# The limitation of a uniform emission charge: the case of Dutch pig farms

*Geert THIJSSEN*

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## Les limites d'une taxation uniforme des effluents : le cas de la production porcine aux Pays-Bas

**Résumé** – L'économie de l'environnement montre que la réduction des émissions polluantes se fait au coût social minimal lorsque les coûts marginaux de dépollution sont identiques pour tous les pollueurs. Dans ce cas, la taxation est la méthode socialement la moins coûteuse pour arriver à un résultat donné. Toutefois, pour y parvenir, on suppose que le coût marginal de pollution est le même pour toutes les entreprises, avant taxation. Cette hypothèse se vérifie lorsque les exploitations sont efficaces en ce qui concerne les produits non désirés. Mais, en réalité, elles ne sont pas toutes efficaces de ce point de vue, en raison de disparités dans l'accès aux ressources (de gestion par exemple).

La recherche empirique doit alors tenter de répondre aux questions suivantes : tous les pollueurs ont-ils le même profit marginal en l'absence d'une politique de protection de l'environnement ? Quelle est la solution la plus économe pour satisfaire une politique donnée : la taxation ou la réglementation ?

On modélise le cas des élevages porcins au Pays-Bas. Pour pallier l'absence de données, on suppose que les nuisances (les émissions d'azote) dépendent linéairement du montant du capital, assimilé ici au nombre de porcs. Par hypothèse les exploitants maximisent leur profit de court terme ; de ce fait, les facteurs ne sont pas tous à leur équilibre de long terme. La recette marginale n'est égale à la dépense marginale que pour les facteurs variables. On utilise une fonction quadratique normalisée comprenant trois facteurs (le cheptel, les bâtiments et le matériel) et un prix normalisé. Le progrès technique est, comme d'habitude, pris en compte par une tendance temporelle.

L'estimation du modèle est faite en utilisant les données d'exploitations porcines de la période 1975-1988. A l'aide de la fonction de profit estimée, on peut calculer le coût marginal de diminution du cheptel dans une grande et dans une petite exploitation. Ce coût marginal varie d'une exploitation à l'autre, ce qui traduit l'existence d'inefficacités par rapport à l'utilisation des produits non désirés.

Si l'on retient le critère coût-efficacité, la réglementation est préférable à la taxation pour les exploitations porcines néerlandaises. Avec la réglementation, solution la plus efficace à coût fixé, la diminution du cheptel touche surtout les grandes exploitations. Lorsque l'on impose une taxation uniforme, elle concerne surtout les petites.

Mots-clés :
pollution, élevage porcin, Pays-Bas, réglementation, taxation, modélisation

## *The limitation of a uniform emission charge: the case of Dutch pig farms*

***Summary*** – *A generally accepted theorem in environmental economics is that an emission charge is the least-cost method for society to achieve a prescribed standard. But this assumes that no inefficiencies with respect to the undesired outputs occur at the level of the farm.*

*However, in the real world farms do not operate efficiently, because of differences in availability of resources (e.g. management). Therefore, the proposition that taxes are the least-cost method to achieve a prescribed standard can be challenged.*

*To illustrate this result a micro-economic model of Dutch pig farms is developed. For the Dutch pig farms, imposing a tax is not cost-effective, regulation is even more cost-effective with respect to minimizing the costs of reducing the number of pigs.*

***Key-words:***
*micro economic model, taxation, regulation, pig farm, Netherlands*

* *Wageningen Agricultural University, Department of Agricultural Economics and Policy, Hollandseweg 1, 6706 KN Wageningen, Pays-Bas.*

ONE of the central concerns in environmental economics is to design reasonably cost effective policies to control externalities. The fiscal and/or legislative instruments that can be used to attain standards serving as targets for environmental quality are evaluated. Under certain conditions taxes (and also marketable permits) turn out to be the least-cost method for society to achieve a given environmental goal (e.g. Baumol and Oates, 1988; Pearce and Turner, 1990). The most important conditions required for this theorem to be valid are: (i) firms seek to minimize the private cost of producing outputs, (ii) no inefficiencies with respect to the undesired outputs occur at the level of the firm, and (iii) the production function is concave. This well-known theorem has been the subject of many empirical studies (for an overview, see Tietenberg, 1990) which have compared the difference between the cost of a control and command system with the least-cost method. The excess costs of a control and command system turn out to be very large, the general conclusion is that the use of economic incentives should be promoted[1].

In environmental economics it is a generally accepted theorem that a charge on emission is the least-cost method for society to achieve a prescribed standard[2]. Various authors have commented on the conditions required for this theorem, and doubts are raised with respect to the empirical studies that claim to support its validity. The concavity of the production function has been challenged by Baumol and Oates (1988). Baumol (1991) argues that empirical studies overestimate the cost savings offered by a system of fees, because they use linear programming but in reality the costs of environmental programmes are distinctly nonlinear. Taking the actual trading process into account Atkinson and Tietenberg (1991) show that the cost savings of marketable permits are much smaller than the cost-effective allocation suggests.

In this paper the second assumption (that there are no inefficiencies in undesired outputs at the level of the firm) is investigated. Inefficiency has been a neglected topic in the analysis of charges, because empirical studies have always started from a normative approach. The use of linear programming models implies that charges work ideally. No allowances are made for inefficiencies. However, in practice inefficiencies can occur and the way in which this can be analysed is presented. As a consequence of these inefficiencies it is shown that taxes are no longer the least-cost me-

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(2) As it is common in literature the costs referred to are the costs due to misallocated resources in production. Transaction costs are not taken into account.

thod to attain a prescribed environmental standard[3]. We illustrate this result using a micro-economic model of Dutch pig farms before conclusions are drawn.

## INEFFICIENCIES AT THE FIRM LEVEL

In the literature on economic efficiency, efficiency is broken down into two multiplicative components: technical efficiency and allocative efficiency. Technical efficiency is defined in terms of the difference between actual output and the maximum output attainable from the bundle of inputs used. Technical inefficiency is mostly caused by limitations in fixed factors, such as management. A firm is allocatively efficient as long as the last unit of a resource that it employs yields as much as it would have yielded in an alternative employment (its opportunity cost). Therefore, the marginal profits of a resource should be equal across firms. If the last unit of a resource yields less than it would have produced elsewhere, the firm is wasteful. (Yotopoulos and Nugent, 1976, pp. 71-77)

In agricultural economics many studies have been done on the measurement of efficiency, often for developing countries (e.g. Lau et Yotopoulos, 1971 ; Dawson *et al.*, 1991), but also for developed countries (e.g. Färe *et al.*, 1990). A recent example of differences in technical efficiency in agriculture is presented by Kalaitzanonakes *et al.* (1992). However, up till now no studies exist in agricultural economics on the measurement of differences in efficiencies with respect to the use of undesired outputs. In this study inefficiencies of undesired outputs will be represented by differences in marginal profits of undesired outputs across firms.

In standard theory on the evaluation of charges, the starting point is cost minimizing behaviour (see Baumol and Oates, 1988, pp. 165-169). As pointed out by Bohm and Russell (1985, p. 398) you can also start from a profit maximizing framework. When the desired output is not fixed it is more convenient to assume that a firm is a profit-maximizer. Another assumption is that some of the inputs are fixed. The profit function of firm $h$ can be written as:

$$\pi_h(p, r, s_h, l_h) = \max_{y_h, v_h} \{p\, y_h - r\, v_h\} \tag{1}$$

subject to the output constraint

$$F_h(v_h, y_h, s_h, l_h) = 0 \tag{2}$$

[3] A complete evaluation of the advantages and disadvantages of charges is beyond the scope of this paper. For the evaluation of stochastic influences, see Baumol and Oates (1988), for a treatment of other dimensions for judging policy instruments, see Bohm and Russell (1985).

where $p$ is a vector of prices of the outputs, $r$ is a vector of the prices of the variable inputs, $v$ is a vector of variable inputs, $y$ is a vector of outputs, $s$ is a vector of undesired outputs, $l$ is a vector of fixed inputs, $\pi$ is the profit function, $F$ is an implicit function of inputs and outputs. The profit function is assumed to be increasing and concave in the pollutant.

A firm is efficient as long as the last unit of a resource yields as much as it would have yielded in another firm. Therefore, the inefficiency for farms generating pollution appears when the variation of profit associated with the emission of an additional unit of pollutant is not equal across firms. This means that the marginal profits linked to a pollutant before an environmental policy is implemented are not identical across firms:

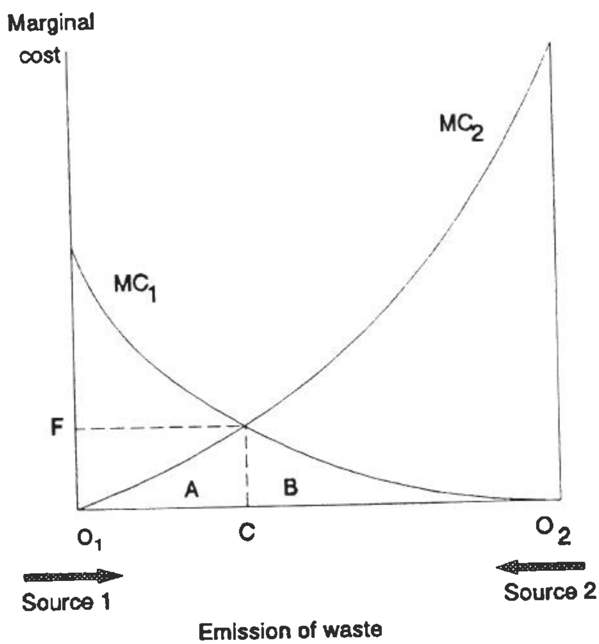
$$\frac{\partial \pi_i (p, r, s_i, l_i)}{\partial s_i} b \neq \frac{\partial \pi_j (p, r, s_j, l_j)}{\partial s_j} b \quad i \neq j \qquad (3)$$

The suffix $b$ refers to the situation before an environmental policy is introduced. The consequence of this divergence will be analysed in the next section.

## THE CONSEQUENCES OF INEFFICIENCY

One of the most important propositions in the economics of pollution control is that the cost of achieving a given reduction in emissions will be minimized if and only if the marginal costs of control are equalized for all emitters. Let us begin with a simplified case which makes it possible to use graphical analysis. Figure 1 demonstrates the proposition.

Figure 1. Efficient allocation of a pollutant



For firm 1 the quantity of emission of waste increases from left to right, for firm 2 the opposite holds. Note that, in contrast with Tietenberg (1992, p. 371), the horizontal axis represents the amount emitted. The curves represent the marginal profit of emission, but also represent the marginal (opportunity) cost of the emission reduction. $MC_1$ represents the marginal cost of the emission reduction for firm 1 and $MC_2$ does likewise for firm 2. In the absence of an environmental policy the waste discharged by source 1 is equal to $O_1O_2$, and we assume that source 2 discharge the same amount ($O_2O_1$).

Assume that the goal of the environmental policy is to halve the total waste discharged by the two sources. The length of the horizontal axis is, therefore, equivalent to the target level of waste emission, each point represents some different combination of reduction by the two sources. The total cost of an emission reduction $O_2C$ by source 1 is equal to area B. The total cost of an emission reduction of $O_1C$ by source 2 is equal to area A. The total cost of the emission reduction $O_1O_2$ by the two sources is equal to area A plus area B. At point C the allocation is cost-effective; any other allocation would result in a higher total control cost. An emission charge F on each unit of pollutant will lead to this point C, because both firms would control their emissions until the marginal control cost equalled the emission charge.

The crucial assumption here is that in the absence of an environmental policy the marginal profit of the emission of waste is equal across firms, and in figure 1 equal to zero. This assumption is only valid when firms are economically efficient with respect to the emission of waste.

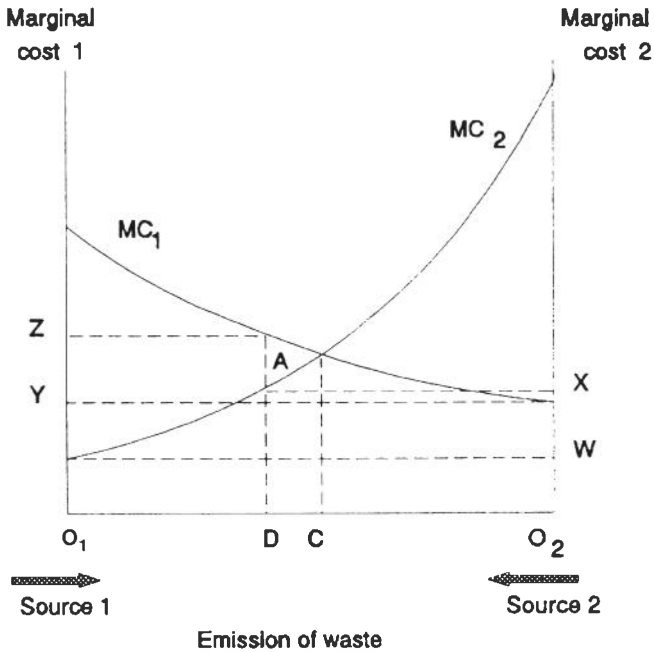
As discussed in section 2 it is more realistic to assume that the marginal profits of waste are not equal in the absence of an environmental policy. The consequence of this divergence is illustrated in figure 2. The marginal cost of waste for source 1 is equal to $O_1Y$ in the absence of an environmental policy. For source 2 this marginal cost is equal to $O_2W$. We assume that after an emission charge is introduced the firms remain as inefficient as in the absence of an environmental policy[(4)]. An emission charge of YZ on each pollutant from source 1 will lead to the waste discharged by source 1 being reduced by $O_2D$. The same tax (WX is equal to YZ) will lead to the waste discharged by source 2 being reduced by $O_1D$. So the total reduction of the waste discharged is equal to $O_1O_2$, which is the goal of the environmental policy.

The uniform tax results in the desired reduction, but this policy is not cost-effective. By comparison with the least-cost policy it involves incurring an additional cost (of area A). In this case regulation is even more cost-effective. Halving the waste discharged by both sources will

[(4)] It is possible that the firms become more or less efficient after a tax is applied. However it is not realistic to assume that firms which are not efficient in the absence of an environmental policy become efficient after the introduction of an environmental policy.

result in a point between D and C. Which policy is the most cost-effective depends on the position of the two marginal cost curves.

Figure 2.
The costs of taxes when some of the inputs are quasi-fixed




Another disadvantage of a tax policy is that the effect of a tax is uncertain. We assume that the firms react to the imposed tax as in figure 2, but is this a realistic assumption when they do not use the inputs and outputs according to the principle that marginal revenue equals marginal cost? However, a full comparison of taxes versus regulation is beyond the scope of this paper.

We will now formalize the result illustrated in figure 2. Taxing the emission by a fixed rate per unit ($F$) decreases the marginal profit of a pollutant by this tax. So both sides of equation (3) will decrease by $F$:

$$\frac{\partial \pi_i (p, r, s_i, l_i)}{\partial s_i} b - F \neq \frac{\partial \pi_j (p, r, s_j, l_j)}{\partial s_j} b - F \qquad i \neq j \qquad (4)$$

As can be concluded from equation (4) the marginal profit of a pollutant differs across firms after the tax $F$ has been imposed. Therefore, charges are not the least-cost method for society to achieve a given environmental goal, when inefficiency is taken into account.

Empirical research is needed to answer the following questions:

– Are the marginal profits of the waste discharged by sources equal across farms in the absence of an environmental policy?

– What is the most cost-effective policy for achieving a prescribed standard: taxes or regulation?

## THE MODEL OF DUTCH PIG FARMS

A model for Dutch pig farms is developed, to answer the questions posed in the previous section. Because of a lack of data it is assumed that the waste discharged (nitrogen emission) is in a linear relation to the amount of capital.

This type of model is widely discussed in Thijssen (1992a) and will be only briefly described here. It is assumed that the farmers are profit maximizers in the short run, so that not all the inputs need to be in full static equilibrium. Only for the variable input is marginal revenue equal to marginal cost. The farmer is a price-taker in the output and variable input markets. This is a reasonable assumption when using data on Dutch pig farms. Even the Dutch pig sector is a price taker, because of the EC common market. According to duality theory the short-run profit maximizing behaviour can be presented by a profit function; see equation (1). The quadratic normalized profit function for farm $h$ is used :

$$\begin{aligned}\pi v_h = {} & \alpha_{oh} + \alpha_q q + \alpha_k k_h + \alpha_l l_h + \alpha_T T + 1/2\, \alpha_{qq} q^2 + \alpha_{qk} q k_h \\ & + \alpha_{ql} q l_h + \alpha_{qT} q T + 1/2\, \alpha_{kk} k_h^2 + \alpha_{kl} k_h l_h + \alpha_{kT} k_h T \\ & + 1/2\, \alpha_{ll} l_h^2 + \alpha_{lT} l_h T + 1/2\, \alpha_{TT} T^2\end{aligned} \qquad (5)$$

where $\pi v$ is the profit normalized by the output price: $q$ is the ratio of the price of the variable input (mainly feed) to the price of the output; $k$ is capital (livestock, buildings and machinery); $l$ is the fixed input (labour); and $T$ is technology. It is assumed that the waste discharged (nitrogen emission) is in a linear relation to the amount of capital:

$$\frac{\partial \pi v_h (q, k_h, l_h)}{\partial s_h} = \frac{\partial \pi v_h (q, k_h, l_h)}{\partial k_h} \frac{\partial k_h}{\partial s_h} = \frac{\partial \pi v_h (q, k_h, l_h)}{\partial k_h} . c \qquad (6)$$

where $c$ is assumed constant over farms.

Data used come from a sample of Dutch farms where accounts of their farming activities are kept for the Agricultural Economics Research Institute. Annual data from pigs farms over the period 1975-1988 were used for estimation of the model. As the farms usually remain in the panel for about five years, the data set forms an incomplete panel. Overall there were 877 observations and 204 different farms in the sample.

Three inputs were included in the profit function: labour, capital (livestock, buildings and machinery), and a normalized price (the ratio of the Tornqvist price index of the variable inputs to the Tornqvist price index of the output). Normalized variable profit is defined as the value of output minus the value of the variable input divided by the price index of the output. Technical change is, as usual, captured in a trend term. Table 1 gives an overview of the data for the average small farm and the average large farm.

Table 1.
**Data on the average small farm and the average large farm**

| | Small farm | Large farm |
|---|---|---|
| Output* | 319,456 | 888,128 |
| Feed* | 241,399 | 655,532 |
| Short-run variable profit | 85,008 | 256,766 |
| Labour (1000 hours) | 3.2 | 5.1 |
| Capital (100 000)* | 4.6 | 12.9 |
| Nitrogen emission (kg N) | 2,882 | 8,158 |

* In 1980 guilders.

The profit function and the related demand function for the variable input are estimated using a Seemingly Unrelated Regression: SUR (Judge *et al.*, 1988). The common transformation of the data for a fixed effects model can also be applied to an incomplete panel and using a SUR estimation method (Thijssen, 1992b).

The parameters of the estimated profit function and the related demand function for the variable input are given in table 2. The adjusted R2 of the profit function is 0.95 and it is 0.98 for the demand equation for the variable input. Six of the fourteen parameters are not significant at the 5 % level. Remark however that the parameters which are related to capital are all significant.

Table 2.
**Parameter estimates of the normalized profit equation and the demand equation for the variable input***

| Parameter | Coefficient | Standard error | Parameter | Coefficient | Standard error |
|---|---|---|---|---|---|
| $\alpha_q$ | - 25,669.1 | 34,578.8 | $\alpha_{qT}$ | -967.7 | 1,201.9 |
| $\alpha_l$ | 4,1571.0 | 11,910.3 | $\alpha_{ll}$ | -6,455.4 | 2,054.6 |
| $\alpha_k$ | 25,350.5 | 4,075.6 | $\alpha_{lk}$ | 3,016.8 | 611.5 |
| $\alpha_T$ | 3,195.4 | 4,751.5 | $\alpha_{lT}$ | -320.5 | 668.9 |
| $\alpha_{qq}$ | 624.5 | 27,845.8 | $\alpha_{kk}$ | -1,147.9 | 266.9 |
| $\alpha_{ql}$ | - 30,770.0 | 3,211.4 | $\alpha_{kT}$ | 1,157.6 | 216.9 |
| $\alpha_{qk}$- | - 30,481.6 | 1,328.7 | $\alpha_{TT}$ | -132.1 | 323.8 |

* The subscripts *q*, *l*, *k*, *T* refer to normalized price, labour, capital, and technology, respectively.

The estimation results are in line with the basic assumption underlying the methodology used in this model *i.e.*, that farmers are profit-maximizers. The normalized profit function decreases in the price of the input and increases in the quasi-fixed input and the fixed input. According to table 2 the normalized profit function is convex in the normalized price ($\alpha_{qq} > 0$) and concave in capital ($\alpha_{kk} < 0$). The assumption of profit maximization behaviour is, therefore, not contradicted by the data.

Using this model, the difference between the shadow price of capital and the capital costs, in the terminology of the previous section the marginal cost of capital reduction (MC), for farm $h$ can be calculated using the estimated profit function:

$$MC_h = \frac{\partial \pi v_h}{\partial k_h} - w \tag{7}$$

$$= [\alpha_k + \alpha_{qk} q + \alpha_{lk} l_h + \alpha_{kk} k_h + \alpha_{kT} T - w]$$

where $w$ are the capital costs. The capital costs depend on: the prices of livestock, buildings and machinery; the discount rate; and the depreciation rates of the different components of the capital good. The prices of buildings and machinery were corrected for investment subsidies. For two farms (the average small farm and the average large farm) the marginal cost of the amount of capital was calculated, see table 3.

Table 3.
**Marginal cost per invested guilder of capital** (a)

| | Small farm | Large farm |
|---|---|---|
| Shadow price of capital | 0.16 (0.02) | 0.12 (0.01) |
| Capital costs (b) | 0.06 | 0.06 |
| Marginal cost of capital | 0.10 (0.02) | 0.06 (0.01) |

(a) in 1980 guilders, standard errors in parentheses
(b) (Thijssen, 1992a, p. 119)

For both farms the marginal revenue of capital stock is not equal to the capital costs. The large farm was more successful in realizing the optimal level for the capital stock than the small farm, because the difference between the marginal revenue and the capital costs is for the large farm more in the neighbourhood of zero than for the small farm. The main conclusion to be drawn from table 3 is that for Dutch pig farms the marginal cost of capital differs across the farms; this is in line with equation (3). Therefore, there are inefficiencies with respect to the use of undesired outputs.

In our model the reduction of the nitrogen emission can only be achieved by a reduction of the number of pigs and is calculated by a reduction of the amount of capital. According to Tamminga and Wijnands (1991) a reduction of the herd size seems to be inevitable to reduce the ammonia emission of the livestock sector and to reduce the application of manure on land. We investigate a reduction of the number of pigs by 20%, see table 4. The calculations are based on equation (7) following the line of reasoning described in the previous section[5].

[5] A full description of these calculations is available from the author upon request.

For the least-cost case the reduction of the number of pigs takes place mainly on the large farm. On the small farm, the reduction of pigs is equal to 2%, the marginal costs of the herd size reduction for the small farm without an environmental policy is 0.10 (see table 3), this is almost equal to the marginal costs of pigs for the least-cost policy (0.102). The cost of this policy is 913 guilders for the small farm and 28,046 guilders for the large farm.

Table 4. Costs and decrease in the number of pigs for the average small and the average large farm, for a total reduction of the amount of pigs by 20%

| | Average small farm | Average large farm | Total |
|---|---|---|---|
| **Costs (a)** | | | |
| Least-cost | 913 | 28,046 | 28,959 |
| Tax policy | 24,936 | 35,120 | 60,056 |
| Tax to pay | 5,635 | 22,341 | 27,976 |
| Costs after repayment | | | 32,080 |
| Regulation | 9,660 | 20,083 | 29,743 |
| **Herd Size reduction (b)** | | | |
| Least-cost | 2 | 26 | 20 |
| Tax | 38 | 14 | 20 |
| Regulation | 20 | 20 | 20 |

(a) in 1980 guilders
(b) in %

When a uniform tax per invested guilders is imposed to reach the standard, the marginal cost of capital rises for both farms by the level of the tax, 0.02. Before an environmental policy is introduced the marginal profit of capital differs for both farms, see table 3. A uniform tax level cannot change this suboptimal situation and, therefore, the costs associated with this policy are higher than the costs associated with the least-cost policy (see figure 2 and equation (4)). The tax reduces the number of pigs for the average small farm and the average large farm, by 38% and 14% respectively. The cost of this policy (including the tax which has to be paid) is equal to 24,936 guilders for the small farm and 35,120 guilders for the large farm. The total cost of this policy is equal to 60,056 guilders after repayment of the revenues of the tax, the total costs are equal to 32,080 guilders. The costs of this policy for the two farms depend on the way these funds are repaid to the two farms[6].

The last instrument which is analyzed is the command and control policy. Both farms have to reduce the herd size by 20%. For the two Dutch pig farms this reduction is more in line with the least-cost policy.

[6] This repayment is not without any problems. For an overview see Oskam *et al.* (1992).

Therefore, in this case regulation is more cost-effective than imposing a tax, the total amount of costs of this policy is equal to 29,743 guilders.

## CONCLUSIONS

One of the most important propositions in the economics of pollution control is that the cost of achieving a prescribed reduction in emissions will be minimized if and only if the marginal costs of control are equalized for all emitters. This leads to the well-known result that charges are the least-cost method for society to achieve a prescribed standard. However, a crucial assumption which has been made to reach this result is that the marginal costs of waste discharged are equal across firms before the charge is imposed. This is a reasonable assumption when firms work in economic terms efficiently with respect to the undesired outputs. However, in the real world firms do not operate efficiently because of differences in availability of resources (e.g. management). Therefore, the proposition that taxes are the least-cost method of achieving a given standard is inaccurate.

To illustrate this result a micro-economic model of Dutch pig farms is developed. The model fits the data well. Using the estimated profit function the marginal cost of reducing pig numbers was calculated for a small farm and a large farm. The marginal cost of reducing pig numbers differs across the farms, therefore taxes are not the least-cost method for society to reduce the amount of pigs. For Dutch pig farms imposing a tax is not cost-effective; regulation is more cost-effective with respect to minimizing the costs of reducing the number of pigs.

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