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# **The impact of alternative agri-environmental policy instruments on the economic and environmental performance of dairy farms on the island of Ireland**

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## **Abstract**

Nitrogen (N) surplus is an important environmental issue on the island of Ireland (Northern Ireland and the Republic of Ireland), with dairy farms contributing more compared to other agricultural sectors. As a result, there has been increased demand for efficient policy measures to improve the economic and environmental performance of dairy farms in both countries. In this study, we employed the positive mathematical programming (PMP) optimization modelling framework to simulate the economic and environmental impact of two alternative agri-environmental policy instruments on different dairy farm types. Specifically, the study considers the effects of N surplus tax and agri-environmental nutrient application standard in which farms are not allowed to apply more than 170Kg of livestock N manure per hectare on dairy farms. The results of the analyses showed that the effects agri-environmental policy instruments vary across the two countries and clusters of dairy farms, resulting in clear differential effects on farm structure and N surpluses. The study concluded that in situations where the nutrient surplus is already high, as with the large farms clusters in this study, the use of manure application standards will be more effective in limiting nutrient surplus to soils compared to the use of nutrient surplus tax.

**Keywords:** Nitrogen surplus; Mathematical programming; Cluster analysis; Dairy farms; Agri-environmental policy

## 1.0 Introduction

The dairy sector is an important sector on the island of Ireland which comprises Northern Ireland and the Republic of Ireland. It contributes the largest share to the national economy when compared to other agricultural sectors (DAFM, 2017; DAERA, 2017a). The abolition of the milk quota system<sup>1</sup> in 2015, combined with the ambitious policy to increase the volume of milk production by 50 per cent by 2020 in the Republic of Ireland and the industry initiative for growth in Northern Ireland (DAFF, 2010; Agri-Food Strategy Board, 2013), has been seen as a good development in terms of expanding dairy sector on the island of Ireland. However, it is also a source of concern from the perspective of the environment as it increases the risk of damage to water quality in the region. This is because, nutrients surplus is already a significant environmental issue on the island of Ireland (Adenuga *et al.*, 2018a; Buckley *et al.*, 2016). Further intensification of dairy farms which has historically contributed more to nutrient balances in the region will therefore put more pressure on the environment. High nutrients surpluses increases the vulnerability of soil to leaching and constitute potential risk to ground and surface water quality. It can lead to significant ecological impacts and eutrophication of waters (EPA, 2016; Buckley and Carney 2013). Already, more than 50 per cent of river water bodies in Northern Ireland and the Republic of Ireland have been classified as ‘moderate’ or ‘worse’ quality and agriculture accounts for more than 30 per cent of the incidence of water pollution (Kleinman *et al.*, 2015; Cave and McKibbin, 2016; EPA, 2017; DAERA, 2017b). In fact, the quality of surface waters has remained relatively static in the last few years and the objective of the water framework directives to achieve a 13% improvement in surface water standards between 2010 and 2015 has not been achieved (EPA, 2017).

The inability to meet the water quality target has been attributed in large part to diffuse nutrient run-off from agriculture (EPA, 2017). It is worth highlighting that, before the abolition of the milk

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<sup>1</sup> The milk quota system was originally introduced in 1984, as a measure to limit public expenditure on the sector, and to stabilise milk prices and the agricultural income of dairy farmers. This was done by controlling supply of raw milk among member states through quota allocation in which each member states were given a reference quantity and consequently, each producer within a state was in turn given individual reference quantity (Donnellan and Hennessy, 2015).

quota system in 2015, various policies have been formulated at the local, national and EU level as part of the common agricultural policies (CAP) to ensure good water quality and environmental protection in Northern Ireland and the Republic of Ireland. The most prominent of these policies is the Nitrates Directive, which was designed and adopted by the European Commission in 1991 – (Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC)), to reduce nitrate pollution of water resources resulting from agriculture (European Communities, 2000). It is focused mainly on the management of livestock manures and chemical nitrogen fertilisers, by setting limits on the amount of livestock manure applied to the land each year. Specifically, it stipulates that “the amount of livestock manure applied in any year to land on a holding, together with that deposited to land by livestock, cannot exceed an amount containing 170kg nitrogen per hectare”. It also sets limits on the application of inorganic nitrogen fertilizer. However, it is possible that land application of up to 250kg N/ha/year from grazing livestock manure under certain conditions may be used, if derogation<sup>2</sup> is sought by an individual farmer and granted by the appropriate authority (European Communities, 2000). Other policies of note are the Water Framework Directive (WFD), which seeks to implement new hydrological plans leading to a ‘good ecological status of water bodies and the current CAP in which, subsidies to farmers are conditional on the fulfilment of a set of environmental requirements (Matthews, 2013). While these policies may have contributed to limiting the damage of nutrient surpluses on the environment and on water quality, it is clear that further environmental policies might be required at the national level to control nutrient surpluses from dairy production in the post milk quota era.

The objective of this study is to analyse the effect of alternative agri-environmental policy instruments on the economic and environmental performance of different dairy farm types on the island of Ireland. This study considers two agri-environmental policy instruments using scenario analyses. First, the study considers the effects of an empirically estimated nitrogen (N) surplus tax as

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<sup>2</sup> Derogation is an EU policy (Commission Decision 2011/128/EU) which permit an increase in the amount of grazing livestock manure that may be applied to land from 170kg N/ha/year up to a limit of 250kg N/ha/year, for intensive grassland farms which meet certain criteria.

an economic instrument to internalise N surplus in dairy farms. The application of taxes on nutrient surplus, which encompasses both inputs, organic manure application and chemical fertilizer, rather than nutrient inputs alone, has been determined in the literature to be a better environmental policy to reduce nutrient surplus (Becker and Kleinhanss, 1995). This is because a levy on fertilizer for example might lead to a reduction in the volume of fertilizer usage, but will consequently lead to an increase in the use of manure, which leads to an increase in nutrient surplus (Becker and Kleinhanss, 1995). Secondly the study considers an agri-environmental nutrient application standard in which derogation is abolished, such that all dairy farms are required to limit their manure N application to not more than 170 Kg N per hectare.

This study contributes to the existing literature in the following way. It is the first study on the island of Ireland that analysed the impact of two alternative agri-environmental policy instruments on the economic and environmental performance of different dairy farm types post milk quota abolition using mathematical programming technique. Secondly, unlike previous studies, the value of the N surplus tax incorporated into the optimization model has been empirically estimated rather than making a blank assumption.

The remaining sections of this paper are organised as follows: In section 2, we describe the methodology and empirical specification of the model, based on positive mathematical programming (PMP). The results of the scenario analyses are reported and discussed in section 3 while section 4 concludes the paper with relevant policy recommendations.

## **2. 0 Methodology**

The existence of heterogeneity and differences in aggregation level among dairy farms alongside varying farm objectives implies that responses to policy changes may vary by farm typology. Hence, this study analyses was carried out in two stages. In the first stage, the K-means non-hierarchical iterative clustering technique was employed to categorise dairy farms into three different farm types of relatively homogeneous units for each region of Northern Ireland and the Republic of Ireland. In the second stage, the positive mathematical programming (PMP) modelling

technique was used to analyse the impact of two alternative agri-environmental policy instruments on dairy farms in the post milk quota era. The methodology involved setting alternative policy scenarios with a base scenario that is used as a reference point for counterfactual analysis.

## **2.1 Representative farm types and cluster analysis**

Disaggregation of farms into different typologies allows for the simulation of varying responses of farms to policy changes with respect to the observed sources of heterogeneities (Moghaddasi, *et al.*, 2009). However, in classifying farms into different typologies, it is essential that the relevant parameters are taken into consideration, as this has the tendency of influencing the interpretation of observed effects of policy changes. On this basis, the K-means cluster analysis has been employed in this study to categorise the dairy farms into different farm types of relatively homogeneous units with respect to their utilisation of production resources, physical size and economic status. The K-means clustering is a non-hierarchical iterative procedure that partitions observations into k groups by minimizing Euclidean distances between them (Tan *et al.*, 2005).

Unlike the hierarchical cluster analysis, the K-means cluster analysis provides the opportunity to pre-determine the final number of clusters needed. The units to be clustered are continually arranged, such that they are clustered in a way that they are as similar as possible within cluster and as different as possible between clusters. The resulting groups identified by this analytical technique represent groups of farms characterized by a similarity in terms of important dairy enterprise variables which include: milk yield, utilised agricultural areas and herd size. These variables are relatively stable with respect to the specialised dairy farms and also fit well to the objective of this study in explaining the effect of the policy change on different farm types. Data was obtained from the Teagasc National Farm Survey (NFS) and Farm Business Survey (FBS) with cluster analysis conducted for a sample of 112 and 74 dairy farms for the Republic of Ireland and Northern Ireland respectively. The method of aggregation conforms to Day, (1963) aggregation criteria which maintained that aggregation bias is minimised when grouping is done on the basis of technological homogeneity, managerial ability, production level and institutional proportionality. The analysis was undertaken

using STATA. A similar analogy has been employed by Shrestha *et al.* (2014); Shrestha *et al.* (2015); Groeneveld *et al.* (2016). The main descriptive statistics for each cluster are shown in Table 1

## **2.2 Positive Mathematical programming model**

The Positive Mathematical Programming (PMP) is a comparative static partial-equilibrium model that maximises an objective value of a total gross margin function with the restriction that economic, technical, environmental, spatial and policy constraints are respected. It was formalized by Howitt (1995) to overcome the problem of overspecialisation associated with LP models and was first introduced to the literature in the late 1980s (Howitt 1995, Paris and Arfini, 1995; Paris and Howitt 1998). Although the structure of the PMP specification takes the form of a mathematical programming model, the main objective of the methodology is to formulate policy recommendations. The model is able to overcome the defects of other mathematical programming models by allowing for the incorporation of *a priori* information from econometric models (Howitt, 1995). Another important advantage of the PMP model over the traditional optimization model is that it is able to calibrate the model exactly to observed values of production output and factor usage with minimal datasets. The PMP model, once calibrated can be used for policy formulation as a predictive tool to investigate farmer behaviour under different conditions.

The calibration of the PMP model is usually in three phases: the first phase is the differential costs recovering phase, followed by the estimation of the non-linear cost function and, finally, the calibration by using a non-constrained production model with non-linear objective function (Howitt, 1995; Arfini *et al.*, 2005). In the first phase, a linear programming problem is solved with the sole purpose of obtaining an accurate and consistent measures of the marginal cost associated with the vector of observed level of activities. Given the LP problem expressed in equation (1)

$$\text{Maximize } \Pi = X_d p_y - X_d p_c$$

Subject to

$$\begin{aligned} AX_d &\leq b && [\lambda_l] \quad (\text{structural constraint}) \\ X_d &\leq X_d^* + \varepsilon && [\lambda_d] \quad (\text{calibration constraint}) \\ X_d &> 0 && (\text{non - negativity assumption}) \end{aligned} \tag{1}$$

Where  $\Pi$  is the objective function to be maximised over a vector of decision variables  $X_d$ , while  $p_y$  and  $p_c$  are the marginal revenue and direct variable cost of the production process respectively.  $A$  is the matrix of technical coefficients involving the limiting inputs levels. Parameter  $b$  is the vector of production or policy constraints and  $X_d^*$  is the vector of observed activity levels.  $\lambda_l$  and  $\lambda_d$  are the vectors of shadow prices associated with the allocable input of the structural constraint and calibration constraints respectively. Shadow prices ( $\lambda_d$ ) associated with the calibration constraints not only capture 'unobserved' costs or misspecification in technology, but rather any type of model misspecification. The following model misspecifications are possible: data errors, aggregation bias, and erroneous price expectations (Heckeley, 1997; Howitt, *et al.*, 2012; Paris and Howitt, 1998). The parameter  $\varepsilon$  is a small number used to decouple the structural and calibration constraints. This is necessary to prevent the model from having degenerate solutions such that during the first stage optimisation, a unique outcome exists for the binding constraints and the partitioned resource matrix. The shadow price or dual vector ( $\lambda_d$ ) is defined as a differential marginal cost vector which combines with the activity accounting cost vector  $p_c$  to obtain the actual variable marginal cost  $MC$  of supplying the observed activity vector  $X_d$  (Paris and Howitt, 1998). This is depicted by expression in equation (2)

$$MC = \lambda_d + p_c \tag{2}$$

The second stage deals with the reconstruction of the marginal costs function in which the parameters of non-linear production functions are calibrated using data, optimal solutions, and shadow prices from the first stage. The integration of the marginal costs function with respect to the output variables within the admissible domain will produce the desired total variable costs function.



These functions combine to form the nonlinear program that produces the base year solution without calibration constraints. The cost function is usually assumed to be a quadratic function due to its computational simplicity and the fact that there are no strong arguments for other type of functions (Heckeley and Britz, 2005). The general version of the quadratic variable cost function is given in equation (3)

$$C = \alpha_{di}X_d + 0.5 X_d' QX_d \quad (3)$$

Where:

$\alpha_{di}$  = vector of parameters associated with the linear term

$Q$  = symmetric, positive semi definite matrix of parameters associated with the quadratic term

The parameters are then specified so that the linear marginal variable cost functions  $MC$  can be given as expressed in equation (4)

$$MC = \frac{\delta C(X_d)}{\delta X_d} = \alpha_{di} + QX_d = \lambda_d + p_c \quad (4)$$

The third stage specifies a non-linear programming model using the calibrated functions from the second stage and the base-year data set. The non-linear programming model includes the original constraints except the calibration constraints. The system of equation (1) becomes equation (5).

$$\text{Maximize } \Pi = X_d p_y - X_d p_c - 0.5 X_d' QX_d$$

Subject to:

$$AX_d \leq b \quad [\lambda_l] \quad (\text{structural constraint}) \quad (5)$$

$$X_d > 0 \quad (\text{non - negativity assumption})$$

The calibrated non-linear programming model is then used for analyses of various agricultural policy scenarios. This is able to reproduce the primal and dual solutions of the first stage LP models (Paris and Arfini 2000).

One limitation of the PMP methodology is that the results lead to underdetermined parameter specification problems by generating non-linear programming models to specify marginal behaviour from one year or averages of multiple years of data (Hackelei, 1997; 2002; Heckeley and Britz, 2000,

2005, Merel and Bucaram, 2010). Two major approaches have been proposed in the literature to overcoming the underdetermining of the parameters in the PMP framework. They include: the use of maximum entropy (ME) criterion and the incorporation of supply elasticities from econometric studies (Paris and Howitt, 1998; Heckeley and Britz, 2005; Heckeley, 2002). The generalized maximum entropy (GME) formulation proposed by Heckeley and Britz (2005) and Paris and Howitt (1998) is particularly attractive. However, the GME procedure has had little use in applied research (Merel and Bucaram, 2010; and Howitt *et al.*, 2012). The case of incorporating exogenous, supply elasticity estimates into PMP models has been popular in recent literature and has been adopted for this study (Merel and Bucaram, 2010; Howitt *et al.*, 2012; Heckeley, 2002; Heckeley and Britz, 2005). It is argued that additional information on supply elasticities reduces, though it does not eliminate, the under-identification problem and overcomes the erratic supply responses usually associated with early PMP models. It provides information on how producers react to changing economic conditions, such that the model reproduces behaviour that are consistent with the prior information.

### **2.3 Data and empirical specification of the model**

The study area is the island of Ireland which comprises the Republic of Ireland and Northern Ireland (Figure 1). The data set employed for this study were obtained from two different sources, the Teagasc National Farm Survey (NFS, Republic of Ireland) and the Northern Ireland Farm Business Survey (FBS, Northern Ireland). They represent detailed stratified nationally representative random samples of farms surveyed annually. Variables captured in both data sources are directly comparable, given that they are both collected as part of the EU Farm Accountancy Data Network (FADN) requirements

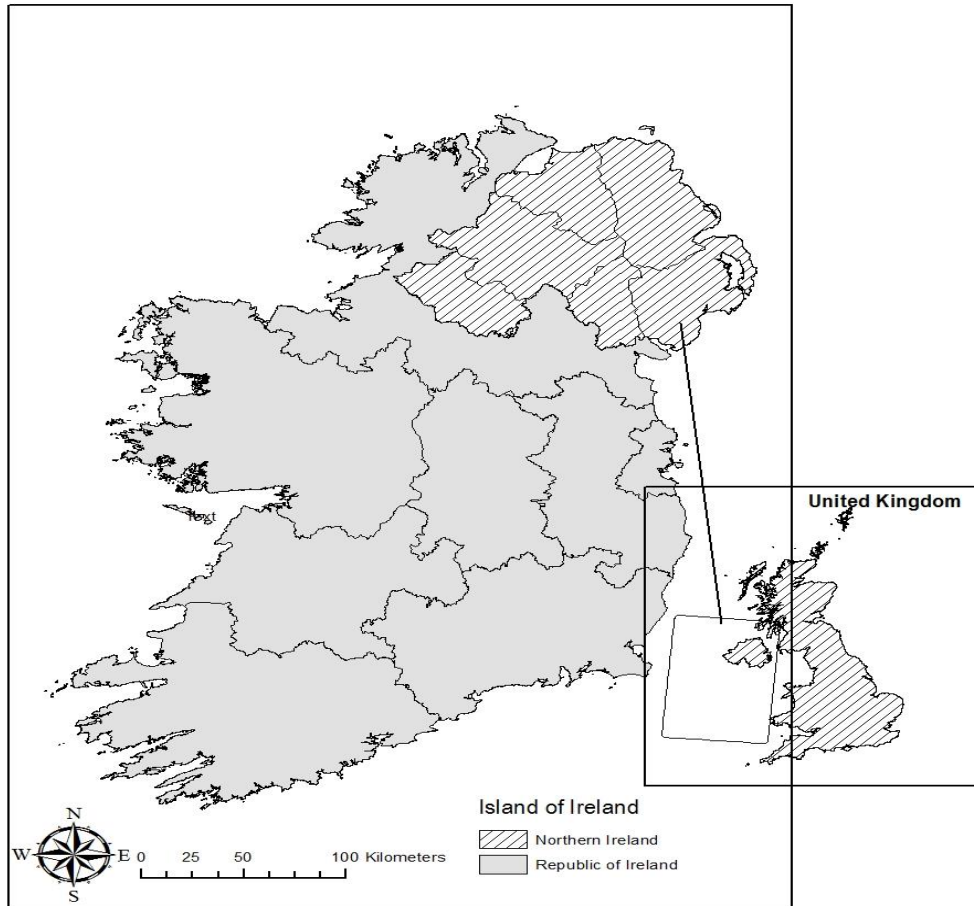


Figure 1: Map of the study area; inset is the map of the United Kingdom  
Source: Author's compilation

The objective function of the PMP model maximizes gross margin, which also gives an indication of the change in farm income resulting from changes in agricultural policy. The gross margin is estimated as the difference between total revenue and total variable costs for the farm type. The N surplus serve as the agri-environmental policy variables and its level give an indication of potential leaching to soils and ground water. Important activities were, milk production, purchase and feeding of concentrates feed, grazing by dairy cows, manure application, purchase and application of synthetic fertilizers etc.

## 2.4 Scenarios

Three scenarios have been explored in this study. They include the scenario in which milk quota is abolished (S1), and two alternative agri-environmental policy instruments scenarios (S2 and

S3) in which, in addition to milk quota being abolished, policies are put in place to limit the nutrient losses to the soils.

The S1 scenario seeks to determine the impact of the milk quota abolition on different farm types, by comparing the scenario to the base simulation in which milk quota remain in place as a constraint to milk production. The base simulation reflects the economic, structural and environmental situation of the farm before milk quota was abolished in 2015.

The S2 and S3 scenarios are compared to the S1 scenario to show the impact of the alternative agri-environmental policy instruments, making use of the with-and-without principle. In the S2 scenario, in addition to milk quota abolition, it is envisaged that future dairy production policy will include the enforcement of a tax regime on farms producing gross N surplus beyond a specific threshold. Two different thresholds have been selected for this study based on the literature (Helming, 1998). These are 170Kg N/ha (scenario S2a) and 100Kg N/ha (scenario S2b). Although there is no universally defined level of gross N surplus that meets the European Legislation leaching limit of 50 mg/litre placed on the levels of nitrate allowable in drinking water, the use of two different thresholds will give a broader view of the likely impact of the N surplus taxation policy. It is also important to note that the relationship between N surplus and the actual leaching of nitrate is not direct as it depends on a range of other biophysical geological and climatic conditions. It is assumed that dairy farmers are required to keep records of nutrient inputs in chemical fertiliser, purchased feed, and manure, and outputs in grass and plant products from their farms from which N surplus per hectare are estimated. Unlike previous studies, (Ondersteijn *et al.*, 2003), the values of the tax per Kg of N surplus for Northern Ireland and the Republic of Ireland have been empirically estimated making use of the hyperbolic environmental technology distance function approach. It can be described as the marginal abatement cost for N, with a value of £5.26 (€ 6.2) per Kg for Northern Ireland and €4.02 per Kg for the Republic of Ireland (Adenuga *et al.*, 2018b). It should be noted that the tax is applied only to the amount of N surplus above the threshold. If a farm type produces N surplus below the threshold, then the farm is not taxed. In scenario 3, it is envisaged that derogation is abolished and

the amount of N from animal manure is limited to the non-derogation limit of 170 Kg N per hectare for the Republic of Ireland.

N surplus was endogenously estimated based on the soil surface balance approach (Adenuga *et al.*, 2018). Labour and capital are assumed not to be constraining factors and farms can rent land up to a maximum of 20 hectares at a cost. Prices are exogenous in the model and like other variables are averaged over a six-year period of 2009/2010-2014/2015 to correct for occasional events. Dairy production is constrained by land availability and dairy quota. The model is run for the average farm for each cluster and shows how each farm will react to the policy changes in a post quota period. Sensitivity analysis was conducted with respect to the effect of changes in milk price on the model outcome. The model was written in the General Algebraic Modelling Systems (GAMS) programming language and was solved using the non-linear solver CONOPT3. Data for the analyses was obtained from the farm business survey (FBS, Northern Ireland) and national farm survey (NFS, Republic of Ireland). A detailed specifications of the model are presented appendix I.

### **3.0 Results and discussion**

#### **3.1 Farm types characteristics**

A summary of the main production characteristics of the farm clusters in Northern Ireland and the Republic of Ireland is presented in Table 1. They represent the average values for all farms in a given cluster. In both countries, the majority of the farms fall into cluster 2 which makes up about 50% of the total farm population, while farms in cluster 3 have the lowest percentage. The cluster 2 dairy farms can be described as the medium sized farms with an average herd size of 63 dairy cows for the Republic of Ireland and about 95 dairy cows for Northern Ireland. On the average, farms in cluster 1 are the smallest, while farms in cluster 3 are the largest in terms of herd size and land area. Also, in both countries, farms in cluster 3 have higher yield per dairy cow but they also have higher concentrate inputs per dairy cow. Generally, dairy farm clusters in Northern Ireland are larger than their respective counterparts in the Republic of Ireland. In terms of nutrient inputs from chemical fertilizer and manure, farms in cluster 3 are found to have higher N inputs compared to the other 2 clusters. Inputs from chemical fertilizer are generally higher in the Republic of Ireland compared to

Northern Ireland. This may be connected to the fact that dairy farms in the Republic of Ireland are more pasture based compared to Northern Ireland and hence the application of more chemical fertilizers. It can be observed in Table 1 that grass grazed per hectare is generally higher in Republic of Ireland compared to Northern Ireland. The stocking density exceeds 2 LU/ha for all three clusters in Northern Ireland and for clusters 2 and 3 for the Republic of Ireland. Farms in cluster 3 have the highest stocking density in both countries. Manure nutrient inputs per hectare is also found to be higher in Northern Ireland's clusters compared to the corresponding clusters in the Republic of Ireland with the average manure N input exceeding 200 Kg N per hectare in cluster 3 for Northern Ireland.

**Table 1: Summary of structural characteristics of the farm clusters in the island of Ireland**

Variables	Republic of Ireland Clusters			Northern Ireland Clusters		
	1 (31)	2 (57)	3 (24)	1 (N=24)	2 (N=36)	3 (N=14)
Grazed grass (kg DM/ha)	7103.1	7231.5	7070.3	6088.0	5531.5	5124.5
Stocking density (LU/ha)	1.96	2.02	2.24	2.03	2.07	2.46
Concentrates (Kg/cow)	836.0	910.5	1416.6	2001.3	2644.3	3790.8
Dairy herd size(numbers)	53.4	63.4	92.6	64.4	94.9	185.8
UAA (ha)	43.8	51.9	70.7	61.3	74.3	116.3
Milk yield (litres/cow)	4119.4	5216.7	6638.6	5155.1	6395.4	8048.4
Chemical N input (Kg N/ha)	139.9	172.2	215.8	134.6	144.0	175.7
Livestock manure N input (Kg N/ha)	141.4	151.7	176.2	149.6	169.4	225.0

### 3.1 Results of Scenario Analysis

The results of simulating alternative policy scenarios from the PMP model are presented in Tables 2, 3 and 4 for each of the 3 clusters respectively. The results show that the effects of the milk quota abolition and the suggested environmental policies vary across the two countries and clusters of dairy farms, resulting in clear differential effects on farm structure, gross margin and N surplus. In all three clusters in the Republic of Ireland, an increase in herd size can be observed as a result of the milk quota abolition in the S1 scenario. However, the percentage increase is higher for farms in cluster 3 which also becomes more intensive compared to the other two clusters. This might be connected

to the fact that farms in cluster 3 are the larger farm types with higher initial endowment of land and are more commercialised compared to the small sized farms with higher production costs per dairy cow. The increase in herd size of all clusters results from the fact that milk quota was binding in the Republic of Ireland prior to its abolition in 2015. This result is in line with that of previous studies in which it was found that the abolition of the milk quota system will lead to increase in the size of dairy farms (Sharma *et al.*, 2018; Groeneveld *et al.*, 2016; Boysen *et al.*, 2015; Dillon, 2011; Huettel and Jongeneel, 2011; Louhichi *et al.*, 2010; Klootwijk *et al.*, 2016) and actual data for 2016 which shows an increase in average herd size relative to 2013 (CSO, 2016).

An increase in gross margin for all three clusters in the Republic of Ireland can also be observed. However, the percentage increase is higher for the larger dairy farms, ranging from about 3% for the cluster 1 dairy farms to about 30% for the cluster 3 dairy farms. The percentage increase in gross margin for the cluster 2 dairy farms is about 19%. The ability of the larger farms to take advantage of economies of scale may have contributed to the higher percentage increase on gross margin. Similar results were obtained by Groeneveld *et al.*, (2016) for dairy farms in the Netherlands. In the model, the dairy farms in the Republic of Ireland, are able to rent extra land up to 20ha at a cost to expand their dairy herd size. In the S1 scenario, all three clusters in the region are able to rent the extra land at their disposal to take maximum advantage of the milk quota abolition. This result is in line with that obtained by Koeijer *et al.*, (2014) in which they found that the abolition of the milk quota system is likely to lead to an increase in the demand for land which might consequently result in a higher price for land.

**Table 2: Effects of policy changes on farm structure and gross margin in Cluster 1**

Variables	Republic of Ireland					Northern Ireland				
	Base	S1	S2a	S2b	S3	Base	S1	S2a	S2b	S3
Herd size	53.4	70.1	70.9	71.0	71.4	64.5	64.5	56.6	53.6	67.8
Stocking density (cow/ha)	1.22	1.10	1.25	1.62	1.12	1.05	1.05	0.92	0.874	1.106
Gross margin (€)	30638	31716	34250	38386	32291	46654	46654	40931	38759	49047
Ext. land(ha)	0	20	13.19	0	20	0	0	0	0	0
N surplus(Kg/ha)	98.2	88.6	100.5	130.9	90.3	132.2	132.2	116.2	110.1	139.3

**Table 3: Effects of policy changes on farm structure and gross margin in Cluster 2**

Variables	Republic of Ireland					Northern Ireland				
	Base	S1	S2a	S2b	S3	Base	S1	S2a	S2b	S3
Herd size	63.4	84.2	84.9	69.9	84.4	95.0	95.0	87.9	76.4	97.1
Stocking density (cow/ha)	1.22	1.17	1.27	1.34	1.18	1.28	1.28	1.19	1.029	1.307
Gross margin (€)	52326	62650	65327	57564	62819	92966	92966	86112	74790	94974
Ext. land(ha)	0	20	13.2	0	20	0	0	0	0	0
N surplus (Kg/ha)	141.5	135.9	151.4	156.3	136.2	161.5	161.5	149.7	130.0	165.1

**Table 4: Effects of policy changes on farm structure and gross margin in Cluster 3**

Variables	Republic of Ireland					Northern Ireland				
	Base	S1	S2a	S2b	S3	Base	S1	S2a	S2b	S3
Herd size	92.6	131.3	111.6	88.6	129.7	183.9	183.9	164.8	150.9	108.8
Stocking density (cow/ha)	1.31	1.45	1.23	1.02	1.43	1.60	1.60	1.42	1.298	0.935
Gross margin (€)	94195	122224	104908	85701	120765	199414	199414	178691	163656	117907
Ext. land(ha)	0	20	20	16.63	20	0	0	0	0	0
N surplus (Kg/ha)	207.28	229.68	195.24	160.93	226.77	239.39	239.39	212.44	194.57	140.18

Base = situation before milk quota is abolished; S1 = milk quota abolition; S2a= tax on N surplus with 170Kg N/ha threshold; S2b = tax on N surplus with 100Kg N/ha threshold; S3 = N from animal manure is limited to 170 Kg N/ha

There is no change in herd size and consequently gross margin for all the clusters of dairy farms in Northern Ireland in the S1 scenario. This is because, the dairy production system in the country was not constrained by quota before its abolition in 2015. It benefited from the flexibility in the management of the UK quota system which gives it access to the single market for milk quota



within the constituent countries of the UK. No additional land was therefore required for expansion, such that the extra land is 0 for all the scenarios

In terms of N surplus per hectare, the abolition of the milk quota system in the S1 scenario will lead to an increase in N surplus per hectare for farms in cluster 3 compared to the base level in the Republic of Ireland. For the dairy farms in cluster 1 and 2, the fact that they were able to rent extra land such that a lower stocking density (number of cows per hectare) is maintained resulted in the N surplus being relatively lower compared to the base scenario. This result implies that access to land will play a vital role in limiting N surplus from dairy production in the post milk quota era.

In the scenario 2 analysis, farms producing N surplus above a specific threshold (Scenario S2a (170 Kg N/ ha) and scenario S2b (100Kg N/ha) in the S1 scenario are taxed. For the Republic of Ireland, only dairy farms in cluster 3 had N surplus above 170 Kg N/ha, while farms in cluster 2 and 3, had N surplus above 100 Kg N/ha. However, for Northern Ireland, all 3 dairy farms clusters have N surplus above 100 Kg/ ha and only farms in cluster 3 have N surplus above 170 Kg/ha (Tables 2, 3 and 4).

Compared to the S1 scenario, an application of the tax policy in scenario 2a and 2b resulted in a decrease in the herd size for all clusters in Northern Ireland. Although it was not expected that the herd size for clusters 1 and 2 should fall below the S1 scenario given that they did not exceed the threshold in the S1 scenario, the slight decrease in herd size may have resulted from the need to be more careful, given that the N surplus in these two clusters was already on the high side. For the Republic of Ireland, only farms in cluster 3 are affected for the N surplus tax policy when the threshold was 170Kg N/ha. There is relatively no change in the herd size of farms in cluster 1 and 2 for the Republic of Ireland. This is understandable given that farms in these clusters produces N surplus that is far less than the considered threshold.

In the case of the S2b scenario in which the threshold is reduced to 100Kg N/ha, a decrease in herd size can be observed for the dairy farms in clusters 2 and 3 for the Republic of Ireland, with

a higher decrease in herd size observed for dairy farms in cluster 3 compared to scenario 2a. For Northern Ireland, there is a decrease in herd size for all three farm clusters just like in scenario 2a.

Relative to the S1 scenario, the tax on gross N surplus resulted in a decrease in gross margin for all clusters in Northern Ireland. However, this also leads to a decrease in N surplus compared to the S1 scenario with higher decrease in the S2b scenario compared to the S2a scenario. This result is similar to that obtained by Helming (1998). For the Republic of Ireland, dairy farms in cluster 3 experienced the same effect as with farms in Northern Ireland with respect to scenario 2a and 2b. However, this is not the case for farms in clusters 1 and 2 where the application of tax on excess N surplus has little or no effect on gross margin or N surplus. The implication of this is that, a nutrient surplus taxation policy in the Republic of Ireland will only affect the large dairy farms, while the smaller dairy farms are more likely to increase the intensity of their dairy production given that they still have more room before they reach the threshold, beyond which they would be taxed. This result is in line with that obtained by Huettel, and Jongeneel, (2009) in which they assert that the abolishment of the milk quota regime is likely to affect the future dairy farm size evolution.

In the S3 scenario it is assumed that derogation is abolished, and dairy farms are not allowed to use more than 170 Kg manure N input per hectare. Results from the Republic of Ireland model shows no significant effect relative to the S1 scenario. This may have resulted from the fact that manure N input in the Republic of Ireland clusters are less than 170 Kg N/ha, except for the cluster 3 dairy farms which is slightly higher. A slight decrease in herd size and N surplus can therefore be observed in the cluster 3 dairy farms compared to the S1 scenario.

The results of the S3 scenario analysis for Northern Ireland showed a significant decrease in the herd size of the cluster 3 dairy farms, while clusters 1 and 2 remain relatively the same when compared to the S1 scenario. A significant decrease in N surplus relative to the S1 scenario can also be observed for the dairy farms in cluster 3 for Northern Ireland. The strict manure policy also resulted in lower gross margin for farms in cluster 3 in both countries. The result of this scenario is similar to

that obtained by Helming and Peerlings (2002) in which they found that the abolition of derogation will lead to decrease in the number of milking cows’.

Comparing the results in scenarios S2a to S2b, it can be inferred, that the effect of the taxation policy will depend to a large extent on the threshold of the nutrient surplus and access of the dairy farmers to land. With access to land, the dairy farms can increase herd size without increasing N surplus by renting more land and reducing the livestock density. This however, will also depend on the price of land. The choice between nutrient surplus taxation policy and application of environmental standards for the control of environmental pressure on land will on the other hand depend on the existing level of nutrient surplus and the dairy production system. In situations where the nutrient surplus is already high, as with the large farms clusters in this study, the use of manure application standards will be more effective in limiting nutrient surplus to soils. This is because, the large farms being highly commercialised do not significantly reduce their N surplus under the nutrient surplus tax scenario as long as they continue to make profit. This however, also depends on the amount of the tax and the nutrient surplus threshold. With the application of environmental standards rather than increasing intensity of production, the farms will have to purchase or rent additional land to be able to meet the nutrient standard requirement. This result is comparable to that obtained by Hellegers (1996) in which they found that the amount of tax and the level of the tax-free nutrient surplus influences the impact of the nutrient surplus taxation policy.

### **3.4 Sensitivity analysis**

The price of milk is a significant factor in the assessment of the effect of agricultural policy changes on dairy production activities. It is assumed that the expansion of the dairy sector might result in a fall in the price of milk. As a result, sensitivity analysis was conducted by reducing the price of milk by 10%. This is based on the information from literature and current data on changes in milk price (Teagasc 2018). All other prices relating to production costs were however kept constant. It is important to note that these prices might also change in the long run and adjustments to price changes is not always instantaneous. The results of the sensitivity analysis is presented in Tables 5, 6

and 7 for clusters 1, 2 and 3 respectively. A fall in the price of milk by 10% under the sensitivity analysis resulted in a less significant increase in herd size compared to the main analysis. Moreover, unlike before, there is a fall in gross margin, following the abolition of milk quota. This result is in line with the current reality in which a decline in milk price has resulted in a fall in gross margin in spite of increase in dairy production output (Teagasc, 2018). Nevertheless, the conclusion regarding taxation policies (S2a and S2b) and environmental standards still holds.

**Table 5: Effects of policy changes in Cluster 1 with 10% price reduction**

Variables	Republic of Ireland					Northern Ireland				
	Base	S1	S2a	S2b	S3	Base	S1	S2a	S2b	S3
Herd size	53.4	57.7	57.7	55.4	60.2	64.5	53.7	45.8	42.8	56.5
Stocking density (cow/ha)	1.22	1.25	1.319	1.27	1.32	1.05	0.89	0.78	0.70	0.92
Gross margin (€)	30638	24006	24737	24980	24981	46654	30940	26382	24652	32547
Ext. land(ha)	0	2.30	0	0	1.65	0	0	0	0	0
N surplus(Kg/ha)	98.2	100.9	106.4	102.1	107.0	132.2	110.3	94.1	87.9	116.1

**Table 6: Effects of policy changes in Cluster 2 with 10% price reduction**

Variables	Republic of Ireland					Northern Ireland				
	Base	S1	S2a	S2b	S3	Base	S1	S2a	S2b	S3
Herd size	63.4	71.5	71.5	67.8	72.3	95.0	79.6	72.6	60.9	81.4
Stocking density (cow/ha)	1.22	1.32	1.38	1.31	1.29	1.28	1.07	0.98	0.82	1.10
Gross margin (€)	52326	44882	45621	37107	44743	92966	63145	57585	48402	64630
Ext. land(ha)	0	2.29	0	0	4.32	0	0	0	0	0
N surplus(Kg/ha)	141.5	153.0	159.9	151.6	149.2	161.5	135.3	123.4	103.7	138.5

**Table 7: Effects of policy changes in Cluster 3 with 10% price reduction**

Variables	Republic of Ireland					Northern Ireland				
	Base	S1	S2a	S2b	S3	Base	S1	S2a	S2b	S3
Herd size	92.6	111.82	91.4	85.9	109.9	183.9	153.5	134.4	120.5	90.8
Stocking density (cow/ha)	1.31	1.23	1.145	1.22	1.21	1.60	1.32	1.16	1.04	0.781
Gross margin (€)	94195	78506	68783	66051	77317	199414	132209	115746	103802	78220
Ext. land(ha)	0	20	9.15	0	20.00	0	0	0	0	
N surplus(Kg/ha)	207.3	195.6	181.6	192.8	192.3	239.4	197.9	173.2	155.4	117.1

Base = situation before milk quota is abolished; S1 = milk quota abolition; S2a = tax on N surplus with 170Kg N/ha threshold; S2b = tax on N surplus with 100Kg N/ha threshold; S3 = N from animal manure is limited to 170 Kg N/ha

An analysis was also performed in which the farms cannot rent additional land when milk quota is abolished for the Republic of Ireland. In this case, it was found that only farms in cluster 3 increases in herd size by about 16% which is less than the increase of about 30% when the dairy farmers were able to rent additional land. Farms in cluster 2 remain relatively the same, while farms in cluster 1 reduced in herd size by about 20%. The reduction in herd size for farms in cluster 1 must have resulted from the fact that, when land becomes a constraint, it becomes more expensive. In that case, only the most profitable farms, (which in this case are the large farms due to being able to take advantage of economies of scale) are more likely to have access to additional land for dairy production while the smaller farms may shrink in size or exit production completely due to competition from the more profitable farms, higher costs of production or a drop in the price of milk. This implies that the abolition of the milk quota system without access of the dairy farms to more land will see the large farm sizes getting bigger, taking land from the smaller farm sizes. However, access to land even at a cost means that all the farm type's increases in sizes with the abolition of the milk quota system

#### 4.0 Conclusion

In this paper a positive mathematical programming (PMP) optimization modelling framework is employed to simulate the effect of alternative agri-environmental policy instruments on the structure and nutrient surpluses of different dairy farm types post milk quota abolition. The dairy farm

types can be broadly described as small, medium and large farms types. Three scenarios were considered and analysed to achieve the study objectives. In the first scenario, it was assumed that milk quota is abolished with all other conditions remaining the same. In the second scenario, in addition to milk quota being abolished, dairy farm types producing N surplus beyond a certain threshold are taxed. In the third scenario, alongside milk quota abolition, a limit was set on the maximum N in manure that can be applied to land in line with the nitrates directive assuming that derogation is abolished.

The results of the analyses showed varying effects on the different farm types and across both countries. In specific terms, the abolition of the milk quota system will result in the expansion of the dairy sector in the Republic of Ireland where milk quota was binding prior to its abolition in 2015 but not in Northern Ireland where milk quota was not binding. The level of expansion of the dairy herds in the Republic of Ireland was higher for the large farm types compared to the smaller farm types. The abolition of the milk quota system was also found to result in an increase in N surplus per hectare in the large farm types in the Republic of Ireland despite access to extra land due to an increase in dairy farming intensity.

In terms of impact on gross margin, the abolition of the milk quota system led to an increase in gross margin. The percentage increase in gross margin was also found to be higher for the large farm types compared to the smaller farm types. However, a reduction in price of milk by about 10% resulted in a fall in gross margin relative to the base scenario in all farm types.

Based on the two environmental policy scenarios simulated, it was shown that the choice of a tax on N surplus or the enforcement of application standard as a form of environmental policy instruments on the island of Ireland will depend on the level of N surplus. The clusters of farm types exhibited different responses to the policy changes in both countries. The impact of the policy options was more pronounced in the large farm types with higher N surplus compared to the smaller farm types. The application of N surplus tax resulted in a decrease in herd size and gross margin for the large farm types. The effect was relatively little for the smaller farm types.

From the results, it can be concluded that land and environmental constraints are likely to be critical factors in the expansion of the dairy sector in the post milk quota era. A limited access to land for example will lead to greater intensification of the dairy farms which might consequently result in excess nutrient surplus going into the soil. To take full advantage of the abolition of the milk quota system especially in the Republic of Ireland, policy makers should therefore focus on increasing dairy farmers' access to land.

It is important to stress that some level of care is necessary in the interpretation of these results. Firstly, the model is a rather simple comparative static PMP model. In reality, farmers respond to changes in policy in a dynamic way. However, modelling the dynamic behaviour of the farmers will require additional technical-economic relationships and information that might be difficult to access. Also, in the model, farm gross margin was simultaneously optimised on the assumption of optimal allocation of dairy production inputs and outputs across farm types. However, the assumption of profit maximization may not always be the goal of all farmers (for example, other objectives may include: minimization of labour use and ensuring minimal environmental impact in dairy production). It is nevertheless in line with economic theory which is necessary to predict economic behaviour of the different farm types. It should also be acknowledged that in the real world, access to land will not be as simple as has been assumed in this study. This is because access to land is usually influenced by other factors such as other agricultural activities and the quality of the accessible land available.

In spite of the aforementioned limitations of this study, the results of the analyses using the PMP modelling approach contributes to the existing literature by providing empirical evidence on the economic and environmental effects of alternative environmental policy instruments in dairy farms. This will be useful in limiting excess nutrient surplus to the soil in the post milk quota era.

Further research in line with this study can be carried out to include other agricultural sectors such as the beef and arable sectors, which will provide an empirical evidence of the impact of the policy changes on other agricultural sectors on the island of Ireland. Such studies could also include looking at the effects of adjustments in the use of production inputs or farming management practices

such as reducing the amount of protein in concentrates or the transfer of surplus manure especially from the large dairy farms with higher manure nutrient inputs to the smaller farms where they can still be utilised.

## References

- Adenuga A. H., Davis J., Hutchinson G., Donnellan T., Patton M. (2018a). Estimation and 713 determinants of phosphorus balance and use efficiency of dairy farms in Northern Ireland: A within and between farm random effects analysis. *Agricultural Systems*, 164:11-19. Available at: <https://doi.org/10.1016/j.agsy.2018.03.003>.
- Adenuga, A. H. Davis, J., Hutchinson, G., Donnellan, T. and Patton, M., (2018b). "Valuing Agricultural Externalities: Nitrogen Surplus in the Dairy Sector on the Island of Ireland," 2018 Conference, July 28-August 2, 2018, Vancouver, British Columbia 277434, International Association of Agricultural Economists
- Agri Food Strategy Board (2013). *Going for Growth: A strategic Action Plan in Support of the Northern Ireland Agri-food Industry*. Available at: <http://www.agrifoodstrategyboard.org.uk/uploads/Going%20for%20Growth%20-%20Web%20Version.PDF> (Accessed 16th August, 2017).
- Arfini F., Donati M., Zuppiroli M. and Paris Q. (2005) Positive Mathematical Programming Approach for Ex-post Evaluation of Set Aside in Italy. Arfini, F. (Ed.) in "Modelling Agricultural Policies: State of the Art and New Challenges", proceedings of the 89th EAAE Seminar, pp. 188 – 206
- Becker, H. and W. Kleinhanss (1995). *The impact of CAP Reform and of fertilizer levies on agriculture and the environment: A regional assessment of the European Union*; Braunschweig-Völkenrode, Institut für Betriebswirtschaft; Arbeitsbericht 3/95
- Boysen O. Miller A. C. and Matthews A. (2015). Economic and Household Impacts of Projected Policy Changes for the Irish Agri-food Sector. *Journal of Agricultural Economics*. doi: 10.1111/1477-9552.12119
- Buckley, C., Wall, D.P., Moran, B, O'Neill S., Murphy P. N. C. (2016). Farm gate level nitrogen balance and use efficiency changes post implementation of the EU Nitrates Directive, *Nutr Cycl Agroecosyst* 104:(1): 1-13. doi:10.1007/s10705-015-9753-y
- Buckley C. and Carney P. (2013). The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level. *Environmental Science and Policy* 25:118-126
- Cave, S.,and McKibbin, D., (2016). River Pollution in Northern Ireland: An Overview of Causes and Monitoring Systems, with Examples of Preventative Measures. NIAR 691-15. Research and Information Service, Northern Ireland Assembly, Belfast Available at: <http://www.niassembly.gov.uk/globalassets/documents/raise/publications/2016/environment/2016.pdf> (Retrieved 15th August 2016).
- Central Statistics Office (CSO, 2016). *Farm Structure Survey 2016*. Ireland. Retrieved from <https://www.cso.ie/en/releasesandpublications/ep/p-fss/farmstructuresurvey2016/da/ls/>.



- Day R. H. (1963). On aggregating linear programming models of production. *Journal of Farm Economics*, 45:797-813
- Department of Agriculture, Environment and Rural Affairs (DAERA) (2017a) *Statistical Review of Northern Ireland Agriculture*. Cap Policy, Economics and Statistics Division, DAERA, Belfast. Available at: <https://www.daera-ni.gov.uk/sites/default/files/publications/daera/Stats%20Review%202017%20final.pdf> Accessed 18<sup>th</sup> June 2018
- Department of Agriculture, Environment and Rural Affairs (DAERA)(2017b). *The Water Environment (Water Framework Directive) Regulations (Northern Ireland) 2017*. Statutory rules of Northern Ireland, No. 81, Environmental Protection, 31pp
- Department of Agriculture Food and the Marine (DAFM) (2017). *Fact Sheet on Irish Agriculture – January 2017. Dublin, Ireland*. Available at: [www.agriculture.gov.ie/media/migration/publications/2016/FactsheetIrishAgriculture180117290517.pdf](http://www.agriculture.gov.ie/media/migration/publications/2016/FactsheetIrishAgriculture180117290517.pdf). Accessed 17<sup>th</sup> June 2018
- Department of Agriculture, Fisheries and Food (DAFF) (2010). Food Harvest 2020, a vision for Irish agri-food and fisheries. Department of Agriculture, Fisheries and Food, Dublin, Ireland.
- Dillon P. (2011). The Irish Dairy Industry - Planning for 2020, in National Dairy Conference, Cork, Ireland
- Donnellan T and Hennessy T., (2015). The Pre-Quota Period. In T. Donnellan, T. Hennessy and F. Thorne (Eds). *The end of the quota era: A history of the dairy sector and its future prospects* (pp. 3-7) Athenry: Rural economy and development programme, Teagasc
- Environmental Protection Agency (EPA) (2016) *Environment and Agriculture In: Ireland's Environment. An Assessment 2016*. B. Wall, J. Derham and T. O'Mahony (Eds). Environmental Protection Agency (pp 187-204), Wexford, Ireland.
- Environmental Protection Agency (EPA) (2017). *Water Quality in Ireland 2010–2015*, Environmental Protection Agency, Wexford, Ireland. Available at: <https://www.rte.ie/news/world/2017/0831/901158-epa/>
- European Communities, (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a framework for Community Action in the Field of Water Policy [2000] OJ L327/1. available at. <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060> (accessed 25th January 2018).
- Groeneveld A., Peerlings J., Bakker M., and Heijman W. (2016). The effect of milk quota abolishment on farm intensity: Shifts and stability. *Wageningen journal of life sciences* 77:25-37
- Hecklei T. (1997), *Positive Mathematical Programming: Review of the standard approach*, CAPRI Working Paper, University of Bonn.
- Heckelei, T. (2002). *Calibration and estimation of programming models for agricultural supply analysis*. Habilitation thesis, Bonn University, Bonn, Germany
- Heckelei, T. and Britz, W. (2000). Positive mathematical programming with multiple data points: a cross-sectional estimation procedure. *Cahiers d'Economie et Sociologie Rurales* 57: 27–50.
- Heckelei, T. and Britz, W. (2005). *Models Based on Positive Mathematical Programming: State of the Art and Further Extensions*. In Arfini, F., (ed), *Modelling Agricultural Policies: State of*

the Art and New Challenges, Proceedings of the 89th European Seminar of the European Association of Agricultural Economists, pages 48–73. Monte Università Parma Editore.

Hellegers P. J. G. J. (1996). *The impact of environmental policy on nitrogen balances at farm level in the European Union*. Agricultural Economics Research Institute (LEI-DLO), 153, 102p. Available at: <https://core.ac.uk/download/pdf/29330123.pdf>. Accessed 14<sup>th</sup> June 2018

Helming, J. F. M., Peeters, L., and Veendendaal, P. J. J. (2001). Assessing the consequences of environmental policy scenarios in Flemish agriculture. In Heckeley, T., Witzke, H. P., and Henrichsmeyer, W., (eds), *agricultural sector modelling and policy information systems*, Proceedings of the 65th EAAE Seminar, March 29-31, 2000 at Bonn University, pages 237–245. Vauk Verlag Kiel

Helming J. and Peerlings J. (2002). *The impact of milk quota abolishment on Dutch agriculture and economy: applying an agricultural sector model integrated into a mixed input-output model*. Paper presented at the X<sup>th</sup> EAAE Congress ‘Exploring Diversity in the European Agri-Food System’, Zaragoza (Spain), 28-31 August. Available at: <http://ageconsearch.umn.edu/bitstream/24911/1/cp02he65.pdf>. Accessed 14<sup>th</sup> January 2018

Helming, J., (1998), *Effects of nitrogen input and nitrogen surplus taxes in Dutch agriculture*, Cahiers d'Economie et de Sociologie Rurales (CESR), 49, issue , <https://EconPapers.repec.org/RePEc:ags:inrace:206221>. 31pp.

HMRC (2017). Foreign exchange rates: yearly averages and spot rates. Available at: <https://www.gov.uk/government/publications/exchange-rates-for-customs-and-vat-yearly>. Accessed 6th December 2017

Howitt, R. E. (1995) Positive Mathematical-Programming. *American Journal of Agricultural Economics*, 77, 329-342

Howitt R. E., Medellín-Azuara J., MacEwan D., Lund J. R. (2012). Calibrating disaggregate economic models of agricultural production and water management. *Environmental Modelling & Software* 38 (2012) 244-258

Huettel, S. and Jongeneel, R. (2009). Impact of the EU Milk Quota on Structural Change in the Dairy Sectors of Germany and The Netherlands. Contributed Paper prepared for presentation at the International Association of Agricultural Economists Conference, Beijing, China, August 16-22, 2009

Kleinman, J. A. P., Sharpley A. N., Withers J. A. P., Bergstrom L., Johnson T. L., and Doody D. G. (2015). Implementing agricultural phosphorus science and management to combat eutrophication. *AMBIO* 44(Suppl. 2): 297-310. doi: 10.1007/s13280-015-0631-2

Klootwijk, C. W., Van Middelaar, C. E., Berentsen, P. B. M. and de Boer I. J. M. (2016). Dutch dairy farms after milk quota abolition: Economic and environmental consequences of a new manure policy. *J Dairy Sci.* 99(10):8384-8396. doi: 10.3168/jds.2015-10781.

Koeijer, T. J. de, PW Blokland, JFM Helming, HH Luesink and A. van den Ham, (2014). *Ex ante evaluation of the bill Responsible growth in dairy farming; Background document; .* Wageningen, LEI Wageningen UR (University & Research center), LEI 2014-019a. 72 pages;

- Kostov, P (2008) A new approach to modelling UK milk production under quota restriction, in P. Di Alberto and C. Costa (Eds.) *New research on livestock science and dairy farming*, Nova Science Publishers, pp 203-210
- Matthews A. (2013). Greening agricultural payments in the EU's Common Agricultural Policy. *Bio-based and Applied Economics* 2(1): 1-27
- Merel, P., and Bucaram, S., (2010). Exact calibration of programming models of agricultural supply against exogenous supply elasticities. *European Review of Agricultural Economics* 37 (3), 395-418.
- Ondersteijn, C.J.M., Beldman, A.C.G., Daatselaar, C.H.G., Giesen, G.W.J., Huirne, R.B.M.(2003). Farm structure or farm management: effective ways to reduce nutrient surpluses on dairy farms and their financial impacts. *Livestock Production Science* 84:171 – 181.
- Louhichi K., Kanellopoulos A., Janssen S., Flichman G., Blanco M., Hengsdijk H., Heckeleei T., Berentsen P., Lansink A. O., Ittersum M. V. (2010), FSSIM: a bio-economic farm model for simulating the response of EU farming systems to agricultural and environmental policies, *Agric. Syst.* 103:585–597.
- Moghaddasi R., Bakhshi A. and Kakhki M. D. (2009). Analyzing the Effects of Water and Agriculture Policy Strategies: An Iranian experience. *Am. J. Agri. & Biol. Sci.*, 4 (3): 206-214
- Paris Q. and Arfini F. (1995). “A positive mathematical programming model for regional analysis of agricultural policies”, in Sotte F., *The regional dimension in agricultural economics and policies*, Proceeding EAAE Seminar, Ancona.
- Paris Q., Howitt R.E. (1998). An Analysis of Ill Posed Production Problems Using Maximum Entropy, *American Journal of Agricultural Economics*, 80: 124-138
- Sharma P., Humphreys J. Holden N. M. (2018). Environmental impacts of alternative agricultural uses of poorly drained farm land in Ireland. *Science of Total Environment*, 637-638:120-131 Available at: <https://doi.org/10.1016/j.scitotenv.2018.04.315>
- Shrestha S., M. Abdalla, T. Hennessy, D. Forristal and M. B. Jones (2015). Irish farms under climate change – is there a regional variation on farm responses? *The Journal of Agricultural Science* 153: 385-398
- Shrestha S., T. Hennessy, M. Abdalla D. Forristal and M. B. Jones (2014). Determining short term responses of Irish dairy farms under climate change, *German Journal of Agricultural Economics* 63(3): 143-155
- Summary of findings of Northern Ireland (2012). *Nitrates Article 10 Report and 2011 Derogation Report (2012)*. Available at [https://www.nienvironmentlink.org/cmsfiles/policy-hub/files/documentation/Freshwater/summary\\_of\\_findings\\_of\\_2012\\_article\\_10\\_report\\_\\_2011\\_derogation\\_report\\_-\\_final\\_-\\_april\\_2013.pdf](https://www.nienvironmentlink.org/cmsfiles/policy-hub/files/documentation/Freshwater/summary_of_findings_of_2012_article_10_report__2011_derogation_report_-_final_-_april_2013.pdf)
- Tan P., Steinbach M. and Kumar V. (2005). Cluster Analysis: Basic Concepts and Algorithms In *Introduction to Data Mining* (1<sup>st</sup> ed., pp. 487-559), Boston: Pearson Addison Wesley

Teagasc (2018). *Agriculture in Ireland; the Irish Food Industry*, Ireland, Teagasc. Retrieved from <https://www.teagasc.ie/rural-economy/rural-economy/agri-food-business/agriculture-in-ireland/>.

## Appendix A: Empirical specification of the PMP model

The empirical specifications of the model are presented in equations A1 to A19.

### First Phase of the PMP Model

$$\begin{aligned} \text{aximize } \Pi = & \sum_d \sum_k X_d p_{dk} y_{dk} - \sum_d \sum_i X_d \omega_{di} p_i - \sum_d \sum_n F_{dn} p_n - \sum_d M_d h_d - \sum_d C_d j_d \\ & - \sum_d L_d v_d \end{aligned} \quad (\text{A1})$$

Where the indices d, k, I, and n represent sets

$\Pi$  = the objective function value

$X_d$  = vector of dairy activities d

$p_{dk}$  = the price per unit for output k for dairy activity d

$y_{dk}$  = the yield of output k for dairy activity d

$\omega_{di}$  = input i per unit of activity d

$p_i$  = accounting costs per unit of input i,

$F_{dn}$  = amount of chemical fertilizer n used

$p_n$  = Price of chemical fertilizer n

$M_d$  = volume of manure for each dairy activity d

$h_d$  = price of spreading manure

$C_d$  = volume of concentrates for each dairy activity

$j_d$  = price of concentrates for each dairy activity

$L_d$  = ha of extra land after milk quota is abolished

$v_d$  = price of extra land for each dairy activity

Equation (A1) is the linear objective function in which the variable costs are described as a linear function of prices and quantities. The first element on the right-hand side of equation represents the revenue from dairy production activities, that is, revenue from the sales of milk, and calves. The

second element is the total variable costs excluding the costs of chemical fertilizer, the cost of spreading manure and the costs of concentrates. The third element is the cost of chemical fertilizer and the fourth element is the cost of spreading manure. The fifth element is the cost of concentrates, while the sixth element is the cost of renting extra land. Labour and capital are assumed not to be constraining factors in the model and farms can rent land up to a maximum of 20 hectares at a cost. The 20 hectares land size is chosen based on the historical data on land area rented by dairy farms in the study area.

The objective function is subject to the following inequality constraints

$$\sum_d \delta_{dl} X_d \leq \sum_d T_d \quad [\lambda_l] \quad (A2)$$

$$T_d \leq B_d + L_d \quad (A3)$$

$$L_d \leq a \quad (A4)$$

The expression in equation (A2) represents the land constraint where  $\delta_{dl}$  is the use of land per dairy activities in hectare per head.  $T_d$  is the total land available per dairy cow activity represented in equation (A3).  $L_d$  is the hectares of land rented while  $B_d$  is the initial land available per dairy cow activity and  $a$  is the maximum amount of land that can be rented.  $\lambda_l$  is the shadow price of land which represents the increase in the objective function if the land variable is made less restrictive.

$$\sum_d \delta_{dq} X_d \leq b_q \quad [\lambda_q] \quad (A5)$$

Equation (A5) represents the dairy quota constraint where  $\delta_{dq}$  is the dairy quota use per dairy cow activity.  $b_q$  represents the dairy quota availability while  $\lambda_q$  is the shadow price of milk quota. It should be emphasized that quota was not a constraint for Northern Ireland and as such was binding only for the Republic of Ireland model.

$$\phi_{dn} X_d - F_{dn} \leq 0 \quad (A6)$$

The expression in equation (A6) represents the chemical fertilizer application balance where  $\phi_{dn}$  is the application of chemical fertiliser n per dairy cow activity in Kg per head.

$$\psi_d X_d - M_d \leq 0 \quad (A7)$$

The expression in equation (A7) represents the manure balance where  $\psi_d$  is the manure input in m<sup>3</sup> per dairy cow activity and  $M_d$  is the volume of manure from each dairy activity.

$$\gamma_n \psi_d X_d - A_{dn} \leq 0 \quad (A8)$$

The expression in equation (A8) is the manure nutrient balance where  $A_{dn}$  is the nutrient from manure variable in Kg and  $\gamma_n$  is the manure conversion ratio per dairy activity, in kg per m<sup>3</sup>.

$$\sum_d \sum_n \gamma_n \psi_d X_d - \sum_d \sum_n \rho_{dn} X_d \leq 0 \quad (A9)$$

The expression in equation (A9) represents the constraints from the nitrate directive. In the model, derogation is allowed as N from manure cannot exceed 250Kg N per hectare. The first expression is the nutrient from animal manure for each dairy production activity measured in Kg while the second expression represents the maximum allowable nutrient from manure.  $\rho_{dn}$  is the manure limit in Kg per head of dairy production activity.

$$\theta_d X_d - C_d \leq 0 \quad (A10)$$

Equation (A10) represents the concentrates balance where  $\theta_d$  is the concentrates per dairy livestock unit measured in terms of energy from concentrates in Feed Unit for Lactation (UFL) per head for each dairy production activity

$$\Omega_d X_d - E_d \leq 0 \quad (A11)$$

The expression in equation (A11) represents the total energy balance where  $\Omega_d$  is the total energy requirement per livestock unit measured in UFL per head for each dairy production activity. 1 kg dry matter of grass equals 1 unit of feed for lactation (UFL) (McCarthy *et al.*, 2011). Subtracting the energy input from concentrates ( $C_d$ ), from the total energy requirement ( $E_d$ ) gives us the energy obtained from grass for each of the dairy production activities as presented in equation (A12). The estimated energy output from grass was found to be comparable to that estimated using the grass calculator for the Republic of Ireland (McCarthy *et al.*, 2011)

$$E_d - C_d = G_d \quad A12$$

To estimate the nutrient output from grass, the energy from grass is converted to Kg dry matter and multiplied by appropriate coefficients ( $\xi_n$ ) measured in kg per kg DM.  $G_d$  is the nutrient output from grass measured in unit of feed for lactation (UFL) (equation A13).

$$\xi_n G_d = N_{dn} \quad A13$$

$N_{dn}$  is the nutrient output from grass measured in Kg.

$$A_{dn} + F_{dn} - N_{dn} = S_{dn} \quad A14$$

The nutrient surplus per dairy production activity  $S_{dn}$  is obtained from expression (A14) by subtracting the total nutrient input from chemical fertiliser and manure from the nutrient output from grass

$$X_d \leq X_d^* + \epsilon \quad [\lambda_d] \quad A15$$

Equation (A15) is the calibration constraint and it forces the program to reproduce base year observed activity levels by putting upper limits on activity levels based on activity levels in the base period (Helming *et al.*, 2001). This is undertaken following Howitt (1995), by including a perturbation ( $\epsilon$ , is a very small number) to decouple the resource and calibration constraints. In the equation,  $\lambda_d$  represents the shadow values of the calibration constraint.

$$X_d, F_{dn}, A_{dn}, M_d, C_d G_d, E_d > 0 \quad A16$$

The expression in equation (A16) is the non-negativity constraint which ensures that no negative activity level is observed.

## Second phase of the PMP

In the second stage of the PMP model, the shadow values of the calibration constraints are used to construct non-linear variable cost functions excluding costs of chemical fertilizer, cost of concentrates and cost of spreading manure. To overcome the problem of underdetermination of the parameters (loss of degree of freedom) of the PMP methodology, in this study, prior information about supply elasticities has been adopted to calculate the parameters of the dairy model costs functions for Northern Ireland and the Republic of Ireland. An approximate price elasticity estimate of 1 obtained from Kostov, (2008) was used in the analysis based on the fact that dairy production activities are

expected to become more commercially orientated and price responsive in the post milk quota abolition era. The shadow values from the first stage calibration constraints are combined with the average production costs to calibrate the quadratic costs function in the model. The slope of the marginal costs curve for the dairy production activities is presented in equation (A17)

$$\beta_{di} = \frac{\lambda_d + \omega_{di}p_i}{\eta_d X_d^*} \quad A17$$

The intercept coefficient of the marginal costs function ( $\alpha_d$ ) is specified in equation (A18) as

$$\alpha_{di} = \frac{(\lambda_d + \omega_{di}p_i) \cdot (\eta_d - 1)}{\eta_d} \quad A18$$

Where  $\eta_d$  equals *a priori* supply elasticity of dairy production activity.

### **Third phase of the PMP**

In the third phase of the PMP, the linear cost expressions in equation (A1) (second element in the equation) is replaced by the quadratic costs functions (equations A19) using equations A17 and A18. The calibration constraints in the first phase (equation A15) are removed. In addition, a new element to analyse effect of the application of an envisaged nutrient surplus tax policy is also included.

$$\begin{aligned} ax \Pi = & \sum_d \sum_k X_d p_{dk} y_{dk} - \sum_d \sum_i (\alpha_{di} + 0.5\beta_{di}X_d)X_d - \sum_d \sum_n F_{dn} p_n - \sum_d M_d h_d - \sum_d C_d j_d \\ & - \sum_d L_d v_d - \sum_d Z_d r_d \end{aligned} \quad A19$$

Where  $Z_d$  is the N surplus above threshold for which the farmer is taxed,  $r_d$  is the levy on N surplus in monetary unit per Kg. The model was written in GAMS programming language and was solved using the non-linear solver CONOPT3. The methodology involved setting alternative policy scenarios with a base scenario that is used as a reference point for counterfactual analysis. For the purpose of allowing for independent simulations based on the decision-making behaviour of the dairy farmers in each country and clusters, each, country has been modelled separately. An HMRC Exchange rate of £1 to €1.178 was used in converting Northern Ireland's Pounds (£) to euros (€).