REFEREED ARTICLE

DOI: 10.5836/ijam/2013-03-04

An analysis of the factors associated with technical and scale efficiency of Irish dairy farms

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ABSTRACT

The objectives of this study were to estimate the levels of technical and scale efficiency for a sample of pasture based Irish dairy producers, to identify the factors that contributed to reaching the optimum scale and to examine the relationship between technical and scale efficiency with farm size, intensification and specialisation. Efficiency scores were calculated using Data Envelopment Analysis (DEA). Technical efficiency was on average 0.757 under constant returns to scale (CRS), 0.799 under variable returns to scale (VRS) and scale efficiency was estimated at 0.951. Twelve per cent of the sample was operating at optimum scale (CRS). Fifty six percent of the sample was operating below optimum scale and 32% of the sample was operating above optimum scale. Overall optimum scale was associated with production systems operating with larger land area, with reduced proportion of rented land, increased amounts of hired labour, a higher quantity of quota and achieving a longer grazing season. It was also shown that increased farm size, intensification and dairy specialisation were associated with increases in technical and scale efficiency at farm level.

KEYWORDS: Scale efficiency; data envelopment analysis; dairy systems; Ireland

1. Introduction

The Common Agricultural Policy (CAP) reform process, in particular the phasing out of milk quota by 2015 will create significant opportunities for Irish and EU dairy farmers to expand their production for the first time unhindered since 1984. The clear potential for expansion of the Irish dairy industry has been recognised (Lips and Rieder 2005; O'Donnell et al., 2008; Department of Agriculture Food and Marine (DAFM), 2011). The Irish dairy industry is targeting a 50% increase in dairy output by 2020 (Food Harvest 2020, DAFM, 2011). If this increase in milk output is to be realised profitably it will need to be facilitated by an increase in scale and technical efficiency at farm level.

More generally, it has been estimated that an expanding world population will need 70 to 100% more food by 2015 (O'Brien, 2011) and this will require producers to substantially increase output from available resources. Moreover, the demand for greater productive efficiency must be balanced with the need to conserve the environment. Within Ireland, key environmental issues include reduction targets for Greenhouse Gas emissions and potential pollution from excessive nitrates and phosphates.

A continual price-cost squeeze and risk factors such as milk and feed price volatility also necessitate that producers focus on becoming more technically and economically efficient. The key to reducing overall costs of production is to maximise efficiency in the use of inputs. This can be done by adopting the best practice management techniques utilised by the most efficient producers. As studies by Tauer (1993), Rougoor et al., (1998), and Hansson and Öhlmér, (2008) have concluded, substantial differences between efficient and inefficient producers were attributed to poor management.

Boyle (2002) and Donnellan et al., (2011) suggested that the competitiveness of the Irish dairy industry will be improved by increasing scale through expansion. Similarly, Shalloo et al., (2004) simulated that dairy farmers must increase scale during the period 2004–2013 to remain profitable. However, new management challenges will arise following the abolition of milk quota as land and labour become more prominent constraints at farm level (O'Donnell et al., 2011; Hennessy, 2005; Shalloo, O'Donnell and Horan, (2007). Successful expansion will require greater focus on technical and scale efficiency at farm level.

The objectives of this study were to estimate the levels of technical and scale efficiency for a sample of pasture based Irish dairy producers, to identify the factors that contributed to reaching the optimum scale and to examine

Original submitted September 2011; revision received January 2013; accepted January 2013.

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the relationship between technical and scale efficiency with farm size, intensification and specialisation.

2. Materials and methods

Concept of efficiency

The efficiency concept in this paper is defined according to the relative efficiency definition of Farrell (1957). Technical efficiency was defined by Farrell (1957) as maximizing output from the lowest set of inputs. Scale efficiency was defined by Coelli et al., (2005), as an indication of the amount that productivity could increase by moving to a point of technically optimal scale, as a business may be technically efficient but not scale efficient. Much of the efficiency measurement work on dairy farms has used Data Envelopment Analysis (DEA) including technical and scale efficiency studies (Jaforullah and Whiteman, 1999); Hansson, 2008; Latruffe et al., 2005).

Methodology

The principal efficiency measurement techniques comprise of the parametric Stochastic Frontier Analysis (SFA) developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), and the non-parametric 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 mis-specification of a functional form with 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 error to inefficiency which may lead to the possibility of biased DEA results. DEA has been widely used in previous technical efficiency studies of dairy farms. For example Jaforullah and Whiteman (1999) used DEA to measure technical and scale efficiency on a sample of New Zealand dairy farms. Barnes (2006) and D'Haese et al., (2009) also used DEA to measure the technical efficiency of a sample of Scottish and Reunion Island dairy farms, respectively. Latruffe et al., (2005) used DEA to measure the effect of specialization on technical and scale efficiency for livestock and crop farms in Poland. A number of studies have compared results of both methods including Balcombe, Fraser and Kim (2006), Johansson, (2005) and Jaforullah and Premachandra (2003). The studies revealed that there are sometimes moderate variations in the efficiency results produced by the different methods. However, Balcombe, Fraser and Kim (2006) noted that neither method could be regarded as entirely superior to the other.

The DEA methodology works by estimating a best practice frontier which is created by enveloping the inputs and outputs of the most efficient decision making units (DMU). Those DMU lying on the frontier are classified as efficient relative to the sample, with a score of 1, while those below the frontier are regarded as inefficient, with a score of less than 1. All efficiency scores lie in the DEA range of between 0 and 1. The level of inefficiency for a DMU is the distance from that data point to the frontier. DEA essentially measures the overuse of inputs for a given level of output (input orientated) or potential increase in output for a given level of inputs (output orientated). According to Coelli et al., (2005) both output and input orientated models recognize the same set of efficient and inefficient DMU. Also, as the DEA methodology does not experience statistical problems like simultaneous equation bias, the choice of orientation is not as critical as opposed to econometric methods.

Both input and output orientated models have been used in previous studies similar to the work presented (Hansson, 2008; Hansson and Öhlmér, 2006; Barnes, 2006). It was noted by Coelli et al., (2005) that orientation should be selected based on which quantities the manager has most control over. In this paper efficiency scores were calculated using output orientated models. This approach was chosen because the quota constraint that has restricted EU dairy producers is soon to be removed and therefore the expected future focus of producers will be to maximise output using the least amount of inputs. DEA models were calculated under the assumption of constant returns to scale (CRS) and variable returns to scale (VRS). The assumption of CRS requires that every increase in input will result in a proportional output increase and this measure of technical efficiency is also known as a measure of overall technical efficiency as it will include both controllable and non-controllable sources of inefficiency (Färe, Grosskopf and Lovell, 1985). In contrast the assumption of VRS, as used by Banker, Charnes and Cooper (1984), incorporates scale inefficiencies and assumes output will not proportionally increase with an increase in inputs and consequently the estimated production frontier envelopes the data points tighter than under the assumption of CRS. This measure is also known as a measure of pure technical efficiency and does not attribute inefficiencies to differences in scale (Färe, Grosskopf and Lovell 1985). As the VRS assumption prescribes that not all producers are operating at optimum scale and the assumption of CRS assumes that producers are scale efficient, this implies that if there is a difference in efficiency scores under both assumptions then scale inefficiencies are present.

Scale efficiency

Scale efficiency is defined by Coelli et al., (1998, 2005) as an indication of the amount that productivity could increase by moving to a point of technically optimal scale. This is because a business may be technically efficient but not scale efficient. If, for example, a farm is experiencing increasing returns to scale (IRS), this indicates that the farm is sub-optimum in terms of its scale and if a change in inputs is less than the change in output then productivity should increase by increasing the size of operation. Decreasing returns to scale (DRS) illustrates that the farm is supra-optimum, highlighting that the productivity of these producers may potentially increase by reducing the scale of operation. If the farm cannot increase productivity by altering its scale and every increase in inputs results in a proportional increase in output then that farm is experiencing CRS or is operating at the optimum scale. Therefore productivity cannot be improved by changing scale.

An example of scale efficiency is shown in Figure 1 which illustrates the effect of scale on productivity and returns to scale following the example of Coelli et al., (2005). This example is a single input, single output mix under the assumption of VRS where the farms A, B and C are all technically efficient because they are all on the production frontier. As productivity relates to the ratio between input and outputs then this is equal to the slope of a ray from the origin through each data point. Looking at farm A, it is experiencing IRS because it could increase productivity by moving towards point B. Farm C exhibits DRS and could increase its productivity by reducing its scale of operation towards farm B. Farm B is at its optimum scale (CRS) or scale efficient as changing scale of operation would not lead to gains in productivity.

Dataset

Data from the National Farm Survey (NFS) in Ireland for 2008 were utilised in this analysis. The NFS is an annual survey of approximately 1,200 farms weighted by size and system to represent a population of 104,800 farms in Ireland. This study uses a sample of 266 farms classified by Connolly et al., (2008) as specialist dairy farms, generating the majority of their farm gross output from the dairy enterprise.

First stage analysis

DEA technical and scale efficiency scores were generated in the first stage analysis using DEAP software, version 2.1 developed by Coelli (1996).

Inputs and outputs used in data envelopment analysis models

All inputs and outputs relating to the dairy enterprise only were used in the analysis. Allocation of costs was minimal as many costs were already allocated within the NFS. For more information on the NFS see (Connolly et al., 2008). Overhead costs that were not allocated to the dairy enterprise were allocated based on proportion of gross output originating from the dairy enterprise which was done using the dairy cost allocation methods, explained in Table 1. Allocation methods like the one described in Table 1 have been widely used in previous studies by Smyth, Butler and Hennessy (2009), Donnellan et al., (2011), Thorne (2004) and Fingleton (1995). As all inputs and outputs were specific to the dairy enterprise only, the analysis concentrates on measuring dairy enterprise efficiency, independent of non-dairy subsidiary activities that might be present on the sample farms. Descriptive statistics for all inputs and outputs used in the DEA models are shown in Table 2[5].

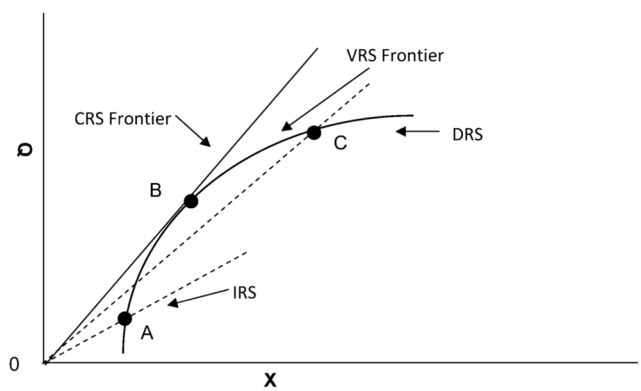

Figure 1: Scale efficiency and returns to scale

Inputs. The model inputs comprised physical quantities of land, milk quota, labour, concentrate, fertiliser and financial value of other direct and overhead costs. Land area included both owned and rented land used by the dairy enterprise. Quota was the amount of milk quota (both owned and rented) in litres for the year 2008. Physical quantities of purchased fertiliser, purchased concentrate and total labour units used by the dairy enterprise were included. Labour was expressed in full time equivalents (FTE) based on total farm labour units and quantified in accordance with NFS specifications including paid (hired labour) and unpaid (family labour). Other direct and overhead costs included depreciation, veterinarian and animal health costs, electricity, repairs, miscellaneous costs attributed to the dairy enterprise.

Output. Output in the analysis consisted of the financial value of milk sold and other dairy farm output including livestock sales from the dairy enterprise.

Second stage analysis

To determine the optimum scale and the factors contributing to optimum scale, producers at CRS, DRS and IRS were compared. In a further analysis the technical and scale efficiency levels were analysed according to farm size, intensification and dairy specialisation. This was undertaken to determine whether efficiency levels increase with increasing levels of farm size, intensification and dairy specialisation.

Identification of optimum scale and factors associated with optimum scale

In this analysis the scale behaviour (whether producers were operating at CRS, DRS or IRS) for all producers was identified. To determine the factors associated with optimum scale, a number of productive and management variables were compared between CRS, IRS and DRS producers. As DEA scores are censored between 0 and 1 with a positive probability a Tobit regression is possible (Hoff, 2007). However as the focus was on the average of the different groups, this analysis follows Barnes et al., (2011) and was completed using an analysis of variance (ANOVA) in SAS (SAS Institute, 2006). The factors considered included land area, average cow numbers, quantities of concentrate per cow, fertiliser per hectare, quantity of quota, levels of output produced, stocking rate, grazing season length, milk production per cow and per hectare.

Efficiency at different levels of scale, intensification and specialisation

To investigate whether technical and scale efficiency scores increased with larger farm size, intensification and specialisation, efficiency scores were compared between producers in groups ranging from smaller to

[5] In mid-March 2013 €1 was approximately equivalent to £0.87 and $US 1.3.

Table 1: Allocation keys used to define variables associated with the dairy enterprise

Variable	Allocation Key
Land	Owned and rented (physical and financial)
Cow	Average number of dairy cows (physical and financial)
Labour	Labour units (physical and financial)
Concentrate	Dairy concentrate (physical and financial)
Fertiliser	Dairy fertiliser (physical and financial)
Other direct and overhead costs	Dairy direct costs (minus costs for concentrate and fertiliser) + Total Overhead costs(minus cost of labour) x Dairy % of Gross Output
Milk Solids	Total milk solids produced and sold (physical and financial)
Other Output	Value of livestock sales from the dairy enterprise

Note: Dairy enterprise use of the resource/input is directly allocated in National Farm Survey

larger levels of scale, intensification and specialisation. Groupings were established based on groupings used in previous Irish studies by O'Brien et al., (2007), O'Brien et al., (2006), Connolly et al., (2008) and Creighton et al., (2011).

Farm size measures included land area, cow numbers and volume of milk produced. Land area was divided into 4 groups following Connolly et al., (2008) of <20ha, 20-30ha, 30-50ha and >50 to reflect a range from low to high scales of production. Cow numbers was divided into three groups of <50 cows, 50-80 cows and >80 cows which were also groupings used by O'Brien et al., (2007). Volume of milk produced was categorised among four groups of 135,000-250,000litres, 250,000-320,000 litres, 320,000-500,000 litres and >500,000 litres following quartiles used by O'Brien et al., (2006).

Measures of intensification were stocking rate and quota per hectare. Stocking rate was divided into three groups similar to groupings used by Creighton et al., (2011), the producers were divided into groups of <1.50 livestock units (LU)/ha, 1.50-2.00LU/ha and >2.00LU/ha. Three milk quota per hectare categories were also used to compare intensification and this varied from <5,000 l/ha, 5,000-10,000l/ha and >10,000l/ha to give a low, medium and high level of intensification.

To investigate whether efficiency increased with dairy specialisation comparisons were undertaken for producers grouped according to proportion (<66%, 66%-75% or >75%) of gross output generated by the dairy enterprise.

An analysis of variance ANOVA in SAS (SAS Institute, 2006) was again carried out to identify if there were significant differences in technical and scale efficiency among producers at the different size, intensification and specialisation categories described above.

3. Results

First stage analysis - efficiency results

Technical and scale efficiency scores for 266 specialist Irish dairy farms calculated in the first stage are shown in Table 3. Overall technical efficiency (CRS) was on average 0.757 for the farmers in the sample ranging from a minimum of 0.332 to a maximum of 1.000 with a standard deviation of 0.148. On average pure technical efficiency (VRS) across the 266 farms was 0.799 ranging from a minimum of 0.451 to a maximum of 1.000 with a standard deviation of 0.154. On average, producers were 20% inefficient (1-0.799) and could become fully efficient by increasing output by 20% with existing input levels. On average scale efficiency across the 266 farms was 0.951 ranging from a minimum of 0.337 to a maximum of 1.000 with a standard deviation of 0.083. A scatter graph of the overall technical efficiency, pure technical efficiency and scale efficiency for the sample of farms is shown in Figure 2.

Returns to scale

Figure 3 contains the proportion of dairy producers that were operating at CRS, DRS or IRS. Twelve percent of the producers in this study had scale behaviour where they were operating at CRS or could be defined as

Table 2: Descriptive statistics of input and output variables used in the efficiency models

Variables	Units	Mean	s.d.	Minimum	Maximum
Inputs					
Land	Ha	35.63	18.43	7.25	119
Labour	FTE	1.15	0.52	0	3.87
Cow		63	36	7	230
Quota	Litres	332,968	257,298	27,306	2,647,727
Fertiliser	Kg	5,565	3,789	328	19,337
Concentrate	Kg	65,307	61,351	900	423,100
Other Costs	€	51,985	41,616	2,034	285,114
Milk Solids (MS)	Kg	20,078	12,361	1,138	81,957
Other dairy output	€	10,993	10,592	0	84,107
Outputs					
MS Price/Kg	€/kgMS	4.60	0.22	3.96	5.27
Stocking Rate	LU/ha	2.01	0.86	0.38	7.30
Solids/cow	Kg/cow	321	94	17	545
Solids/ha	Kg/ha	646	331	33	2,546

Table 3: DEA Efficiency scores

	TEcrs[1]	TEvrs[2]	SE[3]
Average	0.7574	0.7992	0.9495
Minimum	0.3320	0.4510	0.3370
Maximum	1.0000	1.0000	1.0000
Median	0.7485	0.7980	0.9760
St Dev	0.1476	0.1428	0.0836

[1]TE: overall technical efficiency score
[2]TE: pure technical efficiency score
[3]SE: scale efficiency score

operating at the optimum scale. Producers operating at the optimum scale were farming 41 hectares and milking 80 cows. Thirty two percent or 86 producers were found to be experiencing DRS, on average they were farming 51 hectares and 86 cows, (Table 4). Fifty six percent of the sample was experiencing IRS operating with 26 hectares and milking 47 cows.

Second stage analysis

Comparison of optimum, sub optimum and supra optimum scale

Producers operating at supra-optimum levels of scale had a greater percentage of land rented ($P<0.1$) compared to optimum and sub optimum scale producers. Supra optimum scale producers were operating at significantly higher stocking rates ($P<.001$) compared to producers at sub-optimum scale. In terms of labour, producers operating at sub-optimum scale had greater proportion of family labour and lower proportion of hired labour compared to producers at optimum and supra optimum scale ($P<0.01$). There were also significant differences in terms of quota with producers at sub optimum scale having significantly lower levels of quota compared to producers at optimum and supra-optimum scale ($P<0.001$). There was no significant effect of concentrate feeding between the three groups. The supra optimum and optimum producers had higher number of grazing days ($P<0.05$).

Efficiency at different levels of scale, intensification and dairy specialisation

Table 5 contains the results of a comparison of the overall technical efficiency, pure technical efficiency and scale efficiency results at different levels of farm size, intensification and dairy specialisation.

As land area increased to >50ha, technical increased ($P<0.001$), however scale efficiency showed higher levels at land areas of <50ha and <20ha ($P<0.001$).

Similarly as cow numbers increased to >80 cows, technical and scale efficiency increased ($P<0.001$). Technical and scale efficiency also increased as volume of milk produced increased to >500,000l ($P<0.001$).

Technical efficiency increased with an increase in stocking rate of >2 LU/ha and was highest with milk quota per hectare of >10,000 l/ha ($P<0.001$) but there were no significant association with scale efficiency.

As the level of dairy specialisation increased from <66% to >75%, technical efficiency increased ($P<0.01$). Scale efficiency was significantly higher for the specialisation category between 66 and 75% ($P<0.01$).

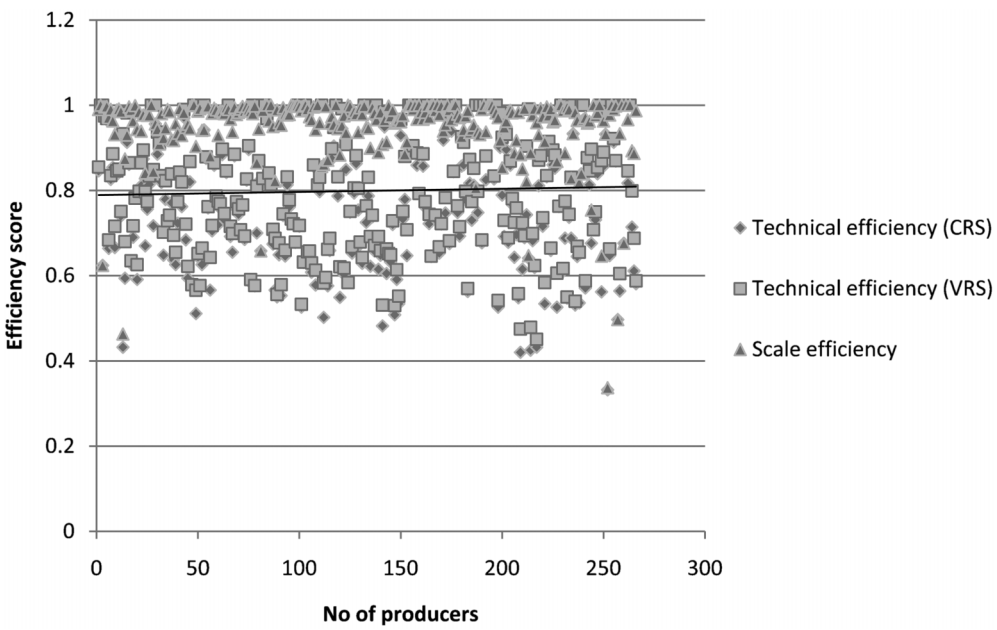

Figure 2: Technical and scale efficiency results

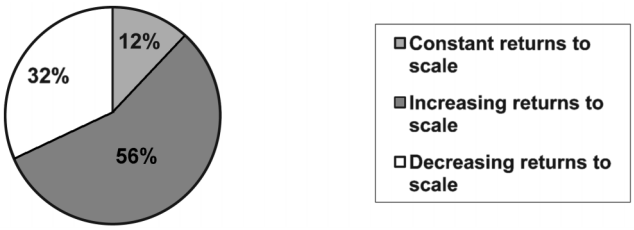

Figure 3: Percentage of sample operating at CRS[1], IRS[2] and DRS[3]

4. Discussion

Technical efficiency results

The results generated in this study show that producers were not fully technically or scale efficient in 2008. Therefore a clear potential to increase technical and scale efficiency exists on Irish dairy farms. Firstly looking at technical efficiency results the mean technical efficiency scores of 0.757 (CRS) and 0.799 (VRS) reveal that producers were generating between 76% and 80% of their potential output at current input levels. Therefore producers could generate on average 24% (CRS) and 20% (VRS) extra output using the current level of inputs. This suggests that there could be substantial increases in output without significant increases in inputs through improved management. The results are also positive as they suggest that the dairy industry has the potential to reach the production targets as set out in the Food Harvest 2020 report (DAFM, 2011) through increasing levels of technical and scale efficiency. The technical and scale efficiency results generated in this paper are in line with results from similar studies in the literature. In a New Zealand study of dairy farm technical efficiency, Jaforullah and Whiteman (1999) found average overall and pure technical efficiency to be 83% and 89% respectively, however the producers in that study were not limited by quota like the producers in this study. Hansson (2008) found on average technical efficiency scores of 0.877 for pure technical efficiency in a study of Swedish dairy producers.

Scale efficiency results

As there were differences in technical efficiency scores under CRS and VRS assumptions, this highlights that scale inefficiencies were present. Scale efficiency was on average 0.951 for this sample of producers. The scale efficiency results were high on average highlighting that this sample of Irish dairy producers were operating near full scale efficiency. The mean value of 0.951 for scale efficiency highlights that producers could generate 5% extra productivity by becoming more scale efficient. Analysis conducted by Jaforullah and Whiteman (1999) found on average scale efficiency to be 94% for New Zealand dairy farmers and in a separate Swedish study by Hansson (2008) scale efficiency was found to be 95%. Therefore the results from this study indicated similar findings to previous studies despite geographical differences, differences in production systems and again the constraint of a quota system in Ireland which is not present in New Zealand.

Returns to scale

The analysis found that 12% of producers were operating at constant returns to scale. The optimum scale was estimated at 80 cows and 41ha for this group of producers. This shows significant potential to

Table 4: Optimal, sub optimum and supra optimum scales of production

Variable	CRS [1] (n=31)	DRS [2] (n=86)	IRS [3](n=149)	Significance [4]
Land (ha)	41.36 [a]	50.64 [b]	25.78 [c]	***
Cow	80 [a]	86 [a]	47 [b]	***
Land Rented %	0.05 [a]	0.09 [b]	0.07 [b]	*
Stocking Rate	1.94 [a]	2.21 [b]	1.91 [a]	*
Labour Units (FTE)	1.82 [a]	2.04 [b]	1.45 [c]	**
Dairy (FTE)	1.29 [a]	1.40 [b]	0.97 [c]	***
Family Labour %	0.73 [a]	0.82 [b]	0.94 [c]	***
Hired Labour %	0.24 [a]	0.18 [b]	0.06 [c]	***
Con [5] per cow	872	938	1,080	NS
Fert [6] per Ha	163	146	158	NS
Quota litres	385,102 [a]	462,565	247,321 [c]	***
Quota per Ha	9,792	8,976	9,612	NS
Milk Solids per Ha	607	711	616	NS
Milk Solids per Cow	311	326	320	NS
Grazing Days	231 [a]	230 [a]	222 [b]	*
TEvrs [7]	0.935 [a]	0.803 [b]	0.767 [b]	***
TEcrs [8]	0.935 [a]	0.775 [b]	0.710 [b]	***
SE[9]	1.0000 [a]	0.967 [b]	0.929 [c]	***

a, b, c and d labels within column represent significant differences at *** <0.001, **0.001-0.01, *0.01-0.05, +0.05-0.1
[1]CRS (constant returns to scale - Optimum Scale)
[2]IRS (increasing returns to scale- Sub optimum scale)
[3]DRS (decreasing returns to scale- Supra optimum scale)
[4]Significance -PROC GLM SAS (2006), *** <0.001, **0.001-0.01, *0.01-0.05, +0.05-0.1, NS>0.1
[5]Concentrate per cow
[6]Fertiliser per hectare
[7]TEvrs: pure technical efficiency score
[8]TEcrs: overall technical efficiency score
[9]SE: scale efficiency score

Table 5: Comparison of efficiency scores at different measures of farm size, intensification andô specialisation

Variable	TEcrs[1]	TEvrs[2]	Scale[3]
Farm Size			
Land (ha)			
<20	0.681 [a]	0.805 [a]	0.985 [a]
<30	0.745 [b]	0.772 [b]	0.965 [b]
<50	0.781 [b]	0.795 [c]	0.982 [a]
>50	0.810 [b]	0.841 [c]	0.962 [b]
Significance[4]	<.0001	<.0001	<.0001
Cow			
<50	0.685 [a]	0.757 [a]	0.913 [a]
50–80	0.782 [b]	0.802 [b]	0.975 [b]
>80	0.844[c]	0.867[c]	0.972 [b]
Significance[4]	<.0001	<.0001	<.0001
Milk (l)			
135,000–250,000	0.691 [a]	0.755 [a]	0.921 [a]
250,000–320,000	0.773 [b]	0.796 [b]	0.972 [b]
320,000–500,000	0.799[c]	0.822 [c]	0.974 [b]
>500,000	0.881 [d]	0.901 [d]	0.975 [b]
Significance[4]	<.0001	<.0001	<.0001
Intensification			
Stocking Rate			
<1.50 LU/ha	0.681 [a]	0.729 [a]	0.943
1.50–2.00 LU/ha	0.764 [b]	0.803 [b]	0.953
>2.00LU/ha	0.811 [c]	0.851 [c]	0.953
Significance[4]	<.0001	<.0001	NS
Quota per hectare			
<5,000 l/ha	0.720 [a]	0.775 [a]	0.933
5000-10,000 l/ha	0.716 [a]	0.762 [a]	0.944
>10,000 l/ha	0.825 [b]	0.857 [b]	0.961
Significance[4]	<.0001	<.0001	NS
Dairy Specialisation			
<66%	0.699 [a]	0.747 [a]	0.941 [a]
66-75%	0.802 [b]	0.829 [b]	0.968 [b]
>75%	0.801 [b]	0.851 [c]	0.943 [a]
Significance[4]	<.0001	<.0001	<.0001

a, b, c and d labels within column represent significant differences at *** <0.001, **0.001-0.01, *0.01-0.05, +0.05-0.1
[1]TEcrs: overall technical efficiency score
[2]TEvrs: pure technical efficiency score
[3]SE: scale efficiency score
[4]Significance -PROC GLMSAS (2006), *** <0.001, **0.001-0.01, *0.01-0.1

enhance productivity by increasing cow numbers from the current national average herd size of 57 cows and 48 hectares (Connolly et al., 2010). The results from this analysis agree with findings of previous studies by Boyle (2002) and Donnellan et al., (2011) which have highlighted the effect of scale on the efficiency of the Irish dairy industry. Both Boyle (2002) and Donnellan et al., (2011) noted that the low level of scale of agricultural activity in Ireland leads to the deterioration of the competitive position of Irish farms when taking into account imputed costs for the owner's resources. The results of this paper showed that 56% of producers were exhibiting IRS and therefore might increase productivity through expansion above their current mean scale of 47 cows and 26ha. The analysis found that 32% of producers were operating at DRS, with an average herd size of 86 cows and 51ha; highlighting that a third of the sample of producers were deemed to be operating above an efficient scale and so could increase their level of productivity by reducing the size of operation. However, the modest difference in mean scales between the group found to be operating at optimal scale and those experiencing decreasing returns to scale suggests that the results should be interpreted with some caution. Other factors correlated with scale may be confounding the results. For example, it is likely that DRS may reflect specific 'scarcity' of one resource (e.g. labour or quota) relative the levels of other resources available. As producers in this sample that were milking 86 cows and farming 51ha were deemed to be exhibiting decreasing returns to scale and optimum scale is only slightly smaller this suggests that constraints to the industry such as quota are potentially causing producers to be operating at decreasing returns to scale. This result may also be due to sample bias and therefore all producers milking 86 cows farming 51 ha may not be operating under DRS. A solution to this problem would be to undertake a DEA slack based model where one can calculate by how much an input or output is being overused. Alternatively DEA results could be calculated based on different size classes. Further reasons why producers were not operating at optimum scale are discussed below.

In comparison with other studies optimum scale identified in this paper was relatively small. For example in a New Zealand study by Jaforullah and Whiteman

(1999) optimum scale was estimated to be 260 cows farming 83 hectares. According to Donnellan et al., (2011) the rate of increase in average herd size is much greater in New Zealand and the USA compared to Ireland. However, Lips and Rieder (2005) argue that Ireland is one of three EU countries that are expected to increase milk production in line with increases in milk quota.

Key factors affecting optimum scale of production

In order to elucidate the factors that were affecting the ability of producers to operate at optimum scale, a number of key variables were analysed. In a further analysis it was investigated whether technical and scale efficiency increased with increased farm size, intensification and dairy specialisation measures.

Farm size measures

Optimum scale production was associated with larger land area as producers at optimum and supra-optimum scale had significantly higher quantities of land compared to producers at sub-optimum scale. This indicates the benefits of economies of scale with larger scale production and that land availability will be central to increasing scale. It was also found that producers at optimum level of scale had a lower percentage of land rented. This may highlight better utilisation of land. A potential reason for inefficiency is farm fragmentation due to lack of land availability adjacent to the milking parlour. Percentage of land rented is likely to be correlated with higher degrees of farm fragmentation and resulting inefficiencies. In contrast optimum scale producers may be more likely to have consolidated holdings offering greater access to land adjacent to the milking parlour. Land quality which was found by Kelly et al., (2012) to be associated with technical efficiency may also be a factor associated with differences in level of land rented, with the influence of soil type and location dictating the quantity of land rented. According to O'Donnell et al., (2008) the largest constraint for Irish dairy farmers post quota will be land availability. It was also noted by Dillon et al., (2006) that land area around the milking platform is known to be a key constraint to expansion at farm level in Ireland. This finding also has policy implications, as land is a limiting factor in Irish agriculture, therefore if Food Harvest 2020 is to be achieved policy makers must focus on initiatives which will increase land mobility.

Increased levels of technical and to a lesser degree scale efficiency were also associated with higher overall milk production, land area and cow numbers suggesting increasing output post quotas will result in increases in efficiency levels. The positive effect of increasing cow numbers, land area and volume of milk produced on efficiency levels therefore highlights the benefits of economies of scale that could be realised in the Irish dairy industry through the relaxation of milk quotas. Yet successful expansion will only be realised if dairy farmers can increase their profitability through increasing efficiency with expansion. The results here mirror results by Kelly et al., (2012) who found increased levels of technical efficiency with greater milk solids produced. Similarly, Hansson (2008) found increased land area resulted in increased technical and economic efficiency for Swedish dairy farmers. However it must be remembered that increasing land area may not be easily achievable for all farmers due to issues such as cost of land, land fragmentation and land availability.

Labour

Optimum and supra-optimum scale producers had a higher number of overall labour units with a greater proportion hired, highlighting that labour options will have to be assessed to expand. Similarly, O'Donovan (2008) found that increasing scale resulted in an increased demand for hired labour. As producers at sub optimum levels of scale, with a potential to expand, had lower amounts of hired labour this may suggest that labour challenges are inhibiting expansion on some Irish dairy farms. Therefore labour will be important to expansion and for sub-optimum scale producers to increase scale and productivity will require the assessment of the labour options available to them. As sub optimum scale producers had higher levels of family labour this may suggest that social issues such as keeping the farm in the family may influence scale inefficiency. Although not analysed in this study, quality of labour may be another factor contributing to increased technical and scale efficiency. It would be anticipated that hired labour potentially possesses a higher labour quality standard as hired staff may have more training compared to family labour. This was also noted by O'Donovan (2008) who concluded that a focus must be placed on quality of labour with the view to creating a more specialised agricultural labour force. The association of labour with increased technical and scale efficiency found in this study also mirror the findings of O'Donnell et al., (2008) who stated that labour challenges will influence future decisions regarding expansion at farm level in Ireland.

Quota

A higher quantity of milk quota was associated with optimum scale production. By comparing the quantity of quota among producers, the results therefore suggest that quota availability is a factor contributing to why 56% of producers were at sub optimum scale. According to Burrell (2004) the constraint of quota thwarts the expansion over time of efficient producers and keeps inefficient producers in production. However milk quota is expected to be removed in the EU by 2015 which will allow expansion at farm level and producers to reap the benefits of increasing scale of production.

When focusing on intensification measures, increased quota per hectare was associated with increased technical efficiency. This may highlight that lower levels of efficiency may be due to the constraint of a quota system currently in place as producers with lower levels of efficiency may have little access to additional quota. Quota availability is another potential reason why some producers have lower levels of intensification. The high cost of purchasing quota and risk factors associated with managing annual farm production to avoid super levy threats are further potential reasons for the impeding effect of milk quotas on efficiency.

According to Lips and Rieder (2005) Ireland is able to increase production in line with increases in quota until quota is eventually removed. Based on the findings presented here, and as was noted by Donnellan et al., (2011) the technical efficiency at farm level and therefore the competitiveness of the Irish dairy sector should increase as scale is increased in a no quota environment.

Stocking rate

Stocking rate was significantly higher for producers at supra optimum scale compared to producers operating at optimum and sub-optimum levels of scale. However, it was also found that higher stocking rates were associated with greater technical efficiency, indicating that to expand in a post-quota scenario, many producers have scope to increase levels of intensification. However producers at higher stocking rates operating at supra optimum scale may have been maintaining a higher stocking rate due to increased proportions of purchased feed in the diet of the cow. As McCarthy et al., (2011) points out stocking rate can be more appropriately defined according to the feed and energy offered per cow. It must also be remembered that higher levels of intensification may lead to greater environmental risks such as increased levels of greenhouse gas emissions. The findings reported in this study are similar to a previous meta-analysis carried out by McCarthy et al., (2011) who reported an association between increased milk production per hectare and increased stocking rates. Gaspar et al., (2009) also found increased levels of technical and scale efficiency with producers with higher stocking rates in a study of Spanish livestock farms.

Dairy specialisation

Higher levels of dairy specialisation were associated with increased technical and to a lesser extent scale efficiency. This highlights potential for a rise in technical efficiency as milk quotas are removed and dairy farmers become more specialised. Previous studies have also found increased levels of technical efficiency with increased specialisation. According to Shalloo et al., (2004), dairy specialisation can be facilitated through expansion and predicted that Irish producers who remained static between 2004 and 2013 would have a 30% reduction in real income while those producers who expanded could maintain or increase their real income. Latruffe et al., (2005) also investigated specialisation and found Polish producers with increased specialisation in livestock to be more efficient compared to crop based farms. However it must also be noted the potential risks associated with specialisation such as output price risk which may affect the producer more in a heavily specialised enterprise compared to a mixed farming system. For example a drop in milk price is likely to have a much bigger impact on specialist dairy producers compared to producers that were operating a dairy alongside other enterprises as this would allow the spread of risk among the different enterprises. Risk management strategies must become a bigger feature of specialist milk producers, with the ultimate focus on cost reductions at farm level thus insulating against output price volatility.

Other productive and management factors

Grazing season length was significantly longer for producers operating at optimum and supra-optimum scales of production compared to producers operating at sub-optimal scale highlighting the association between optimum scale and management practices such as maximising the grazing season length. Lowering costs, by increasing the quantity of grazed grass in the diet of the dairy herd, will be positively associated with increasing scale through expansion in Ireland post quotas. The results in this study reflect those of Shalloo et al., (2004), who found that the grazing season length was associated with differences in production per hectare and Kelly et al., (2012) who found increased technical efficiency associated with increased grazing days. Production per cow and per hectare and concentrate per cow were also compared between optimum, sub-optimum and supra-optimum levels of scale and no statistically significant association was found.

5. Conclusion

The objectives of this study were to estimate the levels of technical and scale efficiency for a sample of pasture based Irish dairy producers, to identify the factors that contributed to reaching the optimum scale and to examine the relationship between technical and scale efficiency with farm size, intensification and specialisation. Technical efficiency was found to be on average 0.757 under constant returns to scale (CRS), 0.799 under variable returns to scale (VRS) and scale efficiency estimated at 0.951. The optimum scale on Irish dairy farms was found to be 80 cows and 41 hectares of land with 12% of the sample operating at their optimum scale (CRS). Fifty six percent of the sample was operating below optimum scale and 32% of the sample was operating above optimum scale. This study found that to achieve optimum scale will require a focus on factors such as land availability, levels of quota, labour options and management issues such as achieving a longer grazing season. It was also shown that increasing farm size, intensification and dairy specialisation will increase technical and to a lesser extent scale efficiency at farm level. The implications of these results are to confirm that a potential exists to enhance productivity through increasing average scale of production on Irish dairy farms as the industry moves to a situation with no quota constraints. As only one year of data were used in this study an extended dataset over a longer time period would be beneficial to future analysis.

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Acknowledgements

The authors would like to thank the farmers who participated in the National Farm Survey and the staff of the National Farm Survey involved in the collection, recording and analysis of data. The authors would also like to thank Brian Moran, National Farm Surveys, Professor Loren Tauer, Cornell University USA, Professor Chris O'Donnell, University of Queensland Australia, Dr. Eoghan Finneran, Teagasc and Dr. Brian McCarthy, Teagasc for their help. Finally the authors would like to acknowledge the contribution of the anonymous reviewers to this article.

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