Modelling regional environmental efficiency differentials of specialised dairy farms in the island of Ireland

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Abstract

Environmental pressures are likely to be an important policy issue in the island of Ireland following the abolition of the milk quota system in 2015. In this study, we assess the environmental performance of specialised dairy farms in four regions of the island of Ireland using a novel environmental Data Envelopment Analysis (DEA) technology. The determinants of environmental efficiency are also studied in a second stage analysis using a truncated linear regression model with bootstrapped non-parametric DEA environmental efficiency estimates as dependent variable. We find regional differences in environmental performance across the four regions of Ireland with a greater environmental burden in Northern Ireland compared to the three regions in the Republic of Ireland. However, from an environmental efficiency perspective which incorporates undesirable output from dairy production, environmental performance indices were higher for Northern Ireland compared to the regions of the Republic. Utilised agricultural area, forage grazed per hectare and adoption of milk recording were found to be statistically significant factors influencing environmental efficiency in the Republic of Ireland while only forage grazed per hectare was statistically significant for Northern Ireland. Results indicated the environmental efficiency potentials of each region and will be useful to policy makers in formulating policies to improve the sustainability of dairy production in the island of Ireland

Keywords: Dairy; Nonparametric technique; truncated regression; data development analysis; eutrophication; environmental performance

1.0 Introduction

The dairy sector is a very important sector in the island of Ireland contributing the largest share to the national economy when compared to other agricultural sectors (DAERA, 2016; CSO, 2013). However, dairy production across the island is diverse with respect to production systems and level of production (Hennessy *et al.*, 2009). One contributing factor to this diversity is the difference in dairy policy implementation strategy across the North and South of the island during the milk quota years before its abolition in 2015. Generally, within the island of Ireland, dairy farms compared to other agricultural enterprises have the highest stocking densities and high fertilizer inputs, putting pressures on the environment (Hennessy *et al.*, 2013; DAERA, 2016). The development of a sustainable dairy production system in the post quota era, requires that a balance is achieved between raising production level and ensuring reduced production externalities in the form of nitrogen and phosphorus surplus. Nitrogen and phosphorus surplus that accompany dairy production are regarded as negative externalities (undesirable outputs) given their potential deleterious effect on the environment and water quality. Nitrogen and phosphorus surplus are key indicators of agri-environmental sustainability and any application in excess of plant requirement can have economic and environmental implications. For example, in the form of leaching and runoff transfers from land to water resulting in eutrophication (Oenema and Pietrzak 2002; Erisman *et al.*, 2007).

Eutrophication of inland surface waters have been identified as a significant pollution problem in the island of Ireland (EPA, 2010; DOE, 2014). Approximately 12 per cent and 10 per cent respectively of river water bodies in Northern Ireland and the Republic of Ireland have been classified as 'poor' or 'bad' quality and agriculture account for more than 30 per cent of the incidence of water pollution ((DAERA, 2016; DOE 2014; EPA, 2010). This is in spite of the fact that the European Union has formulated and implemented a range of agri-environmental policies to protect water quality and improve rural development (e.g. Common Agricultural Policy (CAP), EU Nitrates Directive (91/676/EEC), Water Framework Directive (2000/60/EC), Council Regulations (EC) Reg.92/1765/EEC, Reg. 92/2078/EEC and Reg. 1698/2005) (European Communities 2010).

The overriding aim of this paper is to evaluate the differences in environmental performance of specialised dairy farms across the regions of the island of Ireland incorporating multiple environmentally detrimental variables (phosphorus and nitrogen balance). Environmental efficiency, as defined by Reinhard *et al.* (2000), refers to the ratio of minimum feasible to observe use of environmentally detrimental inputs, relative to observed levels of output and the conventional inputs. It is believed that the usual narrow measures of performance may not always distinguish farming systems best fitted to future requirements (Toma *et al.*, 2013). There is now a lot of pressure on the agricultural sector to improve environmental performance while maintaining competitiveness and economic efficiency as much as possible (Jay, 2007). The relationship between the level of dairy production and environmental performance is a vital issue that must be given due consideration in dairy production studies. This is because, while most farms might be efficient in terms of input-output productivity, there are reasons why they might not be efficient from an environmental point of view (Tyteca, 1996). One such reason is the lack of motivation for the internalisation of negative environmental externalities in the form of environmental costs by farmers. An analysis of the environmental performance of dairy farms is important to ensure sustainability of the dairy production systems and give an indication of the effectiveness of the various agri-environmental policies associated with dairy production. Environmental performance measurement also provides the basis for more quantitative, empirically grounded and systematic environmental policy analysis and decision making (Hsu *et al.,* 2014).

For this study we estimated the phosphorus and nitrogen balance of specialised dairy farms across 4 regions of the island of Ireland using the OECD/eurostat soil balance methodology. We then employed a novel environmental data envelopment analysis (DEA) technology to measure the environmental efficiency of these farms incorporating multiple environmentally detrimental variables. We also analysed the determinants of environmental efficiency using a bootstrap truncated maximum likelihood estimation approach proposed by Simar and Wilson (2007). Comparative analysis of environmental performance of the dairy sector across the regions with differing dairy management systems would improve knowledge of sustainable dairy production systems and aid in the understanding of livestock sector impacts especially in a post quota era. The results of the study could also be useful as benchmarks for rating environmental performance of dairy farms and can provide an early warning of potential future environmental damage that might result from the milk quota abolition

Previous studies that have tried to measure environmental performance in the island of Ireland have focused only on the use of sustainability indicators. However, one important limitation of this approach is that they only reflect segmental characteristics of environmental performance. Besides, it often involves the use of multiple ratios, which has the tendency of complicating decision making (Zhou *et al.*, 2008; Soteriades *et al.*, 2016). There is also no study on the determinants of environmental efficiency incorporating multiple environmentally detrimental variables into an environmental DEA technology in the island of Ireland. This is the first study to the best of our knowledge that tries to estimate and compare environmental efficiency of dairy production systems across all the regions of the island of Ireland, thereby giving room for greater generalizability of results. From a methodological point of view, the DEA-based model unlike the sustainability indicators, is able to analyse environmental performance by providing a standardized index for each decision-making units (dairy farms in this case) (Tyteca, 1996; Zhou *et al.*, 2016). In addition, unlike previous studies for example, Watanabe and Tanaka (2007) and Toma *et al.*, (2013), our use of the bootstrap truncated maximum likelihood estimation approach in investigating the determinants of environmental efficiency means that we are able to overcome the problem of inherent dependency among the DEA efficiency scores giving room for a robust result (Simar and Wilson 2007; Tauchmann, 2016). Furthermore, as against the farm gate approach, the OECD/Eurostat soil-surface balance methodology that we employed in the estimation of nitrogen and phosphorus balance provides a more representative indication of environmental losses and therefore embodies more meaningful assessment of aquatic risk (Eurostat 2013; Toma *et al.*, 2013).

. The remainder of the article is structured into five sections: Section 2 reviews the relevant empirical and theoretical literature. The description of the database and methodology for the study is presented in section 3 while section 4 presents the empirical results. Section 5 gives an interpretation of the main results obtained in the light of economic theory and the final section gives an overview of the paper's conclusion.

3.0 Materials and methods

3.1 Study area

This study was carried out in the island of Ireland which accommodates two countries; the Republic of Ireland and Northern Ireland (which forms part of the United Kingdom). The dairy sector makes a significant contribution to the agricultural economy in both countries (CSO, 2013; DAERA, 2016). The Republic of Ireland has been disaggregated into three regions of "border, midlands and western (BMW)", "South-West (SW)", and the "South-East (SE)" regions based on geographical and structural differences. This grouping follows that of Läpple and Hennessy (2012). The south and the south-west regions accounts for the majority of milk production, having more intensive farms and favourable soil and climatic conditions compared to the BMW region (Läpple and Hennessy, 2012). "Northern Ireland (NI)" is taken as one region so that in total we have four regions that make up the island of Ireland. Each of the four regions has unique characteristics regarding dairy production (CSO, 2013). Figure 1 is a map of the study area showing the four regions of the island of Ireland.

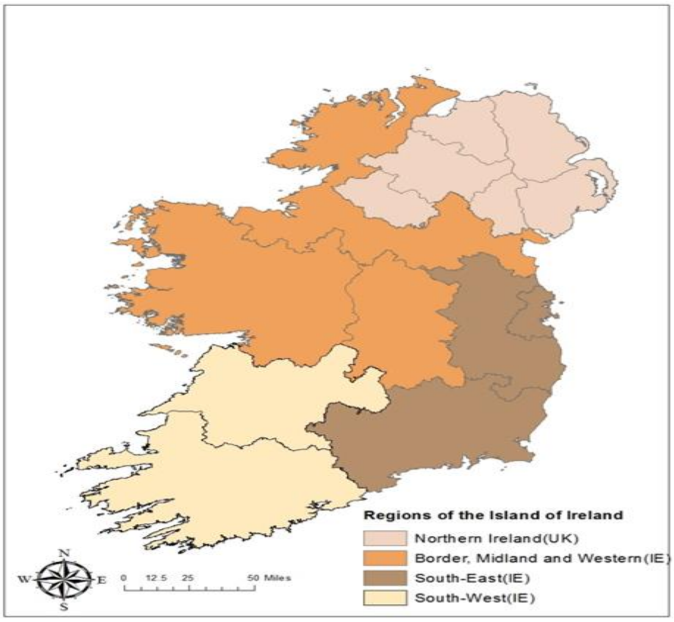

Figure 1: **Map of the Island of Ireland**

Source: Author's compilation; BMW: Louth, Leitrim, Sligo, Cavan, Donegal,Monaghan, Laois, Longford, Offaly,Westmeath, Galway, Mayo, Roscommon. South-East: Carlow, Kilkenny,Wexford, Tipperary S.R.,Waterford Kildare,Meath,Wicklow Dublin. South-West: Cork, Kerry Clare, Limerick, Tipperary N.R. Northern Ireland: Antrim, Armagh, Down, Fermanagh, Londonderry and Tyrone

3.2 Data

The data set employed for this study was 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 set of farm accounts, environmental and enterprise level variables which are stratified nationally representative random sample of farms surveyed annually (Buckley *et al.*, 2015a). The structure and representativeness of the Teagasc NFS data enable us to disaggregate it into "Border Midland and Western" (BMW), "South-east" (SE) and "South-west" (SW) regions of the Republic of Ireland. For this study, data across specialist dairy farms taking part in the farm survey for 2014 was extracted and used for analysis. The number of observations is: BMW, 57, South-East, 95, South-West 112) and Northern Ireland equals 111 specialised dairy farms. The specialised dairy farms are farms that have a minimum of two-thirds of their standard output coming from grazing livestock with dairy cows being responsible for a minimum of three-quarters of the grazing livestock output.

3.3 Nutrient Budget Methodology

The nutrient budget methodology estimates the balance between nutrient inputs to and from an agricultural system expressed on per hectare of agricultural land on an annual basis. Basically, two systems of estimating nutrient balance can be distinguished based on their respective system boundaries. They are the farm gate approach and the soil balance approach. The soil balance approach was adopted for this study because it gives more meaningful assessment of risk to the aquatic environment. (Eurostat, 2013). However, it does not give any information on animal feeding efficiency (Oenema *et al.*, 2003). Some examples of previous studies that have adopted the soil surface budget approach include: (Özbek and Leip, 2015; Bassanino *et al..*, 2007; Picazo-Tadeo *et al.*, 2011). A mathematical representation of the methodology is given in equations (1) and (2). Gross phosphorus and nitrogen surplus is estimated as the difference between their respective total inputs and outputs expressed on per hectare basis (eurostat, 2013).

$$\text{GPSn} = \text{Gross phosphorus surplus (Kg/ha)} = \frac{\text{Phosphorus inputs} - \text{phophorus outputs}}{\text{Utilised agricultural area}} \quad (1)$$

$$\text{GNSn} = \text{Gross Nitrogen surplus (Kg/ha)} = \frac{\text{Nitrogen inputs} - \text{Nitrogen outputs}}{\text{Utilised agricultural area}} \quad (2)$$

An outline of the inputs and output variables according to the OECD/eurostat methodology including the sources of the information used for our analysis is given in Table 1. The inputs from chemical fertilizers were obtained directly from the FBS and NFS data base where the composition and quantities of fertilizers applied to land are recorded for each dairy farm. Nutrients inputs from manure in Kg are estimated based on the excretion coefficient for different types of livestock on the farms taking into consideration milk yield for dairy cows (Eurostat, 2013). The total amount of nutrient input to the soil from seed was estimated by multiplying the hectare of crop cultivated by the recommended seeding rate obtained from literature. Input from atmospheric deposition was also obtained from literature for nitrogen. The nutrient outputs from crops exported in the crop products were established from the quantities of each crop type harvested and applying a standard co-efficient obtained from literature (Ewing, 2002; McDonald *et al.*, 2002).

The estimation of nutrient output from grazed grass at the farm level is usually complex and not straight forward. Previous studies such as Humphrey, (2008) employed expert judgement assuming a fixed amount of nutrient output per hectare. However, such blank assumptions on the amount of pasture consumed is not able to take into consideration the difference in dairy farm management systems and might lead to a bias result on the level on nutrient balance especially in a comparative study like ours. To overcome this shortcoming, we developed a feed requirement model based on the difference between the net energy (NE) provided by feed purchased from off the farm (dry matter of concentrates and forages) and the total NE requirements of livestock on the farm for milk production, pregnancy, maintenance, grazing and walking and body weight change (Gourley *et al.*, 2012). Mathematical representation of the model is given in equation (3). It can be described as a back-calculation approach based on accurate description of the number of grazing animals on the farm, the area under consideration and milk production data (McCarthy *et al.*, 2011). The total NE requirements converted to unit of feed for lactation (UFL) and adapted to local farm conditions are computed based on relevant equations published in the National Research Council publication on “nutrient requirement for dairy cattle” (NRC, 2001). It was assumed that 1 kg dry matter of grass equals 1 unit of feed for lactation (UFL) (McCarthy *et al.*, 2011). Stocking rate was expressed as livestock units (LU) per hectare. The amount of nutrient output from grass can then be obtained by multiplying by the quantity of grazed grass by the appropriate nitrogen and phosphorus coefficients in grass (Eurostat, 2013). This method provides a logical and quantitative framework for analysing between farm differences in productivity and pasture utilisation.

$$\text{NE supplied by grass} = \text{Total NE requirements} - \text{Total NE from supplemetary feed} \quad (3)$$

Table 1: Terms of estimation of nitrogen and phosphorus balance

Terms	Method of Estimation	Sources of Information
Inputs (Kg Phosphorus per ha)		
a. Mineral Fertilizer	Quantity of mineral fertiliser (Kg) * nutrient content	Teagasc National Farm Survey (NFS, Republic of Ireland) Farm Business Survey, Northern Ireland (2014)
b. Organic fertilisers (excluding livestock manure)	Quantity of organic fertilizer (Kg) * nutrient content	The use of organic fertilizer in the study area is negligible and therefore was not included in the calculations
c. Livestock Manure	Annual average population of animals (heads) * Manure excretion coefficients (Kg nutrient $head^{-1}year^{-1}$)	FBS, Northern Ireland (2014), NFS Republic of Ireland (2014). The Nitrates Action Programme Regulations (2014), Yan *et al.* (2006)
d. Other inputs (seeds)	Kg nutrient per ha harvested area * Utilised agricultural area (ha)	OECD and Eurostat nutrient budgets methodology and handbook, and FBS and NFS (2014). Contribution is negligible.
e. Atmospheric nutrient deposition	Utilised agricultural area (UAA) [ha] * nutrient deposition rate ($kgha^{-1}$)	Estimated only for Nitrogen based on data from literature (eurostat, 2013; The European Monitoring and Evaluation Programme (EMEP) 2014 data) Contribution is negligible for phosphorus and therefore was not included in its calculations
f. Biological nutrient fixation	Utilised agricultural area (UAA) [ha] * nutrient fixation rate ($kgha^{-1}$)	Applicable only to nitrogen and a fixed amount was assumed based on literature.
g. Total inputs	a + b + c + d +e +f	
Outputs		
h. Crop production	Crop output (Kg of dry-matter) * nutrient content (kg Kg^{-1} of dry-matter)	Teagasc National Farm Survey (NFS, Republic of Ireland), Farm Business Survey, Northern Ireland (2014), Ewing, 2002, and McDonald *et al.*, 2002
i. harvested and grazed grass	quantity of pasture consumed on-farm through grazing and silage * nutrient content of grass (in kg Kg^{-1} of dry-matter)	NFS, Republic of Ireland (2014), NRC, 2001, Farm Business Survey, Northern Ireland (2014).
j. Crop residues removed	Crop residues removed * nutrient content (kg Kg^{-1} of dry-matter)	Contribution is negligible and therefore was no included in the calculations
k. Total outputs	h + i+ j	
Gross Nutrient Balance(GNB)	g-k	
Nutrient Use Efficiency (PUE)	(k/ g) * 100	

3.4 Data Envelopment Analysis (DEA)

The DEA is a well-established non-parametric methodology developed by Charnes *et al.,* (1978) to evaluate the relative efficiency of a set of comparable entities called decision making units (DMUs) with observed multiple inputs and outputs (Seiford and Thrall, 1990). The method unlike the stochastic frontier does not require the specification of a functional form and the inefficiency disturbance term which may lead to biased results due to potential misspecification error. Instead, a piecewise linear technological frontier is constructed with respect to empirical observations on inputs and outputs of a sample of DMUs. The technological frontier represents best practices, while the distance to it from each DMU in the sample is used to compute a measure of its relative performance (Picazo-Tadeo, 2011). However, DEA does not account for any stochastic variance from the frontier. Given that it is based on the assumption that all observations in the sample belong to the potential production frontier, it is hence sensitive to the presence of outliers in the data. This may lead to unrealistic frontier construction (Simar, 2003). However, this deficiency can be minimised through content-based plausibility check and efficient data management which was taken into consideration in our analysis. Further discussion and technical details of the DEA can be found in Charnes t al. (1978), Seiford and Thrall (1990).

The DEA technique has been widely used to study and compare the efficiency of dairy farms (See, for example, Kelly *et al.*, (2012); Fogarasi and Latruffe, (2007)). It has nevertheless also gained popularity in environmental efficiency measurement in recent years. This is due to its empirical applicability in providing synthetic standardized environmental performance index when pollutants (also called undesirable outputs) are suitably incorporated into the traditional DEA productive efficiency measurement framework. A comprehensive literature review of modelling undesirable factors in efficiency measurement using DEA can be found in Tyteca (1996), Zhou *et al.,* (2008), Zhou *et al.*, (2016). The methodology has been applied mostly in engineering and technology fields for example (see, Zofio and Prieto (2001); Zhou *et al.,* (2006); Yu (2004); Fare *et al.,* (1996, 2004)); Manello (2012).

Some of the few studies that have employed the DEA based environmental technology models to measure environmental performance in the context of agricultural production include: March *et al.* (2016) who analysed the environmental efficiency of diverse milk production systems making use data from experimental dairy farms. Toma *et al.* (2013) compared the environmental efficiency of two divergent strains of Holstein-Friesian cows across 2 contrasting dairy management systems over multiple years. Picazo-Tadeo *et al.,* (2011) estimated the Eco-efficiency scores at both farm and environmental pressure-specific levels for a sample of Spanish farmers operating in the rain-fed agricultural system of Campos County. Depending on how the desirable and undesirable outputs are treated, a variety of DEA based environmental technology models can be formulated (Zhou *et al.*, 2016; Zhou *et al.*, 2008; Tyteca, 1996, 1997; Färe *et al.*., 2004; Zaim, 2004).

Suppose there are n (n=1,2,….,N) decision making units which employ multiple inputs denoted by vector x = ($x_{1k}, x_{2k}, \ldots, x_{Jn}$) $\in R_+^N$ to produce a vector of desirable outputs y = ($y_{1k}, y_{2k} \ldots, y_{Mn}$) $\in R_+^M$ and a vector of undesirable outputs s = ($s_{1k}, s_{2k}, \ldots, s_{Kn}$) $\in R_+^J$ .Then the environmental production technology can be represented by the output set P(x) given in equation (4) (Chung *et al.*. 1997; Zhou *et al.*, 2016).

$$P(x) = \{(y, s): x\ can\ produce\ (y, s)\} \quad (4)$$

In this study we employed the directional output distance function (DODF) DEA based model. The advantage of the DODF is that it simultaneously accounts for expansion of desirable outputs and reduction of undesirable outputs (Färe *et al.*, 2005). The model is able to modify the direction in which to search for an efficient counterpart of each farm allowing for asymmetric treatment of the desirable and undesirable outputs (Chung *et al.*, 2000; Manello, 2012; Picazo-Tadeo *et al.*, 2012; Watanabe and Tanaka, 2007). According to Chambers *et al.*, (1998), Färe and Grosskopf, (2000), the directional distance function stands for a complete functional representation of the production technology in the measurement of (in)efficiency. It also does not suffer from non-linear constraints when compared to other concept of efficiency measure that allow for asymmetric treatment of undesirable and desirable outputs, such as hyperbolic measures (Fare and Grosskopf, 2000). The trade-off between desirable and undesirable outputs means that the model is able to incorporate the economic aspect of the production possibility set given that the directional distance function increases the desirable output and simultaneously decreases the undesirable output (Fare and Grosskopf, 2000; Chung *et al.*, 1997; Picazo-Tadeo *et al.*, 2012). Formally, it is defined as given in equation (6).

$$\vec{D}_o^W = (x, y, s; gy, gs) = \max\{\beta : (y, s) + (\beta gy, \beta gs) \epsilon P(x)\} \quad (6)$$

Where $g = (gy, gs)$ is the directional vector in which output are scaled and $gy \in R_+^M$, $gs \in R_+^J$. The production possibility set P(x) could be empirically solved via DEA by solving, for each farm, the linear problem in equation (7) after fixing a particular directional vector. The technology can be modelled in any direction from the observation point dependent on whether the technology exhibits weak or strong disposability of undesirable outputs (Watanabe and Tanaka, 2007; Färe *et al.*, 2005). In this study we took the vector gy = 1 and gs = -1.

$$\vec{D}_o^W(x^{n'}, y^{n'}\ s^{n'}; y^{n'}, -s^{n'}) = \max \beta_n$$

Subject to

$$\sum_{n=1}^{N} z^n y_m^n \geq (1+\beta) y^{n'}, \qquad m = 1, \dots\dots, M$$

$$\sum_{n=1}^{N} z^n s_k^n = (1-\beta) s^{n'}, \qquad k = 1, \dots\dots, K$$

$$\sum_{n=1}^{N} z^n x_j^n \leq x^{n'}, \qquad j = 1, \dots\dots. J$$

$$z^n \geq 0 \quad (7)$$

β_n is the inefficiency score representing the maximal feasible proportional expansion of desirable outputs and contraction of undesirable outputs for a given dairy farm relative to the best farms on the production possibility frontier. The number of desirable outputs, undesirable outputs and inputs are indexed with subscript m, k, and j respectively why n refers to the number of specialised dairy farms in each region taking values from 1 to N. z^n is the intensity variable. An efficient dairy farm will have β to be equal to zero while any positive values indicate an inefficient dairy farm. (1-β), is taken as a measure of a farm's efficiency following Macpherson *et al.*, (2010). The usual assumptions of null jointness, weak disposability of outputs, free disposability of inputs and desirable outputs applies (Zhou *et al.*, 2016; Fare *et al.* 2007)

The above specification is under constant returns to scale (CRS); the CRS assumption has the advantage of greater discriminative power relative to the variable return to scale (VRS) assumption and it is the most common assumption in the literature for DODF (Zelenyuk and Zheka 2006). However, given that in actual situations the reference technology may not always exhibit CRS (Tyteca, 1996), in this paper, we have separately imposed both assumptions in our analysis. The variable return to scale (VRS) specification can be formulated by imposing the restrictions of intensity variables on the CRS environmental DEA technology in the same manner as that in the traditional DEA framework as given in equation (12).

$$\sum_{n=1}^{N} Z^n = 1 \tag{12}$$

The analysis is in two phases. In the first phase, environmental efficiency is estimated under separate frontiers for each region. The underlying assumption in this case is that production and management types is unique to each region (highly homogeneous groups in terms of soil type, climatic conditions and other physical parameters). The result of this phase provides an indication of the extent of potential contemporaneous expansion and reduction of the desirable and undesirable outputs respectively in each region. In the second phase, we merged the individual sub-samples of data, first for the three regions in the Republic of Ireland (BMW, SE, SW) and then the four regions of the island of Ireland (BMW, SE, SW and NI). The assumption here is that the merged regions have a common production possibility frontier. This is possible within the DEA environmental technology model because input-output production variables across the regions are relatively identical. This gives us the opportunity to investigate the gap in environmental performance of the dairy production systems across the regions of the Republic of Ireland and the island of Ireland. This is often considered as an important advantage of the DEA modelling technique in contrast to the parametric approach as we are able to merge the regions together without having to test for the poolability hypothesis (Fogarasi and Latruffe, 2007). The models were written and analysed using the General Algebraic Modelling System (GAMS).

3.5 Input and output data

The factors considered in the analysis based upon the production process of specialised dairy farms include; inputs, desirable output and undesirable outputs. The four inputs included in the specification of the environmental DEA technology include: total utilized agricultural area measured in hectares, the number of livestock on the farm measured in standardized livestock units (LU), capital measured in terms of depreciation values for building and machinery, variable inputs which consist of costs of livestock feed, fertilizers, seed and others measured in euros. Two desirable outputs are considered which are measured in monetary units. They are revenue from the sales of milk and revenue from the sales of other outputs. The undesirable outputs considered are nitrogen and phosphorus surplus estimated based on the methodology presented in section 3.3 and measured in Kg. We decided to limit the number of variables to this number given that the number of model variables may affect DEA results. A very small percentage of the observations were found to have a negative phosphorus surplus. These observations might result in both theoretical and technical problems since negative values of nutrient balance are not optimal as the soil will lose its fertility (Reihard *et al.*, 2000). They were therefore excluded from the analysis. Summary statistics of the variables included in the model is given in Table 2.

3.6 Second stage analysis

To analyse the determinants of environmental efficiency, previous studies for example, Watanabe and Tanaka (2007); Toma *et al.*, (2013) had employed the Tobit or multiple regression models. However, these models do not take into consideration the inherent dependency between DEA estimates. Simar and Wilson (2007) has shown that DEA derived scores are serially correlated and biased and failure to take proper account of these characteristics can lead to invalid conclusions. In this study, we took this factor into consideration by employing the Simar and Wilson, (2007) bootstraping Algorithm 1 which is based on a truncated regression of the DEA environmental performance estimates on a set of explanatory variables. The bootstrap method has been recognised as a powerful tool to overcome the inherent dependency among the DEA efficiency scores (Jian and Dai, 2014). It allows for a consistent inference to be drawn from efficiency scores while simultaneously producing standard errors and confidence intervals for these efficiency scores (Tauchmann, 2016). With this methodology we are able to explain the sources of environmental performance variations within samples of specialised dairy farms in the island of Ireland. This approach has been adopted by some recent DEA based studies (Tiemann and Schreyögg 2009; Picazo-Tadeo *et al.* 2011).
Let C_n be each corresponding vector of covariates (i.e. structural and economic characteristics). Following Picazo-Tadeo *et al.*, (2011) we assumed the following regression model given in equation (13).

$$\omega_f = \gamma' \tilde{C_n} + \varepsilon_n, \qquad n = 1, \ldots \ldots \ldots \ldots, N \tag{13}$$

Where $\tilde{C_n}$ refers to a vector of covariates hypothesized to influence environmental efficiency, γ' represents a parameter vector, and $\varepsilon_n$is a normally distributed error term with zero mean and unknown variance (i.e $\varepsilon_n \sim N(0,\sigma^2)$). The unknown efficiency scores $\omega_{f,}$ with respect to an unknown technological frontier are estimated based on the DODF framework by w'_f obtained from equation (7). The econometric model is estimated separately for Northern Ireland and the regions of the Republic of Ireland combined via a truncated maximum likelihood technique. The analysis was done in STATA econometric software release 14 (Tauchmann, 2016). The explanatory variables considered as potential determinants of environmental performance, taking into account previous literature include: the total utilised agricultural area (farm size) measured in hectares, the age of the farm manager in years, a dummy variable for access to off-farm income, participation in Agri-environmental Schemes measured as a dummy variable, stocking density measured in livestock units per hectare, membership of discussion groups measured as a dummy variable, forage output in Kg DM per hectare, milk recording measured as a dummy variable, investment per livestock unit measured in relevant monetary unit and access to advisory contact measured as a dummy variable. We ran a separate regression models for Northern Ireland and the Republic of Ireland. Due to data limitation, some of the variables were not included in the Northern Ireland model. The mean values of the production and regression variables is given in Table 2. We obtained the bias-corrected results from 1000 bootstrap iterations, which allowed us to have a more robust and reliable parameter estimates. Studies by Picazo-Tadeo and García-Reche, (2007), Picazo-Tadeo, (2011) have also employed the same number of replications for estimating confidence intervals.

4.0 Results

4.1 Nitrogen and phosphorus balance

The mean regional nitrogen and phosphorus balance estimates obtained based on expressions given in equations (1) and (2) respectively are presented in Table 3 and Table 4 respectively. Inputs from inorganic fertilizer and manure account for more than 90 % of the phosphorus input with the contributions from seeds and planting materials being negligible in all the regions. This is expected given that the study is on specialised dairy farms. There is higher average nitrogen and phosphorus surplus in the NI region compared to the three regions in the Republic of Ireland. This results mainly from lower quantities of nitrogen and phosphorus outputs from the farms in the region relative to inputs. On average, phosphorus use efficiency is higher than nitrogen use efficiency in all regions. This could mean that in the management of nutrient balances, greater priority is given to phosphorus. It may also be linked to the higher price of phosphorus fertilizer. Buckley *et al.*, (2015b) have found that the price of phosphorus fertiliser has a significant effect on phosphorus balance. On average, phosphorus and nitrogen use efficiency was found to be greatest for the regions of the Republic of Ireland compared to the NI region. Nutrients outputs from pasture production was the main contributor to nitrogen and phosphorus outputs and a good level of variation was observed between farms and regions.

Table 2: Summary of structural and socioeconomic variables

Production variables	NI*	BMW	SE	SW
Desirable output variables				
Dairy gross output (€)	270580.8	152158.2	172022.7	137510.3
Other outputs (€)	6919.5	40538.42	40842.15	27785.32
Input variables				
Utilised agricultural area (ha)	81.51	59.48	63.34	57.08
Variable Input (€)	180428.8	65569.82	66972.12	50883.63
Capital Overhead costs (€)	101935.1	65331.55	62482.35	43646.2
Average livestock Units	108.35	75.63	82.56	66.61
Socioeconomic and Structural variables				
Stocking density (LU/ha)	2.07	2.03	2.17	1.89
Milk yield (litres/head)	6980.56	5163.80	5322.53	5126.76
Access to Environmental subsidies (%)	42	31.04	22.78	30.59
Off-farm income (%)	29	8.69	10.31	3.57
Age (years)	59.02	54.11	51.86	53.1
Forage grazed (KgDM/ha)	5506.8	7066.03	8115.04	7207.27
Milk recording (%)		40.43	46.84	55.29
Membership of dairy discussion group		53.19	64.56	54.12
Advisory Contact (%)		65.96	72.15	72.94
Investment per LU (€)		1128.30	1074.01	971.87

* Exchange rate for NI; used £1 = €1.178 (2014 average)
LU = Livestock units

Table 3: Regional estimates of gross nitrogen balance (GNB)

Environmental Variables (Kg/ha)	NI	BMW	SE	SW
Inputs				
Manure Nitrogen	178.67	151.76	166.93	150.32
Chemical Fertilizer	149.15	162.18	180.73	169.32
Seeds	0.05	0.04	0.07	0.02
Atmospheric Deposition	8.96	7.73	7.73	7.73
Biological Nitrogen Fixation	5	9	9	9
Total Inputs	**341.83**	**330.72**	**364.46**	**336.39**
Outputs				
Grazed grass	150.34	182.56	207.08	183.72
Crops	14.35	11.79	20.44	3.90
Total outputs	**164.72**	**194.35**	**227.52**	**187.63**
Gross nitrogen balance	**177.11**	**136.37**	**136.94**	**148.76**
Nitrogen Use Efficiency (%)	**51.06**	**58.77**	**62.43**	**56.66**

Table 4: Regional estimates of gross phosphorus balance (GPB)

Environmental Variables (Kg/ha)	NI	BMW	SE	SW
Inputs				
Manure Phosphorus	27.39	23.80	26.19	23.50
Chemical Fertilizer	10.58	11.68	13.65	10.70
Seeds	0.01	0.01	0.01	0.01
Total Inputs	**37.98**	**35.49**	**39.86**	**34.21**
Outputs				
Grazed grass	22.24	26.99	30.62	27.16
Crops	0.30	0.23	0.42	0.08
Total outputs	**22.54**	**27.22**	**31.04**	**27.24**
Gross phosphorus balance	**15.44**	**8.28**	**8.82**	**6.97**
Phosphorus Use Efficiency (%)	**59.35**	**76.70**	**77.87**	**79.63**

4.2 Environmental efficiency treating each region as a separate frontier

This sub-section presents the results of environmental efficiency estimates calculated by solving linear program presented in equation 7 and treating each region as a separate frontier such that we have four regional production frontiers. As noted in section 3.4, the analysis was undertaken based on separate assumptions of variable returns to scale (VRS) and constant returns to scale (CRS). In the interpretation of these results it should be emphasized that efficiency is a relative concept in which the efficiency score of each farm only reflects its position with respect to the best performing farms in the production frontier being considered. For example, if our production frontier is a sub-sample of dairy farms in the South-East region, each dairy farm within this region is only compared with the best performing farm in the sub-sample of dairy farms in the region. When our production frontier is the sample of all dairy farms in the island of Ireland, then each dairy farm in the sample is compared to the best performing farms in the combined sample. Table 5 and Table 6 presents the descriptive statistics for environmental efficiency computed with respect to the respective regional frontiers under the assumptions of VRS and CRS respectively. These values give an indication of the potential contemporaneous increase of the desirable outputs and reduction of the undesirable outputs by the average farmer in a given region. For example, the estimates for the south east region under the VRS assumption ($\beta = 0.03$) implies that the average farmer in this region can theoretically increase outputs and reduce environmental pressures by 3 per cent if the farm were to adjust its performance towards the most efficient farms in the sample. This implies that with respect to their respective regional frontiers, environmental efficiency (97%) is relatively high in the south east region and the dairy farms are highly homogeneous. The percentage of efficient farms represents the share of farms with an efficiency score of 0 and it was highest in the South-east region with 77 per cent and lowest in the South-west region with 56 per cent under the VRS assumption. The trend across the regions is similar under the CRS assumption though with lower efficiency estimates due to its higher discriminating power. As noted earlier this result is unique and relative to the best farm in each of the regions. That is, the difference in environmental efficiency across region does not represent the gap in environmental efficiency.

Table 5: Regional environmental efficiencies; separate frontiers (VRS)

Regions	BMW	SE	SW	NI
Average EE $\vec{D}_o^W(y, -s)$	0.05	0.03	0.07	0.07
percentage of efficient farms ($\beta = 0$)	72.34	77.22	56.47	63.37
Average efficiency (1- *ß)*	0.95	0.97	0.93	0.93
Maximum efficiency (1- *ß)*	1	1	1	1
Minimum efficiency (1- *ß)*	0.59	0.64	0.57	0.44
Std. dev. of avg. efficiency	0.1	0.07	0.11	0.12

Table 6: Regional environmental efficiencies; separate frontiers (CRS)

Regions	BMW	SE	SW	NI
Average EE $\vec{D}_o^W(y, -s)$	0.07	0.04	0.09	0.09
percentage of efficient farms ($\beta = 0$)	63.83	65.82	44.71	47.52
Average efficiency (1- *ß)*	0.93	0.96	0.91	0.91
Maximum efficiency (1- *ß)*	1	1	1	1
Minimum efficiency (1- *ß)*	0.50	0.64	0.50	0.50
Std. dev. of avg. efficiency	0.13	0.08	0.12	0.12

4.3 Environmental efficiency treating all regions in a single production frontier

In this section we present the results of treating the island of Ireland as a single production frontier. This is useful in assessing the gap in environmental efficiency across the regions. A summary of the results is given in Table 7 and 8 under the VRS and CRS assumption respectively. The average environmental efficiency for dairy farms for the island of Ireland, that is, for all the samples combined is estimated to be 86% ($\beta = 0.14$) and 82% ($\beta = 0.18$) under the VRS and CRS assumptions respectively. Average estimates of environmental efficiency (1- *ß)* were higher for the NI region compared to the regions in the Republic of Ireland. This is followed by the SE region. In other words, it implies the observations for the Northern Ireland region lie, on average, closer to the frontier in the combined sample of dairy farms. The least efficient regions are the BMW and the SW regions. A box plots which reflects the distribution of the dairy farms' environmental efficiency for the four regions is given in figure 2. As can be observed from the box plots, Environmental efficiency scores for NI dairy farms is less variable compared to that of other regions. This might be a reflection of the uniformity of purchased concentrate feeds. As noted earlier, farms in NI had the opportunity raising outputs mainly from increased dairy feed imports as quota wasn't binding during the later parts of the quota years. Overall, the lowest performing farm shows an environmental efficiency score of 33% and 29% respectively under the VRS and CRS assumptions and it is located in the BMW region.

The greatest number of environmentally efficient farms is found in the NI region and the least is in the BMW region. The differences in environmental efficiencies across the regions were investigated using non-parametric statistic. The result of non-parametric Krusksal-Wallis procedure, based on ranks, reject the hypothesis for the equality of medians and distribution implying that the difference in environmental efficiency scores across the regions is statistically significant at 1% level. To analyse the relationship between environmental efficiency and technical efficiency we also computed the technical efficiency of the dairy farms across all regions defined as a common production frontier using the directional distance function approach. The result of our analysis showed a statistically significant and positive correlation (Pearson correlation coefficients of 0.59) between environmental and technical efficiency.

Table 7: Regional environmental efficiencies; island of Ireland as common frontier (VRS)

	BMW	SE	SW	NI
Average EE $\vec{D}_o^W(y,-s)$	0.23	0.14	0.17	0.09
percentage of efficient farms ($\beta = 0$)	23.40	31.65	30.59	49.20
Average efficiency (1- *ß)*	0.77	0.86	0.83	0.91
Maximum efficiency (1- *ß)*	1	1	1	1
Minimum efficiency (1- *ß)*	0.33	0.46	0.41	0.35
Std. dev. of avg. efficiency	0.19	0.14	0.16	0.13

Table 8: Regional environmental efficiencies; island of Ireland as common frontier (CRS)

	BMW	SE	SW	NI
Average EE $\vec{D}_o^W(y,-s)$	0.27	0.18	0.19	0.13
percentage of efficient farms ($\beta = 0$)	14.89	24.05	25.88	36.46
Average efficiency (1- *ß)*	0.73	0.82	0.81	0.87
Maximum efficiency (1- *ß)*	1	1	1	1
Minimum efficiency (1- *ß)*	0.29	0.45	0.40	0.33
Std. dev. of avg. efficiency	0.20	0.15	0.16	0.14

We also analysed the model considering only the three regions in the Republic of Ireland under the VRS and the CRS assumptions. The result of which is presented in Table 9 and Table 10 respectively. The pattern of performance was found to be the same as when all four regions were combined as a single production frontier. That is, the values (1- ß) of SE>SW>BMW. This implies a higher environmental efficiency for dairy farms in the South-east regions compared to other regions of the republic of Ireland.

Table 9: Regional environmental efficiencies; Republic of Ireland as common frontier (VRS)

	BMW	SE	SW	Ireland
Average EE $\vec{D}_o^W(y, -s)$	0.16	0.05	0.1	0.10
percentage of efficient farms ($\beta = 0$)	44.68	58.23	43.53	49.29
Average efficiency (1- *ß)*	0.84	0.95	0.90	0.90
Maximum efficiency (1- *ß)*	1	1	1	1
Minimum efficiency (1- *ß)*	0.37	0.58	0.46	0.37
Std. dev. of avg. efficiency	0.16	0.09	0.13	0.14

Table 10: Regional environmental efficiencies; Republic of Ireland as common frontier (CRS)

	BMW	SE	SW	Ireland
Average EE $\vec{D}_o^W(y, -s)$	0.20	0.08	0.13	0.13
percentage of efficient farms ($\beta = 0$)	29.79	45.57	34.12	37.44
Average efficiency (1- *ß)*	0.80	0.92	0.87	0.87
Maximum efficiency (1- *ß)*	1	1	1	1
Minimum efficiency (1- *ß)*	0.32	0.58	0.42	0.32
Std. dev. of avg. efficiency	0.20	0.10	0.13	0.15

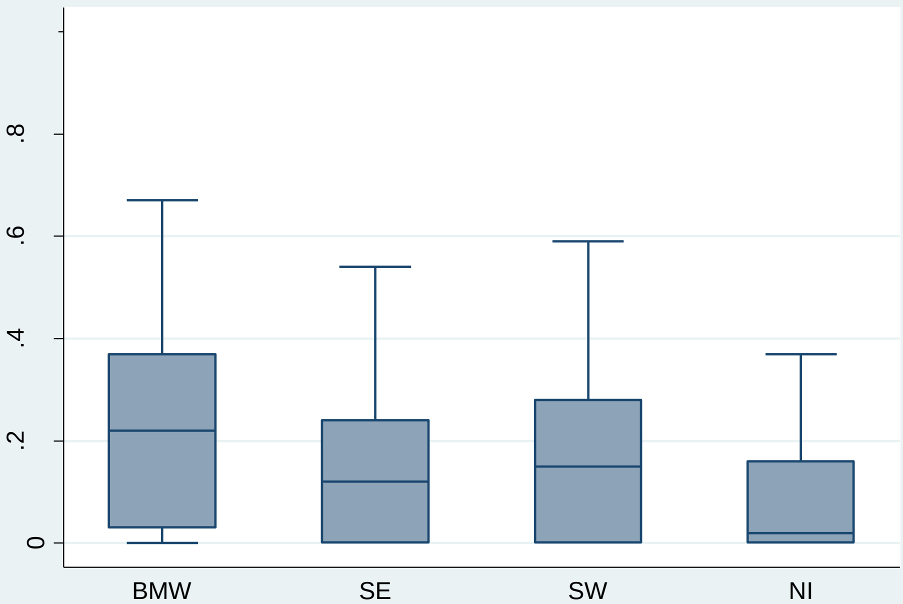

Figure 2: Box plots showing levels of environmental efficiency taking the island of Ireland as a single production frontier

4.4 Factors accounting for variations in environmental efficiency

The result of the bootstrap truncated regression model for Northern Ireland and the Republic of Ireland with efficiency estimates (1- *ß)* of the VRS assumption as dependent variable is presented in Table 11. Based on the bootstrap procedure described in section 3.6 we are able to obtain upper and lower bound of the bootstrap confidence interval and these values are reported for each estimated coefficient in the model. The results of our analysis reveal that forage output per hectare, milk recording and size of utilised agricultural area were statistically significant determinants of environmental efficiency for the Republic of Ireland. Though fewer number of explanatory variables were included in the Northern Ireland model due to data constraints, only the forage output per hectare variable was identified as statistically significant (P<0.05). For the Republic of Ireland, while forage output per hectare and utilised agricultural area were significant at 10% (P<0.1) milk recording was significant at 5% level (P<0.05). Given the positive sign in the coefficient of the forage output per hectare in both Northern Ireland and the Republic of Ireland, it implies that increase in forage output per hectare results in increased environmentally efficiency. In the same vain, farmers that take records of their milk output and with larger farm areas tend to be more environmentally efficient.

Table 11: Results of bootstrap truncated regression of environmental efficiency scores: VRS

	Northern Ireland			Republic of Ireland		
Variables	Estimated Parameters	Lower bound	Upper bound	Estimated Parameters	Lower bound	Upper bound
Age(years)	0.0028	-0.0017	0.0077	-0.0031	-0.0072	0.0014
Land(hectare)	0.0003	-0.0015	0.0021	0.0023*	0.0001	0.0046
Off-farm income (dummy)	0.0149	-0.0973	0.1283	-0.1006	-0.2916	0.1798
Stocking density (LU/ha)	-0.1043	-0.2832	0.0764	-0.1124	-0.3554	0.1374
Agri-environment	0.0456	-0.0653	0.1478	0.0463	-0.0514	0.1439
Forage per ha	0.0001**	8.73e-06	0.0001	0.0001*	-9.99e-06	0.0001
Investment per cow				-0.0001	-0.0003	0.0002
Milk Recording				0.1043**	0.0073	0.2020
Advisory contact				0.0002	-0.0990	0.0939
Discussion group				-0.0277	-0.1149	0.06295
Constant	0.8025***	0.3212	1.2396	1.0773***	0.4588	1.7304
Sigma	0.1293***	0.0774	0.1568	0.1660***	0.1189	0.1931
No of observations	101			206		

Statistical significance: ***= 1 per cent ** = 5 per cent, * = 10 per cent

Aside from the aforementioned relationships, all of the other remaining variables were not found to have statistically significant effect on environmental efficiency.

5.0 Discussion

5. 1 Comparison of the nutrient balance of the four regions

On average nitrogen and phosphorus balance is lower for the regions of the Republic of Ireland compared to Northern Ireland. Recent studies by Mihailescu *et al.* (2014, 2015), Buckley *et al.*, (2015b) has shown that nitrogen and phosphorus surplus has reduced significantly in the last few years, attributing the decrease mainly to the impact of the good agricultural practice regulation (GAP) in the Republic of Ireland. The higher nitrogen and phosphorus for Northern Ireland reflects the lower forage output and consequently higher use of concentrates feeds in order to increase yield per dairy cow. The two regions NI and BMW with lower forage output per hectare had higher environmental impacts in terms of nitrogen and phosphorus balance when compared to the SE and SW regions with higher forage output per hectare. This gives an indication that increasing the forage output per hectare might be one effective strategy to reduce nitrogen and phosphorus balance in absolute terms. Nutrient use efficiency reflects the level of nutrient output relative to input. It is particularly high for regions of the Republic of Ireland compared to Northern Ireland. The results presented here are in the same range with previous studies reported in the literature. For example, Buckley *et al.* 2015b found that Specialist dairying systems had an average nitrogen balance of 145.5 kg nitrogen per ha and a nitrogen use efficiencies of 24.6%. Mihailescu *et al.,* (2015) reported average phosphorus use efficiencies of 71 per cent and surpluses of 4.93 kg phosphorus per ha from a study of nineteen dairy farms in Southern Ireland. The difference of course could have been influenced by the different method of estimation and underlying assumptions. For example, Bassanino *et al.* (2007) estimated the nitrogen balances and nitrogen use efficiencies for 41 commercial Italian livestock farms using the soil surface nutrient budget and a farm-gate budget methodology. The result of the study showed a higher nitrogen surpluses and lower nitrogen use efficiencies for the farm-gate balance (FGBS) approach compared to the soil surface balance approach for all farm types including dairy farms.

5. 2 Comparison of the Environmental Efficiency of the four regions

Understanding and improving agricultural productivity whilst minimizing the impact of environmental pressure are crucial steps to achieving more sustainable dairy production. In the context of an envisaged expansion of the dairy sector in the island of Ireland following the milk quota abolition in 2015, an empirical analysis of environmental efficiency in the dairy sector is essential. This will provide the necessary empirical evidence to support policy formulation aimed at achieving sustainable development in agriculture. Measuring regional environmental efficiency differential at different production frontier levels helps to explain the sources and level of environmental performance variation in dairy production within the analysed regional sub-samples. In explaining our results, it should be emphasized that higher environmental efficiency level does not necessarily imply better environmental management system or guarantee sustainability of the dairy production system (Picazo-Tadeo *et al.*., 2011). This is because the coefficient of environmental efficiency only measures the relative level of environmental burden in relation to the volume of economic activity, which in this case is dairy farm outputs. Also, as pointed out by Huppes and Ishikawa (2005) environmental efficiency improvements at micro-level does not automatically translate to improved environmental quality at the macro-level. Besides, while the coefficients are interpreted in terms of the direction of expansion of the desirable output and the reduction of the undesirable outputs, it should be acknowledged that such movements are theoretical in nature. The sources of inefficiency might in fact not be completely attributable to the managerial ability of the farmer but may also be as a result of other factors beyond his control which are more difficult to observe and quantify.

Irrespective of the limitations, the measurement of environmental efficiency provides a cost-efficient way of reducing environmental pressure and improvement in environmental efficiency are relatively easy for policy makers to implement without restricting the level of economic activities impacts (Ekins, 2005). In fact, policies promoting environmental efficiency often results in a win-win outcome from being able to contemporaneously increase economic activity and reduce environmental burden. Comparing the results of the nitrogen and phosphorus balance with the estimates of environmental efficiency across the region reflected a contrasting scenario. This is because while nitrogen and phosphorus balance are higher for Northern Ireland compared to the regions of the Republic of Ireland, its estimates of environmental efficacy is lower implying a better environmental performance. This can be explained based on the different methodologies employed. While the estimation of nitrogen and phosphorus balance measure environmental impact in absolute terms, the directional distance function DEA environmental technology measures environmental impact in relative terms. Northern Ireland has had the opportunity of increasing yield per dairy cow by securing quota from other regions of the United Kingdom. The implication of this is that, dairy farms in Northern Ireland have expanded in the last few years such that milk production per kilogram of nitrogen surplus for example is higher in Northern Ireland compared to the regions of the Republic of Ireland. With environmental efficiency being a relative measure of environmental performance, it therefore seems to have a more favourable environmental efficiency compared to the regions of the Republic of Ireland. However, as noted earlier, and according to (Picazo-Tadeo *et al.*, 2011), both relative and absolute measure of environmental performance are essential and do complement each other. Taking cognizance of the absolute measure is particularly necessary to ensure ecosystem carrying capacity is not exceeded. Our results of relative measure of environmental efficiency is supported by that obtained by Toma *et al.*, (2013) in which they employed the Tyteca (1996) DEA based environmental technology model and found that low forage systems (in our case Northern Ireland) to be more environmentally efficient than the high forage systems (in our case regions of the Republic of Ireland).

Given the positive correlation between technical and environmental efficiency it can be said that to be environmentally efficient, farms have to be technically efficient and proper implementation of environmental policies are required to ensure sustainable dairy production. This fact has also been demonstrated by Picazo-Tadeo and Reig-Martínez (2006, 2007), who show how farmers overuse inputs (nitrogen in their case studies), mostly because of inefficient management, and how environmental pressures could be reduced by merely promoting best farming techniques. This however, do not mean exceptions do not occur in practice at the individual farm level given that the positive relationship is a statistical tendency and is also dependent on the regional and managerial characteristics of each production systems. That is, high environmental efficiency is not strictly confined to higher production systems. Our estimate of technical efficiency for the Republic of Ireland is in line with the findings of Kelly *et al.* (2012) who employed the DEA model to estimate technical efficiency of dairy farms in the Republic of Ireland.

5.3 Factors influencing environmental efficiency

Identifying the factors that influence environmental efficiency provides policy makers with relevant information needed to formulate policies to reduce environmental pressure especially in a post quota era. Forage output per hectare was found to be statistically significant both for Northern Ireland and the Republic of Ireland. This result is in line with that obtained by Basset-Mens *et al.* (2009) and Casey and Holden, (2005) in which they highlighted that low-input grass-based dairy systems have a better environmental performance when compared with more intensive systems.

Though we found a negative relationship between environmental efficiency and stocking density, it was not a significant factor influencing environmental efficiency in the study area. This result is supported by Mihailescu *et al.* (2014) in which they found a weak impact of stocking density on nitrogen surplus, indicating that with good management practice, it is practically possible to simultaneously increase dairy output per hectare with increased stocking rate and reduce environmental impact. However, further research is required in this regard. This is because contrasting results from previous studies does not give ample space to make a definitive answer as to what is the ideal or permissible stocking rate in dairy farms. For example, while Basset-Mens *et al.*, (2009), Casey and Holden (2005) reported that increasing the stocking rate reduces the eco-efficiency of dairy farms both in terms of milk production and land use functions, Crosson *et al.* (2011) in their review of 31 studies concluded that increased output per hectare obtained through intensification reduce emission per kilogram of products. Socio-economic variables such as age of the farm manager, access to off-farm income and membership of discussion groups though with the expected signs were not statistically significant in our analysis. Similar result was obtained by Picazo-Tadeo *et al.*, 2011 in which they explained that eco-efficiency is hardly explained by traditional socio-structural variables.

Conclusion

In this paper we analysed the environmental efficiency of specialised dairy farms in the regions of the island. In contrast to previous studies we empirically estimated nitrogen and phosphorus balance using the OECD/eurostat methodology across different regions of the island of Ireland with varying dairy production systems. We also went further by employing a modern econometric technique (Simar and Wison (2007) bootstraping Algorithm 1 to analyse the relationship between environmental efficiency and farm structural and socio-economic variables. We obtained the environmental efficiency indices for the four regions of the island of Ireland under different production frontiers. Our results showed that potentials exist for simultaneously increasing dairy outputs and reducing environmental impacts. Another interesting result from our study is that we found a positive and significant relationship between technical and environmental efficiency. This demonstrates that the adoption of best production management practices also contributes to improvement in environmental performance of dairy farms. Overall, there is a significant level of variation in environmental performance of dairy farms across the regions of the island of Ireland. The estimated status of environmental performance, however, can be influenced by the methodology employed.

From a policy perspective, this study provides empirical evidence to inform the formulation of policies relating to improvement of environmental performance in dairy production systems. Dairy farmers should be educated on the need to adhere strictly to environmental regulations and promote environmentally-friendly techniques and practices. Taking into account the significance of forage output per hectare in improving environmental efficiency, it is important that more emphasis is placed on increased incorporation of grass-based feeding systems and better inputs management. Enhancement of farmers' skills and knowledge on production data management is also very essential. Another way to ensure sustainable dairy production is to ensure a more broad and practical implementation of the agri-environmental schemes and ensuring stricter compliance given its positive relationship with environmental efficiency. Only phosphorus and nitrogen balance were included as our environmental variables in this study. This could be expanded to include other variables to account for biodiversity and carbon footprints in future studies.

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