become stricter. The removal of manure will become increasingly expensive when the phosphate standards become tighter. Where the margins between monetary outputs and inputs are rather small, increasing the costs with some percentage leads to a strong reduction in income.

Table II.2 gives an overview of the economic situation in pig farming in the last twenty years. The economic situation is well characterised by the labour income, which is defined by us as the difference between the revenues and costs (excluding labour). The labour income per fattening pig in the period

Table II.2. Revenues and costs in pig farming per animal per year (fl)

Period	Fattening pigs			Sows		
	Revenues	Costs (excl. labour)	Labour income	Revenues	Costs (excl. labour)	Labour income
1971–1975	705	648	57	1771	1289	482
1976–1980	799	764	35	1958	1654	304
1981–1985	971	914	57	2504	2023	481
1986–1989	825	795	30	2181	1946	235

Source: Poppe (1991)

1970–1990 was approximately 40 guilders per pig. From year to year there were heavy fluctuations in labour income due to fluctuations in output prices, feed prices and prices of piglets. Despite a continuing improvement in technical results the labour return per pig (in real terms) is declining because of deteriorating price ratios. Therefore, the average size of the farms had to increase continuously to realize an acceptable labour income per farmer.

Feed costs are about 50% of the total costs whereas costs for piglets account for about 40%. For sows, feed costs amount to 60% of total costs.

The manure of a fattening pig contains about 16 kg nitrogen (N) per year, which means that the labour income per kg N is about 2.5 guilders. For a sow the N-production per year is 35 kg, which comes down to a labour income of 10 guilders per kg N. The labour income per kg of feed is approximately 0.10 guilders per fattening pig and 0.25 guilders for sows. These figures are indicative for the consequences of a levy on N production or on feed that are considered in this paper.

3. Theoretical Considerations

The theoretical background of this paper is the neoclassical production theory. This theory is widely discussed in literature (e.g. Varian, 1984) and will be only briefly described here. Attention will be focused on a rather new element: the incorporation of a bad output in the production theory.

It is assumed that the objective of the farm family is the maximization of short-run profit and that the farm family is a pricetaker in the output and variable input markets. Therefore, the firm is in static equilibrium with respect to output and a subset of inputs (the variable inputs) that is conditional on the level of the remaining inputs (fixed inputs). Similar to the fixed inputs we include the quantity of waste discharged (the bad outputs) in the production function. This is standard in the theory of environmental economics, see e.g. Baumol and Oates (1988). Profit, normalized by the output price, is maximized by the farm, subject to a production technology governing the relationship between inputs, bad outputs and farm output. Thus,

$$\pi(p, z, s) = \max_{q,\, x}(q - p'x), \tag{3.1}$$

subject to:

$$q = q(x, z, s), \tag{3.2}$$

where π is the profit function normalized by the output price; p is the ratio of the price vector of the variable inputs to the price of the output; q is the output; x is a vector of variable inputs; z is a vector of fixed inputs; s is a vector of bad outputs. The state of technology is included into the vector z to simplify notation.

According to duality theory, the optimizing behaviour of farmers constrained by technology can equivalently be represented by the profit function π, given in Equation (3.1). 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 maximizing 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; and increasing and concave in the bad outputs. The profit function is normalized by the price of the 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. 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 output, and the supply function for the bad outputs; and (iii) negative profits are allowed. The normalized profit function is written as:

$$\pi = \alpha_0 + \alpha'p + \beta'z + \gamma's + {}^1\!/_2\, p'Ap + {}^1\!/_2\, z'Bz + {}^1\!/_2\, s'Cs + p'Dz + p'Es + z'Fs, \tag{3.3}$$

where $a_{ij} = a_{ji}$; $b_{ij} = b_{ji}$; $c_{ij} = c_{ji}$; α_0 is a parameter; α, β, γ are vectors of parameters; A, B, C, D, E, F are matrices of parameters.

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

$$x = -\alpha - Ap - Dz - Es. \tag{3.4}$$

The output supply function is, using the definition of the normalized profit

$(\pi = q - p'x)$,

$$q = \alpha_0 + \beta'z + \gamma's - \tfrac{1}{2}p'Ap + \tfrac{1}{2}z'Bz + \tfrac{1}{2}s'Cs + z'Fs. \tag{3.5}$$

The model consists of the Equations (3.3), (3.4), and (3.5). The consequences of a levy on the variable inputs in the short-run can be calculated straightforwardly by using Equations (3.3)–(3.5). In the short-run it is assumed that the quantity of the bad output is fixed.

In the long-run it is assumed that the quantity of the bad output is variable and that the quantity 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 output. The bad output cannot be altered instantaneously and is in a way considered as intermediate between a variable and fixed output. To the policy makers only the long term responses are of interest. We also treat the short-run responses for reasons of comparison. Using the profit function (Equation (3.3)) we derive the shadow prices of the bad outputs as

$$r = \partial\pi/\partial s = \gamma + E'p + F'z + Cs, \tag{3.6}$$

where r is a vector of shadow prices of the bad outputs. Equation (3.6) is depicted by Fig. 3.1. The relation between the bad output's shadow price 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 (3.6) the consequences of a levy on a bad output in the long-run can be calculated. This is illustrated graphically by Fig. 3.1. For example, assume that the actual situation for a farm is given by point A of Fig. 3.1. The amount of the bad output is equal to s_1 and the related shadow

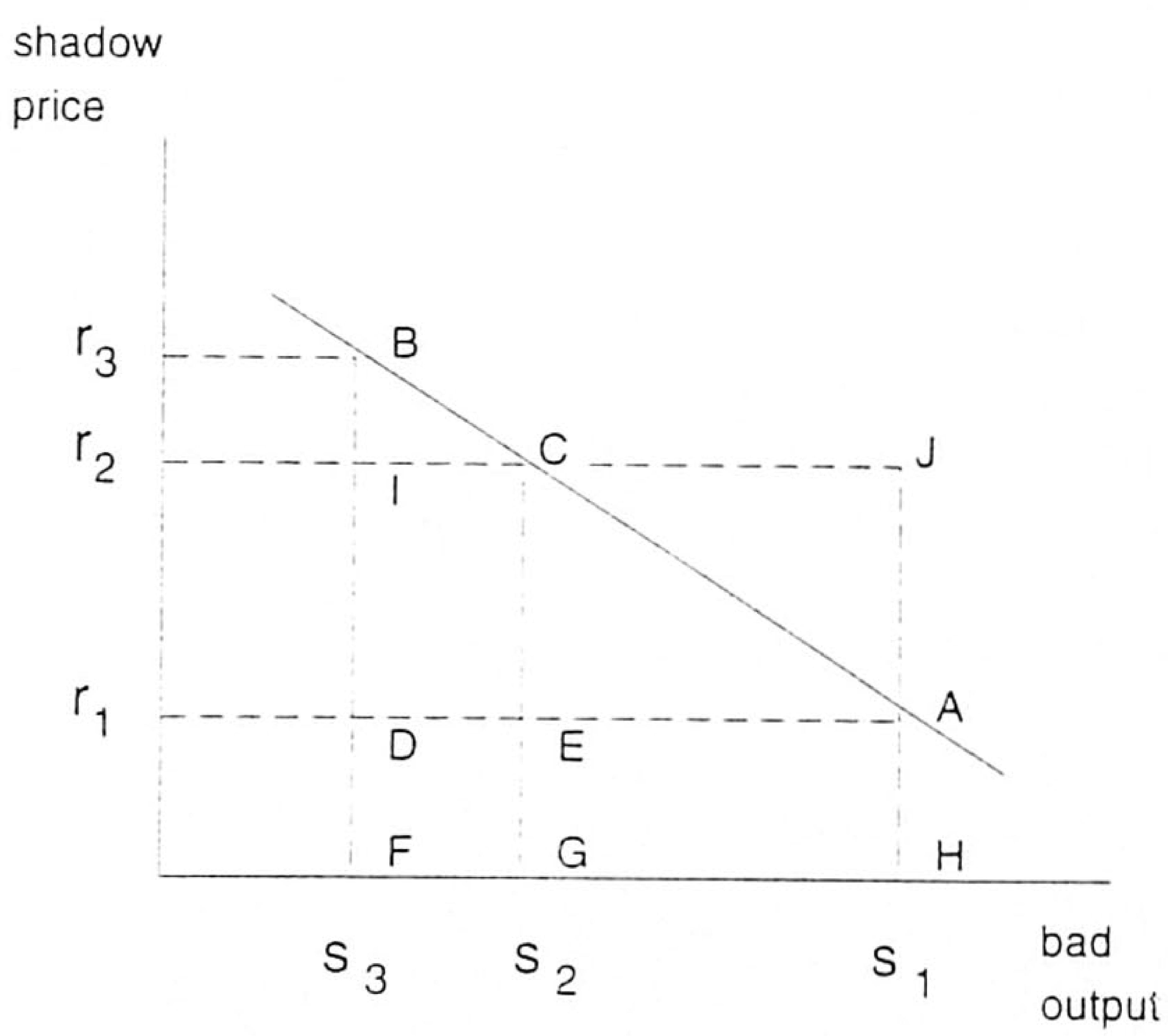

Fig. 3.1. The relation between the shadow price and the bad output.

price is equal to r_1. Assume that from an environmental point of view a quantity of waste discharged equal to s_3 by the farm is acceptable. The related shadow price in point B is r_3. The surplus of the bad output on the farm is equal to $s_1 - s_3$. Now, we analyze a levy of $r_2 - r_1$ on the bad output. When the farmer decides to stay in point A, he will not be confronted by a decrease of 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 in point A are equal to the area $AJID$. When the farmer decides to reduce the 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 in point B are equal to area ABD. When the farmer is a profit maximizer he will decrease the amount of the bad output in the long-run by $s_1 - s_2$. In 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 Fig. 3.1, in point C the sum of the profit loss and the paid levies are the lowest in 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 (3.4) and (3.5).

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 results in a price change of the variable inputs. The effects of this price change on the bad outputs can be calculated by rewriting Equation (3.6) as

$$s = C^{-1}(r - \gamma - E'p - F'z). \tag{3.7}$$

The change in the bad outputs results in a change in the variable inputs, see Equation (3.4).

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

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

$$(\partial x/\partial p)_{sr} = -A. \tag{3.8}$$

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

$$(\partial q/\partial p)_{sr} = -Ap. \tag{3.9}$$

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

$$\partial\pi/\partial z = \beta + D'p + Bz + Fs. \qquad (3.10)$$

The long-run (LR) responses of the variable inputs and the bad outputs can be calculated from Equation (3.4) and (3.7):

$$(\partial x/\partial p)_{lr} = (\partial x/\partial p)_{sr} + (\partial x/\partial s)_{sr}\,(\partial s/\partial p)_{lr} = -A + EC^{-1}E', \qquad (3.11)$$

$$(\partial s/\partial p)_{lr} = -C^{-1}E', \qquad (3.12)$$

$$(\partial x/\partial r)_{lr} = (\partial x/\partial s)_{sr}\,(\partial s/\partial r)_{lr} = EC^{-1}, \qquad (3.13)$$

$$(\partial s/\partial r)_{lr} = C^{-1}. \qquad (3.14)$$

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 one thousand farmers. These farmers are allowed to participate up to seven years in a rotating panel, though some exit earlier. So the survey is an unbalanced panel. Furthermore, only farms with a size (measured in standard value added) larger than half the size per labourer on large efficient farms are included. Despite the fact that in this way almost one third of the farmers are excluded, only 5 to 10% of agricultural production is left out.

The data used span the period 1975–1989 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 the breeding and fattening of pigs, only farms are selected from the survey for which over 2/3 of the standardized value added contributes to one of these two specific sectors. This results in data on 668 breeding farms and 139 fattening farms remaining for estimation purposes.

One variable input 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 $\log(P_F) = \Sigma_k\ {}^1\!/_2(w^1_{kF} + w^0_k)\log(p^1_k/p^0_k)$, with w^1_{kF} and w^0_k the budget share of good k with price p^1_k and p^0_k in the period of interest and the reference period respectively. The share w^0_k 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). For every year a Törnqvist index number is calculated for pig breeding and pig fattening farms separately. The variable input consists of feed for fattening pigs, feed for breeding sows, feed for other animals, energy, hired labour, pesticides, the cost of the prevention and cure of diseases and the cost of inputs for crop growth. Feed for other animals consists of feed for laying hens, feed for broilers, feed for fattening calves and feed for cattle (in case of the latter both power feed and roughage). Of these components of the variable input feed for fattening or breeding sows is by far the most important. Almost 90% of the value of the input is accounted for by this feed. This is the main reason why all inputs are aggregated into one, which we will refer to as feed. The variable output consists of sows, pigs for fattening, pigs for consumption, eggs, other animal output and the output of crop growth. Other animal output consists of laying hens, broilers, horses, sheep, cows, calves and fattening calves. 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 one component strongly dominates, which is pigs for fattening in case of breeding farms or pigs for consumption in case of fattening farms. This is the main reason why all outputs are aggregated into one, which we will refer to as the output of pigs (or meat). Profit is determined by the difference of the value of the above mentioned variable output and variable input. Of course normalisations by the price of the variable output are carried out in our calculations as described in Section 3.

As for the inclusion of the bad output(s) several possibilities arise. Though both nitrogen and phosphorous (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 estimating the parameters of Equations (3.3) to (3.5).

The fixed inputs, finally, 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.

The calculated Törnqvist indices for the variable input, variable output and the fixed input buildings and machinery are tabulated in Table IV.1. It can be seen that there is nearly no difference between the breeding and fattening sector in case of the fixed input buildings and machinery. A steady increase of the price over time has occurred for both sectors. The prices of the variable input and output show larger differences between the breeding and fattening sector. Trends, however, are equal for both sectors. The price of pigs (or meat) in 1989 is almost equal to that of 1975. Also, the price of

Table IV.1. Törnqvist price indices for the variable input, variable output and the fixed input buildings and machinery. All are presented for both the fattening pig sector and the breeding sow sector over the time period 1975–1989

Year	Input fattening pigs	Input breeding sows	Output fattening pigs	Output breeding sows	Buildings machinery fattening pigs	Buildings machinery breeding sows
'75	1.00	1.00	1.00	1.00	1.00	1.00
'76	1.11	1.11	0.94	0.95	1.06	1.06
'77	1.15	1.16	0.92	0.94	1.13	1.13
'78	1.04	1.06	0.83	0.86	1.21	1.21
'79	1.12	1.14	0.90	0.87	1.28	1.28
'80	1.19	1.22	0.89	0.83	1.43	1.44
'81	1.29	1.33	1.03	1.00	1.52	1.52
'82	1.29	1.34	1.04	1.14	1.57	1.58
'83	1.34	1.39	1.03	1.09	1.58	1.58
'84	1.37	1.44	1.03	1.07	1.60	1.59
'85	1.25	1.32	0.98	1.07	1.61	1.60
'86	1.15	1.21	0.85	0.94	1.63	1.64
'87	1.04	1.10	0.73	0.81	1.68	1.68
'88	1.06	1.11	0.80	0.91	1.73	1.73
'89	1.10	1.15	0.96	1.01	1.76	1.76

feed in 1989 is only 10% above the level of 1975 and almost equal to the level of 1976.

A summary of sample means of the other variables of interest are presented in Table IV.2. It is very clear from this table that farms are rather specialized. Only 4% of value added comes from fattening pigs on a farm where over 2/3 of the value added comes from breeding sows and only 0.4% for the other case. This high degree of specialisation is a further justification

Table IV.2. Mean and standard deviation of variables of interest, for the breeding sows and fattening pigs sector

	Breeding sows		Fattening pigs	
	Mean	Standard dev.	Mean	Standard dev.
% labour on breeding sows	96.0%	7.7%	0.4%	2.8%
% labour on fattening pigs	4.0%	7.7%	99.6%	2.8%
Nitrogen (kg)	9600	700	21500	13400
Labour (years)	1.56	0.68	1.23	0.60
Buildings/index (fl)	295000	226000	268000	173000
Land (hectare)	7.11	5.67	6.89	7.81
Normalized profit (fl)	145000	131 000	152000	138000
Value inputs (fl)	325000	26000	557000	336000
Value outputs (fl)	468000	372000	696000	441000

of our aggregation of the outputs into one. Most farms are small (have little land), with a mean of about 7 hectare, which results in a production of 1 000 to 1 700 kg nitrogen per hectare, which is way above environmentally acceptable values of about 300 kg/ha.

5. Estimation

5.1. ESTIMATION THEORY

Embedding the model, given by Equations (3.3)–(3.5), in a stochastic framework, we obtain

normalized profit:

$$\Pi_{it} = \alpha_0 + \alpha' p_{it} + \beta z_{it} + \gamma' s_{it} + \tfrac{1}{2} p'_{it} A p_{it} + \tfrac{1}{2} z'_{it} B z_{it} + \tfrac{1}{2} s'_{it} C s_{it} + p'_{it} D z_{it} + p'_{it} E s_{it} + z'_{it} F s_{it} + u_{it}^{(1)}; \quad (5.1)$$

demand for variable inputs:

$$x_{it} = -\alpha - A p_{it} - D z_{it} - E s_{it} + u_{it}^{(2)}; \quad (5.2)$$

output supply:

$$q_{it} = \alpha_0 + \beta' z_{it} + \gamma' s_{it} - \tfrac{1}{2} p'_{it} A p_{it} + \tfrac{1}{2} z'_{it} B z_{it} + \tfrac{1}{2} s'_{it} C s_{it} + z'_{it} F s_{it} + u_{it}^{(3)}. \quad (5.3)$$

The double subscript "*it*" refers to farm i in year t. The observation period is 1975–1989 (15 years). The data represent a rotating panel where each farm is represented in the sample for a maximum period of 7 years (some farms much shorter). The total number of farms in the sample over the whole period is 807 and these are treated as independent observations.

The variables have the following meaning and dimensions:

Π = profit, normalized by the output price;

$p = (p_1, p_2)$ = price of variable inputs (mainly feed) normalized by the output price:
- p_1 = for fattening pigs,
- p_2 = for breeding sows;

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

$s = (s_1, s_2)$ = bad outputs, that is, nitrogen excretion
- s_1 = of fattening pigs (kg),
- s_2 = of breeding sows (kg);

q = output

$x = (x_1, x_2)$ = variable inputs, that is, feed:
x_1 = for fattening pigs,
x_2 = for breeding sows.

Because of restrictions on the parameters there are 30 structural parameters to be estimated. Let us define a dummy parameter v as:

$v = 1$ for fattening pigs
$v = 0$ for breeding sows

and a 2×1 vector υ as $\upsilon = (v, 1 - v)'$. The restrictions are as follows:

(1) $\alpha = \alpha_1 \upsilon$, $A = \alpha_2 \upsilon \upsilon'$, because either the price of inputs for a fattening farm or the price of inputs for a breeding farm is of relevance,
(2) C is diagonal ($C_{12} = C_{21} = 0$, $C_{11} = C_1$, $C_{22} = C_2$), because either the bad output of fattening farms or the bad output of breeding farms is of relevance,
(3) $D = \upsilon d'$ ($d' = (d_1, d_2, d_3, d_4)$), $E = \varepsilon \upsilon \upsilon'$, see 1),
(4) $F = f(1, 1)$ ($f' = (\varphi_1, \varphi_2, \varphi_3, \varphi_4)$), see 2),

while β, γ and B are not restricted (apart from the symmetry of B).

Regarding the stochastic structure we assume that the observations are uncorrelated, but that the three equations are correlated, that is,

$$\text{var}[(u_{it}^{(1)}, u_{it}^{(2)}, u_{it}^{(3)})'] = \Sigma.$$

This adds 6 further parameters to be estimated.

The system of equations is thus a system of seemingly unrelated regressions and can be estimated by standard two-step techniques.

5.2. ESTIMATION RESULTS

The estimates of the parameters of the model are presented in Table V.1. The R^2 of the profit function is 0.69; the R^2 of the demand function for the variable inputs is 0.95; and the R^2 of the output supply function is 0.95. Fourteen of the thirty 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 non-linear 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 are caused either by effects that are common to all farmers but vary across years (like the occurrence of certain diseases that spread across the entire country) or by omitted, farm specific variables (like the personal skills of a farmer). We will illustrate both cases and comment on the sign of the corre-

Table V.1. Parameter estimates of the normalized profit function, the demand function for feed and the supply function of the output (a) and the correlations of residuals of Eqs. (5.1) to (5.3) (b)

Parameter	Estimate	'T' Ratio
α_0	22680	1.05
α_1	11770	0.97
α_2	48710	5.18
β_1	11160	0.55
β_2	66160	8.96
β_3	−3256	−2.03
β_4	3126	0.99
γ_1	19.38	16.42
γ_2	23.22	14.90
B_{11}	23300	2.13
B_{12}	−15290	−5.66
B_{13}	−1455	−1.95
B_{14}	937	0.64
B_{22}	646	0.46
B_{23}	216	0.82
B_{24}	−749	−1.22
B_{33}	319	3.00
B_{34}	107	0.84
B_{44}	18.3	0.05
φ_1	4.101	5.89
φ_2	0.5257	1.89
φ_3	0.08896	1.82
φ_4	0.5095	4.88
d_1	−41800	−14.93
d_2	−15690	−15.10
d_3	−253	−1.05
d_4	−6051	−20.00
ε	−18.87	−96.29
C_1	−0.0002435	−4.43
C_2	−0.0004660	−4.81

Correlations of Residuals Eq	(5.1)	(5.2)	(5.3)
(5.1)	1.0000	−0.2380	0.6216
(5.2)	−0.2380	1.0000	0.6111
(5.3)	0.6216	0.6111	1.0000

lations. First, the occurrence of diseases which affect all farmers in a certain year causes a relatively low profit in combination with a relatively high consumption of feed and a relatively low output. This leads to a negative correlation between Equations (5.2) and (5.1) and a positive correlation between Equations (5.3) and (5.1), in accordance with Table V.1. Second, high personal skills of a farmer cause a high profit in combination with a relatively low consumption of feed and a relatively high output, also in accordance with our estimated correlations. Nonetheless, effects can be thought of which cause correlations of opposite sign.

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-maximizers. Results of testing the assumption of monotonicity are displayed in Table V.2. Table V.2 shows that the data are relatively well behaved in relation to the theory, except with respect to the monotonicity condition of land. This, however, is no severe violation of the model since land is of minor importance in the pig breeding and pig fattening sector. Also, in case of the pig breeding sector, labour does not fulfil the monotonicity conditions. There appears to be a surplus of labour. According to Table V.1 the normalized short-run profit function is convex in the normalized price ($\alpha_2 > 0$) and concave in the bad outputs ($C_1 < 0$ and $C_2 < 0$). The assumption of short-run profit maximization behaviour is, therefore, not rejected by the data.

The short-run price elasticities of feed and output (meat and pigs) were calculated using Equations (3.8) and (3.9), see Table V.3. The shadow prices of the bad outputs and the fixed inputs were calculated using Equations (3.6) and (3.10), see Table V.4. The variances of these elasticities are calculated by a bootstrapping technique. The price elasticities and the shadow prices of

Table V.2. Percentage of farms that fulfils the monotonicity conditions

% that fulfils monotonicity derivative of profit by:	Fattening pigs	Breeding sows
Input price	100	100
Output price	100	100
Labour	83	20
Buildings	100	98
Land	34	23
Nitrogen	56	99

Table V.3. Short term price elasticities for the average pig fattening farm and the average pig breeding farm, period 1987–1989 (standard errors in brackets)

	Price of feed	Output price
Pig fattening farm		
Feed	–0.10 (0.02)	0.10 (0.02)
Meat	–0.04 (0.01)	0.04 (0.01)
Pig breeding farm		
Feed	–0.17 (0.03)	0.17 (0.03)
Pigs	–0.06 (0.01)	0.06 (0.01)

Table V.4. Shadow prices for the average pig fattening farm and the average pig breeding farm, period 1987–1989 (standard errors in brackets)

	Pig fattening farm	Pig breeding farm
Nitrogen	2.70 (0.7)	10.70 (1.17)
Human labour per year	56400 (16500)	–8510 (10370)
Capital per guilder	0.30 (0.06)	0.20 (0.04)
Land per hectare	1820 (1140)	–339 (911)

the fixed inputs differ across the average pig fattening farm and the average pig breeding farm because the elasticities are measured at different points of the functions. The shadow prices of nitrogen differ also because the related coefficients differ, see Section 5.1.

As can be concluded from Table V.3, the own price elasticity of the demand for feed is small: –0.10 for pig fattening farms and –0.17 for pig breeding farms. The own price elasticity of the output is even smaller: 0.04 for meat of pig fattening farms and 0.06 for pigs of the pig breeding farms. The cross price elasticities are the opposite of the own-price elasticities because the output supply and the input demand functions are homogeneous of degree zero in prices.

The shadow price of nitrogen for the average pig fattening farm is 2.70 guilders, see Table V.4. This means that the short-run profit (that is, the difference between revenues and costs of the variable inputs, see Eq. (3.1)) rises by 2.70 guilders when nitrogen production increases by 1 kilogram. This is caused by the relation between pigs and the nitrogen production: an increase in nitrogen implies an increase in pigs. An increase in pigs results in an increase of the short-run profits. For the average pig breeding farm the shadow price of nitrogen is greater (10.70 guilders), a reasonable result because the profit per fattening pig is much smaller than the profit per sow (see Section 2.2).

Labour is scarce on the pig fattening farm in comparison to the pig breeding farm. Because of environmental regulations there is a surplus of labour in the pig breeding sector. The shadow price of capital is the profit which can be used to pay the capital interest and depreciation costs. The results are reasonable and similar. Land is scarce on the pig fattening farm in comparison to the pig breeding farm, however the standard errors are very large.

Finally, long term price elasticities were calculated using Equations (3.11), (3.12), (3.13), and (3.14). The price elasticities rise considerably in comparison to the short term elasticities, see Table V.5. These large price elasticities are caused by the small margins on pig farms. A rise of the price of feed with 1% results in a decline of the short-run profit margin by 10% for the pig fattening farm and 4% for the pig breeding farm (see Table II.2). A rise of the shadow price of nitrogen by 1% has a larger impact in the pig breeding

Table V.5. Long term price elasticities for the average pig fattening farm and the average pig breeding farm, period 1987–1989 (standard errors in brackets)

	Price of feed	Shadow price of nitrogen
Pig fattening farm		
Feed	–3.2 (0.7)	–0.3 (0.1)
Nitrogen	–3.6 (0.8)	–0.4 (0.1)
Pig breeding farm		
Feed	–2.8 (0.6)	–1.2 (0.3)
Nitrogen	–4.3 (0.9)	–1.9 (0.4)

sector than in the pig fattening sector because the shadow price in the pig breeding sector is larger than the shadow price in the pig fattening sector (see Table V.4). 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.

6. Simulations

6.1. METHOD OF SIMULATIONS

As pointed out in Section 3, the effect of a levy on feed or nitrogen on the output of nitrogen can be calculated with the aid of Equation (3.7). In the simulations presented in the next sections Equation (3.7) 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

$$\Delta s = C^{-1}(\Delta r - E'\Delta \text{p}), \tag{6.1}$$

with $\Delta r = 0$ or $\Delta p = 0$ in case of a levy on feed or nitrogen respectively. In case of a levy on nitrogen the levy is only applied to the amount of nitrogen excretion which exceeds the environmentally acceptable limit. In our simulations this limit is set to 300 kg/ha. We arrived at this figure by multiplying the ratio of the nitrogen to phosphate content of manure by the existing environmental phosphate standards. In this way the phosphate standard will be just met if a farmer just fulfils our nitrogen standard. Thus the levy paid equals ($s - z_3$ * 400 kg/ha) times the levy per kg N, with s the amount of nitrogen excretion after the levy is applied. The exact magnitude of the figure 300 kg/ha, however, is not of extreme importance to our simulation results, as most farmers produce far more than 300 kg nitrogen per hectare. Three cases occur:

- 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.

- if the levy causes the amount of nitrogen to drop from above to below the threshold value, Δs is adjusted so 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 kg excess nitrogen is imposed.
- 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 (6.1). The levy paid is equal to the amount of kg of nitrogen above the threshold value times the levy per kg. This is the most common situation.

Every farmer has the possibility to 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 and consequently manure has to be transported over larger distances. In fact, transportation costs may increase by the exact levy indebted if no transportation had taken place, if the accepting farmer has to pay the same levy over the accepted manure. Furthermore, as long as the imposed levy does not exceed the cost of transportation of about 1 guilder per kg N no transportation will take place anyway.

Also, if a very high levy on feed is applied, Δs as calculated by Eq. (6.1) could become so large that it causes the total amount of nitrogen to become negative. If this occurs Δs is adjusted such that s is zero after the levy on feed. Avoiding this levy in a way other than by buying less or different feed is impossible. But, a farmer may start to grow feed of his own. This may be a problem if the farmer uses a lot of polluting fertilizers in doing so. Fortunately, this is a highly unlikely scenario as most pig farmers have (nearly) no land to do so.

Once Δp or Δr are set and Δs and s after the levy is applied are calculated for every farm by means of Equation (6.1), the profit and the amount of in- and outputs can be calculated from Equations (3.3), (3.4) and (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 Eq. (3.3). 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 V.1. 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 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 nation wide institution of a levy on feed or nitrogen.

Table VI.1. Relative change in profits (in %) caused by a levy on feed of 1% at different ways of refunding the levy, pig fattening farms

Kilogram nitrogen per hectare before tax	Before levy profit (in guilders)	
	< 100000	> 100000
Without refund		
0–7500	–8.8	–5.1
>7500	–17.5	–4.7
Refund per SFU		
0–7500	–3.4	–1.7
>7500	11.2	–1.9
Refund per hectare		
0–7500	1.5	0.9
>7500	–10.9	–0.4
Refund per farm		
0–7500	–0.2	–2.8
>7500	7.5	–2.1

6.2. SIMULATION RESULTS

Levy on Feed

In the short-run a levy on feed has hardly any effect on the demand for feed, the short-run price elasticities of feed are very low (see Table V.3). Because of data limitations we distinguish only one variable input (mainly feed) in our model. Therefore, substitution possibilities between different categories of feed are not taken into account. In the long-run the price elasticities are larger, see Table V.5. The effects of a levy on feed in the long-run are depicted in Fig. 6.1 for pig fattening farms and in Fig. 6.2 for breeding pig farms.

In the long-run a levy on feed results in a reduction of the amount of pigs on the pig fattening and the pig breeding farms. This results in a reduction of the output of nitrogen. For example a levy on feed of 6% results in a reduction in the output of nitrogen of about 40% for pig fattening farms and pig breeding farms. This levy has a great effect on profits, which is the difference between revenues of variable outputs and variable costs. We assume that the number of farms remains the same, but probably the number of farms will decrease and therefore the profit loss for the remaining farms is not so disastrous.

In Fig. 6.1 and Fig. 6.2 the decrease in profits is not corrected for restitution of the levy revenues. We analyzed three options for restitution of these revenues: (i) per standard farm unit (SFU), (ii) per hectare, (iii) per farm.

To illustrate our calculations Table VI.1 gives the relative changes in profit

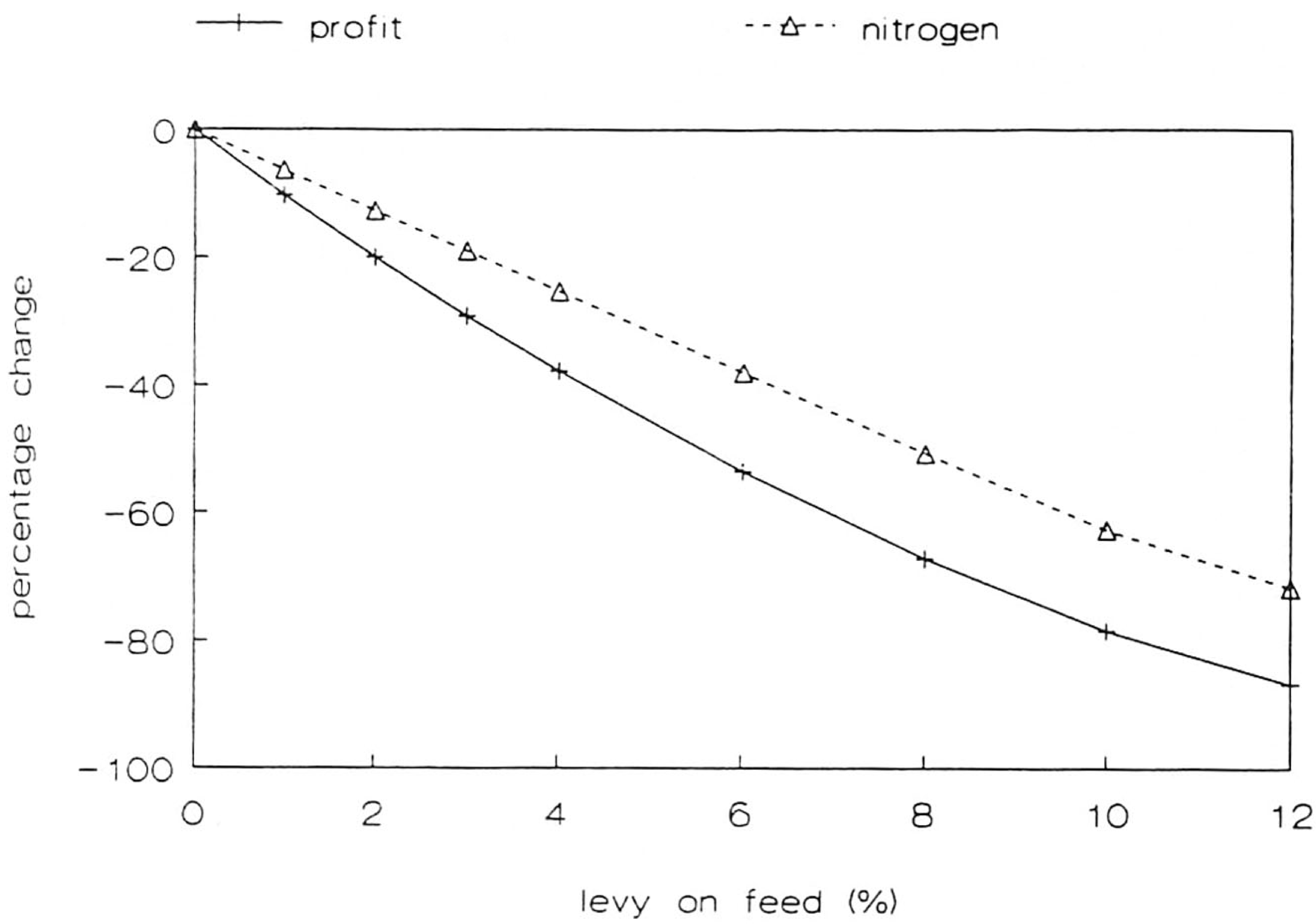

Fig. 6.1. Pig fattening farms.

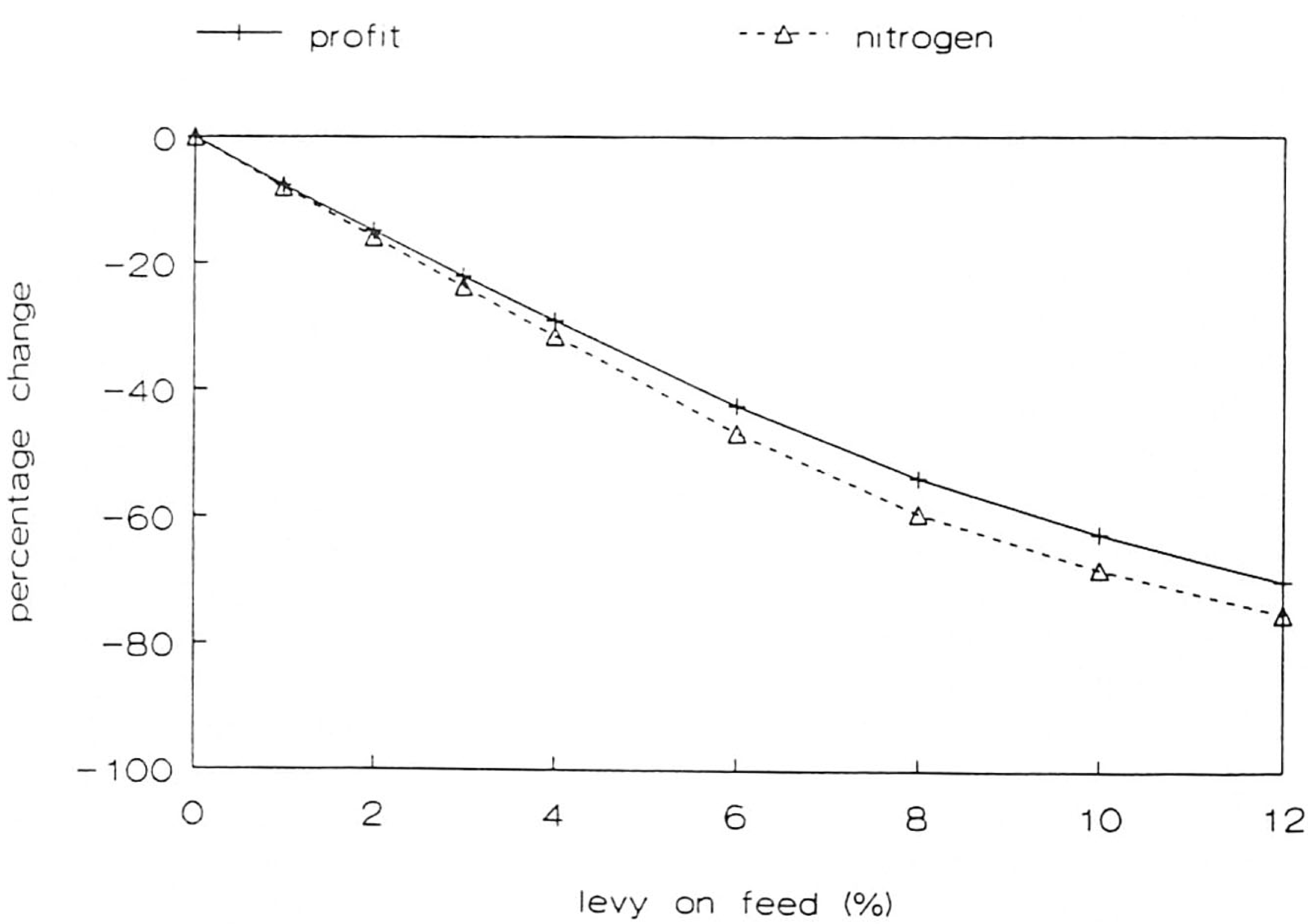

Fig. 6.2. Pig breeding farms.

for pig fattening farms. The other calculations are available from the authors upon request.

The first two rows of Table VI.1 give the effect on profit without refunding the revenues of the levy. The effect of a levy of 1% on farms with a profit of less than 100 000 guilders and an output of nitrogen which is less than 7500 kilogram per hectare is equal to – 8.8%. Farms with a profit of more than 100 000 guilders are confronted with a smaller decrease in profits. This is partly caused by the linear relationship between the output of nitrogen and the price of feed (Equation (3.7)).

Because of the assumptions made in constructing the model, refunding the revenues of the levy has no effect on production behaviour. It is a lumpsum transfer, which only affects the level of profits. It turns out that restitution per hectare is the option which results in the smallest decrease in profits of farms with the lowest output of nitrogen per hectare for pig fattening farms (see Table VI.1) and pig breeding farms.

Levy on Surplus of Nitrogen

In the short-run a levy on the surplus of nitrogen has no effect, because we assumed that the amount of nitrogen is fixed in the short-run. In the long-run a levy on the surplus of nitrogen will result in a decrease in the output, the amount of feed and the number of pigs. Therefore, profits and the output of nitrogen will decrease, see Figs. 6.3 and 6.4.

As can be seen from Figs. 6.3 and 6.4 a levy on nitrogen of 1.50 guilders will result in a decrease of the output of nitrogen by 39% for pig fattening farms and by 43% for pig breeding farms. The effect on profits is 43% for pig fattening farms and 31% for pig breeding farms.

A levy on the surplus of nitrogen is a more cost-effective way to reduce the output of nitrogen than a levy on feed. The decrease in profit by an equal decrease in the output of nitrogen is smaller for pig farms, compare Figs. 6.1 and 6.3 for pig fattening farms and Figs. 6.2 and 6.4 for pig breeding farms.

For a levy on the surplus of nitrogen, restitution per hectare is the option which results in the smallest decrease in profits of pig farms with the lowest output of nitrogen per hectare.

7. Conclusions and Caveats

In this paper an econometric model of the Dutch pig sector is presented. 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 difference between the total

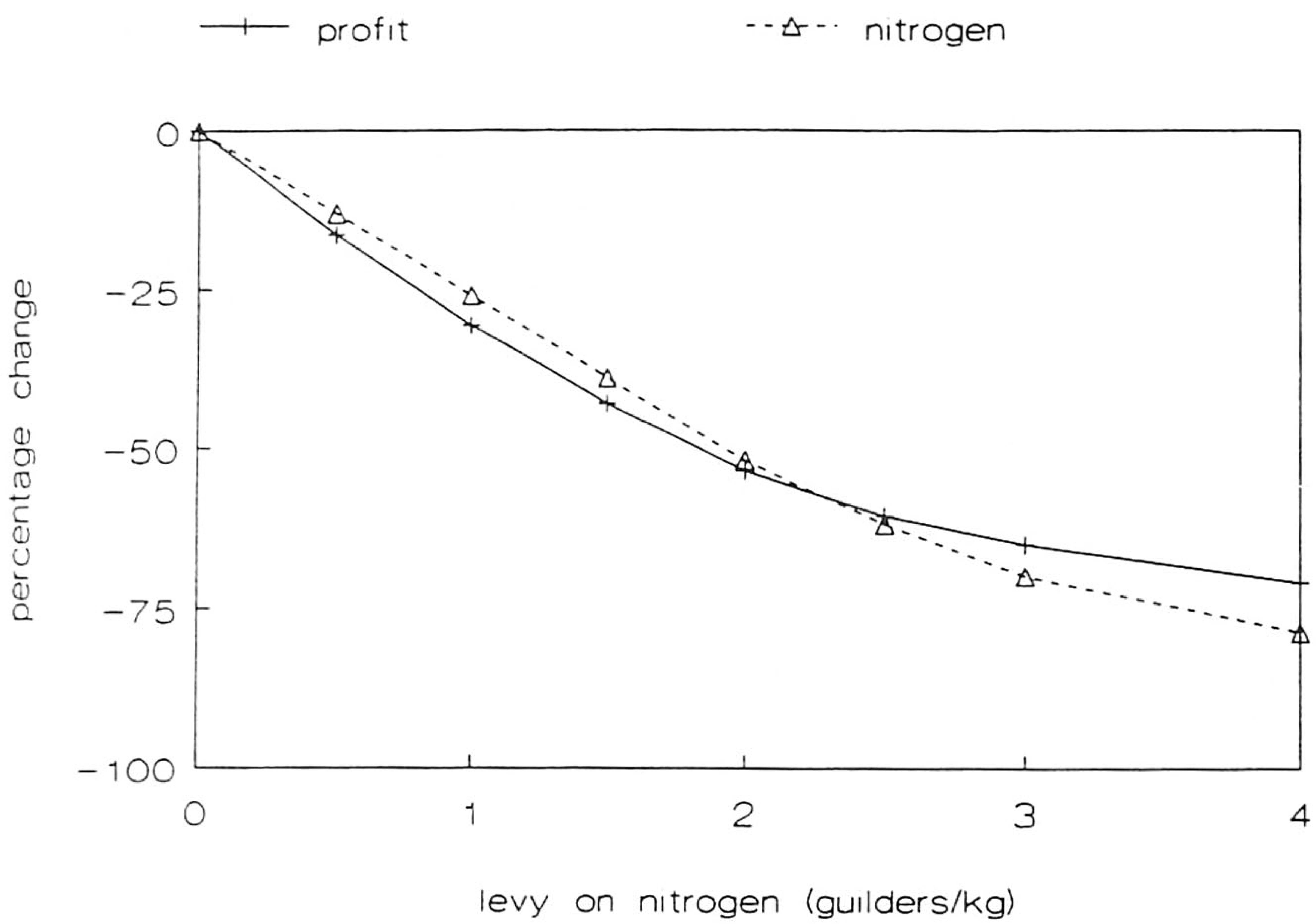

Fig. 6.3. Pig fattening farms.

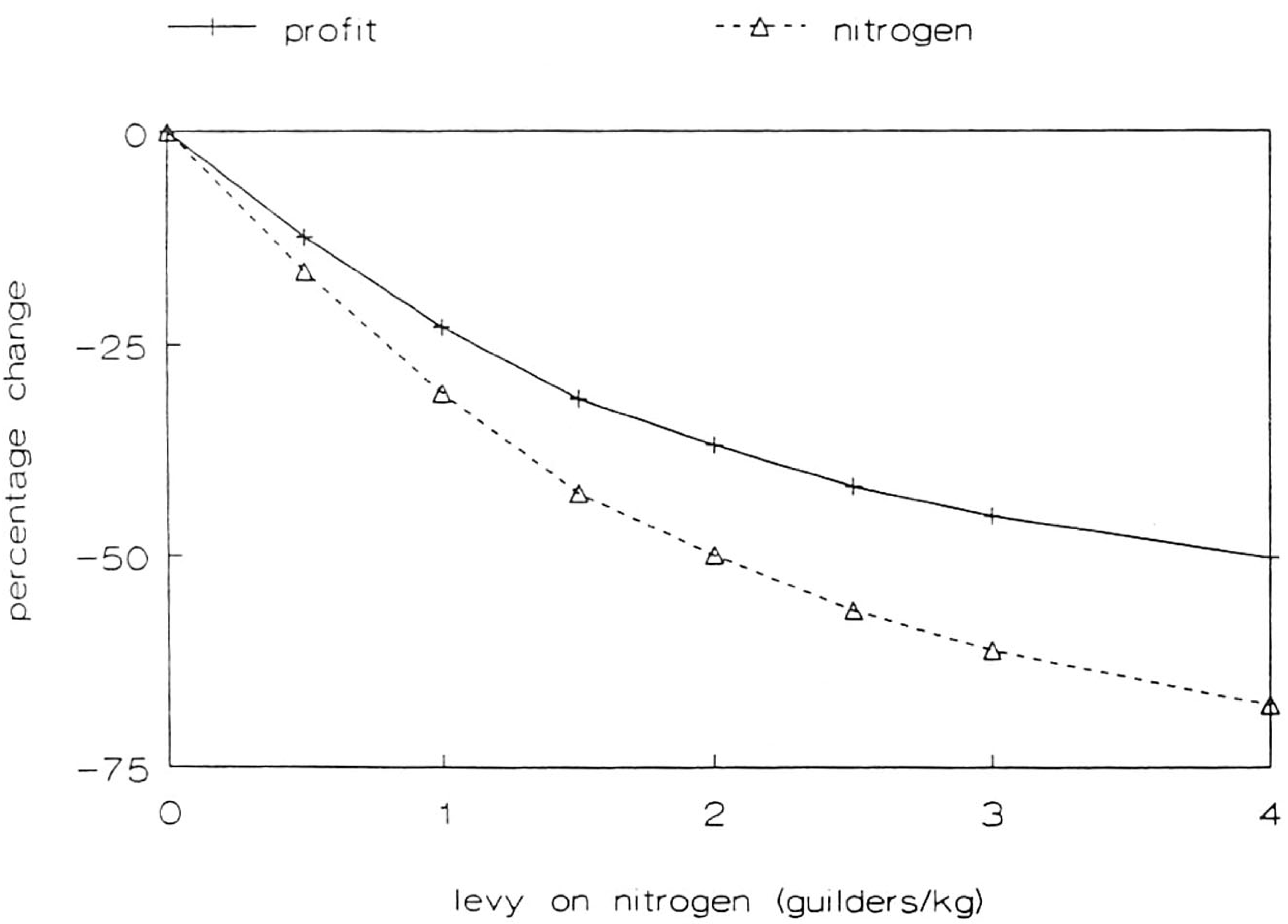

Fig. 6.4. Pig breeding farms.

excretion of nitrogen by pigs and the amount of nitrogen taken up by crops (300 kg per ha).

The estimated model does not conflict with the theoretical assumptions. Short term price elasticities of supply and feed demand are very low. This is not surprising because of the assumption that the size of the livestock is kept fixed in the short term. Long term elasticities are substantial. The long term price elasticities of the demand of feed are –3.2 for the pig fattening farms and –2.8 for the pig breeding farms. The long term price elasticities of nitrogen are –0.4 and –1.9 for the two farm types.

A reduction of the nitrogen excretion with 40% can be realized with a levy of 6% on feed or a levy of 1.50 guilders on the nitrogen surplus. Profits are then reduced with some 30 or 45 per cent, depending on the farm type and the type of levy.

With the levy on feed the profit reduction associated with a certain reduction in the nitrogen excretion is larger than with the levy on the surplus.

Of course the results of this paper 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 and the amount of feed. In pig production there are only few substitution possibilities for the main production input. So, the response of the farmer mainly comes down to a decrease of the size of the livestock. Possible adaptations in the feed composition (feed with less N) 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. A more normative approach like the one followed by Baltussen and van Horne (1992) gives insight in the possible responses of farmers with respect to the mineral content of the feed that is purchased. Their study can be seen as complementary to ours. Their main conclusion is that possible adaptations in the feed composition are very costly.

The definition of the nitrogen surplus deserves some attention. It is assumed that the total amount of nitrogen excretion has to fall under the levy (except an amount of 300 kg per ha). This means that for farms without land all excretion is considered to be polluting. However, 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 which have possibilities to apply the manure in an environmentally acceptable way. Only when the size of the levy is lower than the costs of transportation, the results in this paper can easily be interpreted. If the size of the levy is higher than the transportation costs, farmers will chose to evade the levy by transporting the manure. At present transportation costs are in the range between 0.50 and 1.00 guilders per kg N, but it can not be excluded that in the future this will increase to a level of 2.00 guilders or more per kg.

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 1.50 guilders the nitrogen excretion is reduced with 40%, which means that the manure surplus at the national level is reduced enormously. The possibilities to transport manure at low costs 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 tacid assumption that output prices are determined by factors outside our model. This assumption is justified only in case international competition in the pig market is strong, which is valid to a high degree for the Netherlands as a member of the European Union.

The results in this paper relate to specialized pig farms. However, only one third of the fattening pigs and only half of the breeding sows are kept on specialized farms.

As a final caveat we mention that our study assumes that all existing farms continue production. In practice some farms will stop production totally.

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