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REFEREED PAPER

CONTROLLING AGRICULTURAL EMISSIONS OF NITRATES: REGULATIONS VERSUS TAXES

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A number of policy instruments, including input taxes and regulations, can be used to deal with nitrate pollution. However, in practice command and control (CAC) measures such as input regulations and management practices, as outlined in Action Programmes under the EU Nitrates Directive, rather than economic instruments, are commonly used to deal with nitrate pollution from agricultural sources. This paper tests the hypotheses that the objectives of the Nitrates Directive, in terms of organic and inorganic N application rates, would be (a) more effectively and (b) more equitably achieved by regulation, than by a tax. The analysis is undertaken for a sample of dairy farms in the southwest of Ireland. The results support the hypotheses tested.

Keywords
Nitrates Directive; Input taxes; Regulations; Effectiveness; Equity

1. Introduction

Pollution of waters by nitrates is a serious problem throughout the EU, including in Ireland, and agriculture is one of the main contributors to the problem. Nitrate emissions from agriculture are diffuse in nature and are very difficult to monitor. For this reason taxes or quotas on emissions, the standard economic approaches to pollution control problems cannot be applied and regulators are instead forced to rely on 'second-best' policies where controls are targeted at inputs seen as responsible for raising emission levels, rather than the actual emissions themselves (Kampas and White 2000a; Hanley 1997). This is known as a command and control (CAC) approach and is the approach adopted by the European Union (EU) in the form of the Nitrates Directive.

Environmental policies, such as the Nitrates Directive impose production constraints on some farms and can result in reductions in farm income. Research undertaken by Lally and Riordan (2001; 2002) and by Hennessy *et al*. (2005), estimates the impact on farm incomes of restrictions on organic nitrogen use on Irish dairy farms. Lally and Riordan (2001) also estimated the impact on farm incomes of a tax on inorganic nitrogen. However, there is a shortage of studies evaluating the effects of different policy instruments on individual farming systems in Ireland. The aims of this study are: (i) to reduce this deficit by undertaking an empirical estimation of the impact on Irish dairy farms of restrictions on both organic and inorganic nitrogen use as outlined in the Irish Action Programme, and of a tax on inorganic nitrogen; and (ii) to test the hypotheses that the limits on applications of nitrogenous materials on farms in Ireland would be achieved (a) more effectively and (b) more equitably by regulation than by taxation. The measure of effectiveness will be the compliance cost of the control regime to farmers and to public administration while the measure of equity will be proportionality between the likely cost of the measure to individual farmers and the size of their likely contribution to the problem in the absence of a control regime.

The paper begins by providing a background to the study and outlining details of the Irish Action Programme under the Nitrates Directive. This is followed by details of the methodology. The first part of the results section outlines the impact on farm incomes of restrictions on organic and inorganic nitrogen use as outlined in the Action Programme, while the second section estimates the rate of *ad valorem* tax on nitrogen in manufactured fertilisers required to move the profit maximising level of applications below the limit in the Action Programme. This is followed by a discussion of the results and the paper concludes by commenting on the effectiveness and equity of regulations versus taxation in terms of achieving the objectives of the Nitrates Directive.

2. Background

Agricultural nitrate emissions from land receiving both mineral 'inorganic' fertiliser and livestock 'organic' manure are very difficult to observe or cannot be observed at a reasonable cost. "This is due to the diffuse source of the pollutant, the complexity of its transportation pathways through the hydrological system and its role in modern agricultural production. In combination these attributes make emission taxes or quotas, the standard economic approaches to pollution control, prohibitively expensive to administer" (Kampas and White 2000a). However, according to Kampas and White (2002) "biophysical models may provide sufficient information to set a cost-effective emission tax". Biophysical models have been combined with economic analysis in a number of studies and have been used to evaluate different types of policy instruments for dealing with nitrate pollution (e.g. Johnson *et al*. 1991; Mitz *et al*. 1998; Kampas and White 2000a; Albiac and Martínez 2004; Martínez and Albiac 2006; and Hanley *et al*. 2006). Four of these studies have shown that an emission tax is more efficient than an input tax but these studies fail to take into account transaction or administrative costs. Kampas and White (2000b; 2002; 2004) found that in the absence of transaction costs a uniform emission tax minimizes abatement costs but when transaction costs are added to abatement costs it is efficient to "pursue input-based policies" to regulate nitrate emissions. Controls must be targeted at the processes/inputs that result in emissions, rather than actual emissions (Hanley 1997).

Two policy instruments that can be used to deal with diffuse pollution and with nitrate pollution in particular are input taxes and input regulations. Griffen and Bromley (1982) found that within a theoretical framework an input tax is equivalent in terms of its cost efficiency to a single tax on point source emissions, with the two policies only differing in terms of the point of monitoring. In the case of an input tax inputs rather than emissions are monitored. Input regulations, like input taxes can also achieve the desired environmental target at least cost. However, in order to apply input taxes or input regulations knowledge of the non-point pollution production function is required. Without it emissions cannot be related to input use and policy benefits cannot be ascertained.

Non-point pollution functions are likely to differ between farms thus farmers should be charged according to the actual pollution production function for their farm. However, in reality it would be impractical to apply a pollution production function related tax. In addition, it would tend to levy different charges for the same input. This too would be impractical in the absence of market separation as farmers who face low or zero charges could resell the input to those facing higher charges. If then polluters cannot be charged differently according to their non-point pollution function the least-cost objective cannot be attained. Helfand and House (1995) considered more practical but imperfect measures for curtailing non-point source pollution (identical input taxes for all pollution sources, identical reductions in inputs contributing to pollution on a percentage basis for all sources, identical taxation of single inputs, identical restriction on single inputs) and found that uniform instruments do not lead to large losses in welfare relative to the least cost solution.

Economists usually concentrate on the relative cost-efficiency of policy instruments, but other criteria also exist: for example, the level of uncertainty regarding policy outcome; the equitable distribution of costs; political acceptability; and co-ordination with existing policy in the wider sphere (either agricultural or environmental). No policy option is likely to be preferred simultaneously on all of these grounds, thus "policy choice is also implicitly a choice among competing criteria" (Hanley 1997).

In practice, command and control (CAC) measures such as input regulations and management practices rather than economic instruments are commonly used to deal with nitrate pollution from agricultural sources (Parsche and Radulescu 2004; O'Shea 2002). The EU has adopted a CAC approach, in the form of the Nitrates Directive, to deal with the problem of nitrate pollution. Considering the criteria, other than cost-efficiency, on which instruments are rated, gives some insight into why the EU chose a CAC approach rather than imposing a tax on nitrogen inputs. Imposing an input tax on nitrogen would prove very difficult for the EU as the level of taxes required to achieve the objective of the Nitrates Directive in terms of organic and inorganic nitrogen application rates would vary significantly across countries and even between producers within each country. Also there is no direct link between an input tax and the level of nitrate emissions which means that there is a high level of uncertainty regarding policy outcome. Additionally and importantly the tax only targets the quantity of fertilizer purchased. Furthermore, a tax on nitrogen inputs would have little or no impact on other risk factors that may cause pollution of waters by nitrates, particularly the time when fertilizer, slurry and animals go on the land.

The main objective of the Nitrates Directive is to reduce nitrate concentrations to below an acceptable level of 50mg/litre. A number of studies have been undertaken to compare different instruments in terms of achieving such ambient levels, for example, Hanley *et al*. (2006); Albiac and Martinez (2004); and Kampas and White (2000b). These studies have used biophysical economic models which are quite complex and include highly developed nitrate leaching and hydrological models and are undertaken on a geographical or water catchment area level. There are few examples in the literature of studies undertaken at farm level to compare different instruments in terms of achieving reductions in nitrogen use. Martínez and Albiac (2006) analyze the cost efficiency of several policy instruments to curb nitrogen pollution in an area of Spain, Wu and Babcock (2001) analyze the relative efficiency of uniform taxes and standards on agricultural chemical use in the presence of spatial heterogeneity in the Oklahoma high plains and Whittaker *et al*. (2003) compare an economic incentive policy (an input tax) for reduction of agricultural fertilizer application with a CAC policy in the Colombia plateau.

Studies at farm level have tended to concentrate on evaluating the impact of a particular type of instrument used to reduce nitrogen applications. Berntsen *et al*. (2003) use the whole farm model FASSET to evaluate the environmental and economic consequences of implementing different nitrogen taxes. Hennessy *et al*. (2005) determine the effect of different implementation strategies of the restrictions on organic nitrogen use as outlined in the Nitrates Directive (whole farm or field by field) on the overall farm system and farm profitability of case study Irish dairy farms. Picazo-Tadeo and Reig-Martínez (2006) evaluate the impact on Spanish citrus farmers' income of a mandatory reduction in nitrogen application rates and Rigby and Young (1996) evaluate the impact on a group of English dairy farmers of restrictions on organic nitrogen and phosphorus applications. Berentsen and Giesen (1995) estimate the impact on a dairy farm of a levy on N losses above 150 kg/ha and Lally and Riordan (2002) evaluate the impact on Irish dairy farm incomes of restrictions on organic nitrogen use.

A small number of studies have evaluated different types of policy instruments at farm level. Berentsen and Giesen (1994) evaluate the impact of different policies, including restrictions on nitrogen use and a levy on nitrogen inputs, to reduce nitrogen applications on Dutch dairy farms. Lally and Riordan (2001) estimate the impact on Irish dairy farm incomes of restrictions on nitrogen use and of a 10 per cent tax on nitrogen inputs and Picazo-Tadeo and Reig-Martínez (2007) assess the impact on Spanish citrus farmers' income of two policies aimed at reducing consumption of inorganic nitrogen – levies on purchased nitrogen and nitrogen use permits for farms.

According to Baldock *et al*. (2002) and Picazo-Tadeo and Reig-Martínez (2007) there is a shortage of detailed empirical studies evaluating the effects of different policy instruments on individual farming systems which is making it difficult to integrate environmental concerns into European agricultural policies. One of the aims of this study is to reduce this deficit by undertaking an empirical estimation of the impact on Irish dairy farms of different policy instruments.

This study adds to the literature on the impact of the Nitrates Directive on Irish dairy farm incomes. Previous studies by Hennessy *et al*. (2005) and Lally and Riordan (2001; 2002) were undertaken prior to the finalization and implementation of the Irish Action Plan under the Nitrates Directive. This study estimates the impact on Irish dairy farm incomes of restrictions on both organic and inorganic nitrogen as specified in the Action Plan which commenced in January 2006. In addition, this study builds on these previous studies by estimating the level of tax on inorganic nitrogen required in order to achieve the objectives of the plan, and tests the hypotheses that the objectives of the Nitrates Directive, in terms of organic and inorganic N application rates, would be more effectively and more equitably achieved by regulation, than by a tax.

3. Irish Action Plan Under the Nitrates Directive

Ireland's first National Action Programme commenced on a phased basis on 1st January 2006, and will run for a period of four years."The primary aims of the action programme are to reduce water pollution/eutrophication caused or induced by nitrates and phosphates from agricultural sources and to prevent further such pollution/ eutrophication. In addition, a specific objective is to increase the efficiency of nitrogen use in agriculture using 2006 as a base year" (DAF 2005). To this end the first National Action Programme specifies the following:

1). The amount of livestock manure applied in any year to land on a holding, together with that deposited on land by livestock, cannot exceed an amount containing 170 kg nitrogen per hectare

2). The amount of inorganic N that farmers can apply is estimated based on:

a) a farm's stocking rate as expressed in terms of their expected emission of nitrogen in urine and faeces per hectare per year
b) the prescribed nitrogen availability (%) rates from managed livestock manure applied in the year of application and
c) the length of the winter housing period on the farm, the length of the winter period varies depending on the area of the country (details in Annex I). For a farm located in Zone B in 2007 with a stocking rate of 170 kg/ha the amount of inorganic nitrogen it can apply is calculated as follows: 226 –((170/52) x 18 x 0.30) = 226 – 18 = 208.

3). Farmers undertake farm practices, such as spreading of slurry and manure, in such a manner as to prevent water pollution by fertilisers, and keep records in relation to production activities, fertiliser application rates and farm practices.

4. Methodology

Positive mathematical programming (PMP) is used in this study. PMP is based on the principle of linear programming. Linear programming models are often used for whole farm planning and there are many examples of the use of linear programming models in the literature, particularly in studies concerned with the estimation of the economic impact of environmental regulations, for example, Berentsen *et al*. (1992); Berentsen and Giesen (1994); Berentsen and Giesen (1995); and Rigby and Young (1996).

While linear programming models are very useful and have advantages, especially for the type of study being undertaken here, they also have disadvantages. Linear programming models should calibrate against a base year or an average over several years in order to be useful for policy analysis.

However, in general, the optimal solutions tend to be overly specialised and do not conform to the number and level of realised activities observed on the farms under investigation. In addition analyses based on such results that deviate substantially from observed production quantities are not very useful for policy making and are unlikely to be accepted by elected decision-makers.

A methodology to calibrate linear programming models, known as Positive Mathematical Programming (PMP) was developed by Howitt in the late 1970's, and has been employed in a series of policy oriented modeling exercises since then. It was used in studies by House (1987), Kasnakoglu and Bauer (1989), Bauer and Kasnakoglu (1990) and Horner *et al*. (1992). PMP allows exact calibration of a model solution to observed quantities, and constrains the simulation behaviour of the models less severely than previously employed approaches. These two properties have led to a significant interest and a continuing implementation of this approach in the area of agricultural sector modeling and it has been used by Arfini (1996) and Röhm and Dabbert (2003).

The idea of PMP originated from the observation that unit costs recorded in farm accounts do not reflect the true cost of production. Farmers production decisions are based on the costs recorded in farm accounts and other unobserved costs which may be due to technology, environment, risk etc.. "The observed levels of outputs, therefore, are the result of a complex decision based, in large part, on a cost function known to (or perceived by) the entrepreneur but difficult to observe directly. Furthermore, as the cost function is the dual to the production function, the recovery of the former is a perfect substitute for a detailed specification of the latter" (Paris 1997).

PMP methodology consists of two stages – calibration and prediction. The calibration stage involves estimating or recovering a cost function, which takes the place of the hidden unobservable cost function used (either explicitly or implicitly) by the entrepreneur for making their decisions. This stage of the PMP methodology calibrates the model in such a way that it is capable of reproducing the base-period results. The prediction stage of PMP uses the calibrated model to generate responses in the endogenous variables induced by variations of some relevant parameters.

PMP models are more useful for policy analysis than linear programming models but also have some limitations. One limitation is that activities whose initial observed value is zero during the reference period are not included in the models. The means that the models do not allow farms to switch to such activities e.g. renting land, when faced with policy changes, such as restrictions on nitrogen use.

5. Farm models

Positive mathematical programming (PMP) models are estimated for the case study farms. The PMP models are based on linear programming and calibrate the base period results on the case study farms. The models are then used to predict the impact on farm incomes of: (i) restrictions on organic and inorganic nitrogen; and (ii) a tax on inorganic nitrogen.

PMP models are based on an objective function which is optimised subject to a number of constraints. Farmers are assumed to be profit maximizers and consequently the objective function in the PMP models is the maximization of total gross margin subject to a number of constraints. Overhead costs are deducted from gross margin to estimate farm income.

A number of production activities are included in the objective function. The number of livestock activities included in the farm models varies between three and five depending on the farms. Dairy is the main activity while all farms also have an additional and separate cattle activity. The cattle activity is determined according to age category and according to male or female animals in some cases. Feed production (grass and silage) and the purchase of fertilizers and concentrates are included as separate activities in the objective function. The feed production activities are a piecewise linear combination, representing the effect of nitrogen on grass and silage production at different levels of application. The costs of grass and silage production at different nitrogen application rates are included in the objective function. The amount of nitrogen used on farm and the amount of concentrates purchased are determined within the model and so the costs are included in the objective function.

Farmers are limited in their production levels by a number of constraints and these are included in the farm models. The two most important constraints are land availability and the milk quota. Land availability places a physical limit on the amount of land available for grass and silage production, which largely determines the number of animals that can be maintained on farm. For the case study farms all land is owned and no land is rented in or out. Therefore renting of land is not included in the base period PMP models. This means that the models do not allow farms to achieve compliance with the restrictions on nitrogen use by increasing their land area through renting.

Irish dairy farms are limited in their production levels by the milk quota. The milk quota on each of the case study farms is equal to the level of observed milk production, the quota is owned and there is no renting or leasing of quota. As renting or leasing of quota is not included in the base period PMP models, farms cannot engage in this activity in responding to policy changes.

The following additional constraints are included in the model. A herd replacement balance constraint is included. It is assumed that cows will be in the milking herd for five years, requiring that 20 per cent of the cows are replaced annually. When faced with restrictions on organic and inorganic use farmers may reduce the number of livestock on the farm in order to comply with the restrictions. This replacement constraint ensures that the minimum number of calves required for the replacement of the dairy herd is maintained on farm.

In Ireland most or all of the grass and silage fed to animals is produced on farm. Therefore a grass supply balance constraint is also included in the model. This ensures that the amount of grass and silage produced is sufficient to feed the number of animals on the farm.

There is little or no hired labour on the farms being considered in this study and therefore a labour constraint is included in the farm models. This ensures that the labour requirements of the activities on the farm do not exceed the amount of labour available.

A number of feed requirements are included in the model to ensure that the minimum feed requirements are satisfied and to ensure that the maximum feed allowances are not exceeded. Two other constraints are included to: (i) link the level of grass and silage production and the amount of fertilizer purchased; and (ii) link the level of animal production and the amount of concentrates purchased.

6. Study Area and Farms

A number of case study farms are considered in this study. The case study farms are specialist dairy farms located in the southern part of Ireland, namely counties Cork, Limerick, Kerry, Waterford and Tipperary where dairy production is most intensive.

Two independent techniques were used for data collection. First, data was obtained from the National Farm Survey (NFS) conducted by Teagasc[1] in 1996. The NFS is collected annually as part of the Farm Accountancy Data Network requirements of the European Union (FADN 2005). The sample is weighted to be representative of farming nationally across Ireland. Interviews are conducted with farmers on site by a team of trained NFS recorders. Second, a sample of specialist dairy farms from the 1996 NFS were analysed and a number of case study farms were selected for analysis. NFS economic and structural data was used to calibrate the PMP farm models to the base period results, and these calibrated models were then used to estimate the impact on farm incomes of restrictions on nitrogen use and of a tax on inorganic nitrogen.

7. Results

The objective of this paper is to test the hypotheses that the limits on applications of nitrogenous materials on farms in Ireland as specified in the National Action Programme under the Nitrates Directive would be achieved (a) more effectively and (b) more equitably by regulation than by taxation. In order to do so, the impact on dairy farm incomes of restrictions on organic and inorganic nitrogen use is estimated, as is the level of tax on inorganic nitrogen required in order to achieve the objectives of the plan. The results are outlined below.

Restrictions on organic and inorganic nitrogen use

Under the National Action Programme farmers are allowed to apply a maximum of 170 kg organic nitrogen/ha. Farmers applying this rate are allowed to apply a maximum of 208 kg inorganic N/ha. Of the eight farms considered in this study, four exceeded these limits on the application of both organic and inorganic nitrogen, and one exceeded the limit on inorganic

1. Weights used are based on the sample number of farms and the population number of farms (from the Census of Agriculture) in each farm system and farm size category. The sample number of observations by size/system is simply divided by the population number of observations by size/system to get the weights that make the sample representative of the actual farming population. The method is based on the EU FADN typology – see Commission Decision 78/463.

nitrogen. The remaining three farms are within these limits (Table 1). This is not surprising given that 90 per cent of farms in Ireland already operate within the limit of 170 kg organic nitrogen/ha (DAF 2005).

*Table 1 Baseline application rates of organic and inorganic nitrogen on the selected farms**

Farm	Organic nitrogen (kg/ha)	Inorganic nitrogen (kg/ha)
A	189	261
B	180	302
C	197	344
D	214	249
E	170	250
F	144	154
G	152	198
H	150	161

* Nitrogenous applications on Farms A-D were in excess of the limits in the Action Programme with respect to both organic and inorganic nitrogen application rates. Farm E was above the limit for inorganic nitrogen use only and the remaining three farms were within the limits.

In order to estimate the impact on farm incomes of restrictions on nitrogen application rates as specified in the Action Programme the farm models for farms A to D were run with a restriction on the use of organic and inorganic nitrogen of 170 kg/ha and 208 kg/ha respectively and the farm model for farm E was run with a restriction on the use of inorganic nitrogen use. All five farms experience a reduction in farm income, ranging from 1 per cent to 15 per cent (Table 2). The reduction in farm income is most pronounced for the farms which are most intensive in terms of milk production and where the highest levels of nitrogen were applied, farms C and D. In contrast, farm E, already within the limit on organic nitrogen use, experiences an insignificant drop in farm income of 0.2 per cent.

Table 2. Nitrogen application rates and percentage changes in farm income under the Nitrates Directive Action Programme

Farm	Organic Nitrogen (kg/ha)	Inorganic Nitrogen (kg/ha)	Change in farm income (%)
A	170	190	-3
B	165	208	-1
C	170	161	-9
D	169	89	-15
E	162	208	-0.2

A tax on inorganic nitrogen

A tax on inorganic nitrogen could be imposed as an *ad valorem* tax, or as a value added tax (VAT) as suggested by Scott (2005), or it could be imposed as a specific tax per unit of nitrogen purchased. Demand for inorganic nitrogen is very inelastic and therefore the imposition of VAT at a rate of 13.5 per cent or 21.5 per cent would have very little impact on demand and would not achieve the objectives of the Nitrates Directive. Similarly a specific tax per unit of nitrogen would have to be very substantial to achieve the required reduction in nitrogen use. The objective of this part of the study is to estimate the rate of *ad valorem* tax on nitrogen in manufactured fertilisers required to move the profit maximising level of applications below the limit in the Action Programme. To this end the farm models for farms A to E, that is those with applications in excess of limits in the Action Programme, were run with an *ad valorem* tax on inorganic nitrogen. It was found that the level of taxation required to incentivise compliance differed between the five farms. The lowest tax required was 4 per cent for farm E which was already in compliance with the restriction on organic nitrogen, and resulted in a 1 per cent reduction in farm income. The highest tax required was 266 per cent for farm D, resulting in a 26 per cent reduction in farm income. The results for all five farms, Table 3, show that a tax on inorganic nitrogen imposes a much larger compliance cost on farmers than does regulation of nitrogen use.

Table 3. Nitrogen application rates and percentage changes in farm income with a tax on inorganic nitrogen

Farm	Tax rate required to achieve compliance (%)	Organic Nitrogen (kg/ha)	Inorganic Nitrogen (kg/ha)	Change in farm income (%)
A	49	163	143	-15
B	48	163	200	- 6
C	145	169	162	-14
D	266	170	80	-26
E	4	159	199	- 1

For three of the five farms, achieving compliance with nitrogen application rates using a tax on inorganic nitrogen is five times more expensive for them than imposing regulations on nitrogen use. For the remaining two farms, their compliance costs are over one and half times what they would be with regulations on nitrogen use.

Given that the level of taxation required to incentivise compliance differed between farms, individualised tax rates should ideally be imposed on each farm that would otherwise tend to exceed the limit on nitrogen application rates permitted under the Action Programme. No tax would be imposed on farms already in compliance with the directive. However, this would be administratively expensive and ineffective for the reasons outlined in the background section. Therefore, in practice a uniform *ad valorem* tax on sales of nitrogenous fertiliser, approaching 266 per cent would have to be imposed and borne by all farms.

The farm models for all eight farms were run with a uniform tax of 266 per cent to estimate the cost to them of complying with this measure. The results, outlined in Table 4, show that the compliance cost is very significant for all farms, ranging from a 20 per cent to a 38 per cent reduction in farm income. A 266 per cent tax has a very significant effect on the quantity of inorganic fertiliser applied by all farms, especially farm A, and farms F to H, the farms already in compliance with the restrictions on nitrogen use.

Table 4. Results from case study farms of imposing a 266 per cent ad valorem tax on sales of nitrogen fertiliser

Farm	Organic Nitrogen (kg/ha)	Inorganic Nitrogen (kg/ha)	Change in farm income (%)
A	133	17	-32
B	160	147	-23
C	166	142	-38
D	170	80	-26
E	118	24	-31
F	97	16	-29
G	115	20	-21
H	150	5	-20

The results show that a uniform tax on inorganic nitrogen is inequitable. Farms F to H, which are already in compliance with the restrictions on nitrogen application rates are severely penalised. The cost imposed on these farms in terms of reductions in farm income of 20 per cent to 29 per cent is not that much lower than the costs imposed on farms A to E where rates of applications were above the Action Programme limits.

8. Conclusions

The results reported in the previous section show that a tax on inorganic nitrogen imposes a much larger compliance cost on the case study farms than does regulation of nitrogen application rates and is consistent with the findings of Picazo-Tadeo and Reig-Martínez (2007). However, when comparing the two policy instruments it is important to consider not just the compliance cost imposed on farmers, but also the administrative cost of the regimes (Kampas and White 2000a; 2000b; 2002; 2004; Segerson and Walker 2002).

Enforcement of the regulations on nitrogen use in the Action Programme consists of two elements – restrictions on stocking density and on application rates of inorganic nitrogen along with enforcement of the Code of Good Agricultural Practice. The administrative costs of imposing the restriction on the use of organic nitrogen should not be particularly large. Data on livestock numbers on all farms in the country are already recorded as part of the Cattle Movement Monitoring System (CMMS) and these are related to records of farm areas for the making of direct payment to farms.

Enforcement of the Code of Good Agricultural Practice, adopted as part of the Nitrates Directive Action Programme, involves farmers being required to keep records of their nitrogen fertiliser purchases and dates and times of applications of both chemical and organic nitrogen for inspection by farm inspectors. This should not add much to the record keeping burden as farmers are already required to keep similar records for other purposes. Enforcement takes the form of spot checks as it would be impractical to monitor each farm's management practices. This system of spot checks is already used under the system of cross compliance. Farm inspectors carry out spot checks on farms to ensure that they are complying with requirements for receipt of the single farm payment. While every farm cannot be visited, visits of the inspectors to a number of farms, with the accompanying risk of fines, can raise the overall standard of compliance. Publicity for the Action Programme and the Code of Good Agricultural Practice will also encourage a climate of adherence to its rules.

One of the advantages of a tax on fertiliser cited in the literature is that the administrative cost of the regime is lower than that of a regulatory measure. However, this may not be true for the control of nitrate emissions from agriculture. Before a tax could be implemented further research would be required in order to estimate the appropriate tax rate. The results of this research indicate that a tax rate approaching 266 per cent may be required though this result is based on a very small sample of dairy farms. Ongoing research and analysis would be required to ensure that the tax is set at the appropriate level. The appropriate level could change over time for a number of reasons, including changes in output and fertiliser price levels, and changes in farming practices and structures. A reduction in the price of nitrogen may encourage increased use, and therefore a higher tax may be required. Similarly, if output prices fall farmers may use less nitrogen and a lower tax may be required.

A tax on nitrogen could be imposed as an *ad valorem* tax, as applied to the case study farms. The Revenue Commissioners would be involved in the administration of such a tax. Collection of the tax alone would not automatically ensure compliance with restrictions on organic and inorganic nitrogen use. Farms would still be required to keep records of their nitrogen fertiliser purchases and dates and times of applications of both chemical and organic nitrogen and data on livestock numbers on farms recorded as part of the Cattle Movement Monitoring System (CMMS) would still have to be checked to ensure compliance with the restriction on organic nitrogen use. In order to achieve the overall objectives of the Nitrates Directive, a tax on inorganic nitrogen would have to be accompanied by monitoring of farming practices. As a result achieving the objectives of the Directive through a tax on inorganic nitrogen would still involve the same monitoring costs as the CAC approach. Adding to this the costs incurred by the Revenue Commissioners in administering the tax, it appears that the overall administrative cost of a tax on sales of inorganic nitrogen could well be greater than that of the regulatory measure.

A tax on inorganic nitrogen would be inequitable and would most likely be politically unacceptable unless accompanied by some form of rebate system. However a rebate system for an *ad valorem* tax as considered in this study or for a value added tax on inorganic nitrogen as suggested by Scott (2005) would impose further administrative costs on the public authorities tending to make a tax on nitrogen more administratively expensive than a regulatory measure. Also, a rebate would reduce the incentive for farmers to change their behaviour and their use of nitrogen.

It is suggested that the findings from the case studies reported here would largely reflect the differing impacts on dairy farms in Ireland of the CAC and taxation methods to limit applications of nitrogenous fertilisers due to the care taken in the selection of the case study farms. This conclusion is also supported by similarity between findings of the case study work of Lally and Riordan (2001) and results from a larger sample analysed by Hennessy *et al*. (2005).

The overall conclusion from this study is that the limits on applications of nitrogenous material on farms in Ireland would be achieved more effectively and more equitably by regulation than by a uniform tax on nitrogen fertilizer.

The results of this study contribute, with additional evidence, to the discussion on the choice of appropriate instruments for nitrogen abatement from agricultural sources, and particularly to the efficiency and equity of a uniform tax on nitrogen inputs and restrictions on nitrogen use. The final conclusion is that the choice of CAC measures rather than taxation instruments for the control of nitrate emissions from agriculture is an application of the Polluter Pays Principle that takes account of technological conditions in the industry[2].

2. The importance of the technological conditions in an industry for the design of instruments to control its emissions was a general conclusion suggested by Gerry Boyle.

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