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Controlling Agricultural Emissions of Nitrates: Regulations versus Taxes

Breda Lally^{*1}, Brendan Riordan^{**}, Tom M. van Rensburg*

* Department of Economics, NUI Galway, Ireland

** Formerly of Rural Economy Research Centre, Teagasc, Ireland

Abstract

Two policy instruments, 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 (*Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC)*), rather than economic instruments, are commonly used to deal with nitrate pollution from agricultural sources. Action Programmes are meant to ensure that the applications of nitrogen to farmland are within limits calculated to avoid a level of nitrate emissions to water supplies that would put them above the concentration limit of 50mg/litre specified in the Directive. The premise of the Action Programmes is that farmers should take all reasonable steps to prevent or minimise the application to land of fertilisers in excess of crop requirements. To this end the Irish Action Programme specifies that 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 170kg nitrogen per hectare (ha) and also sets limits on the application of inorganic (manufactured) nitrogen. However, the objective of the Nitrates Directive, at least in terms of organic and inorganic nitrogen application rates, could theoretically be achieved by imposing a tax on nitrogen inputs. This paper 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. The results of the analysis indicate that this is the case.

Keywords

Nitrates Directive; Input taxes; Regulations; Effectiveness; Equity

¹ Correspondence should be addressed to breda.lally@nuigalway.ie

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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. Agriculture generates many environmental public goods but in some cases these are negative due to practices that put pressure on the environment (EPA, 2004; EEA, 2003a). Livestock production in the EU is an example for, as it has become more specialised and intensive, it has had negative effects on biodiversity, and on water quality in particular. High livestock population densities are associated with excessive concentrations of manure leading to an increased risk of water pollution. Enrichment of waters by nitrogen and phosphorus is widespread throughout the EU, with diffuse losses from agriculture being one of the main sources of nitrate pollution in European waters (EEA, 2003b; EEA, 2005). Agriculture is the largest contributor of nitrogen to groundwater in the EU and concentrations of nitrate are highest in the rivers of Western-Europe where agriculture is most intensive (EEA, 2003a). According to the EEA (2003a; EEA, 2005), the nitrogen surplus in EU countries is generally 50-100kg per hectare of agricultural area, but countries with very intensive agriculture such as the Netherlands have even higher surpluses. The highest nitrate surpluses are found in areas with intensive agriculture and high livestock densities (EEA, 2003a).

Like much of European agriculture, Irish agriculture has become more intensive in recent decades and is having some negative impacts on the environment, particularly on water quality. Water quality in Ireland has deteriorated over the past thirty years and eutrophication of inland waters is now considered to be Ireland's most serious environmental problem (DAF, 2005). This eutrophication of waters has arisen from excessive inputs of phosphorus and nitrogen from agriculture, sewage systems, industry and other sources. Estimates of the contribution of agriculture to nitrogenous materials to Irish waters put it at 73 per cent of the total load and of phosphoric compounds at 82 per cent of the total. The conclusion is that agriculture is responsible for a very significant proportion of water pollution in rivers, lakes, estuaries and groundwater (EPA, 2004; EPA, 2006a). It is also estimated that almost half of all river pollution in Ireland is due to agriculture (EPA, 2005).

The emission of nitrates from the agricultural sector is an externality problem since increased nitrate levels in water impose potential welfare losses on society through ecological damage due to eutrophication and postulated adverse health effects (Taylor et. al., 1992; EPA, 2006b). Water pollution by nitrates arises due to incomplete markets for environmental assets such as rivers and lakes. Originators of degrading emissions do not bear the costs of the damage they do to these assets and consequently do not consider all the costs of their activities. With incomplete markets there is little incentive for farmers and others to control emissions or switch to less polluting practices. An antidote is environmental policies that offer incentives for farmers and others to change their behaviour and ensure that a socially acceptable level of pollution is not exceeded.

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 & Martínez, 2004; Martínez & 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 production function for their farm. However, in reality it would be impractical to apply a 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 command and control (CAC) approach, in the form of the Nitrates Directive, rather than economic instruments, 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, which is an ambient level. 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 & 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.

The objectives of the Nitrates Directive, at least in terms of organic and inorganic nitrogen application rates, could theoretically be achieved by imposing a tax on nitrogen inputs. The objective of this paper is 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. Specifically, the measure of effectiveness will be the compliance cost of the control regime to farmers and to public administration. 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 test will be a comparison of the levels of these measures arising from each of the regimes for achieving levels of applications of nitrogen within the limits specified in the Irish Action Programme, namely by using: (i) controls on the application of nitrogenous materials from organic (animal) and inorganic fertiliser sources; or (ii) taxation of purchases of manufactured fertilisers. The methodology used to estimate the effects of these two methods of controlling applications of nitrogenous materials to farm land is positive mathematical programming (PMP).

The plan of the paper is as follows. Sections 2 and 3 outline details of the Nitrates Directive as it applies in Ireland, and the materials and methods employed in the study. This is followed by results, discussion and conclusions in sections 4, 5 and 6.

2. The Nitrates Directive

The Nitrates Directive was adopted by the European Commission in 1991. The main objective of the Directive is to reduce water pollution caused or induced by nitrates from agricultural sources and to prevent further such pollution, with the primary emphasis being on the management of livestock manures and other fertilisers. “The Directive imposes a limit on the amount of livestock manure per hectare that can be applied to land on a farm each year except in certain specified circumstances. The limit is the amount of livestock manure containing 170 kg of nitrogen” (DAF, 2005).

Under the Nitrates Directive each member state is required to draw up an Action Programme which includes measures such as input regulations and management practices. Action programmes are to constrain applications of nitrogen to farm land to within limits calculated to avoid a level of nitrate emissions to water sources that might put them above the concentration limit of 50 mg nitrates/litre specified in the

Directive. The premise of the Action Programme is that farmers should take all reasonable steps to prevent or minimize the application to land of fertilizers in excess of crop requirements.

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 170kg 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). In 2007, farms with a stocking rate of ≤ 170 kg/ha who house their animals for 18 weeks over the winter period are permitted to apply 208 kg/ha inorganic nitrogen. This falls to 205 kg/ha in 2008 and to 202 kg/ha in 2010².
- 3) Farmers undertake farm practices, such as spreading of slurry and manure, in such a manner as to prevent water pollution by fertilisers, to this end the regulations will specify the times of year when inorganic fertilisers may not be spread on farm land and the prohibited times for spreading animal manures. Allied with these limits on manure spreading the regulations will stipulate:
 - a) The minimum capacity of storage facilities for livestock manure and other organic fertilisers, soiled water and effluents from dungsteeds to be provided on farms;
 - b) The design, siting, construction, maintenance and management of storage facilities to prevent run-off or seepage directly or indirectly, into groundwater

² The application rate of inorganic nitrogen permitted is calculated based on the length of the housing period, prescribed nitrogen availability (%) rates from managed livestock manure applied in the year of application, and the amount of nitrogen which can be applied as inorganic fertiliser, 226 kg/ha. The prescribed nitrogen availability rate for 2007, 2008 and 2010 is 30%, 35% and 40% respectively. The formula for calculating the amount of inorganic nitrogen a farm can apply is as follows:

The amount of nitrogen which can be applied as inorganic fertiliser – ((stocking rate expressed as kg organic nitrogen per hectare/52 weeks) x (number of weeks animals are housed) x (prescribed nitrogen availability rates from managed livestock manure applied in the year of application))

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:

$$226 - ((170/52) \times 18 \times 0.30) = 226 - 18 = 208.$$

or surface water of livestock manure, other organic fertiliser, soiled water and effluents from dungstead.

- 4) Records farmers are to keep in relation to production activities, fertiliser application rates and farm practices.

3. Materials and methods

3.1 Methodology

Positive mathematical programming (PMP) models are estimated for case study farms and are employed to estimate the impact on farm incomes of restrictions on organic and inorganic nitrogen use and of a tax on inorganic nitrogen. 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 this type of study being undertaken here, they also have disadvantages. The main disadvantage of linear programming models is that the optimal solutions tend to be overly specialized and, in general, do not conform to the number and level of realized activities observed on the farms under investigation. In most cases overspecialization of the solution occurs because the number of empirically justified resource constraints is usually less than the number of observed activities. Since the number of nonzero activities in linear programming framework is upper bounded by the number of resource constraints overspecialization may occur by design. Linear programming models should calibrate against a base year or an average over several years in order to be useful for policy analysis. Model solutions that deviate substantially from observed production quantities are very difficult to sell to political decision-makers.

A methodology to calibrate linear programming models, known as Positive Mathematical Programming (PMP) was developed by Howitt in the late 1970's. A rigorous treatment of the methodological background to PMP was presented by Howitt (1995), but the approach had been employed in a series of policy oriented modeling exercises long before 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). PMP can be used to model any economic situation, from an individual farm to an entire sector of the economy. It all depends on the amount of available information.

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 her 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.

3.2 Farm models

It is assumed that farmers are profit maximisers. Farmers maximise an objective function subject to a number of constraints. The objective function in the farm models is the maximization of total gross margin. A number of activities and production and resource constraints are included in the models. The number of livestock production activities included in the farm models varies between three and five depending on the farms. Dairy is the main activity with all farms also having a cattle activity. The cattle activity is broken down 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. 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. 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. In the model it is assumed that all land is owned and no land is rented in or out. Irish dairy farms are limited in their production levels by the milk quota. It is assumed that the milk quota on each farm is equal to the level of observed milk production. In the model it is assumed that the quota is owned and that there is no renting or leasing of quota.

A replacement balance constraint is included in the model. This ensures that the dairy herd is maintained at its present level. 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. It is assumed that all grass and silage fed to animals is produced on farm. Therefore a supply balance constraint is included in the model. This ensures that the amount of grass and silage fed to animals is less than or equal to the amount of grass and silage produced on farm.

A labour constraint is included in the model as there is little or no hired labour on the farms being considered in this study.

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.

3.3 Study Area and Farms

An earlier study concluded that farms most likely to apply nitrogen in excess of 170kg per hectare, as stipulated by the Nitrates Directive, were intensive dairy farmers in the southern part of the country (Lally and Riordan, 2001). Hence five counties, namely Cork, Limerick, Kerry, Waterford and Tipperary, constituted the study area for selection of farms for analysis.

Data for a sample of 120 specialist dairy farms from the selected study area was obtained from the 1996 National Farm Survey³. Estimates of the amount of nitrogen per animal from different types of animals came from the Department of Agriculture and Food (DAF). Analysis of the rates of nitrogen applied per hectare on the selected farms indicated that nitrogen application rates increased with the amount of milk produced on the farm. Thus, the sample of farms was divided into five subgroups according to quota size. The size categories were (i) less than 10,000 gallons; (ii) 10,000 – 25,000 gallons; (iii) 25,000 – 40,000 gallons; (iv) 40,000 – 60,000 gallons; and (v) over 60,000 gallons. Farms in size class (i), less than 10,000 gallons of quota, had relatively low levels of nitrogen per hectare from organic and inorganic sources and would be largely unaffected by the restrictions on nitrogen use that would apply under the Nitrates Directive, and were therefore excluded from further analysis. Two farms from each of the size categories (ii)-(v) were selected for analysis in the study, giving a total of eight farms. These are the eight farms considered in the study presented here.

4. 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. The results of the study are outlined below.

4.1 The Nitrates Directive

The objective of this part of the study is to estimate the impact on eight dairy farms of the restrictions on organic and inorganic nitrogen use specified in the National Action Programme. Under the National Action Programme farmers are allowed to apply a maximum of 170kg organic nitrogen/ha. Farmers applying this rate are allowed to apply a maximum of 208kg inorganic N/ha⁴. 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 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 170kg organic nitrogen/ha (DAF, 2005).

³ The National Farm Survey is an annual survey undertaken by Teagasc.

⁴ Two of the counties in the study area are located in Zone B as defined in the Action Programme and therefore we are using the restriction on inorganic nitrogen that applies to farms in this zone.

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

Farm	Organic nitrogen (kg/ha)	Inorganic nitrogen (kg/ha)
1	189	261
2	180	302
3	197	344
4	214	249
5	170	250
6	144	154
7	152	198
8	150	161

* Nitrogenous applications on Farms 1-4 were in excess of the limits in the Action Programme with respect to both organic and inorganic nitrogen application rates. Farm 5 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 1-4 were run with restrictions on the use of organic and inorganic nitrogen of 170 kg/ha and 208 kg/ha respectively and the farm model for farm 5 was run with a restriction on the use of inorganic nitrogen use. All five farms experience a reduction in family 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 3 and 4. In contrast, farm 5, already within the limit on organic nitrogen use, experiences an insignificant drop in family farm income of 0.2 per cent.

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

Farm	Organic Nitrogen (kg/ha)	Inorganic Nitrogen (kg/ha)	Change in family farm income (%)
1	170	190	-3
2	165	208	-1
3	170	161	-9
4	169	89	-15
5	162	208	-0.2

The results of this analysis are similar to those obtained by Lally and Riordan (2001) and are consistent with results of an analysis of the impact of restrictions on organic nitrogen on dairy farms undertaken by Hennessy et al. (2005).

4.2 A tax on inorganic nitrogen

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 1-5, 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 5 which was already in compliance with the restriction on organic nitrogen, and resulted in a 1 per cent reduction in family farm income. The highest tax required was 266 per cent for farm 4, 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 family 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 family farm income (%)
1	49	163	143	-15
2	48	163	200	- 6
3	145	169	162	-14
4	266	170	80	-26
5	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.

The results indicate that, for farmers, the least costly method of achieving compliance with the restrictions on nitrogen use through taxation would be to impose individualised tax rates 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 introduction. 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 family farm income. A 266 per cent tax has a very significant effect on the quantity of inorganic fertiliser applied by all farms, especially farm 1, and farms 6-8, 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 family farm income (%)
1	133	17	-32
2	160	147	-23
3	166	142	-38
4	170	80	-26
5	118	24	-31
6	97	16	-29
7	115	20	-21
8	150	5	-20

The results show that a uniform tax on inorganic nitrogen is inequitable. Farms 6-8, 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 family farm income of 20 per cent to 29 per cent are not that much lower than the costs imposed on farms 1-5 where rates of applications were above the Action Programme limits.

5. Discussion

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. Other farming systems, such as tillage, could be required to pay an even higher tax rate to achieve compliance with the Action Programme. 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 price levels and farming practices and structures.

A tax on nitrogen could be imposed as an *ad valorem* tax, as applied to the case study farms, or as a value added tax, as suggested by Scott (2005)⁵, or it could be imposed as a specific tax per unit of nitrogen purchased. The Revenue Commissioners would be involved in the administration of all of these taxation methods. 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. Scott (2005) suggested a rebate system for a value added tax on inorganic nitrogen. However this system would impose further administrative costs on the public authorities tending to make this tax on nitrogen more administratively expensive than a regulatory measure. 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).

⁵ Under a value added tax (VAT) system farmers registered for VAT would reclaim the tax while farmers not registered for VAT would get a flat rate rebate.

6. Conclusions

The objective of this paper was 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 results indicate that this is the case. The demand for inorganic nitrogen is very inelastic and the case studies show that a very substantial tax, 266 per cent in this example, would be required in order to achieve compliance with the application rates of organic and inorganic nitrogen specified in the Action Programme. Such a tax on sales of inorganic nitrogen would impose a larger compliance cost on farmers and on public authorities than would a regulatory measure. The tax would also be inequitable as farms already in compliance with the Action Programme would incur substantial losses in family farm income. Given that a tax on inorganic nitrogen is inequitable and that it would impose a much higher compliance cost on farmers than would the regulatory measure, it would be highly unlikely that such a measure would be politically acceptable. The inequities might be reduced by some form of rebate system, however, this would impose further administrative costs on the public authorities. 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.

While this conclusion is based on a small sample of dairy farms in Ireland the results are consistent with the findings of Picazo-Tadeo and Reig-Martínez (2007), who analyzed the impact on Spanish citrus farmers' income of a tax on nitrogen inputs and restrictions on nitrogen use. This suggests that these results may apply to other farming systems in other countries. Given that this is the case, it is also possible that in other countries and other farming systems a uniform tax on nitrogen inputs would be more inequitable than restrictions on nitrogen use.

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 industry⁶.

⁶ 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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ANNEX I

Details of the Action Programme for Ireland

The Action Programme specifies that the storage capacity for livestock manure on all farm holdings shall be sufficient for the full housing period. The housing period is defined in the Action Programme and depends on where farms are located. The country is divided into three zones A, B and C. Farms in zones A and B are required to have 16 and 18 weeks storage capacity respectively, while farms in zone C are required to have 20 or 22 weeks storage capacity. Zone A consists of counties Carlow, Cork, Dublin, Kildare, Kilkenny, Loais, Offaly, Tipperary, Waterford, Wexford and Wicklow. Zone B includes counties Clare, Galway, Kerry, Limerick, Longford, Louth, Mayo, Meath, Roscommon, Sligo and Westmeath and Zone C includes counties Cavan, Donegal, Leitrim and Monaghan.