REFEREED ARTICLE

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Reducing nitrogen applications on Irish dairy farms: effectiveness and efficiency of different strategies

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ABSTRACT

In the EU, nitrate pollution from agriculture is regulated by a command and control approach – the Nitrates Directive, with which all member states are expected to comply. Nitrogen restrictions impose production constraints on some farms and can result in reductions in farm income. This paper employs positive mathematical programming (PMP) to estimate the impact of nitrogen restrictions on farm incomes among dairy farms in the Republic of Ireland. The paper also investigates if compliance with the Nitrates Directive in terms of nitrogen application rates would be achieved more effectively by regulation than by taxation. Results show that restrictions on nitrogen use under the Nitrates Directive Action Plan imposes a cost on intensive dairy farms with reductions in income ranging from 0.1% cent to 36%. Findings also show that the limits on applications of nitrogenous material on dairy farms in Ireland would be achieved more effectively and more equitably by regulation than by a uniform tax on nitrogen fertilizer. In some cases a tax on inorganic nitrogen is found to be an ineffective way of achieving the levels of organic nitrogen permitted under the Nitrates Directive.

KEYWORDS: Nitrates Directive; input taxes; regulations; effectiveness

1. Introduction

Nitrate pollution is a serious problem throughout the EU and agriculture is one of the main contributors to the problem (EEA, 2012). The regulation of nitrates on farms in the EU is governed by the 1991 Nitrates Directive[3], with which all member states are expected to comply. The consequences of the Nitrates Directive have been explored from a number of angles including acceptance by farmers (Buckley, 2012), spatial optimization (Van der Straeten *et al.*, 2010), changes in productivity (Piot-Lepetit and Le Moing, 2007) and effects on farm income (Rigby and Young, 1996; Rigby, 1997; Lally and Riordan, 2001; Hennessy, Shalloo and Dillon, 2005; Lally, Riordan and van Rensburg, 2009; Belhouchette *et al.*, 2011; Van der Straeten *et al.*, 2012). The main objective of the Nitrates Directive is to reduce nitrate concentrations to below an acceptable level of 50 mg/litre and in theory a number of policy instruments such as emission or input taxes and tradable permits could be used to achieve this ambient level of pollution. However, in practice regulations are applied which restrict the use of organic and inorganic nitrogen. These restrictions may limit other abatement opportunities for farmers and impose production constraints on some farms and can result in reductions in farm income.

A number of studies have been undertaken to compare different instruments in terms of achieving ambient levels of pollution such as those specified in the Nitrates Directive. For example, Hanley, Aftab and Black (2006) and Martínez and Albiac (2004) have used biophysical economic models which are quite complex and include highly developed nitrate leaching and hydrological models which are undertaken on a geographical or water catchment area level. At farm level a small number of studies have been conducted to evaluate the impact of different types of policy instruments aimed at reducing nitrogen application rates and nutrient leaching (Berentsen and Giesen, 1994; Lally and Riordan, 2001; Picazo-Tadeo and Reig-Martínez, 2007; Semaan *et al.*, 2007; Fezzi *et al.*, 2008; Lally, Riordan and van Rensburg, 2009). However, studies that consider different instruments in terms of achieving the specific aims of the Nitrates Directive at farm level are rare. Some preliminary work on this topic has been conducted in Ireland (Lally, Riordan and van Rensburg, 2009), although this was confined to a small sample of specialist dairy farms located in the Munster region of Ireland. This present work is nationally representative and allows for a more comprehensive treatment of the effectiveness of regulatory and tax instruments in achieving the specific targets relating to nitrogen

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[3] The main objective of 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)) is to reduce nitrate concentrations to below an acceptable level of 50 mg/litre. Under the Directive each member state must implement an Action Plan that ensures 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 level specified in the Directive. The premise of the Action Plan is that farmers should take all reasonable steps to prevent or minimise the application to land of fertilisers in excess of crop requirements.

application rates as set out in Ireland's National Action Programme. To our knowledge this is a novel exercise and the results reveal some new findings. In particular, this study shows that a tax on inorganic nitrogen may not always be effective in achieving the objectives of the Nitrates Directive in terms of nitrogen application rates.

The objectives of this paper are as follows:

1. To estimate the impact on farm incomes of restrictions on nitrogen use, as specified in the National Action Plan (NAP) under the Nitrates Directive, on dairy farms in the Republic of Ireland;
2. To evaluate the hypothesis that the limits on applications of nitrogenous materials on farms in Ireland as specified in the NAP would be achieved more effectively by regulation than by taxation.

The structure of the paper is as follows: the next section reviews the literature on measures to deal with nitrate emissions from agriculture; this is followed by a description of the methodological approach and an outline of the Irish NAP under the Nitrates Directive; results are then presented and a discussion and conclusions follow.

2. Background

Nitrate emissions from agriculture are diffuse in nature and follow a complex pathway through the hydrological system, making them very difficult to monitor. For this reason taxes or quotas on emissions, the standard economic approaches to pollution control problems, cannot be applied or cannot be applied at a reasonable cost. Instead policy makers are forced to rely on second-best policy instruments such as input taxes and input regulations. Ideally, such measures should be based on individual farmers' non-point pollution production functions. However, non-point pollution production functions are (i) often not known and (ii) likely to vary across farms, making it impractical for policy makers to apply pollution production function related measures. They are often therefore forced to rely on uniform measures as a means of dealing with nitrate emissions from agriculture. Helfand and House (1995) considered a number of uniform measures for dealing with non-point pollution and found that they do not lead to large losses in welfare relative to the least cost solution.

Many studies have been undertaken over the last twenty years to evaluate different uniform instruments in terms of achieving reductions in nitrogen use and nitrate emissions in different regions and in different farming systems. Examples of studies undertaken at regional level include Wu & Babcock (2001), Whittaker *et al.* (2003), Martínez and Albiac (2006), and O'Shea and Wade (2009).

Studies at farm level can be divided into two categories, those that evaluate the impact of a particular type of instrument and those that compare different instruments. Lally and Riordan (2002) and Hennessy, Shalloo and Dillon (2005) evaluate the impact on Irish dairy farm incomes of restrictions on organic nitrogen use. Picazo-Tadeo and Reig-Martínez (2006) evaluate the impact on Spanish citrus farmers' income of a mandatory reduction in nitrogen application while a number of other studies evaluate the environmental and economic consequences of a particular type of instrument (Berentsen and Giesen, 1995; Rigby and Young, 1996; Berntsen *et al.*, 2003; Belhouchette *et al.*, 2011).

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% tax on nitrogen inputs. 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. Semaan *et al.* (2007) uses a bio-economic model to analyse the effects of three agricultural policies on farmers' revenue and nitrate leaching in the Apulia region of Southern Italy and Fezzi *et al.* (2008) assess the economic impact on UK farms of four nutrient leaching policies.

All of the above studies have evaluated the impact of different instruments from an economic and/or environmental perspective at either farm or regional level. This study compares the cost and effectiveness of (i) input regulations and (ii) a tax on inorganic nitrogen, as means of achieving the objectives of the Nitrates Directive in terms of permitted nitrogen use, on a sample of 30 case study Irish dairy farms.

3. Materials and methods

Methodology

Positive mathematical programming (PMP) is used in this study to evaluate the effects of restrictions on nitrogen applications on dairy farm incomes. PMP is a methodology used to calibrate linear programming models. Linear programming (LP) models should calibrate against a base year or an average over several years in order to be useful for policy analysis (Howitt, 1995). However, in general, the optimal solutions tend to be overly specialized and do not conform to the number and level of realized 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.

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 modelling and it has been used by Arfini (1996), Röhm and Dabbert (2003), Buysse *et al.* (2007), Kan *et al.* (2009), Gallego and Gomez-Limon (2008), Gallego-Ayala and Gomez-Limon (2009), Fragoso *et al.* (2011), and Howitt *et al.* (2012).

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 simulation. 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 variable induced by variations of some relevant parameters.

'The general idea of PMP is to use information contained in dual variables of calibration constraints which bound the LP problem to observed activity levels (Phase 1). These dual variables are used to specify a non-linear objective function such that observed activity levels are reproduced by the optimal solution of the new programming problem without bounds (Phase 2)' (Heckelei & Britz, 2005).

Phase 1 involves running a linear programming model with calibration constraints which bound activity levels to observed levels:

$$\begin{aligned} &\text{Max}\ \underset{x}{Z} = p'x - c'x \\ &\text{subject to} \\ &Ax \le b\ [\lambda] \\ &x \le x^0\ (1+\varepsilon)\ [\rho] \\ &x \ge [0] \end{aligned} \qquad (1)$$

where:

Z= objective function value, p=$(n \times 1)$ vector of product prices, x=$(n \times 1)$ vector of production activity levels, c=$(n \times 1)$ vector of variable cost per unit of activity, A=$(m \times n)$ matrix of coefficients in resource constraints, b=$(m \times 1)$ vector of available resource constraints, x^0=$(n \times 1)$ vector of observed activity levels, ε=$(n \times 1)$ vector of small positive numbers, λ= dual variables associated with the resource constraints and ρ= dual variables associated with the calibration constraints.

Adding calibration constraints to a linear programming model forces the optimal solution of the model to exactly reproduce the observed base year activity levels x^0, 'given that the specified resource constraints allow for this solution' (Heckelei and Britz, 2000). A perturbation parameter, ε, is included to guarantee that all binding resource constraints of the original model remain binding in the extended model.

At least one level of activity in the LP model is bounded solely by one of the fixed resource constraints and not by its calibration constraint. Therefore the 'vector x can be divided into a vector or preferable activities (x^p) bounded by the calibration constraints, and a vector of marginal activities (x^m), which are constrained by the resource constraints' (Fragoso, Carvalho and Henriques, 2008). Assuming all elements in x^0 are non-zero and all resource constraints are binding, 'the Kuhn-Tucker conditions imply that:

$$\rho^p = p^p - c^p - A^{p'}\lambda \qquad (2)$$

$$\rho^m = [0] \qquad (3)$$

$$\lambda = (A^{m'})^{-1}(p^m - c^m) \qquad (4)$$

The dual values of the calibration constraints are zero for marginal activities (ρ^m), as shown in (3) and equal to the difference of price and marginal cost for preferable activities (ρ^p), as seen in (2) the latter being the sum of variable cost per activity (c) and the marginal cost of using fixed resources $(A^p\lambda)$.

In Phase 2 of the procedure, the dual values of the calibration constraints, ρ^p, are employed to specify a non-linear objective function, such that the marginal costs of the preferable activities are equal to the respective price at the base year observed activity levels, x^0' (Heckelei and Britz, 2005). For computational simplicity, a quadratic cost function is usually employed.

$$C^v = d'x + \tfrac{1}{2}x'Qx \qquad (5)$$

where:

d=$(n \times 1)$ vector of parameters associated with the linear term and

Q=$(n \times n)$ symmetric, positive semi-definite matrix of parameters associated with the quadratic term.

The parameters are then specified such that the linear 'marginal variable cost' (MC^v) functions fulfil:

$$MC^v = \frac{\partial C^v\ (x^0)}{\partial x} = d + Qx^0 = c + \rho \qquad (6)$$

The standard specification solves the problem of the quadratic cost function by letting d=c and setting all off-diagonal elements of the Q matrix equal to zero. The n diagonal elements of Q, q_{ii}, can then be calculated as:

$$q_{ii} = \frac{p_i}{x_i^0}\ for\ all\ i = 1, \ldots\ldots, n \qquad (7)$$

The final nonlinear programming problem that is exactly calibrated to base year activity levels is

$$\begin{aligned} &Max\ \underset{x}{Z} = px - cx - \tfrac{1}{2}\,x'Qx \\ &\text{subject to :} \\ &Ax \le b\ [\lambda] \\ &x \ge [0] \end{aligned} \qquad (8)$$

PMP models are useful for policy analysis 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. This means that the models do not allow farms to switch to such activities, such as renting in land, when faced with policy changes such as restrictions on nitrogen use.

Farm models

The PMP models calibrate the base period results on the 30 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. It is assumed that dairy farmers maximize profits. Therefore the objective function in the PMP models is the maximization of total gross margin subject to a number of constraints. Overhead costs are then deducted from total 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. The feed production activities are a piecewise linear combination, representing the effect of nitrogen on grass and silage production at different levels of application[4]. 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. 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. The milk quota is equal to quota owned plus quota leased.

The following additional constraints are included in the model. A herd replacement balance constraint ensures that a minimum number of calves required for the replacement of the dairy herd are 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. A number of feed requirement constraints for grass, silage and concentrates are included in the model to ensure that the minimum feed requirements for the animals are satisfied and to ensure that the maximum feed allowances are not exceeded[5].

[4] Observed fertiliser response data and a quadratic function are used to estimate the relationship between fertiliser application rates and grass and silage yields. This estimated function is then used to calculate grass and silage yields at different nitrogen application levels, using linear incremental increases of 25 kg/ha (See Appendix). This information is then incorporated into the farm models in order to capture the relationship between nitrogen applications and grass and silage production which impacts on the carrying capacity of the farms.

[5] The feed constraints included in the models are based on the farm data and on advice from Teagasc advisors.

Study area and farms

Thirty case study specialist dairy farms located throughout the Republic of Ireland are considered in this study. Two independent techniques were used for data collection. First, data was obtained from the National Farm Survey (NFS) conducted by Teagasc[6] in 2006[7]. The NFS is collected annually as part of the Farm Accountancy Data Network (FADN) requirements of the European Union (FADN 2013). 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 313 specialist dairy farms from the 2006 survey was selected for analysis and 75 of those farms, representing 4,639 farms, were found to exceed the 170 kg/ha limit on organic nitrogen application specified in the Nitrates Directive. Twenty one of the 75 farms, representing 1,310 farms, exceeded the limit of 170 kg/ha by a very small amount and were excluded from the study. Excluding those farms, farms with sheep and horse enterprises and outliers meant a sample of 30 case study farms, which applied in excess of 180 kg/ha organic nitrogen were selected for analysis. These 30 farms represent 1,681 dairy farms. NFS economic and structural data was used to calibrate the PMP farm models to the base period results, and those calibrated models were then used to estimate the impact on farm incomes of restrictions on nitrogen use and of a tax on inorganic nitrogen[8].

4. Ireland's Action Plan under the Nitrates Directive

Ireland's first NAP commenced on a phased basis on 1st January 2006, and ran for a period of four years. The plan was subsequently reviewed and extended in 2010, and again in 2013. Under the Plan farmers are required to comply with the regulations set out in the legislation[9] including restrictions on organic and inorganic nitrogen use as specified below:

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

[6] 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.

[7] 2006 data is used as it coincides with the implementation of the Ireland's first NAP.

[8] Variable costs, labour costs and overhead costs are drawn from the farm data. Prices are drawn from the farm data and from Management Data for Farm Planning, a planning guide published by Teagasc.

[9] S.I. No. 31 of 2014 European Union (Good Agricultural Practice for Protection of Waters) Regulations 2014.

c) The length of the winter housing period on the farm. In this study we assume an average winter housing period of 18 weeks.

Farms with a winter housing period of 18 weeks and a grassland stocking rate of 170 kg/ha can apply a maximum of 202 kg inorganic nitrogen per hectare.[10]

Under the Nitrates Directive member states can apply to the European Commission for a derogation to go beyond the livestock manure limit of 170 kg nitrogen per hectare specified in the Directive. Ireland applied for a derogation in 2004 and it was granted in 2007 (OJEU, 2007). This allows individual farms with at least 80% grassland (on application to DAFM) to apply livestock manure up to a maximum of 250 kg per hectare, subject to strict conditions. Farms must apply for a derogation on an annual basis. The European Commission approved renewal of the derogation in 2011 (OJEU, 2011) and it ran until the end of 2013. Ireland has requested a further renewal of the derogation and is awaiting approval from the European Commission.

5. Results

All 30 farms considered in this study could potentially apply for a derogation. Seventeen of the 30 farms are within the application limits permitted for both organic and inorganic nitrogen under the derogation, two exceed the application limit for organic nitrogen (250 kg/ha) (Table 1) and the remaining 11 exceed the limit permitted for inorganic nitrogen only. Hence, 17 farms would be unaffected if granted a derogation, two would have to adjust their stocking levels and 11 would have to reduce their use of inorganic nitrogen. Given that the majority of the farms would be unaffected if granted a derogation this paper focuses on estimating the impact on all 30 farms if they could not qualify for a derogation and had to comply with the limits on organic and inorganic nitrogen set out in the NAP.

Of the 30 farms considered, 18 exceeded the limits set out in the NAP on the application of both organic (170 kg/ha) and inorganic nitrogen (202 kg/ha), and the remaining 12 exceeded the limit on organic nitrogen only (Table 1).

In order to estimate the impact on farm incomes of restrictions on nitrogen application rates as specified in the NAP all 30 farms models were run with restrictions on the use of organic and inorganic nitrogen of 170 kg/ha and 202 kg/ha respectively. Restrictions on organic nitrogen use alone leads to a reduction in the quantity of inorganic nitrogen applied on all 30 farms (Table 2) and in 28 cases this reduction brings the farms into compliance with the restrictions on inorganic nitrogen use[11]. The average reduction in inorganic nitrogen applications across all 30 farms is 120 kg/ha or 51%.

Table 1: Baseline application rates of organic and inorganic nitrogen (kg/ha) on the selected farms

Farm	Organic nitrogen	Inorganic nitrogen
1	227	344
2	208	258
3	226	313
4	236	311
5	193	226
6	193	171
7	191	282
8	191	231
9	197	160
10	204	260
11	184	147
12	243	355
13	229	300
14	204	204
15	229	308
16	202	155
17	213	286
18	230	308
19	224	177
20	220	236
21	261	139
22	216	196
23	192	121
24	184	220
25	205	337
26	284	135
27	189	186
28	197	134
29	181	328
30	191	200
Average	211	234
Minimum	181	121
Maximum	284	355

The restriction on organic nitrogen leads to a reduction in the number of animals on all farms which in turn leads to a reduction in the overall feed requirements. As a significant amount of the feed comes from grass and silage the inorganic nitrogen application falls as the number of animals falls.

Close inspection of column four shows that all farms experience a reduction in family farm income, ranging from 0.1% to 36%, with an average reduction of 7.9%. The reduction in farm income is most pronounced for the farms which are most intensive in terms of organic nitrogen applications, and which have to reduce the size of their dairy herd in order to comply with the restriction on organic nitrogen application rates. Eleven farms reduce the size of their dairy herd in order to comply with the restriction. While all farms considered experience a reduction in farm income due to the restriction on organic nitrogen of 170 kg/ha, it is possible for farmers to apply for a derogation which would allow them to farm up to 250 kg organic nitrogen per hectare.

A tax on inorganic nitrogen

A further goal of the paper is to establish if the limits on applications of nitrogenous materials on farms in Ireland would be achieved more effectively by regulation than by taxation. To this end, the study estimates the rate of *ad valorem* tax on inorganic nitrogen required to move organic and inorganic nitrogen applications on

[10] The amount of inorganic nitrogen farms can apply is calculated using the following formula: Available nitrogen (kg/ha) – ((Grassland stocking rate (kg/ha)/no. of weeks in the year) x (weeks storage required) x appropriate nitrogen availability from livestock manure)). For a farm with a winter housing period of 18 weeks and a grassland stocking rate of 170 kg/ha the amount of inorganic nitrogen it can apply per hectare is calculated as follows: 226 – ((170/52) x 18 x 0.4) = 226 – 24 = 202. This calculation is based on the assumption that farms do not export organic manure.

[11] With the restrictions on both organic and inorganic nitrogen all farms with the exception of farm 29 applies 170 kg organic nitrogen per hectare. For Farm 29, the restriction on inorganic nitrogen applications results in a lower than permitted application rate of organic nitrogen at 161 kg/ha.

Table 2: Nitrogen application rates (kg/ha) and percentage changes in family farm income under the Nitrates Directive Action Plan

Farm	Inorganic Nitrogen (kg/ha)	Change in inorganic N (kg/ha) %	Change in family farm income (%)
1	113	−67.3	−12.8
2	113	−56.1	−10.2
3	167	−46.6	−7.9
4	91	−70.7	−19.7
5	175	−22.5	−1.6
6	110	−35.7	−2.6
7	165	−41.6	−1.7
8	159	−31.2	−1.5
9	106	−33.8	−6.2
10	113	−56.5	−8.0
11	104	−29.0	−0.2
12	66	−81.5	−35.9
13	136	−54.6	−7.8
14	81	−60.5	−5.6
15	131	−57.5	−1.6
16	69	−55.3	−1.7
17	119	−58.3	−3.8
18	135	−56.1	−4.5
19	44	−75.0	−9.9
20	47	−80.2	−9.8
21	49	−64.4	−34.1
22	114	−42.0	−8.1
23	76	−37.1	−1.7
24	170	−22.6	−1.3
25	202	−40.1	−5.3
26	0	−100	−28.8
27	147	−20.9	−0.1
28	99	−26.0	−0.8
29	202	−38.5	−1.8
30	118	−40.8	−0.6
Average	114	−50.1	−7.9

all 30 farms to within the limits specified in the NAP. The findings show that (i) the level of taxation required to incentivise compliance differs between farms and (ii) a tax is ineffective in reducing the application of organic nitrogen to the limits permitted on nine of the 30 farms. The average tax rate required to bring the other 21 farms into compliance with the restrictions on organic and inorganic nitrogen is 101 per cent. The lowest rate required is 15% and the highest is 239% (Table 3). This is in line with the findings of an earlier study by Lally, Riordan and van Rensburg (2009).

Excluding the nine farms which are ineffective to the tax the results for the 21 remaining farms show that a tax on inorganic nitrogen imposes a much larger compliance cost on farmers than does regulation of nitrogen use. The last two rows in column six show that the average reduction in farm income under regulation of nitrogen use is 3.8% while with the ad valorem tax the average reduction is 11.7%. The ad valorem tax results in a transfer to the government which on average is equivalent to 53% of the reduction in farm income.

For nine farms a tax on inorganic nitrogen is ineffective in achieving an organic nitrogen application rate of 170 kg/ha as specified in the NAP. The rates at which the tax becomes ineffective in reducing organic nitrogen applications range from 54% to 275% as outlined in Table 4.

On average these nine farms have higher incomes and a higher number of dairy cows than the other 21 farms for which the tax is effective. This may explain why the tax is ineffective for these farms. In order to comply with the restriction of 170 kg/ha organic nitrogen under the regulation scenario the first seven farms have to reduce the size of their dairy herd. Dairy is the most profitable activity on all farms considered in this study and therefore farms will not reduce the size of their herd unless absolutely necessary. With the regulation the seven farms have no choice but to reduce their dairy herd, but with the tax they have more flexibility. With the tax they reduce the amount of cattle on the farm (as they do with the regulation) but they do not reduce the number of dairy cows. As dairy cows are more profitable farms absorb the high rates of tax rather than reduce the size of the dairy herd and as a result organic nitrogen application rates continue to exceed those permitted under the regulation. A tax therefore may be an ineffective method of achieving the permitted application levels of organic nitrogen on farms which would have to reduce their dairy herd under a command and control system of regulation.

For the 21 farms where the tax is effective, 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 with no tax being imposed on farms already in compliance with the directive. This, however, would be administratively expensive and ineffective. In practice, a uniform *ad valorem* tax on sales of nitrogenous fertiliser would have to be applied. Applying a uniform tax rate of 101 per cent (the average effective tax rate) would over penalise 12 of the 21 farms, and would not be fully effective for the other nine farms. These nine farms would reduce their applications of organic and inorganic nitrogen but would not be in compliance with the limits specified in the Action Plan. For the nine farms where a tax is ineffective, farm incomes and inorganic nitrogen applications would fall with little or no impact on the applications of organic nitrogen.

6. Discussion

This study set out to explore the impact of restrictions on nitrogen use on Irish dairy farm incomes under the Irish NAP. The results show that restrictions on nitrogen use under the Nitrates Directive Action plan imposes a cost on dairy farms with reductions in income ranging from 0.1% to 36%. A further goal of the study was to see if the limits on applications of nitrogenous materials on farms in Ireland would be achieved more effectively by regulation than by taxation. The results indicate that in some cases a tax on inorganic nitrogen is ineffective in achieving the objectives of the NAP in terms of the application of organic nitrogen. In those cases the farms will absorb the cost of the tax, rather than reduce the size of their dairy herd and thereby their level of organic nitrogen.

Demand for inorganic nitrogen is very inelastic and the 21 case study farms where a tax is effective show that a very substantial tax, up to 239%, would be required in order to achieve compliance with the nitrogen application rates specified in the NAP. Ongoing research and analysis would be required to ensure that the tax, if deemed an effective instrument, is set at the appropriate

Table 3: Nitrogen application rates (kg/ha) and 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 inorganic N (kg/ha) (%)	Change in family farm income (%)
1	143	167	89	−74.1	−26.7
3	141	168	65	−79.2	−31.8
5	62	168	100	−55.7	−7.5
6	70	170	97	−43.1	−9.9
8	65	170	124	−46.2	−7.1
9	239	170	48	−70.3	−19.3
11	27	161	63	−56.9	−1.6
13	181	170	81	−73.0	−17.7
14	149	170	71	−65.4	−12.5
15	96	170	129	−58.2	−6.9
16	99	170	61	−60.5	−5.1
17	136	170	104	−63.5	−10.8
18	109	168	117	−62.0	−12.3
20	174	170	45	−81.1	−18.1
23	70	164	44	−63.4	−4.8
24	61	170	148	−32.4	−9.8
25	150	161	119	−64.8	−25.8
27	15	166	105	−43.2	−1.9
28	58	170	52	−61.4	−5.2
29	55	161	202	−38.6	−6.4
30	28	168	111	−44.5	−4.0
Average	101	168	94	−58.9	−11.7
Average with restrictions on organic and inorganic nitrogen applications		170	127	−43.6	−3.8

level. The appropriate level could change over time for a number of reasons, including changes in price levels and farming practices and structures. Dairy is the most profitable enterprise on the farms considered and further expansion in the dairy sector is expected when milk quotas are abolished in 2015. The profitability of the dairy sector in the future may have a significant impact on the effectiveness of a tax and on the rate at which it would be effective.

Where a tax on inorganic nitrogen is effective in achieving the application rates of organic and inorganic nitrogen specified in the NAP it imposes a much larger compliance cost on the case study farms than does regulation of nitrogen application rates. The tax would also be inequitable as farms already in compliance with the NAP would incur substantial losses in family farm income.

Reaction to policy changes depends on marginal changes in costs and in this study the changes in fertiliser cost due to the tax are quite substantial and are far removed from the baseline. Using the PMP models to predict the impact of such large changes in fertiliser costs may lead to some potential bias in the results. However, the results are useful in providing an indication of how farmers may react to a tax on inorganic nitrogen and they show that demand for nitrogen is inelastic, a finding that is consistent with studies by Breen *et al.*, (2012), Boyle (1982), Higgins (1986) and Burrell (1989).

As well as considering the compliance cost and effectiveness of the two measures considered in this study it is also important to consider the administrative cost of the measures.

The administrative cost of enforcing the regulations on nitrogen applications as specified in the Irish NAP should not be particularly large for two reasons. Firstly, the restrictions on organic nitrogen are relatively easy to enforce as data on livestock numbers on all farms in the

Table 4: Nitrogen application rates (kg/ha) and changes in family farm income with a tax on inorganic nitrogen

Farm	Rate at which tax becomes ineffective in reducing organic nitrogen applications (%)	Organic Nitrogen (kg/ha)	Inorganic Nitrogen (kg/ha)	Change in inorganic N (kg/ha) (%)	Change in family farm income (%)
2	54	190	179	−30.4	−3.2
4	67	202	181	−41.9	−5.5
10	180	174	125	−51.8	−17.1
12	121	217	207	−41.8	−12.8
19	105	187	66	−63.0	−5.8
21	159	214	0	−100.0	−24.2
26	275	214	1	−99.3	−12.1
7	67	172	171	−39.5	−5.3
22	67	217	160	−18.3	−4.1
Average	122	199	121	54	10.1

country are already recorded as part of the Cattle Movement Monitoring System (CMMS) and these are related to farm records for the making of direct payments to farms. Secondly, under the NAP all farms are required to comply with the regulations set out in the legislation. Enforcement takes the form of spot checks, a system that is already used under a system of cross compliance. Farmers subject to a spot check must be found to be in compliance with the legislation in order to receive their single farm payment. Under the legislation, farmers are required to keep records of (i) their nitrogen purchases and (ii) the dates and times of applications of chemical and organic nitrogen. As farmers may be subject to inspection under a spot check there is a strong incentive for them to comply with the restrictions on inorganic nitrogen use.

The results of this research indicate that in some cases, a tax may be an ineffective means of achieving the objectives of the Nitrates Directive in terms of the application of organic nitrogen. Therefore, a tax on inorganic nitrogen would have to be complemented with a restriction on organic nitrogen use, increasing both the compliance cost to farmers and the administrative cost. Combining a tax with restrictions on organic nitrogen use would over penalise farmers and it would be unnecessary, as the restriction on organic nitrogen application rates alone would bring 93 per cent of the farms into compliance with the restriction on inorganic nitrogen use.

Collection of the tax alone would not automatically ensure compliance with restrictions on organic and inorganic nitrogen use and the tax would have to be accompanied by monitoring of farm practices. Farming practices would have to be monitored in the same way as under the regulatory approach and would involve the same monitoring costs. These costs when added to the costs incurred by the Revenue Commissioners in administering the tax would make the tax a more expensive instrument to administer than a regulatory measure. While the administrative costs of the tax would exceed those of a regulatory measure, a tax does have some appeal for policy makers in that it would generate revenue for the government. However, a tax would be inequitable and would probably be politically unacceptable unless accompanied by some form of rebate system. Such a system would reduce the net revenue from the tax to the government and would impose even further administrative costs on the public authorities.

7. Conclusions

The main contribution this paper makes is in evaluating different instruments as a means of achieving the aims of the Nitrates Directive at farm level. The overall conclusions are (i) that restrictions on nitrogen use as specified in the NAP result in a reduction in farm income on intensive dairy farms and (ii) that the limits on applications of nitrogenous material on dairy farms in Ireland would be achieved more effectively and more equitably by regulation than by a uniform tax on nitrogen fertilizer.

The results and conclusions are consistent with those reached by Lally, Riordan and van Rensburg (2009) and moreover this present study uses a more recent and larger data set. Notably this work reveals some new findings regarding a tax on nitrogen. It indicates that for some farms the tax becomes ineffective beyond a certain level. In those cases the farms will absorb the cost of the tax, rather than reduce the size of their dairy herd, making the tax an ineffective way of achieving the levels of organic nitrogen permitted under the Nitrates Directive.

In an ideal world policy makers might wish to employ market instruments of emission taxes or quotas to deal with nitrate pollution from agriculture. In such circumstances farmers would have flexibility in how they respond and could adopt a range of abatement measures which would mitigate damage done to farm incomes. However, in reality due to the diffuse nature of nitrate pollution from agriculture, a command and control measure, the Nitrates Directive is used to deal with the problem in Europe. With regulation, abatement opportunities are more limited and the Nitrates Directive imposes production constraints on intensive farms through restrictions on nitrogen use which in turn can result in reductions in farm incomes, as shown in this study. Since the Nitrates Directive applies across all European countries intensive dairy farms in other member states may be similarly affected. Using tools such as positive mathematical programming to investigate the effects of nitrogen restrictions on income is therefore unlikely to remain an isolated phenomenon, particularly in the light of future changes to the dairy quota.

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Appendix

Table A: Nitrogen response function for silage and grazing land

Nitrogen Application Rate (kg/ha)	Silage Land	Grazing Land
	Yield (Tons DM/ha/Year)	Yield (Tons DM/ha/Year)
0	7.3	5.8
25	7.8	6.2
50	8.3	6.6
75	8.8	7.0
100	9.3	7.4
125	9.7	7.8
150	10.1	8.1
175	10.5	8.4
200	10.9	8.7
225	11.1	8.9
250	11.4	9.1
275	11.7	9.4
300	11.9	9.5
325	12.1	9.7
350	12.3	9.8
375	12.4	9.9
400	12.6	10.1
425	12.6	10.1
450	12.7	10.2
475	12.8	10.2
500	12.8	10.2

