A Deposit-Refund System Applied to Nitrogen Emissions from Agriculture

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A Deposit-Refund System Applied to Non-Point Nitrogen Emissions from Agriculture

(Brief title: **Deposit-Refund System for Non-Point Emissions**)

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Abstract: *The purpose of this paper is to describe a nitrogen based deposit-refund system for regulating non-point nitrogen emissions from agriculture. We develop a formal model of a polluting production sector with substance content of inputs and outputs as an explicit quality dimension. With in this framework two input-output based tax schemes for regulation of agricultural nitrogen emissions are compared while taking regulator monitoring costs into account. Incentive regulation of nitrogen emissions from Danish agriculture is discussed in this light. It is concluded that a nitrogen based deposit-refund system seems a logical focal point of analysis for a policymaker considering introduction of incentive regulation of non-point nitrogen emissions from agriculture.*

Key words: *deposit-refund systems, non-point emissions, nitrogen emissions, agriculture.*

1. Introduction

Emission of nitrates and ammonia from agriculture are considered important environmental problems in many European countries and regulation through norms and standards for agricultural practices and production technology is widely applied.

In Denmark, a national system of norms and standards was implemented in 1987 and it has been tightened several times since. The Danish experience has been that regulation by norms and standards has not had the desired effect on nitrogen emissions, partly because compliance has not been controlled effectively, and partly because of a disappointing effect on leaching of those regulations that have been controlled effectively. It seems reasonable to conclude from national Danish studies (Rude, 1987; Hansen, 1991; Dubgaard, 1991; Rude, 1991) that reaching the environmental goals in Denmark will entail substantial compliance and control costs if norms and standards are used. This has brought the potential advantages of incentive based regulation as an alternative to norms and standards into focus in the Danish policy discussion. The interest in incentive based regulation of agricultural nitrogen emissions seems also to be increasing in other European countries and in the EU.

Incentive regulation based on direct measurement of nitrate and ammonia emissions (i.e. first-best Pigovian emission taxation) is not feasible due to high measurement costs. However, administratively cheap taxes on chemical fertilizer have been applied in e.g. Austria, Finland Norway and Sweden as have taxes on livestock fodder in e.g. the Netherlands. Recently, the Netherlands has implemented in a farm level tax on calculated nitrogen loss (based on the MINAS farm level nutrient accounting system). This incentive system is more administratively demanding, but may also come closer to emulating first-best Pigovian incentives. Finally there is a growing theoretical literature on regulatory mechanisms for non-point emissions based on measured ambient concentrations of pollutant in the damaged ecosystem[1]. Such mechanisms can (under certain conditions) emulate the Pigovian tax incentives and may therefore be able to induce first best allocations. However taxes based on ambient concentrations have not been applied in practise and are not as yet a viable policy alternative. In the following the first best Pigovian allocation serves only as an ideal reference

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[1] Basing emission taxes on ambient concentrations was originally suggested by Segerson (1988). See Dosi and Tomasi (1994) for a state of the art collection of papers and e.g. Smith and Tomasi (1995), Xepapadeas (1997), Hansen (1998) and Horan *et al.* (1998) for more recent contributions.

point for evaluating more realistic second best regulatory schemes.

In this paper we present a formal model for analysing the allocative properties of different second-best input/output tax schemes for regulating nitrogen emissions (including the schemes mentioned above) and then introduce monitoring costs into the model in a simple, but consistent way. The main purpose of this paper is to describe a nitrogen based *deposit-refund system* for regulating non-point nitrogen emissions from agriculture and compare it with charges based on calculated *residual substance loss* at the farm level (like the Dutch MINAS system)[2].

In section 2 we develop a formal model (inspired by Holtermann, 1976) of a polluting production sector (i.e agriculture) as a common framework for comparing the allocative properties of different input-output based incentive schemes. We then introduce a simple explicit representation of regulator monitoring costs in order to compare the schemes in a setting with substantial monitoring costs and second-best abatement incentives. In section 3 incentive regulation of nitrogen emissions from Danish agriculture is discussed as an example after a presentation of the Danish agricultural system and nitrogen related environmental problems. In section 4 it is concluded that a nitrogen based deposit-refund system would seem a logical focal point of analysis for a policy maker considering introduction of sector level incentive regulation of non-point nitrogen emissions from agriculture.

2. Incentive Regulation of Agricultural Nitrogen Emissions

Compared to other production sectors the agricultural sector has numerous and small firms. Nitrogen flow on a typical farm is illustrated in Figure 1. Animal husbandry takes crops and feed bought on the market as inputs producing animal products (which are sold on the market) and manure used on the farm as outputs. Manure may be used on the farm or sold. Crop production has crops sold and crops used as animal feed on the farm as output categories with manure and chemical fertilizer as input categories. The aggregate goods described are composed of a large number of primary goods all containing nitrogen and nitrogen may be

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[2] The allocative properties of charges based on calculated *residual substance loss* at the farm level (like the Dutch MINAS system) have been analysed by e.g. Huang and LeBlanc, 1994, and Fontein *et al.*, 1994. The potential administrative advantages of deposit-refund systems have been pointed out in the literature by e.g Bohm, 1981; Bohm and Russell, 1985 Huppes, 1993.

leached in several qualitatively different forms from the crop process (nitrate leaching and N_2/N_2O loss through denitrification) and from the animal husbandry process (ammonia evaporation).

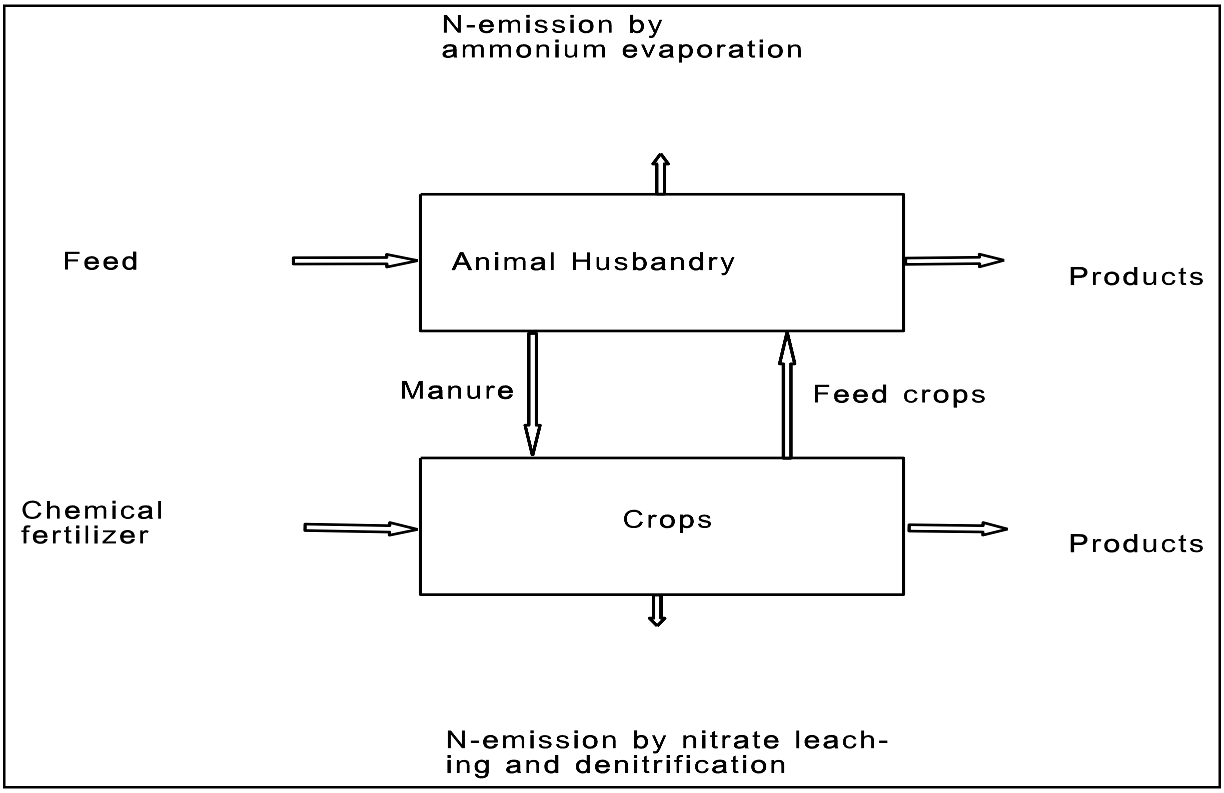

Fig. 1. Illustration of Nitrogen flow on a typical farm

2.1 THE MODEL

In order to develop a formal model assume that the agricultural sector consists of n profit maximizing farms each potentially emitting r different harmful nitrogen compounds while producing one and consuming another subset of the m agricultural input and output goods in the economy.

Many of the m goods contain nitrogen and we assume that each good has two quality dimensions: one proportional to the goods' usual volume measure and one proportional to the goods' nitrogen content. Thus a shipment of good i supplied to farm k from farm j is characterised by its volume measure (y_{ijk}) and its nitrogen content ($n_{ijk} = \alpha_{ijk}{*}\ y_{ijk}$ where α_{ijk} is the corresponding unit nitrogen content that may vary across producers of the same good)[3]. Let y_{ij} denote the total net output of good i from farm j (output being positively signed) and let n_{ij} denote the total net output of nitrogen contained in good i from farm j (output being

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[3] In some cases the volume measure is correlated with nitrogen volume. In case of perfect correlation (e.g. nitrogen fertilizer) α_{ijk} is constant across producers.

positively signed). We then have that $y_{ij} = \sum_{k=1}^{n+1} y_{ijk}$ and $n_{ij} = \sum_{k=1}^{n+1} n_{ijk}$ where subscript $k=n+1$ indicates net exports to the rest of the economy[4]. In the following we use the shorter notation y_{*j} to denote the vector $(y_{1j}, \dots, y_{mj})$, y_{**} to denote the vector $(y_{11}, \dots, y_{1n}, y_{21}, \dots, y_{2n}, \dots, y_{ij}, \dots, y_{m1}, \dots, y_{mn})$ etc.

Each farm is characterized by a well behaved production function $f^j(y_{*j}, n_{*j}) \leq 0$. Formally this is a multi output production function with 2m goods, but we generally expect the good and its nitrogen content to be highly complementary outputs in production. Goods of a given type supplied by different producers are perfect substitutes as is nitrogen contained in a given good type supplied by different producers (i.e. before production the farm mixes all inputs of a given type to form a homogenous input good). Each good and its nitrogen content are bought and sold in the relevant goods market as a composite good and we assume existence of perfectly competitive markets for all *m* goods with given world market prices for each quality dimension (p_i^y and p_i^n). Thus, the price for a given good shipment y_{ijk} is $p_{ijk} = p_i^y + \alpha_{ijk} p_i^n$. For some goods nitrogen content is not in itself a valuable attribute in which case p_i^n will be zero. In other cases p_i^n will be positive (e.g. manure, composite fertilizers etc.).

Further, each farm is characterised by a set of *r* emission functions $z_{qj} = g^{qj}(y_{*j} n_{*j})$ where z_{qj} denotes the amount of nitrogen compound of type *q* emitted by farm *j*[5]. The environmental damage function is denoted $U(z_{**})$.

The model allows farms to have different multi-output production technologies and each good to have a continuum of quality types depending on nitrogen content. Goods produced by some farms may be used as input by others. Some goods may be used exclusively as intermediate goods and some goods may be exclusively imported from or exported to the rest of the economy. Finally, environmental damage caused by emissions may vary across emission types and across farms.

Pareto optimum is found by maximising the sum of farm profits and environmental damage subject to the production function constraints giving the following lagrangian:

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[4] When y_{ijk} is positive it indicates the volume of good *i* produced by farm *j* supplied to farm *k*. When y_{ijk} is negative it indicates the volume of good *i* used by farm *j* supplied from farm *k*. Thus by definition $y_{ijk} = - y_{ikj}$.

[5] This specification of the emission function follows Holtermann (1976).

$$\sum_i\sum_j(p_i^y y_{ij} + p_i^n n_{ij}) + U(g^{11}(y_{*1}, n_{*1})\ldots g^{qj}(y_{*j}, n_{*j})\ldots g^{rn}(y_{*n}, n_{*n})) - \sum_j \lambda_j\, f^j(y_{*j}, n_{*j}) \qquad (1)$$

If the regulating agency can implement farm specific input and output taxes and subsidies as well as emission charges market equilibrium is found by letting farms maximize profit net of emission taxes subject to the production function constraint giving the following set of lagrangian functions:

$$\sum_i [(p_i^y - t_{ij}^y) y_{ij} + (p_i^n - t_{ij}^n\ n_{ij})] - \sum_q t_{qj}^z\, g^{qj}(y_{*j}, n_{*j}) - \mu_j\, f^j(y_{*j}, n_{*j}) \qquad for\ j = 1\ldots n \qquad (2)$$

where t_{qj}^z is a farm and type specific emission tax and t_{ij}^y and t_{ij}^n are good and farm specific tax /subsidy based on each of the two quality dimensions of the *m* traded composite goods. Using (y_{**}, n_{**}) as control variables this gives the following first order condition for :

Pareto optimum [from (1)]	Market equilibrium [from (2)]
$p_i^y + \sum_q [U_{qj} g_{y_{ij}}^{qj}] - \lambda_j f_{y_{ij}}^j = 0$	$(p_i^y - t_{ij}^y) - \sum_q [t_{qj}^z g_{y_{ij}}^{qj}] - \lambda_j f_{y_{ij}}^j = 0$
$p_i^n + \sum_q [U_{qj} g_{n_{ij}}^{qj}] - \lambda_j f_{n_{ij}}^j = 0$	$(p_i^n - t_{ij}^n) - \sum_q [t_{qj}^z g_{n_{ij}}^{qj}] - \lambda_j f_{n_{ij}}^j = 0$
$for\ i = 1\ldots m, j = 1\ldots n$	$for\ i = 1\ldots m, j = 1\ldots n$

There are in general many tax solutions that are consistent with Pareto optimum. Among these is the standard uniform emission charge solution characterized by:

$$t_{qj}^z = -U_{qj} \qquad for\ q = 1\ldots r, j = 1\ldots n$$

$$t_{ij}^y = 0 \quad for\ i = 1\ldots m, j = 1\ldots n$$

$$t_{ij}^n = 0 \quad for\ i = 1\ldots m, j = 1\ldots n$$

where no input/output taxes are levied. Such a charge cannot be implemented when emissions are non-point[6].

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[6] As noted above emulating an emission tax through charges based on ambient concentrations is an intriguing theoretical possibility, but at present not a viable policy

However, Pareto optimum may also be achieved by a system of input-output tax/subsidies alone without levying emission taxes. This solution is characterized by:

$$t^{z}_{q\,j} = 0 \quad for\, q = 1 \ldots r\,,\, j = 1 \ldots n$$

$$t^{y}_{i\,j} = -\sum_{q} U_{qj}\, g^{qj}_{y_{ij}} \quad for\, i = 1 \ldots m\,,\, j = 1 \ldots n$$

$$t^{n}_{i\,j} = -\sum_{q} U_{qj}\, g^{qj}_{n_{ij}} \quad for\, i = 1 \ldots m\,,\, j = 1 \ldots n$$

Thus the regulator must calculate and apply the following set of taxes:

$$t_{i\,j\,k} = t^{y}_{i\,j} + t^{n}_{i\,j} = -\sum_{q} U_{qj}\,(\,g^{qj}_{y_{ij}} - \alpha_{i\,j\,k}\, g^{qj}_{n_{ij}}\,) \qquad for\, i = 1 \ldots m\,,\, j = 1 \ldots n, k = 1 \ldots n+1 \quad (3)$$

In order to implement this tax-subsidy system the regulator must acquire knowledge of each farm's set of emission functions $g^{qj}(.)$ each farms complete input-output vector y_{***} and the corresponding vector of unit nitrogen content coefficients α_{***} .

2.2 MASS-BALANCES AND INPUT/OUTPUT BASED REGULATION

When the sector to be regulated consists of many technologically different farms (as is the case for agriculture) the regulator's information and control costs of calculating and controlling the tax-subsidy system given by (3) would be substantial. However, under certain assumptions the regulator's implementation problem can be simplified by use of mass-balance conditions.

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alternative vis- à-vis agricultural nitrogen emissions.

We know that the general mass-balance condition must hold for any given substance that like nitrogen is not destroyed or created through the production process. Assuming that the mass-balance equation also holds when it is restricted to marketed inputs and outputs and emissions we have[7]:

$$\sum_q \alpha^z_{qj}\, z_{qj} = -\sum_i \sum_k y_{ijk}\alpha_{ijk} \quad j=1\ldots n \tag{4}$$

where α^z_{qj} denote the weight of nitrogen per unit of emission q. Inserting $z_{qj} = g^{qj}(.)$ and n_{ijk} = α_{ijk}* y_{ijk} and differentiating with respect to y_{ij} we have:

$$\sum_q \alpha^z_{qj} \left(g^{qj}_{y_{ij}} + \alpha_{ijk}\, g^{qj}_{n_{ij}} \right) = -\alpha_{ijk} \qquad j=1\ldots n, k=1\ldots n+1 \tag{5}$$

so that the effect on total nitrogen emission of a marginal change in any input or output is the unit nitrogen content of that input or output (appropriately signed). We now define the first critical assumption that environmental damage only is a function of emitted nitrogen at the given location and is independent of type of emission through which nitrogen is lost i.e.:

Assumption I: $U_{qj} = \tilde{U}_j \alpha^z_{qk} \qquad q=1\ldots r$ (6)

where $\tilde{U}_j$ is environmental damage of emitted nitrogen at location j. Given this assumption we have:

$$t_{ijk} = -\sum_q U_{qj} (g^{qj}_{y_{ij}} - \alpha_{ijk} g^{qj}_{n_{ij}}) = -\sum_q \tilde{U}_j \alpha^z_{qj} (g^{qj}_{y_{ij}} - \alpha_{ijk} g^{qj}_{n_{ij}}) = \tilde{U}_j \alpha_{ijk}$$

by inserting (6) and (5) into (3).

Thus, under assumption I the mass-balance condition ensures that Pareto optimal tax rates can be calculated by the regulator without him having to acquire knowledge of each farm's set of emission functions $g^{qj}(.)$. However, knowledge of each farm's input-output vector y_{***} and the corresponding vector of unit nitrogen content coefficients α_{***} are still required.

Now define the second critical assumption that damage per unit nitrogen emitted does not vary across farms, i.e.:

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[7] With the important exception of leguminous plants (to which we will return in the next section) the assumption would seem to hold for nitrogen in the agricultural sector.

Assumption II: $\tilde{U}_j = \tilde{U} \qquad j = 1 \ldots n$ (7)

where $\tilde{U}$ is environmental damage of emitted nitrogen. Under assumption II the Pareto optimal tax rates then become:

$$t_{ijk} = \tilde{U}_{\tilde{z}}\, \alpha_{ijk} \qquad i = 1 \ldots m, i = 1 \ldots n, k = 1 \ldots n \tag{8}$$

Since farm *j*'s output (input) of good *i* delivered to (received from) farm *k* is the same physical good flow as farm *k*'s input (output) of good *i* received from (delivered to) farm *j* we have by definition:

$$\alpha_{ijk} = \alpha_{ikj} \qquad i = 1 \ldots m, \; j = 1 \ldots n, k = 1 \ldots n+1 \tag{9}$$

so that for each market transaction of good *i* between two farms we have

$$t_{ijk} = \tilde{U}\, \alpha_{ijk} = \tilde{U}\, \alpha_{ikj} = t_{ikj} \qquad i = 1 \ldots m, \; j = 1 \ldots n, k = 1 \ldots n+1 \tag{10}$$

Though the tax rates that are to be applied differ for different shipments of a given good the tax rate to be applied to the buyer and to the seller of a given shipment of any good is always the same (i.e., the unit tax to be applied to the buyer is numerically equal to the unit subsidy to be paid to the seller).

When implementing a tax (or subsidy) on a shipment of goods being transacted in a competitive market it is irrelevant whether the tax (or subsidy) is actually collected from (paid to) the buyer or the seller. Thus tax collection/subsidy payment may be shifted from the buyer to the seller or vice versa without affecting the resulting market transaction. We may then concentrate tax collection/subsidy payment on one side of the market by either shifting tax collection to the supply-side of the market or by shifting payment of subsidies to the demand side of the market without affecting market equilibrium. When we do this taxes and subsidies with respect to trade among farms inside the sector cancel out (since the applied rates to buyer and seller are numerically equal). Thus, implementation of the optimal indirect tax system only necessitates collecting taxes from the rest of the economy when supplying goods to the sector and paying subsidies to the rest of the economy when receiving goods from the sector. Thus, under assumptions I and II Pareto optimal incentives can be achieved by implementing a deposit-refund system for the sector based on the mass conserved substance (nitrogen) with the deposit/refund rate equal to the corresponding optimal emission charge per unit of the substance. Not having to engage in control of sector internal trades (i.e. control for tax/subsidy arbitrage between farms inside the production sector) further reduces the regulator's implementation problem since the regulator only needs to control flows to and from the sector (i.e. only requiring knowledge of the part of the input-output vector interacting with the rest of the economy y_{**k+1} and the corresponding vector of unit nitrogen content coefficients α_{**k+1}).

2.3. TRADING OFF REGULATION BENEFITS AND MONITORING COSTS

In the previous subsection we showed necessary conditions (assumptions I and II) for Pareto optimality of tax schemes with successively smaller demands on the regulator's information and control effort. In general, these conditions are not satisfied and the crucial policy question is whether the loss in private regulation benefits entailed by simpler regulatory systems is outweighed by the resulting savings on regulator monitoring costs. In the following we make a number of heroic assumptions in order to get a manageable expression of the second-best regulation choice problem. The resulting analysis is based on what may be called a first order approximation of the second-best choice problem and does bring some important aspects of the problem into focus.

We assume that marginal environmental damage rates $U'(z_{**})$ are constant and follow a bivariate normal distribution $\Phi(u,u,\upsilon_q,\upsilon_f,0)$ where u denotes mean marginal environmental damage of nitrogen emission across farms and emission types, υ_q denotes variance of marginal environmental damage of nitrogen emission over emission types, υ_f denotes variance of marginal environmental damage of nitrogen emission over farms and covariance is assumed to be zero. Without regulation u , υ_q , υ_f also characterise the distribution of the resulting emission price distortions, and note that υ_q is an indicator of the magnitude of the system's deviation from *assumption I* (i.e. if assumption I holds $\upsilon_q = 0$) and υ_f is an indicator of the magnitude of the system's deviation from *assumption II* (i.e. if assumption II holds $\upsilon_q = 0$).

When a regulatory incentive scheme is introduced emission price distortions are changed (reduced). Let t denote the average marginal cost of emission induced by a given tax system and let τ_q denote the resulting reduction in emission price distortion variance over emission types and let τ_f denote the resulting reduction in emission price distortion variance over farms eliminated. With regulation the distribution of the remaining emission price distortions has a mean of $u - t$ and variances of $\upsilon_q - \tau_q$ and $\upsilon_f - \tau_f$ in the two respective dimensions. Let $L(u - t, \upsilon_q - \tau_q , \upsilon_f - \tau_f)$ denote expected welfare loss from the mis-allocation caused by the emission price distortions remaining after implementation of the regulatory scheme. If all emission price distortions are corrected by the regulatory scheme then mean and variance of the remaining price distortions are zero and there is no welfare loss from mis-allocation (i.e. by definition $L(0,0,0) = 0$). If mean distortion deviates from zero, expected welfare loss increases. Further increasing variance of resulting distortions also increases welfare loss because of the standard convexity assumptions. Thus, allocation benefit of implementing a tax scheme becomes $B(u-t\,,\upsilon_q-\tau_q,\upsilon_f-\tau_f) = L(u\,,\upsilon_q,\upsilon_f) - L(u-t\,,\upsilon_q-\tau_q,\upsilon_f-\tau_f)$ where $B(.)$ is concave and has its maximum in $B(0,0,0)$.

Costs of monitoring a tax scheme are assumed to be a function of incentives to engage in tax evasion. Let $c^n(t,\tau_f\,)$ denote average costs of controlling a tax scheme at the farm level where t indicates incentives to engage in illicit trade with firms outside the sector and τ_f indicates incentives to engage in illicit trade with farms inside the sector. Let $c^s(t)$ denote average costs of controlling a tax scheme at a firm trading with the agricultural sector (grain and feedstuff firms, dairies and slaughterhouses) where t indicates incentives to engage in illicit trade with other firms inside or outside the agricultural sector. Let s be the number of firms outside the agricultural sector engaging in trade with farms inside the agricultural sector and remember that n is the number of farms in the sector.

When implementing a residual substance loss tax scheme the regulator can select t and τ_f whereas $\tau_q = 0$ and as noted monitoring is at the farm level so that n farms must be controlled. The regulator's problem is to set t and τ_f so as to maximise allocation benefits less monitoring costs:

$$\underset{t,\tau_f}{\text{MAX}}\; B(u-t,\upsilon_q,\upsilon_f-\tau_f\,)-nc^n(t,\tau_f\,)$$

Let t^R and τ_f^R denote the solution to this problem.

When implementing a deposit-refund scheme the regulator can only select t whereas $\tau_f = 0$ and $\tau_q = 0$ and as noted only the s firms outside the agricultural sector trading with it need to be controlled. The regulators problem is

$$\underset{t}{\text{MAX}}\; B(u-t,\upsilon_q,\upsilon_f\,)-sc^s(t)$$

Let t^D denote the solution to this problem.

When choosing between the two instruments the regulator should compare allocation benefits less monitoring costs at the optimal parameter values for each instrument:

Allocation benefit less monitoring costs

Residual substance loss: $B(u-t^R, \upsilon_f-\tau_f^R, \upsilon_q-0)$ $-\ n\, c^n(\tau_f^R, t^R)$

Deposit-refund system: $B(u-t^D, \upsilon_f-0, \upsilon_q-0)$ $-\ s\, c^s(t^D)$

Two important factors influence the comparison:

- The monitoring cost advantage of a deposit-refund system increases with the *n/s*-ratio (i.e. with the number of farms in the sector relative to the number of firms in the rest of the economy engaging in trade with the sector).
- The potential allocative advantage of using residual substance loss regulation grows with σ_f but if the potential is utilized so does its monitoring cost disadvantage.

When comparing the two instruments for a given regulation problem the key parameters to evaluate are the n/s- ratio (and the corresponding monitoring cost ratio) and τ_f (the part of u_f that can be alleviated by residual substance loss regulation when account is taken of the effect on monitoring costs). If costs of monitoring the residual substance loss scheme increase significantly when tax rates are differentiated between farms its allocative advantage is reduced and may not outweigh the general increase in monitoring cost associated with farm level monitoring.

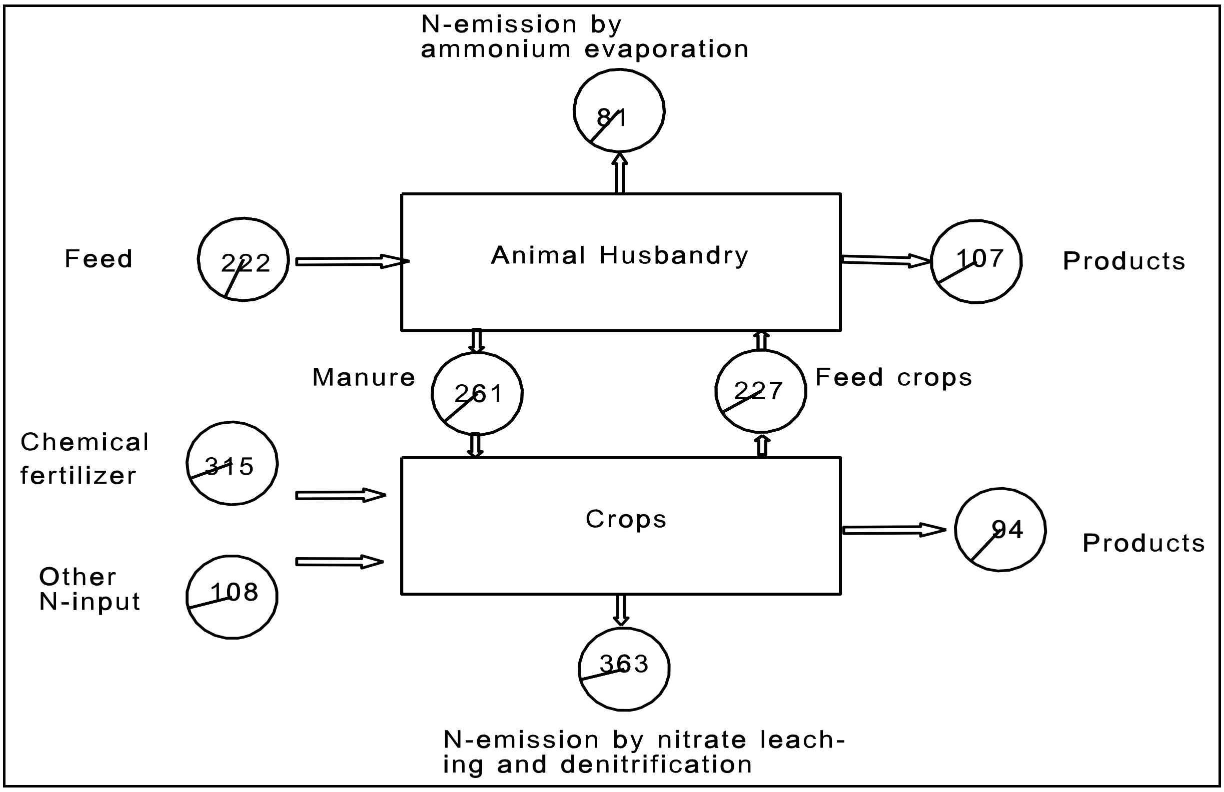
3. Incentive Regulation of Agricultural Nitrogen Emissions in Practice

In this section we present a description of the nitrogen cycle and production processes in the Danish agricultural sector and a qualitative assessment of key parameters pointed out above. We then make a tentative comparison of regulating residual substance loss at the farm level with a deposit-refund system and define the role for input-output based regulation with in a more comprehensive system of regulatory measures for agricultural nitrogen emissions. Finally, we attempt an informal analysis of different variations over the simple single rate deposit-refund system with the aim of pointing to administratively manageable improvements.

3.1. NITROGEN EMISSION AND AGRICULTURAL PRODUCTION IN DENMARK

Nitrogen flow in the Danish agricultural sector is illustrated in Figure 2. Animal husbandry takes crops and feed imported from the rest of the economy as inputs producing animal products (which are sold to the rest of the economy) and manure as outputs. Crop production has crop sold to the rest of the economy and crops used as animal feed as output categories with manure and chemical fertilizer as input categories. All the aggregate goods described contain nitrogen. In Figure 2 storage and spreading of manure are considered part of the animal husbandry process.

Fig. 2. Average annual nitrogen flow (1993/94-1995/96) for the Danish agricultural



sector (numbers indicate flow in thousand tons nitrogen)

Note: The diagram is based on Linddal, 1998. Of the total nitrogen loss from crop production it is estimated that nitrate leaching accounts for at about 200 thousand tons nitrogen. Other nitrogen input to crop production consists of nitrogen fixation (41 thousand tons) and nitrogen deposition (67 thousand tons). Calculations assume zero net growth of nitrogen stock in humus, as reliable estimates of net growth are not available.

Danish agriculture is characterised by a sizable dairy production and a large production of pork meat. Thus, manure loading per hectare is relatively high by European standards (although still substantially smaller than e.g. Belgium and the Netherlands, see e.g. Brouwer *et al.,* 1995). Figure 2 indicates that the nitrogen flow through each of the two aggregate production processes is comparable in size and that there are large flows of nitrogen between the two production processes. Nitrogen loss in per cent of flow through for the aggregate crop process increases significantly with the proportion of manure to fertilizer used in crop production.

Each of the aggregate goods is composed of a large number of goods with large variations in nitrogen content. Studies of the production processes of different crops show large variations in nitrogen loss in per cent of economically optimal flow through (all other things being equal) and that several important low flow through crops have relatively high nitrogen loss percentages while some high flow through crops have low loss percentages. The nitrogen loss percentage for a given crop rises with increased nitrogen flow through, all other things being equal. The use of catch crops generally reduces nitrogen-loss percentages, all other things being equal.

Loss of nitrogen percentages for animal husbandry processes themselves primarily depends on other factors than the output type (e.g. stall and storage facilities and method of manure spreading), however, nitrogen loss percentages from manure during and after spreading are to some extent influenced by feed composition and output (livestock) type. Generally, nitrogen loss from manure after spreading is greatly influenced by the timing of manure spreading relative to crop growth etc.

It is safe to say that there is no simple relationship between Nitrogen emission and a subset of inputs used. Nitrogen loss is related in a complex way to most input-output flows containing nitrogen. It is also notable that nitrogen content in a number of major inputs and outputs is measured today as it is important for production decisions and output valuation.

Mass-conservation in traded goods and emissions would seem to hold for nitrogen. It is, however, important to note that though nitrogen fixating leguminous crops are not a substantial input category at present, they are a potentially important alternative to marketed nitrogen inputs. It should also be noted that the stock of nitrogen in the system is large compared to flow through. Nitrogen stocks in field humus are probably on the order of 25 to 50 times as large as flow through (Miljøstyrelsen, 1993) though only a small part of this stock is accessible in the short run.

As indicated in Figure 2 several nitrogen compounds are emitted. The animal husbandry processes (including manure storage and spreading) primarily emit ammonia gas (NH_3) while crop processes primarily emit water-diluted nitrates (NO_3^-) through leaching and a mix of N_2 and N_20 gases through denitrification. Soil composition, temperature and rainfall are the factors of primary importance to the proportion of nitrogen loss through denitrification to loss through leaching (Lind *et al.*, 1990). These factors are not controlled by farmers. The way these uncontrolled factors affect denitrification may cause systematic and quite substantial differences in the proportion of denitrification to leaching from region to region. The proportion of N_2O to N_2 when denitrification occurs is highly volatile and does not seem to depend in any stable and systematic way on the type of fertilizer used or on factors that vary regionally (Lind *et al.*, 1990).

Table I. Environmental problems caused by nitrogen emissions from agriculture

Nitrogen compound:	Local/regional damages:	Inter-regional damages:	Global damages:
Ammonia evaporation (NH_3):	- Eutrophication of lakes and other ecosystems	- Eutrophication of coastal sea areas and other ecosystems - Acid rain	- Global warming - Ozone depletion (2. order effects through denitrification)
Nitrate leaching (NO_3^-):	- Contamination of ground water - Eutrophication of lakes	- Eutrophication of coastal sea areas	- Global warming - Ozone depletion (2. order effects through denitrification)
Denitrified N_2O:	none	none	- Global warming - Ozone depletion
Denitrified N_2:	none	none	none

A number of environmental effects of the emitted nitrogen compounds have been sited in Danish studies (Fenger, 1989; Gundersen, 1989; Miljøstyrelsen 1990 and 1993). These are specified in Table I ranked according to whether the effect is regional, interregional or global.

Valuation of these damages may lead to substantial differences in average damage caused per ton emitted nitrogen through the three emission processes. Emission effects on interregional environmental problems also vary spatially depending on diffusion and removal in natural eco-systems during diffusion.

3.2 THE ROLE OF MASS-BALANCE BASED REGULATION OF NITROGEN EMISSIONS FROM DANISH AGRICULTURE

The fundamental assumption of mass conservation in traded goods and emissions and of competitive markets would seem to hold for nitrogen in the agricultural sector[8]. Further, the potential problem of excess farm information costs that mass-balance based regulation may induce is probably limited. Information on nitrogen content is an important quality parameter for farmers today and is in many cases already being measured. Nitrogen emissions are causally connected with nitrogen contents of a wide spectrum of inputs and outputs, so if increased measurement is induced in most cases this will not be inefficient.

The two assumptions necessary for achieving a first-best solution with a deposit-refund system or a residual substance loss regulation are clearly not satisfied since environmental damage from nitrogen emissions probably varies substantially across emission types and across farms (i.e. $\upsilon_f >>0$ and $\upsilon_q >>0$). Thus, when comparing a deposit-refund system with residual substance loss regulation the second-best comparison undertaken in the previous section is the relevant framework.

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[8] It should be noted that if non-marketed nitrogen input to agriculture through N-fixating leguminous plants becomes a problem supplementary regulation (e.g. by taxing output of these crops, seed inputs or acreage) may become necessary. Also the implicit capital costs of nitrogen stocks that an input-output based incentive regulation would impose on farmers should be noted . The implicit capital costs give farmers an inefficient incentive to reduce nitrogen stocks.

The agricultural sector is characterized by having many relatively small farms. At the same time the major part of trade volume with the rest of the economy is channelled through relatively few wholesale suppliers and wholesale crop firms and relatively few large slaughterhouses, dairy processing firms and other food processing firms. On the output side private households constitute a potential alternative outlet for farm goods, however, since mass-balance tax schemes imply refunds for outputs this does not pose a control problem[9]. Thus the sector is characterised by a high *n/s*-ratio indicating that the administrative cost savings of moving from control at the farm level to control at the sector level may be substantial. Further, although environmental damage varies substantially across farms (i.e. $\upsilon_f >> 0$) the notorious problems of controlling inter-farm trades in the agricultural sector suggests that only a small part of this potential can be efficiently captured by residual substance loss regulation (i.e. $\tau_f \approx 0$).

This and the high *n/s*-ratio indicate that the monitoring cost advantages of deposit-refund regulation vis-à-vis residual substance loss regulation may offset its allocative disadvantages.

Within a more comprehensive system of regulatory measures for agricultural nitrogen emissions deposit-refund regulation might have an important role to play as an administratively cheap *baseline regulation* to be supplemented by controllable farm level regulations like production norms in *high damage regions*.

Residual substance loss regulation may have a role to play as supplementary regulation in *high damage regions*. However, other farm level regulatory systems that are *not* susceptible to inter-farm arbitrage problems may also be relevant. Systematic differentiation of production norms and standards (e.g. manure storage capacity requirements, manure spreading rule etc.) between farms has not been attempted in Denmark, but the possibility of doing so is an important characteristic of this type of farm level regulatory instruments.

3.3. OPTIMISING DEPOSIT-REFUND REGULATION OF AGRICULTURAL NITROGEN EMISSIONS.

In this subsection we proceed on the assumption that it is reasonable to give a sector level

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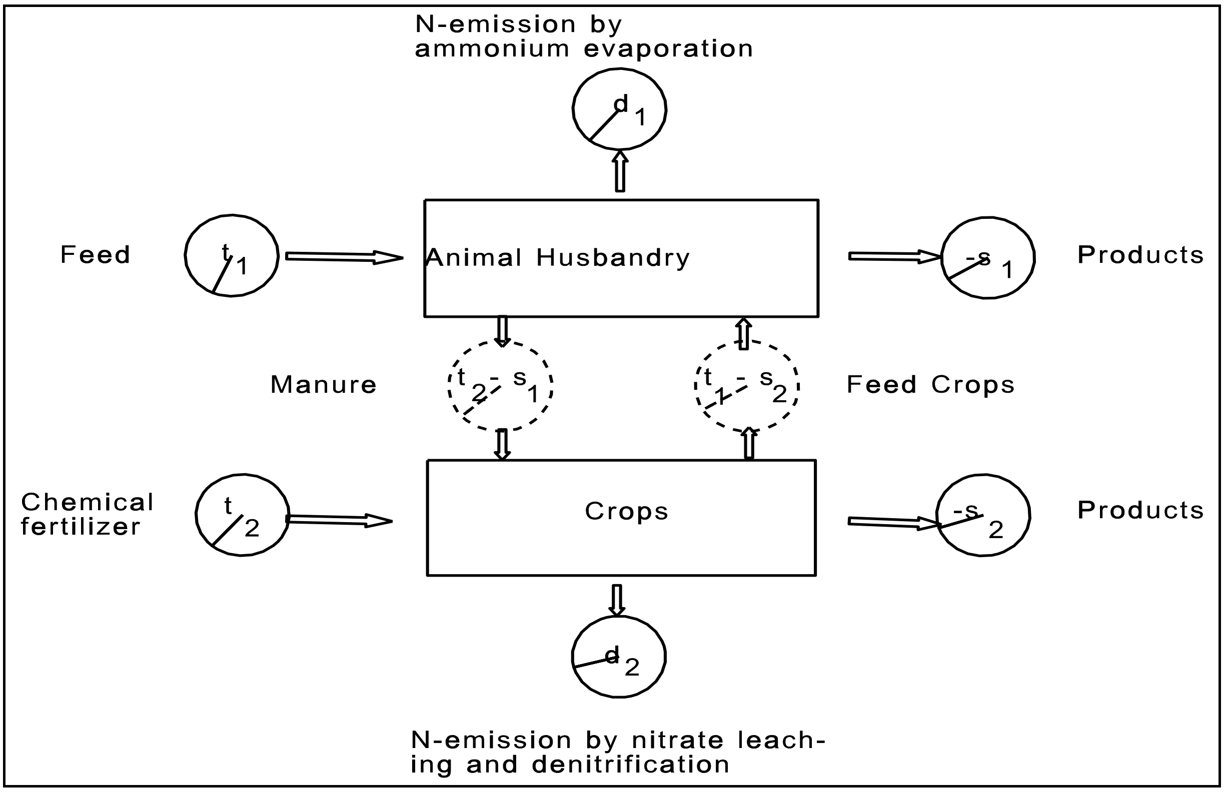
[9] Actually a mass-balance based scheme may have a substantial advantage since incentives to evade VAT and income tax through 'black market' sales to households are reduced.

deposit-refund system the role of an administratively cheap *baseline regulation* of nitrogen emissions and consider whether differentiation of taxes and subsidy rates between goods might improve regulatory performance since damage as noted in section 3.1 probably varies across emission types. We address the simple fertilizer tax in this context as it can be seen as an (extreme) example of rate differentiation.

The discussion will be conducted within the framework of the aggregate two-sector, six good model illustrated in Figure 3. We consider specification of four policy variables (t_1 and t_2 being input taxes per unit nitrogen in feed and fertilizer respectively and s_1 and s_2 being output subsidies per unit nitrogen in products from animal husbandry and crop production respectively). Average damage per unit nitrogen emitted being d_1 and d_2 for animal husbandry and crop production respectively.

Fig. 3. Aggregated model of the agricultural production system under sector level incentive regulation



If the regulator has a reliable aggregate model describing inputs, outputs and emissions it is possible to optimize the regulatory system (at the aggregation level of the model) by differentiating taxes and subsidies between goods. Here we only attempt a tentative discussion basis of the general structure of aggregate production functions.

When there are substantial differences in d_1 and d_2 the ideal solution would be separate deposit-refund systems for each emission type so a natural starting point would be to differentiate between tax/subsidies for animal husbandry on one hand and tax/subsidies for crops on the other so that $t_1=s_1=d_1$ and $t_2=s_2=d_2$. If traded products between the two agricultural sectors have low elasticities of substitution then the distortions created by not being able to apply net taxes of t_1-s_2 per unit nitrogen to the import of feed to animal husbandry and net taxes of t_2-s_1 for the import of manure to crop production are small and the optimal system of input-output taxes will resemble the differentiated system above. If, however, trade volume is large and the possibilities of substitution are good in both sectors the optimal system will resemble a uniform rate system. As N-trade volume between the animal husbandry and crop sectors is large and substitution possibilities are good the welfare loss of not differentiating taxes and subsidies over goods may be small even when damage rates differ substantially.

The policy discussion in Denmark has until recently been centred on the pros et cons of regulation by input charges alone and in particular centred on regulation by an input charge on chemical fertilizer (i.e. setting $s_1=s_2=t_1=0$). Since this type of regulation also has been in focus in other countries we attempt a qualitative efficiency comparison of input charges with the uniform rate deposit-refund system.

For an input charge based system to come close to optimality, emissions should be close to proportional to inputs. From the description in subsection 3.1 it is clear that this is far from being the case. The large variations in loss-percentages between different crops (where possibilities of substitution clearly are large) and between crops and animal husbandry as such suggest that the efficiency cost of regulation by input charges is appreciable. The gain vis-à-vis a uniform rate deposit-refund system is saved monitoring costs since the regulator would only have to control nitrogen fertilizer flow to the sector. Whether saved measurement costs can outweigh efficiency losses from distorted incentives is an empirical question. However, if governments are considering incentive regulation of nitrogen emissions at the sector level there would seem to be strong arguments for making a nitrogen based deposit-refund system rather than a fertilizer tax the focal point of policy evaluation or at least including such a system in the spectrum of policy alternatives being considered.

4. Conclusion

A Nitrogen based deposit-refund system could have an important role to play as an administratively cheap *baseline regulation* of nitrogen emissions to be supplemented by farm level regulation in high damage areas (such as production norms etc. and possibly farm level residual nitrogen loss taxes).

If there are substantial differences in damage caused by the different nitrogen compounds being emitted and the regulator has a reliable aggregate model describing inputs, outputs and emissions it is possible to increase efficiency of a sector level deposit-refund system by differentiating taxes and subsidies for different goods. If fine tuned optimisation along these lines is not possible then a simple uniform rate nitrogen based deposit-refund system (rather than a tax on fertilizer) seems the logical starting point for a policy maker seeking a cost-effective base line incentive scheme for regulating nitrogen emissions from agriculture.

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