

# Application of data envelopment analysis to measure technical efficiency on a sample of Irish dairy farms

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**The aim of this study was to determine the levels of technical efficiency on a sample of Irish dairy farms utilizing Data Envelopment Analysis (DEA) and to identify key management and production factors that differ between producers identified as efficient and inefficient. DEA was used in this study to generate technical efficiency scores under assumptions of both constant returns to scale (CRS) and variable returns to scale (VRS). The average technical efficiency score was 0.785 under CRS and 0.833 under VRS. Key production characteristics of efficient and inefficient producers were compared using an analysis of variance. More technically efficient producers used less input per unit of output, had higher production per cow and per hectare and had a longer grazing season, a higher milk quality standard, were more likely to have participated in milk recording and had greater land quality compared to the inefficient producers.**

*Keywords:* dairy, data envelopment analysis; Ireland; technical efficiency

## Introduction

Irish dairy farmers are facing new challenges and opportunities arising from reform of the European Union (EU) Common Agricultural Policy (CAP) and in particular

the removal of milk quotas by 2015. This will allow expansion unlimited by quota for the first time since milk quotas were introduced in 1984. Under the past CAP regime, milk price supports through import

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tariffs, export subsidies and intervention stabilized prices in the EU compared to those outside the EU (O'Donnell *et al.* 2008). However, a potential world trade organisation agreement is likely to result in reduced EU milk prices through lower domestic support, tariff cuts and an abolition of export refunds (Dillon *et al.* 2008). Therefore price volatility regarding dairy farm output, including milk price in particular, and also in relation to farm inputs has emerged as a major phenomenon in Ireland and the EU over the last five years (Donnellan *et al.* 2011).

Profitability in an environment of lower and more volatile milk prices (through reduced price support) requires producers to become even more focused on maximizing efficiency of milk production as markets become more dependent on supply and demand of milk. This can be achieved by more judicious use of inputs, lowering of costs, innovation and increased productivity with a view to increasing levels of technical efficiency (TE).

The majority of efficiency measurement research is based on the frontier analysis work of Farrell (1957). This led to the development of methodologies such as the parametric Stochastic Frontier Analysis (SFA) developed by Aigner, Lovell and Schmidt (1977) and Meusen and van den Broeck (1977), and the non parametric Data Envelopment Analysis (DEA) developed by Charnes, Cooper and Rhodes (1978). The main advantage of DEA over SFA is the fact that DEA does not require the specification of a functional form for the formation of the production frontier. Barnes (2006) noted that the potential misspecification of a functional form with the SFA approach may also lead to biased results. It must be acknowledged however that DEA is unlike SFA as it is non-parametric, does not contain an error term and therefore attributes all measurement error to inefficiency. This problem with

DEA can be overcome using bootstrapping techniques (Simar and Wilson 2007). Data Envelopment Analysis has been widely used in previous TE studies of dairy farms. For example Jaforullah and Whiteman (1999) used DEA to measure TE on a sample of New Zealand dairy farms. Barnes (2006) and D'Haese *et al.* (2009) also used DEA to measure TE of a sample of Scottish and Reunion Island dairy farms, respectively. Latruffe *et al.* (2005) used DEA to measure the effect of specialization on TE for livestock and crop farms in Poland. Based on the positive use of DEA as a methodology prevalent in the literature and the non requirement for a functional form, DEA has been chosen as the methodology to measure TE in this study.

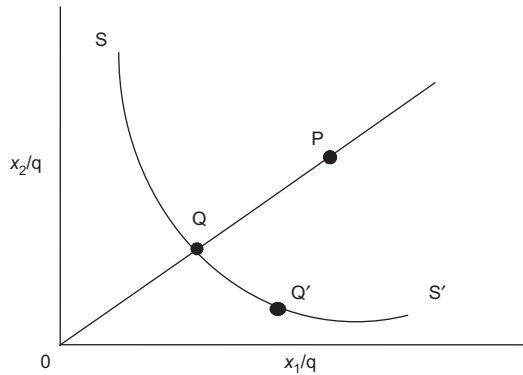
The objectives of this study were firstly to determine the levels of TE on a sample of Irish dairy farms using DEA and secondly to determine the key production characteristics of efficient and inefficient producers under differing definitions of efficiency.

## Materials and Methods

### Methodology

Farrell (1957) described TE as maximising output from a given set of inputs given a technology. A frontier was used to illustrate efficiency with units on the frontier being fully efficient and those below the frontier considered inefficient with a measure of efficiency relative to the best practice businesses on the frontier. Farrell (1957) considered an input orientated production process with two inputs  $x_1$  and  $x_2$  and one output  $q$  which was held constant. In Figure 1, the fully efficient farms are represented by the isoquant<sup>1</sup> curve

<sup>1</sup> Isoquant is a curve that represents the combinations of inputs which, when combined efficiently, produce a specified level of output.



P and Q=Decision Making Units (DMU) i.e. Farms  
 Q'=projected point on the isoquant or technically efficient frontier  
 SS'=technically efficient frontier (isoquant)  
 $x_1$  and  $x_2$ =inputs  
 q=output

Figure 1. Farrell measure of efficiency.

SS' that indicates TE. For example farm P is not operating on the isoquant curve and has a level of inefficiency equal to the distance QP which is the amount by which all inputs could be proportionally reduced without reducing output. QP/OP is a ratio that represents the reduction required in all inputs to gain TE. Thus TE of farm P can be measured by the ratio:

$$TE = OQ/OP$$

A score of 1 indicates TE and a measure of inefficiency is 1 minus the relative efficiency score or the distance from the inefficient point to the frontier.

*Data Envelopment Analysis*

Based on the work of Farrell (1957), DEA was developed by Charnes *et al.* (1978) as an empirical frontier analysis technique. Data Envelopment Analysis is a non parametric method of efficiency analysis that employs linear programming to estimate the 'best practice' or most

efficient production frontier. The estimated frontier envelopes the input/output data of the most efficient decision making units (DMU), each farm in the analysis, consequently those DMU lying on the frontier are referred to as TE, with a score of 1, while those below the frontier are regarded as inefficient, with a score of less than 1. All efficiency scores in DEA range between 0 and 1 and lower scores indicate lower efficiency. Data Envelopment Analysis can be either input or output orientated. The original DEA model by Charnes *et al.* (1978) was an input orientated model, whereby under the assumption of constant returns to scale, inputs were minimized, output remained constant and inefficiencies were calculated in terms of the inputs. Alternatively, output orientated DEA models were developed whereby the model is set up to maximize output and inputs remain at a constant level with inefficiencies calculated in terms of the outputs. It was noted by Coelli *et al.* (2005) that both output and input

orientated models will identify the same set of efficient DMU and that as linear programming does not experience statistical problems like simultaneous equation bias, then choice of orientation is not as critical as opposed to econometric SFA methods.

#### *DEA models*

The following is an input orientated model under the assumption of constant returns to scale (CRS) as defined by Charnes *et al.* (1978) and Coelli *et al.* (2005). The assumption of CRS requires that every increase in all inputs will result in a proportional output increase. Firstly assume that there are  $I$  farms with  $N$  inputs and  $M$  outputs and they are represented for the  $i$ -th farm by the vectors  $x_i$  and  $q_i$ . Data for the  $i^{\text{th}}$  farm are represented by the  $N \times I$  input matrix  $X$  and the  $M \times I$  output matrix  $Q$ .

$$\text{Subject to } \begin{array}{l} \text{Min}_{\theta, \lambda} \theta, \\ -q_i + Q\lambda \geq 0, \\ \theta x_i - X\lambda \geq 0, \\ \lambda \geq 0, \end{array}$$

where  $\theta$  is a scalar and  $\lambda$  is an  $I \times I$  vector of constraints.

This model works by taking a farm ( $i$ -th farm) and minimizing the input vector  $x_i$  while still remaining in the feasible set of inputs and outputs. A projected point is produced  $(X\lambda, Q\lambda)$  when the input vector,  $x_i$  is contracted by  $\theta$ . The value of  $\theta$  is the efficiency score for the farm and satisfies the constraint  $0 \leq \theta \leq 1$ . In contrast, variable returns to scale (VRS) as used by Banker, Charnes and Cooper (1984) incorporates scale inefficiencies and assumes output will not proportionally increase with an increase in inputs. To assume VRS, the convexity constraint  $\mathbb{1}'\lambda = 1$  (where  $\mathbb{1}$  is a new matrix with the dimensions  $I \times 1$ ) replaces the constraint,  $\lambda \geq 0$  and the frontier envelopes the data points more tightly than the CRS model.

As VRS assumes that not all producers are operating at optimum scale and CRS assumes that producers are scale efficient, this implies that if there is a difference in efficiency scores under the alternative returns to scale assumptions then scale inefficiencies must be present. In this study an input orientated DEA model was calculated under the assumptions of CRS and VRS. The efficiency scores were estimated using DEA Frontier Software developed by Cook and Zhu (2008).

#### *Dataset*

Data from the Teagasc National Farm Survey (NFS) (Connolly *et al.* 2008) were used for the analysis in this study. The NFS is an annual survey of approximately 1200 farms weighted by size and system to represent a population of 104,800 farms in Ireland. Data are collected by trained technical recorders who personally meet producers to undertake the survey. As the focus of this study was on dairy farming only, NFS data for 190 specialist dairy farms were used in the analysis.<sup>2</sup> These specialist dairy farms are defined as generating over 66% of the value of their total gross output from the dairy enterprise (as defined by the NFS). Producers with predominantly spring calving herds only were analysed as there was a small sample of liquid milk producers. Farms in this study were from a variety of different regions across Ireland and consequently the sample is heterogeneous with respect to factors such as land quality, topography and rainfall conditions. In particular, the implications of variations in land quality

<sup>2</sup>The analysis was restricted to a sample of 190 farms due to the technical capacity of the software (Cook and Zhu 2008) used in the estimation. There were 256 specialist dairy farms in the NFS sample for 2008 and the subset of 190 farms used in the analysis were randomly selected from this group.

are considered in the interpretation of the analysis. Descriptive statistics for inputs and outputs in the dataset of 190 farms are presented in Table 1.

#### *Inputs and outputs*

The inputs used in the DEA model comprised land area in hectares (ha), average dairy cow numbers, labour units in full time equivalent (FTE), kg of purchased concentrate, kg of fertilizer and other costs (€). These represent all of the important inputs on specialist Irish dairy farms (Connolly *et al.* 2008) and are explained in more detail below. Following Hansson and Öholmér (2008) all inputs and outputs were taken on a whole farm basis thereby avoiding the need to use ad hoc rules to apportion indirect costs to farm enterprises.

#### *Inputs*

*Land size* – The area of land in hectares used on the whole farm, both owned and rented.

*Cow numbers* – The mean number of cows being milked in the herd for 2008 and was used as a proxy for capital

investment. This approach was also used by Tauer (1993) as a representation of capital size in the measurement of TE of New York dairy farms.

*Concentrate* – The physical quantity of purchased concentrate used for 2008 expressed in kg. This input represented 43% of direct costs on dairy farms in Ireland in 2008.

*Fertilizer* – Total amount of purchased N, P and K by the farm for the year expressed in kg. Fertilizer represented 19% of direct costs on specialist dairy farms for the year 2008.

*Labour* – The number of labour units on the farm including hired, family and casual labour expressed in full time labour equivalent (FTE).

*Other costs* were the value (€) of other direct and overhead farm costs apart from those already accounted for (concentrate, fertilizer and labour). These included costs such as depreciation, veterinarian and animal health costs, purchased feed costs other than concentrates, electricity, repairs and miscellaneous.

**Table 1. Descriptive statistics of inputs and outputs used**

Input	Units	Mean	s.d.	Minimum	Maximum
Land	Ha	60.10	35.91	8.20	281
Labour	FTE	1.69	0.72	0.56	5.16
Cow no.		64	38	7	231
Quota	L	328,960	228,200	27,306	1,476,615
Fertilizer	kg	9012	6523	0	34,656
Concentrate	kg	68,906	65,765	900	423,100
Other costs	€	72,849	54,350	3568	331,301
Milk solids (MS)	kg	20,469	13,419	1128	81,957
Other output	kg	7581	6272	637	40,790
Stocking rate	LU <sup>1</sup> /ha	1.81	0.51	0.57	3.63
MS/cow	kg	320	95	17	537
MS/ha	kg	358	163	19	785
Fat (per farm)	kg	10,937	7171	588	43,362
Protein (per farm)	kg	9533	6253	514	38,595
Concentrate/cow	kg	1009	529	124	3012
Days breeding		145	96	15	365
Days at grass		224	29	162	304

### Outputs

*Milk solids and other output* – The output variable used in the DEA model was expressed in milk solids (kg) per farm and this also included the output from subsidiary farm enterprises (e.g. dairy herd replacements, crop sales, livestock sales) expressed as its equivalent value in kg milk solids. This was calculated by dividing the value of other output by the price per kg of milk solids as calculated in the NFS. This was a similar approach to Tauer (1993) who also generated a milk equivalent of other output by dividing the value of other output by the milk price level. Similar to the inputs, the outputs were also attributed to the whole farm.

### Analysis

In order to quantify the management and productive characteristics that contribute to overall efficiency, producers were grouped according to their efficiency score and were compared. This analysis was undertaken using two different comparisons:

Comparison 1: Technically efficient producers were defined as those with a score of 1. Therefore efficient producers with a score of 1 were compared to technically inefficient producers with a score of  $<1$ .

Comparison 2: Technically efficient producers and producers that had efficiency scores between  $>0.9$  and  $\leq 1$  were combined and compared to producers with efficiency scores of  $\leq 0.9$ . This second analysis was carried out to test the robustness of the results, in order to ensure that the same productive factors that were statistically significantly different between fully efficient and inefficient farms held true for comparisons including lower levels of TE. Another reason for undertaking a second comparison is that as DEA assigns all error including statistical noise

to inefficiency, producers that were near the frontier at greater than 90% efficient may have been deemed inefficient due to statistical noise or measurement error.

The comparative analysis tested for significant differences in the group mean levels of a set of variables considered likely to be associated with observed efficiencies. Simple t-tests for continuous variables and  $\chi^2$  tests for discrete variables were used. Following Barnes *et al.* (2011) this was completed using an analysis of variance (ANOVA) in SAS (SAS Institute, 2006). The following are the variables that were used in the analysis.

*Grazing season length* refers to the average number of full days cows spent at grass.

*Breeding season length* was the average number of days it took to complete the breeding season.

*Milk quality* was measured using the cost of milk penalties and the financial benefit from milk bonuses. Milk penalties arise from poor quality milk and milk bonuses were financial rewards for better quality.

*Soil quality* was measured using the soil quality index from the NFS. This is a dummy variable on a scale of 1–6 with 1 indicating the best soil with the widest range of uses and 6 the worst with most limited uses. This index captures average land quality per farm but does not reflect variability in land quality on each farm.

*Stocking rate* was measured as livestock units per hectare of total land. A milking platform stocking rate was also calculated as the number of dairy cows per hectare of land on the milking platform.

*Milk recording* was measured using a dummy variable of 0 or 1. Milk recording is a tool provided by milk processors and Irish Cattle Breeding Federation (ICBF) to identify how each cow in the herd is performing individually. Producers using



the tool were assigned 1 indicating 'YES' and 0 indicating 'NO'.

*Output* was total output (milk and milk equivalent of other farm output) produced per farm in kg.

*Production per cow and per hectare* was milk solids produced per cow and per hectare.

*Protein and fat* was the amount in kg of fat and protein produced per farm. These are important variables as producers are paid for milk either on a kg of milk solids basis or with milk bonuses for composition of milk.

*Quota* was the mean quantity of quota in litres that each producer had for the year 2008 indicating the size of the dairy unit.

## Results

### *Technical efficiency*

Estimated TE scores are presented in Table 2 below. Under CRS the mean efficiency score across the 190 farms was 0.785 ranging from a minimum of 0.184 to a maximum of 1.00 with a standard deviation of 0.178. Under VRS the mean efficiency score was 0.833. The minimum efficiency was 0.197 with a maximum of 1.00 and the standard deviation was 0.158. Hence the TE scores under VRS were on average higher than the average efficiency scores under CRS. The differences in mean efficiency scores under the two different returns to scale assumptions

highlight that scale inefficiency was present (Fried *et al.* 2008). Approximately 16% of the sample (31 DMU) was fully efficient under CRS compared to 23% (44 DMU) under the assumption of VRS. Figure 2 shows the frequency distribution of the results and that there was a wider spread in overall TE scores under CRS ranging from 0.184 to 1.00 as compared to a range of 0.197 to 1.00 under the assumption of VRS.

### *Characteristics of efficient and inefficient producers*

Efficient and inefficient producers were analysed by comparing the key production characteristics of both groups. The results are separated into two sections based on the two comparisons explored in the analysis.

Comparison 1: Table 3 presents the characteristics of the TE and inefficient producers under CRS in the first comparison. Mean TE score was 0.785 for the technically inefficient producers (n=159) compared to a mean score of 1.000 for the TE producers (n=31). The efficient producers had 33% more milk solids in total relative to the inefficient producers (P<0.001). Milk solids per cow and milk solids produced per hectare were respectively 24% and 27% higher (P<0.001) for efficient compared to inefficient producers. The total protein and fat produced were both significantly higher for the more efficient producers with approximately 5000 kg of

**Table 2. Technical efficiency scores**

	Constant returns to scale	Variable returns to scale
	Technical efficiency	Technical efficiency
Average	0.7851	0.8328
Minimum	0.1840	0.1969
Maximum	1.0000	1.0000
s.d.	0.1782	0.1578

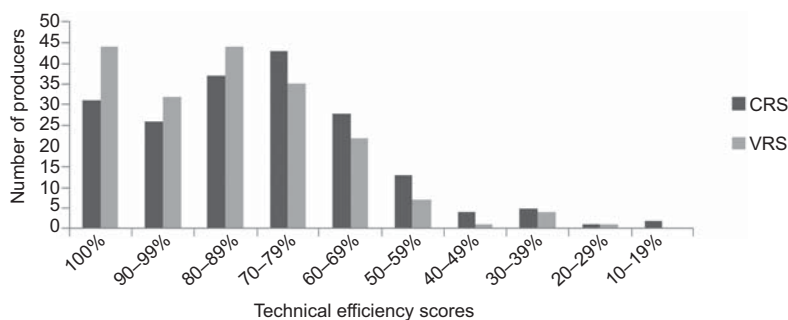


Figure 2. Frequency distribution chart of technical efficiency scores under constant returns to scale (CRS) and variable returns to scale (VRS).

extra fat and protein ( $P < 0.001$ ) produced. Milk quality was superior on the more efficient farms with milk bonuses on average €1500 higher ( $P < 0.01$ ) for efficient producers than inefficient producers. The grazing season length was 10 days longer for the efficient producers ( $P < 0.05$ ). For

the other variables tested, land area, cow numbers, stocking rates, breeding season length, quota quantity and milk recording there were no statistically significant differences between the groups.

Comparison 2: Table 4 presents the results from the second comparison

Table 3. Technically efficient versus inefficient producers under constant returns to scale (CRS) – Comparison 1

Variable Input	TE <sup>1</sup> =1 (n=31)		TE<1 (n=159)		Significance
	Mean	s.e.	Mean	s.e.	
TE CRS	1.000	0.01	0.743	0.01	***
Land (ha)	61	6.47	60	2.86	
Cow no.	67	6.83	63	3.02	
Stocking rate (SR)	1.82	0.09	1.80	0.04	
SR dairy platform	1.88	0.17	2.04	0.08	
Output (kg/ha)	616	32	459	14	***
Milk solids (MS) (kg)	28,319	2334	18,939	1031	***
MS/cow (kg)	401	15.86	305	7.00	***
MS/ha (kg)	460	28	338	12	***
Fat (kg)	15,064	1249	10,132	551	***
Protein (kg)	13,255	1086	8807	480	***
Quota (L)	368,903	40,971	321,173	18,091	
Concentrate (kg/cow)	956	95	1019	42	
Milk bonus (€)	2665	524	1139	232	**
Milk penalties (€)	257	215	553	95	
Milk recording <sup>2</sup>	1.45	0.09	1.56	0.04	
Soil quality <sup>3</sup>	1.79	0.25	2.31	0.11	
Days at grass	232	5.21	222	2.33	*
Days breeding	137	17	147	8	

<sup>1</sup>Technical efficiency.

<sup>2</sup>Milk recording was measured using a dummy variable of 0 or 1.

<sup>3</sup>Soil quality was measured using the soil quality index from the National Farm Survey. This is a dummy variable on a scale of 1–6 with 1=best soil and 6=worst soil.



**Table 4. Technically efficient versus inefficient producers under constant returns to scale (CRS) – Comparison 2**

Variable Input	TE <sup>1</sup> >=0.9 (n=57)		TE <0.9 (n=133)		Significance <sup>2</sup>
	Mean	s.e.	Mean	s.e.	
TE CRS	0.975	0.02	0.7037	0.01	***
Land (ha)	57	4.76	62	3.12	
Cow No.	64	5.04	64	3.30	
Stocking Rate (SR)	1.85	0.07	1.79	0.05	
SR Dairy Platform	1.98	0.12	2.03	0.08	
Output (kg/ha)	618	22.05	427	14.44	***
Milk Solids (MS) (kg)	26,270	1709	17,983	1119	***
MS/cow (kg)	396	10.76	288	7.05	***
MS/ha (kg)	470	19.29	310	12.63	***
Fat (kg)	14,017	914	9617	598	***
Protein (kg)	12,254	796	8367	521	***
Quota (L)	357,371	30,205	316,784	19,774	
Concentrate (kg/cow)	937	95	1039	46	
Milk bonus (€)	1901	391	1168	256	
Milk penalties (€)	239	157	619	103	*
Milk recording	1.39	0.07	1.61	0.04	*
Soil quality	1.81	0.24	2.44	0.12	*
Days at grass	236	3.72	218	2.47	***
Days breeding	131	12.72	151	8.49	

See footnotes to Table 3.

with an average efficiency score of 0.975 (n=57) for the TE producers and 0.704 (n=133) for the technically inefficient producers. Like comparison one, total output, total milk solids, milk solids per cow and per hectare and grazing days differed significantly ( $P < 0.001$ ) between the more technically efficient and less efficient producers. Soil quality which had no significant difference in the first comparison was significantly different in the second comparison ( $P < 0.05$ ). There were a higher number of efficient producers engaged in milk recording than inefficient producers ( $P < 0.05$ ). Milk quality was again affecting efficiency, however, milk bonuses were not significant in this comparison but milk penalties were significant ( $P < 0.05$ ). Overall results were similar from both comparisons with the majority of variables that were significant in the first comparison being significant in the second comparison.

Grazing season length, milk quality, production per cow, production per hectare are all affected the level of efficiency irrespective of whether Comparison 1 or Comparison 2 was used while milk recording and soil quality did not maintain the same statistically significant differences across the two comparisons.

## Discussion

### *Methodology*

Data Envelopment Analysis measures efficiency for each individual farm and identifies benchmarks for farms that are not performing to the highest levels of efficiency. By identifying these efficient or inefficient farms it allows potential further second stage investigation into (a) the management practices of these producers and (b) the source and level of efficiency/inefficiency (Jaforullah and Whiteman 1999). However, it must be remembered that

DEA does not contain an error term and therefore attributes all deviations from the frontier to inefficiency. Data Envelopment Analysis also provides the opportunity to evaluate the effect of changing the input mix to achieve more efficient production, therefore, focusing on the amount by which an input is overused or underused and the effect of that change on the level of efficiency (Stokes, Tozer and Hyde 2007).

#### *Inputs and outputs*

The inputs used in this analysis were land, cow numbers, labour, purchased concentrates, purchased fertilizer and other costs. The output variables were included as milk solids and a milk solids equivalent of other farm output. Previous studies have predominantly used land as an input to reflect scale, including D'Haese *et al.* (2009) who investigated the inefficient use of land in Reunion Island and Stokes *et al.* (2007) who found an over investment in land in Pennsylvania, USA. In Ireland, land is an important variable as O'Donnell *et al.* (2008) found land to be underutilized and it was also noted by Dillon *et al.* (2006) that land area around the milking platform is a key factor that will eventually limit expansion at farm level in Ireland. Purchased feed and fertiliser which constitute a high proportion of direct costs on Irish dairy farms (Connolly *et al.* 2008) were also used as inputs in most studies including Tauer (1993), Jaforullah and Whiteman (1999), Barnes (2006), and Hansson and Öhlmér (2008). Labour use has been used in previous studies including Stokes *et al.* (2007) who found it to be overused in his study of Pennsylvania dairy farms. Other direct and overhead costs were used in this study and similarly defined additional costs have been used previously in studies by O'Neill and Matthews (2001) and D'Haese *et al.* (2009) who included livestock expenses and operational costs.

#### *Technical efficiency*

On average the farms in this study were technically inefficient and there was significant variation across farms, highlighting a potential for many to increase their level of TE. Specifically, the inefficiency pointed to the fact that many producers were overusing inputs to produce their level of output. These TE results are in line with those in previous DEA studies. For example the average levels of efficiency estimated in this paper are similar to those obtained by Tauer (1993) in an efficiency analysis for New York dairy farms under the assumption of CRS. Hansson and Öhlmér (2008) in a study using Swedish data found that the mean TE scores under VRS were similar to the mean results generated in this study under VRS. However, it is necessary to recognize the important differences between dairy systems across countries when drawing comparisons between studies. By focusing on results in this study it was found that there is potential to increase efficiency at farm level.

#### *Efficient versus inefficient*

To understand the factors behind the efficiency differences across the dairy farms studied in the remainder of this paper, we compared inefficient producers to higher performing efficient producers. To quantify the management and productive characteristics that contribute to overall efficiency, producers were grouped according to their efficiency scores and were then compared. Variables which did not significantly affect efficiency were concentrate per dairy cow, land area, stocking rate, quota quantity and breeding season length. Although non significant in this study, stocking rate and total land were found to be significantly different between technically efficient and inefficient producers in a previous Irish study by Carroll, Newman and Thorne

(2007) who also found AI use positively affected TE. The following section focuses on a number of key production factors that were used to compare efficient and inefficient producers.

#### *Grazing season length*

Increasing grazing season length was found to increase TE at farm level in Ireland. This indicates that improved grassland management to make maximum use of available land resources should be targeted to enhance levels of TE. Increasing grazed grass in the diet reduces purchases of inputs such as supplementary feeds thereby increasing TE. Kennedy *et al.* (2005) found that milk production increased with increased grazed grass in the diet of the cow. However, differences in grazing season length may also be due to environmental factors, such as local weather conditions and land quality that are outside the control of management. Läßle *et al.* (2012) found that location factors affect the length of grazing season on Irish dairy farms but they also highlighted the cost benefits of extending the length of the grazing season. The beneficial effect of increasing the proportion of grazed grass in diet has been shown in a number of studies previously (Dillon *et al.* 2002; Kennedy *et al.* 2007; Shalloo *et al.* 2004). Internationally, Dartt *et al.* (1999) studied the benefits of grazing on Michigan dairy farms and found more profit with those producers using intensive grazing management versus conventionally managed dairy farms. In a Dutch study Rougoor *et al.* (1999) also found that grassland management reduced feed costs and had a positive effect on gross margin. Similarly Hanson *et al.* (1998) found greater milk production on farms in New York and Pennsylvania with more extensive grazing.

#### *Soil quality*

There was a statistically significant difference in the mean soil quality on farms where producers were defined as more technically efficient compared to those defined as technically inefficient. Farms with better quality land (soil index 1) as defined by the NFS had on average higher TE scores than those on poorer quality land. Poor soil quality may lead to reduced grass production therefore resulting in an increase in purchased feeds and ultimately a reduction in TE. As the aim of this study was to measure TE at a national level, farms in this study were from a variety of different regions and land quality was not homogenous. Therefore land quality differences must be taken into account when interpreting results. An Irish simulation study by Shalloo *et al.* (2004) highlighted the significant physical and financial performance advantages for a dairy farm operated in an area with a free draining soil type and lower rainfall compared to a similar unit in an area with heavy soil and higher rainfall. Soil quality was also found by Carroll *et al.* (2007) to have a positive effect on TE of Irish dairy farmers.

#### *Milk quality*

Increased milk quality was estimated to have a significant effect on TE. Causes of poor milk quality could be due to high somatic cell count (SCC) or clinical cases of mastitis and poor milk quality potentially reduces production per cow. This is therefore an indication of the effect of differences in management on TE. The effect of poor milk quality on production has been highlighted in previous studies including Hortet and Seegers (1998) who found reductions in milk yield and composition resulting from increased cases of clinical mastitis. In a similar American study Barbano, Rasmussen and Lynch (1991) found that increased SCC in milk

reduced protein and fat concentration, therefore indicating a negative effect of reduced milk quality on output. In an Irish study Geary *et al.* (2012) found increased milk production and profitability for producers with reduced SCC highlighting that increased milk quality will lead to greater milk production and ultimately economic performance.

#### *Milk recording*

Producers that participated in milk recording were more technically efficient than producers who did not use this service highlighting the positive impact of improved managerial information. Milk recording is a decision support service provided to identify individual cow performance providing information from milk yields to milk quality with the options of economic breeding data (ICBF 2011). Providing this information for individual cows allows identification of the best and worst performing cows. This therefore influences management decision making. Deviations in milk quality and production per cow may be more readily identified and addressed using information provided from milk recording.

#### *Total output*

Farms that were more technically efficient had higher total output and increased milk solids output. The mean level of protein and fat produced per farm was statistically higher on those farms defined as more technically efficient than on farms defined as technically inefficient. This highlights the potential link between scale and TE in Irish dairying. Differences in efficiency are explained further below in terms of production per cow and per hectare.

#### *Production per cow*

There were significant differences in terms of milk solids per cow between efficient

and inefficient producers. Potential reasons for differences in production per cow may be due to breeding and genetic management differences. It was found that no significant difference existed between efficient and inefficient producers regarding breeding season length. However, as information on the genetics of the cows was unavailable this cannot be clarified but it highlights the need for further investigation into the breeding practices of the efficient farmers in the future. As noted previously, differences in production per cow may be linked to poor milk quality and use of the milk recording service which was also associated with differences in TE. Participation in milk recording provides information on individual cows regarding production, quality and breeding data. Previous studies have found differences in breeding to be associated with differences in milk solids production and profitability. In Ireland it was found that breeding cows using a higher genetic merit for profitability increased reproductive performance (Coleman *et al.* 2009) and that increasing the economic breeding index (EBI) resulted in increased milk solids production per cow (Coleman *et al.* 2010). In a separate Irish study, McCarthy *et al.* (2007) found differences in profitability among different genotypes. The amount of grazed grass in the diet may also be a contributory factor to production of milk solids per cow. Kennedy *et al.* (2007) found increased fat and protein content with higher proportions of early grazed grass in the diet of the cow. This may be the case in this study as the more technically efficient producers had a longer grazing season.

#### *Production per hectare*

There were differences in total output per hectare and milk solids per hectare between efficient and inefficient

producers. This highlights production per hectare as an indicator of efficiency. Although previous literature has found a positive impact of stocking rate on production per hectare (MacDonald *et al.* 2008, McCarthy *et al.* 2011), the current study found no significant differences between efficient and inefficient producers in terms of stocking rate which suggests that the differences in production per hectare were as a result of differences in grassland management and soil quality. As there were significant differences in production per cow this suggests that potentially cow type and management of the cow was also central to increased production per hectare of the more efficient producers. McCarthy *et al.* (2011) also make the point that stocking rate could be more appropriately defined according to the feed and energy offered per cow, however as information on the quantity and quality of the feed offered on each farm was not available in the NFS data this could not be examined. As this sample of producers was from different regions, land quality was not homogeneous and the significant differences among producers in terms of soil quality may be responsible for much of the observed differences in production per hectare. According to Shalloo *et al.* (2004) qualitative differences in land are important in achieving high grass utilization. Differences in production per hectare can also be explained by grazing season length which according to Shalloo *et al.* (2004) is associated with differences in feed costs and ultimately profit. Another reason for the poor production per hectare may be the presence of a quota system which according to O'Donnell *et al.* (2008) has limited expansion at farm level and therefore constrained the considerable potential for increasing the efficiency of dairy farms in Ireland through expansion.

### Conclusions

The objectives of this paper were firstly to determine the levels of TE on a sample of Irish dairy farms using DEA and secondly to identify key production and management characteristics that differ between efficient and inefficient producers. The results of the TE models show that on average the majority of Irish dairy farmers in 2008 were not operating at maximum efficiency and have a marked potential to improve. Productive, managerial and qualitative differences were found between technical efficient and inefficient producers. It was shown that differences between the efficient and inefficient producers were associated with differences in grazing season length, milk quality, production per cow, production per hectare, total output, participation in milk recording and soil quality. In 2015 EU dairy producers will no longer have production limited by the milk quota system and price volatility is expected to increase. To prosper in a post quota scenario producers need to maximise TE by fulfilling land potential, undertaking land improvements to enhance land quality and enhancing management through increasing length of pastoral grazing season and improving milk quality subject to meeting relevant environmental legislation. As only one year of data was used in this study it would be beneficial to look at efficiency over a longer period of time so as to ascertain if the association between management factors such as grazing days and milk recording and efficiency remains constant over time. The issue of economies of scale that was not captured in this study is also of interest and further investigation of this factor would also add to our understanding of the determinants of Irish dairy farm efficiency.

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