REFEREED ARTICLE

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Using a farm micro-simulation model to evaluate the impact of the nitrogen reduction mitigation measures on farm income in Ireland

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ABSTRACT

The introduction of the Water Framework Directive in 2000 (European Parliament and Council 2000) has incentivised policy-makers to bring the quality of all water streams in EU member states up to a 'good ecological status' by 2015. Although a lot of work has been carried out since the introduction of the Directive, it is also evident that progress in improving water quality has been very slow. The main reason for such slow progress is the lack of robust evidence about the sources of pollution and the effects of possible mitigation measures. Also, there is insufficient knowledge regarding the economic implications of the various mitigation options. In this paper we introduce a microsimulation model that can help policymakers to evaluate the economic impact of Nitrogen (N) mitigation measures. In this initial case study, two measures are considered: 1) a stocking rate reduction to achieve a maximum level of organic nitrogen of 170 kg/ha; 2) a 20 percent stocking rate reduction. The results of this study confirm the hypothesis that introduction of these measures would lead to reduction in farm gross margins, which is consistent with the previous research in Ireland and UK.

KEYWORDS: Water Framework Directive; Nitrates Directive; microsimulation; policy evaluation; water quality; environmental policy

1. Introduction

Nutrient enrichment of water streams has been identified as an important environmental problem (Novotny, 2003, Johnson *et al.*, 2010). The main impact of excess nutrients in water bodies is eutrophication, causing an increase in biological and chemical oxygen demand, an unpleasant odour from the water, a loss of habitats, changes to the river bed that affect ship/boat navigation as well as negatively impacting on recreational usage. Thus, there are significant socio-economic effects associated with nutrient enrichment in addition to the environmental effects. These considerations led to the introduction of legislation that aims to restrict pollution of water bodies and to protect their habitats (Habitat Directive (Council of the European Union 1992)), Freshwater Fish Directive (Council of the European Union 1978), Birds Directive (Council of the European Union 1979)); to protect the uses of the streams (Drinking Water Directive (Council of the European Union 1980), Bathing Water Directive (Council of the European Union 1976), Sewage Sludge Directive (Council of the European Union 1986), Urban Waste Water Treatment Directive (Council of the European Union 1991a)); and to restrict nitrogen and other pollutants' loss to overland/ground waters (Nitrates Directive (Council of the European Union 1991b)) amongst others. Perhaps the most comprehensive legislative document to date is the Water Framework Directive (WFD), which not only protects water resources from deterioration but also demands improvement in water quality to 'good ecological status' by 2015 (European Parliament and Council 2000).

The complexity of environmental interactions poses a problem for researchers in identifying the sources of pollution and establishing robust causal relationships between different human activities and the volume of pollutants in streams. Lally *et al.* (2009) state that emissions of organic and inorganic nitrogen cannot be observed at a reasonable cost. O'Donoghue *et al.* (2010) studied the statistical relationship between water quality at over 3,000 monitoring sites in Ireland and human activities in the upstream areas and found that there was a significant statistical relationship between agricultural activities (in addition to other activities) and lower water quality in the downstream areas. This is in line with the findings of the Department of Environment, Community and Local Government (DEHLG) (2010),

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which states that intensively farmed agricultural land may be a source of excess nutrients in Irish waters. There are a large number of pollutants from agriculture that may present a potential problem to the wider environment and to water resources in particular, however the main pressure to water quality comes from nutrient enrichment (Schulte *et al.*, 2006; Doole, 2012, 2013).

Nitrogen (N) is an important nutrient and is essential to the production and growth of all organisms. The present structure and high output levels of agriculture could not be maintained without the widespread use of synthetic and organic fertilisers (Merrington *et al.*, 2002). However, in excess, N becomes a pollutant (Doole, 2012). There is some evidence, that despite the efforts of Irish farmers to reduce N loss from their land, the production processes used and the prevailing weather conditions still lead to the loss of nutrients to the wider environment (Donohue *et al.*, 2006; John, 2008). However recent evidence has shown that there have been improvements over time, possibly as a result of Agri-Environmental measures and improved nutrient management on farms (O'Donoghue *et al.*, 2014).

A large volume of literature discusses the diffuse pollution from agricultural land (Ritter, 2001; Merrington *et al.*, 2002; Novotny, 2003; Donohue *et al.*, 2005; Donohue *et al.*, 2006; O'Donoghue *et al.*, 2010). The Environmental Protection Agency (EPA) in Ireland reports that in 2008 out of 180 river sites of Nitrogen monitoring five sites had the highest values; 7 percent of groundwater monitoring sites failed to comply with the Irish Threshold Value concentration in the same year and 1 percent failed to comply with the Drinking Water maximum allowable concentrations, which is related to areas with more intensive agricultural practices (John, 2008).

The primary factors that encourage N leaching from Agriculture are over-fertilisation, excessive livestock numbers, improper use of manure, and exposure of bare soil during drainage periods (Fezzi *et al.*, 2008; Bateman *et al.*, 2007). Measures that aim to reduce N leaching should thus be targeted at these factors. The appropriate choice of mitigation strategies is connected to the N cycle in the agricultural environment as these strategies would aim to impact particular stages of the N cycle. There are three main pathways through which different forms of N and its compounds circulate in the agricultural environment: inputs (into the soil), transformations (within the soil), and losses (out of the soil) (Merrington *et al.*, 2002). Mitigation strategies aim at controlling these pathways through either restricting excessive N input use or reducing N losses to the environment that are already in the system. Due to the weather and other environmental variations it is easier to target the reduction of N inputs to the ecological system as less N is introduced into the environment, less can potentially be lost through undesirable pathways (Ritter, 2001; Merrington *et al.*, 2002; Novotny, 2003). The input of N into agricultural system comes from chemical fertiliser application, animal manure and crop residue (IFA, 2007). A number of mitigation options are available to decision-makers to address N loss from agriculture.[4]

In this paper, within a microsimulation framework, the potential impact of two N pollution reduction measures on farm income for dairy farms in Ireland is estimated. The two considered mitigation measures have previously been assessed by Hennessy *et al.* (2005) and Fezzi *et al.* (2008) are considered, and are 1) a stocking rate reduction to achieve a maximum organic N of 170 kg per hectare; 2) a 20 percent livestock units reduction.

A dairy cow produces 5.3 m^3 of slurry in 16 weeks of housing (S.I. 610 of 2010), which contains approximately 19 kg of N. This manure/slurry has to be spread overland or exported from the farm. Livestock also deposits manure/urea directly on fields during grazing periods. In Ireland the Good Agricultural Practice regulations (S.I. 610 of 2010) place a restriction on the amount of manure and inorganic fertilizer that may be applied per hectare - presently the amount is capped at 170 kg of N per hectare, with a possibility to derogate to 250 kg of N per hectare. This is the basis for our first scenario. It has been suggested in the literature that in order to achieve the objectives of WFD, the introduction of changes such as a 50 percent reduction in the application of fertilisers to crops and grass, sheep stocking rates to be halved and a reduction in cattle stocking rates of 20–25 percent may be needed (Haygarth *et al.*, 2003; Bateman *et al.*, 2006). For dairy farms the latter requirement is likely to be most pertinent so we consider a 20 percent reduction in livestock units.

Some work has explored the costs of mitigation measures: Cuttle *et al.* (2006), Hennessy *et al.* (2005) and Lally *et al.* (2009) used linear programming in their estimations, while Fezzi *et al.* (2008) used a farm accounting approach to find the possible cost of the mitigation measures. This paper contributes to this nascent literature by introducing a model that allows the simulation of impacts associated with policy responses such as a change in N production, and resultant changes in farm income, at the farm level.

The rest of the paper is structured as follows: the data set that is used for the estimations is discussed along with summary statistics in section 2. The methodology is explained in section 3. The results are presented in section 4 and conclusions are drawn in section 5.

2. Methodology

Estimation of N produced on the farm

In this paper we developed a model that can allow us to readily assess the impact of N reduction measures on farm N budgets and on farm incomes within the context of implementation of the Water Framework Directive. In doing so it is first necessary to decide how to estimate the farm's N budget. Often researchers focus on modelling the run-off and undesirable losses of N from farm land. This approach leads to difficulties for modellers as it requires the development of a separate hydro-geological model that would allow the prediction of N losses through different pathways. This would require a lot of hydro-geo-ecological data in very high resolution. Such data seldom exists nationally. As an alternative approach, we approximate N losses using a 'reduce inputs' approach. The assumption behind this

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[4] The full discussion is beyond the scope of this paper. The interested reader is referred to Cuttle *et al.*, 2006; Novotny, 2003; Merrington *et al.*, 2002 and Ritter, 2001 for a more comprehensive treatment of mitigation startegies.

approach is that if less N is introduced into the environment during the production process on the farm, then less is subsequently lost through undesirable pathways – via volatilisation, run-off, and /or leaching. A proportional reduction is assumed throughout.

The total N on a farm depends on the number of livestock units (LU)[5] (organic N) and on the amount of chemical fertiliser used as a part of the production process (chemical N). Haygarth *et al.* (1998) and Merrington *et al.* (2002) report that 70–80 percent of N ingested by the animals during grazing and/or feeding on concentrates is subsequently excreted in manure. The level of organic N used in enterprise *j* is calculated by multiplying the number of LU of type *k* in that enterprise of the farm (NLU_{kj}) by the annual N excretion rate of that LU type (E_k) and summing across the *K* types of LU. This is then added to the Inorganic N for enterprise j and summed over the *J* enterprises to obtain the total N on the farm, as is given by:

$$N_i = \sum_{j}^{J} \Big(\sum_{k}^{K} \left(E_k NLU_{kj} \right) + Inorganic\, N_j \Big) \tag{1}$$

We used the 'annual nutrient excretion rates (E_k) for livestock' tables as published in Good Agricultural Practice for Protection of Waters (European Communities 2010) to determine the N produced by each animal on the farm −85 kg of N per dairy LU, 65 kg of N per beef LU and 7 kg of N per sheep LU[6]. The number of kg of chemical fertiliser purchased by the farmers was used to determine the amount of chemical fertiliser used on the farms.

Estimation of the farm profit

Econometric techniques were utilised for determining the output and cost functions. Animal numbers and chemical fertiliser each affect the output volume (Y) and the costs (C) on the farms (equations 2 and 3). Farms in Ireland usually engage in more than one enterprise. Each enterprise is modelled separately here due to the fact that only dairy farms are considered. However, when the farm system is not important adopting a 'whole farm' approach may yield better estimates. X_{ij} is a vector of explanatory variables, where i denotes individual farm and j denotes each farm enterprise (dairy, beef or sheep), and variables include the size of farm, the volume of fertiliser and concentrated used, number of livestock units, forage area, etc. (see Table 2 and Table 3 for a full list of variables used in the model for each function estimation). These variables determine the level of Y_{ij} and C_{ij} in equations 2 and 3. When more LU are on the farm, more output is produced, however more organic N is also produced on the farm and costs incurred by a farmer to feed and maintain animals are also greater.

$$Y_{ij} = \left(X_{ij} \middle| \beta_j, \varepsilon^{y}_{ij} \right) \tag{2}$$

$$C_{ij} = \left(X_{ij} \middle| \gamma_j, \varepsilon^{c}_{ij} \right) \tag{3}$$

Thus through manipulating (reducing) the number of animals and the amount of chemical fertiliser used, farmers could reduce the N budget on the farm and hence reduce environmental pressures. A positive relationship is assumed between animal numbers, the amount of fertiliser and the value of gross output and costs.

There are a variety of functional forms one could use when estimating output or costs and since the true functional form cannot be known, the problem is to choose the form that best suits the task at hand (Griffin *et al.*, 1987). The most commonly used functional form is the log-log, Cobb-Douglas and trans-log. However, recently Flichman (2011) discussed the use of functional forms in bio-economic models and criticised the Cobb-Douglas functional form as inferior to trans-log functions. However, in our model using a trans-log specification would lead to a loss of degrees of freedom. Production and cost functions are estimated using log-polynomial ordinary least squares (OLS) regressions. A similar parametric approach was used by Fezzi *et al.* (2010) who used linear regression models to estimate the change in farm gross margin that arises from different policy measures. Their approach allowed avoiding model complication by estimating only one function. In contrast to Fezzi et al (2010), we estimate separate equations for gross output and direct costs and then calculate gross margin. This allows the impact of shocks on these components to be explored and the simulation of changes in these components at a farm system level and thus maybe more useful for modelling purposes. Three production and three cost functions are estimated in our model: dairy gross output, dairy direct costs, cattle gross output, cattle direct costs, sheep gross output, and sheep direct costs (equations 2 and 3). The level of farm gross output and direct costs determine a farm's profit (equation 4):

$$\pi_i = Y_i - C_i - FC_i \tag{4}$$

Farm profit π_i is calculated as the farm's gross output (Y_i) less farm's direct costs (C_i) and fixed costs (FC_i).

Developing a micro-simulation model

The model (as described in equations 1–4) allows the simulation of changes in farm profits due to output or cost changes at an enterprise level. The impact of different measures to reduce N can differ in both the economic and in the environmental dimensions across farms, thus the analysis should be carried out at a farm level. Microsimulation techniques allow us to conduct analyses at this scale. Microsimulation techniques have been widely used for many years and are an effective tool for evaluating the socio-economic impacts of different mitigation options where it is difficult or impossible to conduct a real life experiment (Merz, 1993; O'Donoghue, 2013). The microsimulation

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[5] In NFS a dairy cow is taken as the basic grazing livestock unit. All other grazing stock is given equivalents as follows: Dairy cows 1.0; Suckling cows 0.9; Heifers-in-calf 0.7; Calves under 6 mths. 0.2; Calves 6-12 months 0.4 Cattle 1-2 years 0.7 Cattle over 2 years 1.0 Stock bulls 1.0; Ewes and rams 0.20 (lowland) 0.14 (hill); Lambs to weaning 0.00 (lowland), 0.00 (hill); Lambs after weaning 0.12 (lowland), 0.10 (hill); Hoggets and wethers 0.15 (lowland), 0.10 (hill). For more details see Connolly *et al.* (2008).

[6] A N excretion rate of 7kg per sheep livestock unit is used in this paper, despite the fact that for lowland sheep the N excretion rate is 13kg (European Communities, 2006). However, this excretion rate covers both the ewe and its lambs and would thus result in an over-estimate of N/ha on the farms and hence subsequently produce a lower cost per unit of N abated in the second scenario.

approach is widely used for income generation modelling, tax system evaluation and pension schemes evaluation *inter alia* (Mitten *et al.* 2000; Sparado 2007; O'Donoghue, 2013). Microsimulation can be carried out using various techniques, for example, linear programming (Hennessy *et al*, 2005), partial budgeting (Fezzi *et al.*, 2008) or econometric regression analysis (Fezzi *et al.*, 2010).

All of these techniques allow for the modelling of changes at the farm level. The choice of a particular technique depends on the objective of the model. Hennessy *et al.* (2005) utilise the FAPRI-Ireland Farm Level Model, which is a dynamic gross margin maximizing model and was first described by Breen and Hennessy (2003). The linear programming approach allows model optimization, however in our model we are not trying to optimize farm production but rather to understand how the farm system affects the costs of the mitigation measures. In the Fezzi *et al.* (2008) farm budget model the underlying assumption in the 20 percent LU reduction scenario is that the output and costs would be reduced by 20 percent as well. However, this assumption may not hold in reality as the relationships and dependencies between variables are more complex. In this work we follow Fezzi *et al.* (2010) in adopting a regression framework. Regression analysis was chosen for our model as the most appropriate technique for our estimations as it allows us to capture the marginal effect of changes in the variables of interest, e.g. the change in the number of livestock units.

The schematic of the overall simulation procedure is depicted in Figure 1. The model input is the farm level data which is described in the next section of this paper. The scenarios considered in the model are the two mitigation options to reduce N on the farms. These measures would lead to changes in the farm inputs and/or outputs through reductions in the dry stock, fertiliser usage, feed change etc.

The impact of the alternative mitigation measures on individual farm profit (π_i) is simulated using estimates of output and cost functions based on farm-level data (equations 2 and 3). The fixed costs are not affected by the scenarios in the simulations, thus, the changes in the farm profit are due to changes in farm gross margin (GM) (equation 5).

$$GM_i = Y_i - C_i \tag{5}$$

$$Y^{\circ}_{ij} = (X^{\circ}_{ij} | \beta_j, \varepsilon^{y}_{ij}) \tag{6}$$

$$C^{\circ}_{ij} = (X^{\circ}_{ij} | \gamma_j, \varepsilon^{c}_{ij}) \tag{7}$$

$$\pi^{\circ}_{ij} = \sum Y^{\circ}_{ij} - \sum C^{\circ}_{ij} \tag{8}$$

$$\Delta\pi_i = \pi^{\circ}_i - \pi_i \tag{9}$$

The simulations are carried out by holding the regression coefficients (β_j, γ_j) and the error terms (ε^{y}_{ij}, ε^{c}_{ij}) constant and changing the explanatory variables (X^{o}_{ij}) according to the scenarios (in our case study scenarios it is the number of LU that is altered). When the parameters of the model are estimated the new levels of production and cost are predicted for each enterprise (denoted as C^{o}_{ij}, Y^{o}_{ij} in equations 6 and 7). The results are then aggregated to the farm level (equation 8). The impact of the simulated changes in the animal numbers and/or fertiliser is the difference between farm profit before (π) and after the change (π°) (equation 9).

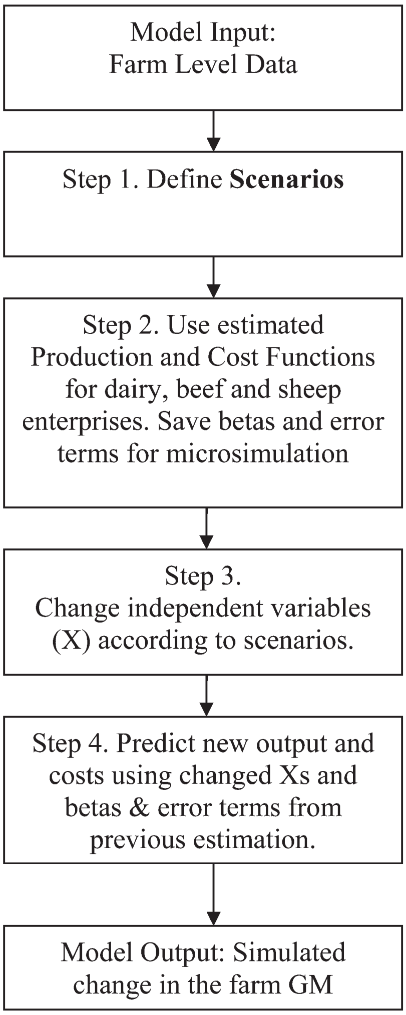

Figure 1: Simulation Model Flow Diagram

$$N^{\circ}_i = \sum_j^J \Big(\sum_k^K \left(E_k NLU^{\circ}_{kj} \right) + Inorganic\, N_j \Big) \tag{10}$$

The changes in N come from the change in animal numbers according to the particular scenario. In this case study we explored two scenarios: 1) a stocking rate reduction to achieve maximum organic N of 170 kg per hectare; 2) a 20 percent LU reduction. In the first scenario farmers are assumed to reduce livestock units starting with the enterprise that has the lowest gross margin per LU to reach 170 kg of N per hectare. The adjusted number of livestock units is NLU°_{kj} (equation 10), where k is a type of a LU – dairy, beef or sheep. The underlying assumptions about the way farmers would drop LU are different in each scenario. In the first scenario it is assumed that farmers would drop the LU with the lowest GM per animal. In the second scenario the assumption is that farmers would reduce all types of LU proportionally by 20% if required to do so.

$$NLU^{\circ}_{ki} = (0.8 \times NLU_{ki}) \tag{11}$$

In the second scenario the number of LU on each farm is reduced by 20 percent for each enterprise (equation 11) and the new N° on the farm is calculated as in equation 10.

The final change in N on the farm is the difference between the N level before the simulations and the level, N^{o}, that is simulated for the farm after the mitigation measure introduction (equation 12).

$$\Delta N_i = N_i^{\circ} - N_i \tag{12}$$

$$Av.C = \frac{\Delta \pi_i}{\Delta N_i} \tag{13}$$

Thus, this methodology allows us both to simulate the changes in farm profit and to simulate the change in N on the farm as a result of the mitigation measures. It can potentially be used by decision-makers in determining not only the level of abatement that can be achieved through different measures and the cost associated with them but also to compare the average cost of abatement (Av.C) for each individual farm (equation 13).

3. Data

In order to simulate the changes at a farm-level, socio-economic data at the farm level is required. Teagasc - The Irish Agriculture and Food Development Authority- has conducted the National Farm Survey (NFS) on an annual basis since 1972 (Connolly *et al.*, 2010). The resultant dataset contains information for a sample of approximately 1,200 farms per annum that are nationally representative of over 100,000 farms in Ireland. This sample, however, excludes pigs and poultry farms due to an inability to obtain a representative sample for these types of farms. It is also not representative of very small farms. The NFS dataset contains socio-economic information which allows analysis of the physical and economic performance of the different farming sectors in the Republic of Ireland.

In this paper NFS data for the year 2008 is used as in later years there was high volatility in farm outputs/inputs, making the estimations potentially less reliable. Farms in the NFS are assigned to one of six possible systems: specialist dairy; dairying other; cattle rearing; cattle other; mainly sheep; mainly tillage (Hennessy *et al.*, 2011). The category assignment is based on the dominant enterprise, which is established based on the Standard Gross Margins (SGMs) under the EU FADN typology set out in the Commission Decision 78/463 (Hynes *et al.*, 2008). Under this methodology SGM is assigned to each type of farm animal and each hectare of crop. Farms are then classified into groups called particular types and principal types, on the basis of the proportion of the total SGM of the farm which comes from the main enterprises (after which systems are named). This methodology was adapted to suit Irish conditions more closely (the reader is referred to Connolly *et al.*, 2008 for further details). Farms in Ireland typically engage in more than one enterprise. For the purpose of our research we are focussing on farms that are identified in the NFS as 'specialist dairy' (from now on referred to as dairy) and 'dairy and other activities' (from now on referred to as dairy other).

The number of farms in the NFS sample varies from year to year from 1,279 farms in 1994 to 1,102 in 2008, which reflects the decreasing number of farms in Ireland, however the farms are getting bigger in size and more specialised. National weights are applied to represent the population of farms in Ireland. National weights are produced by Teagasc on the basis of the Census of Agriculture tables produced by the Irish Central Statistics Office (CSO). All summary statistics and model results reported in this paper are produced on the basis of weighted NFS data.

There are two primary reasons for focusing on dairy farms in this research:

- the relatively good economic performance of dairy farms in Ireland and
- environmental pressures generally associated with intensive dairy farm systems.

In terms of economic significance, dairy farms in Ireland have gross margins that are high relative to other farm systems and dairy farms' gross margins are growing at a faster rate. Gross Margin (GM) is a good indicator of farm performance because it represents the difference between Gross Output (GO) and Direct Costs (DC). Furthermore, movements in GO (Figure 2) and DC (Figure 3) provide useful information about the source of changes in GM (Figure 4).

It can be seen in Figure 4 that dairy and dairy other farms have significantly higher GM than cattle, cattle rearing and mainly sheep systems. It is also evident that dairy GM is growing at a rate higher than in other systems during the period. This is due to the high growth rate of dairy output (Figure 2) despite the fact that for the dairy farms the value of direct costs was growing at the same time (Figure 3). The rapid growth in dairy farms' GO was caused by both increased milk yield per animal and due to consolidation in the industry with fewer farms producing more milk.

Dairy and dairy other farms are not only leaders in terms of economic performance; they also have higher organic N production and chemical N use per hectare (Table 1) relative to other systems. The national average (which is lower than the non-derogation requirement of 170 kg N per hectare under SI 610/2010 (European Communities 2010)) disguises the range of organic N application across Irish farms with 27 percent of the farms in Ireland producing more than 170 kg of organic N per hectare. At the moment farmers that are over the requirement of 170 kg of organic N per hectare can apply for derogation, but the regulation may become more stringent in the future.

The dairy system turns out almost twice as much organic and chemical N per hectare as any other system. Dairy other farms, despite reducing N emissions over the previous few years, still turn out higher amounts than in other systems. Twenty one percent of the dairy farms and four percent of dairy other farms in Ireland in 2008 exceeded the limit of 170 kg N per hectare (Table 1). Additionally, 3 percent of dairy farms were found to have exceeded chemical N limit per hectare.

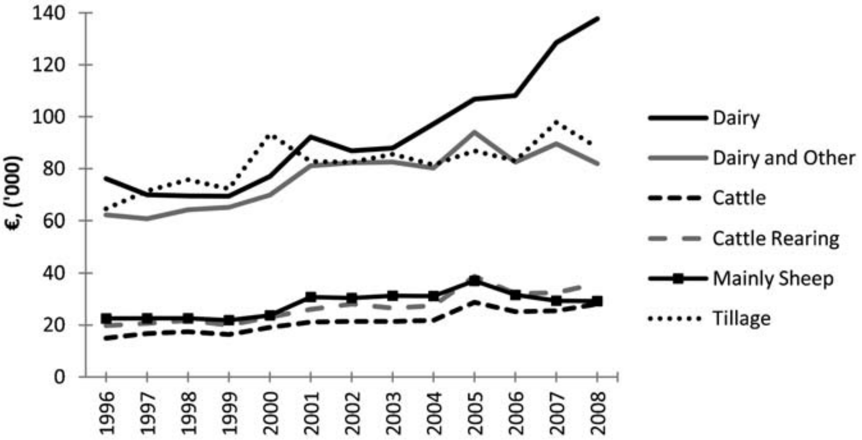

Figure 2: Dynamics of Gross Output on farms in Ireland (1996–2008)

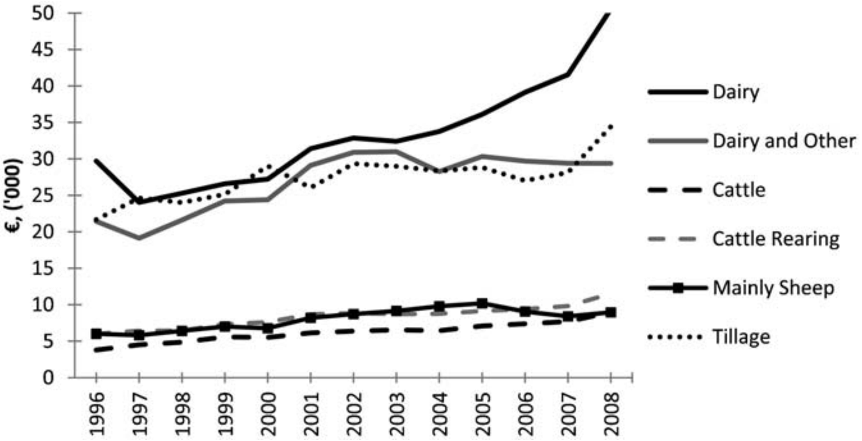

Figure 3: Dynamics of Direct Costs on farms in Ireland (1996–2008)

4. Results

Model Estimates

The production and cost functions were estimated for each enterprise on the farm using log-polynomial ordinary least squares (OLS) regressions. All of the explanatory variables used in the estimations are enterprise-specific, with the exception of farm size. All results are based on NFS data weighted to represent dairy farms nationally.

The estimated production functions for dairy, beef and sheep enterprises are reported in Table 2 and estimates of the cost functions for dairy, beef and sheep enterprises are reported in Table 3. The significance levels of the estimates and the standards error are also reported. Concentrates and fertiliser usage are the main drivers of both production and costs on dairy farms, which are grass-based in Ireland. Both variables are driving the output and the costs up with the effect of fertiliser usage less profound for costs on the dairy farms in Ireland. Farm size and number of livestock units are included in the model to capture economies of scale. The number of dairy livestock units on dairy farms drives output per LU up and the negative coefficient the square term shows the diminution return to scale. At the same time the costs per LU are falling indicating cost savings per LU for larger farms. Size of farm variable estimate is positive, but insignificant. Other costs mainly relate to enterprise specific expenses such as routine veterinary checks/treatments and expenses on artificial insemination. These expenditures are necessary for farms' operations and are driving an output up, however, they also present a considerable cost on the dairy farms in Ireland.

Gross margin analysis of policy scenarios

The analysis is focused on the farm GM because it changes in the short run while fixed costs are only adjusted in the long term. Table 4 presents the farm GM and the enterprise specific GM, GO and DC (with a prefix D representing dairy, C for cattle and S for sheep enterprises) that are anticipated to result under each mitigation scenario. Baseline figures, which reflect the average farm gross margins on the affected farms before simulations, are presented in parentheses. The simulated outcomes suggest that farm gross margin would decline significantly following a reduction of LU by 20 percent, decreasing from €63,779 down to €50,675 – a loss of an average €13,104 per farm[7]. Gross margins decline on average across all enterprises. Fezzi *et al.* (2008), using a farm budgeting model, which is based on similar UK

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[7] In late May 2014, €1 was approximately equivalent to £0.81 and $1.37 (www.xe.com)

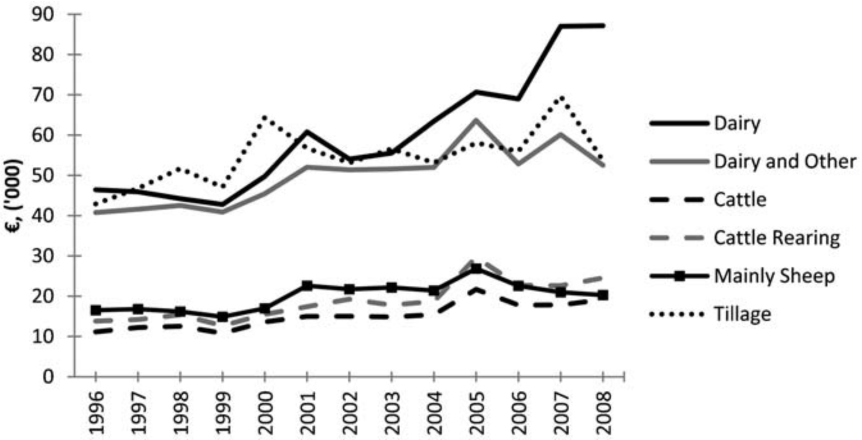

Figure 4: Dynamics of Gross Margin on farms in Ireland (1996–2008)

farm data, reports an average loss of £7,011 due to this measure, which is broadly consistent with our findings.

When the mitigation approach is instead to reduce organic N on the farm to a maximum of 170 kg org. N per hectare, the GM on the affected farms would decline on average by €4,237, or by €113 per hectare. This measure is more likely to affect farms engaged in relatively intensive production with stocking rates close to or over 2 LU per hectare and an average farm GM higher too (Table 4). This measure affects mostly beef gross output (CGO) and direct costs (CDC) which fall on average by €12,762 and €9,444 respectively leading to a loss in beef GM of €3,318 on average for the dairy and dairy other farms. The underlying assumption here is that the farmers drop the livestock with the lowest GM per animal. Results from the NFS sample in 2008 indicate that beef LU attract on average low GM returns on dairy and dairy other farms in Ireland and hence this enterprise is most affected.

The percentage change in GM, GO and DC as a result of the simulated policy scenarios is reported in Table 5. Reducing LU to achieve 170 kg organic N per hectare yields a decrease in farm GM of 5.21 percent-mostly due to fall in GM from the beef and dairy enterprises (Table 5). This is despite an associated fall in costs. The results also revealed that not all farms that exceed the 170 kg of organic N per hectare threshold are equally affected. Twenty five percent of dairy and dairy other farms exceed the limit in 2008 based on the weighted NFS data. If these farms were to reduce their emissions to comply with the stated limit, approximately 90.5 percent of these farms would have a reduction in GM and 9.5 percent would have a gain in GM due to the fact that on some farms the GM from beef cattle is zero or even negative.

Hennessy *et al.* (2005), using NFS data for 2002, found that 22 percent of dairy farms that exceed the limit would be negatively affected by this measure, with 10 percent of farms losing less that 10 percent of farm GM, 8 percent losing 10–20 percent of the farm GM and 5 percent losing more than 30 percent of farm GM. The rest of the farms would either be unaffected or benefit from this measure according to their study. In our study on the 2008 NFS data, 8.9 percent of affected farms would lose over 30 percent of their farm GM; 7.6 percent would lose between 20 to 30 percent of their farm GM and 58 percent of affected farms would lose between 10 and 20 percent of their farm GM.

If the farmers in Ireland were to reduce their livestock units by 20 percent, their GM per hectare would on average decrease by 21 percent. This measure would negatively affect all farm enterprises (dairy, cattle and sheep) on dairy farms and would lead to falls in DGM, CGM and SGM of approximately 20 percent, 24 percent and 38 percent respectively across these enterprises. These measure would not only lead to a loss of output squeezing already narrow farm margins, but would also be inconsistent with the Food Harvest 2020 agenda, an Irish policy, which requires the growth of agricultural output by about 33 percent (Food Harvest 2020).

Farm nitrogen implications under each mitigation scenario

The potential N reduction that would result from the mitigation measures would have important environmental

Table 1: Mean N per hectare and percentage of farms in N categories, 2008

	Org. N (kg per hectare)			Chemical. N (kg per hectare)			
Farm System	<170	>170	Mean	<226	226–279	>279	Mean
Dairy	79%	21%	142	92%	5%	3%	134
Dairy other	96%	4%	82	99%	1%	0	67
Cattle	99%	1%	72	100%	0	0	40
Cattle rearing	99%	1%	79	100%	0	0	42
Sheep	100%	0	36	100%	0	0	36
Tillage	100%	0	22	78%	1%	21%	62

Table 2: Results for dairy farms production function estimations

Dairy Enterprise		Beef Enterprise		Sheep Enterprise	
Ln(GO/LU)	**β**	**Ln(GO/LU)**	**β**	**Ln(GO/LU)**	**β**
Winter forage/LU	−0.0005** (0.0003)	Number of LU	−0.0041*** (0.0015)	Number of LU	−0.0042 (0.0235)
Other costs/LU	0.0011*** (0.0003)	Fertilizer/LU(€)	.0010*** (0.0006)	Forage Area	0.0223 (0.0169)
(Other costs/LU)^2	-1.37×10^{-7}** (3.5×10^{-5})	Concentrates/LU	0.0012** (0.0005)	Size of farm	−0.0211 (0.0217)
Concentrates/LU	0.0004*** (0.0001)	Other costs/LU	$-1.34 \times 10-7$ ($9.31 \times 10-7$)	Size of farm^2	0.00003 (0.0001)
Number of LU	0.0001 (0.0015)	(Other costs/LU)^2	4.00×10^{-7} ($1.12 \times 10-7$)	Fertilizer (kg)	−0.00004 (0.0004)
(Number of LU)^2	-7.24×10^{-6}** (7.07×10^{-6})	Forage area	0.0023 (0.0019)	Fertilizer (kg)^2	$1.94 \times 10-8$ ($4.90 \times 10-8$)
Size of farm	0.0004 (0.0011)	Forage area^2	9.13×10^{-6} (0.00001)	Constant	5.834*** (0.61784)
(Size of farm)^2	2.94×10^{-6} (5.09×10^{-6})	Size of farm^2	-6.04×10^{-6} (9.00×10^{-6})		
Fertilizer	0.00005*** (8.47×10^{-6})	Fertilizer (kg)	0.00003 (0.00002)		
Fertilizer^2	-1.24×10^{-9}** (2.98×10^{-10})	Fertilizer (kg)^2	-4.06×10^{-10} (5.58×10^{-10})		
Constant	6.8384*** (0.0674)	Constant	6.0821*** (0.1000)		

Note: *** significant at 1% level; ** significant at 5% level; *significant at 10% level.

Table 3: Results for Dairy Farms Cost Function Estimations

Dairy Enterprise		Beef Enterprise		Sheep Enterprise	
Ln(DC/LU)	**β**	**Ln(DC/LU)**	**β**	**Ln(DC/LU)**	**β**
Winter forage/LU	0.0002*** (0.00009)	Number of LU	−0.0034*** (0.0004)	Number of LU	−0.0280** (0.0129)
Other DC/LU	0.0021*** (0.0001)	Concentrates/LU	0.0030*** (0.0001)	Concentrates	0.0002*** (0.00004)
(Other DC/LU)^2	-1.08×10^{-6}*** (1.16×10^{-7})	(Concentrates/LU)^2	-2.38×10^{-6}** (2.48×10^{-7})	Winter forage	0.0002 (0.0004)
Concentrates/LU	0.0025*** (0.00008)	Other DC/LU	0.0025** (0.00009)	Size of farm	−0.0048 (0.0082)
(Concentrates/ LU)^2	-1.47×10^{-6}*** (1.17×10^{-7})	(Other DC/LU)^2	-8.19×10^{-7} (7.07×10^{-8})	Size of farm^2	0.00003 (0.00006)
Number of LU	−0.0046 (0.0005)	Forage area	−0.0010 (0.0005)	Fertilizer (kg)	0.0006** (0.0002)
(Number of LU)^2	0.00001 (2.31×10^{-6})	Forage area^2	-1.52×10^{-6}*** (3.39×10^{-6})	Fertilizer (kg)^2	-8.39×10^{-8}*** (2.56×10^{-8})
Size of farm	0.0005 (0.0004)	Size of farm^2	9.14×10^{-6} (2.32×10^{-6})	Constant	4.9767*** (0.2803)
Size of farm^2	5.75×10^{-7} (1.66×10^{-6})	Fertilizer (kg)	0.00004*** (3.80×10^{-6})		
Fertilizer (kg)	0.00004 (2.78×10^{-6})	Fertilizer (kg)^2	-8.97×10^{-10} (1.38×10^{-10})		
Fertilizer (kg)^2	-7.66×10^{-10} (9.78×10^{-11})	Constant	5.2264*** (0.0272)		
Constant	5.3906*** (0.0233)				

Note: *** significant at 1% level; ** significant at 5%level; *significant at 10%level.

implications. Both measures offer the potential for N reduction on the farms in the form of organic N reductions (i.e. less manure). Table 6 summarises the amount of organic N on the farms under the two case study scenarios and the percentage changes that would be anticipated. A relatively high organic N reduction (20 percent) can be achieved by reducing the number of LU by 20 percent on Irish dairy and dairy other farms; under the LU reduction to achieve 170 kg organic N per hectare on average 19 percent of organic N can be mitigated on affected farms, or 5 percent on average across all dairy and dairy other farms (Table 6).

In order to compare the measures, the average cost per unit of N abated through each measure is presented in Table 7. The average cost per unit N reduced in the scenario reducing LU by 20 percent measure is €9.51 while the cost of complying with the organic N limits is €3.39 per unit of N abated. However, the latter offers relatively small opportunities for N mitigation (20 percent versus 5 percent), which translates into 26,162 tonnes of organic N abated at a cost of approximately €254 million for the scenario with LU reduction by 20 percent and 5,740 tonnes of N mitigated at a cost of €18 million if the target of no more than 170 kg of organic N per hectare was enforced on the dairy and dairy other farms in Ireland. Thus, if specific targets for N reductions were to be introduced, farmers may need to introduce a combination of different measures in order to achieve the targets. The costs of a combination of methods could potentially be higher and are more difficult to assess.

Table 4: Farm and enterprise GM, GO, DC under each scenario

Scenario	FGM	DGM	DGO	DDC	CGM	CGO	CDC	SGM	SGO	SDC
Reduce LU 170 kg	77023 (81260)	73045 (73965)	121145 (122777)	48100 (48812)	3807 (7126)	15860 (28623)	12053 (21497)	171 (171)	246 (246)	75 (75)
Reduce LU −20%	50675 (63779)	44638 (55786)	72137 (89709)	27499 (33922)	5845 (7685)	20841 (24698)	14996 (17013)	192 (308)	555 (676)	363 (369)

Note: the baseline amounts are reported in the brackets, the averages are produced for affected farms only (for example, 'reduce LU170 kg affects only farms that produce more than 170 kg of organic N per hectare').

Table 5: Percentage change in farm and enterprise GM, GO, DC under different scenarios

Scenario	FGM	DGM	DGO	DDC	CGM	CGO	CDC	SGM	SGO	SDC
Reduce LU to 170 kg/ha N	−5.21	−1.24	−1.33	−1.46	−46.57	−44.59	−43.93	0.00	0.00	0.00
Reduce LU by 20%	−21.08	−19.98	−19.59	−18.93	−23.95	−15.62	−11.85	−37.53	−17.99	−1.69

5. Discussion and Conclusion

From an environmental point of view a wide range of N mitigation options are available to decision-makers. However, there is a great deal of uncertainty regarding the economic impacts that these measures would have on individual economic agents and on farm incomes in particular. In this paper a microsimulation model that would help to asses such impacts is developed. A case study analysis of two mitigation measures is explored namely: 1) a stocking rate reduction to achieve a maximum level of organic N of 170 kg per hectare; 2) a 20 percent livestock reduction.

Both measures discussed here could potentially lead to a reduction in N loss from agricultural land. These measures were chosen as they have been the basis of previous studies using other microsimulation models, thus, are suitable for assessing the consistency of our model specification with the existing research literature. The results are compared to the results by Fezzi *et al.* (2008) for a 20 percent LU reduction and Hennessy *et al.* (2005) for a LU reduction to achieve 170 kg N per hectare scenario.

The results of our model are consistent with those previously obtained by Lally *et al.* (2009), Fezzi *et al.* (2008) and Hennessy *et al.* (2005) and confirm that the measures would lead to a reduction in farm gross margins if introduced. In addition our model allows the volume of N mitigated to be assessed and hence an average cost per unit of N mitigated to be calculated. A major limitation of our model is that it does not presently allow for a combination of the mitigation measures to be considered - this may be needed if specific N reduction targets are to be introduced. As a static model, it does not allow for dynamics in farmers' behaviour. Thus, further extensions to the model are necessary to improve the model's capabilities.

Table 6: Changes in N per hectare under different scenarios

Scenario	OrgN	
	Kg/ha	%
Reduce LU to 170 kg N per hectare	164.4 (199.9)	−18.79%
Reduce LU by 20%	115.01 (143.77)	−20.00%

Note: brackets indicate the baseline amounts of organic N per hectare.

The results of the case study scenarios reported in this paper should be interpreted with care as the results of the model are conditional on the validity of the assumptions underlined. The presented results are average results for all dairy farms in the country and hence may obscure differences in the impacts of the considered N mitigation measures for individual farms. Notwithstanding these cautionary remarks, the model represents a considerable advance in determining the costs and other impacts of the mitigation measures.

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Table 7: The average of mitigation measures

Measure	€/N
Reduce LU to 170 kg N Per hectare	3.39
Reduce LU by 20%	9.51

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