REFEREED ARTICLE

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Effects of scale, intensity and farm structure on the income efficiency of Irish beef farms

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ABSTRACT

Data envelopment analysis (DEA) was employed to develop a model of income and scale efficiency for Irish beef farms. The objective was to identify and quantify management, farm structural and intensity indicators of efficiency for over 400 representative farms over two production systems and two years. Bootstrapping techniques were employed to measure and correct efficiency scores for sampling bias. Less than 10% of the sample exhibited constant or increasing returns to scale. The remaining farms exhibited decreasing returns to scale meaning that they were larger than optimal scale. Greater income efficiency was associated with lower levels of concentrate feeding and lower overhead costs per livestock unit (LU). Fragmentation, paid labour and capital investment were significantly negatively associated with income efficiency. There was a positive relationship between market gross output per LU and income efficiency. Negative market net margins tended to be subsidised by greater off-farm income on smaller (more scale efficient) farms and by greater direct payments on larger (more scale inefficient) farms. Consequently, prospects for increasing beef output via scale expansion are negative in an external environment of declining subsidies and reduced off-farm employment in rural areas. Increased output from Irish beef farms must therefore come primarily from farm system structural changes rather than scale changes, otherwise farm income efficiency will decline.

KEYWORDS: Suckler beef production; efficiency; DEA; scale efficiency; bootstrapping; whole-farm comparative analysis

1. Introduction

Farm level comparative analysis

Agricultural economists have for centuries sought to identify and measure the management and structural differences between successful and unsuccessful farms (Sheehy and McAlexander, 1965). The objective of such comparative analysis is to identify specific farm systems and strategies likely to increase farm level profits (Fleming *et al.*, 2006). However, many authors have been critical of some common measures of profitability used in farm comparative analysis. For example, gross margin per hectare (GM/ha) is commonly used as a profit measure when comparing farms employing pasture-based production systems (McCall and Clark, 1999; Crosson *et al.*, 2006). There are two substantial criticisms made of the ''partial accounting'' nature of this measure:

1) The exclusion of fixed or ''overhead'' costs from gross margin calculation means that farm systems which employ inherently higher ratios of fixed costs to variable costs appear to achieve greater profits (Firth, 2002; Shadbolt, 2012).
2) The expression of profit on a per hectare basis neglects the productivity of other assets employed. It creates a bias in favour of farms which substitute other fixed assets (e.g. buildings or machinery) for land in their production system (Farrell, 1957; Fleming *et al.*, 2006; Shadbolt, 2012).

The solution to the first criticism is to include the full economic cost of farm production (where such data is available) so that long-term as well as short-term profitability can be deduced (Tauer, 1993). The second criticism applies to all measures of profitability which use a single factor of production as the scale denominator, e.g. profit per cow, profit per labour unit. A solution to this is the measurement of *whole-farm economic efficiency*. This concept is based on the principles described by Farrell (1957) and further developed by many economists in the subsequent decades (Shephard, 1970; Charnes *et al.*, 1978; Fried *et al.*, 2008). Whole-farm, rather than partial measures of efficiency permit more robust specification of strategies associated with improved profitability and economic sustainability over both the short and long-run (Tauer, 1993; Stokes *et al.*, 2007).

Efficiency and Irish beef production

Beef farming, relative to other pasture based enterprises, has been characterised by low measures of productivity

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and efficiency and consequently poor profitability and economic sustainability in many countries (Farrell, 1957; Boyle, 2002; Rakipova *et al.*, 2003; Thorne, 2004; Newman and Matthews, 2007; Deblitz, 2010; Barnes, 2012). In Ireland, the majority of beef enterprises are run either subsidiary to other farm enterprises or off-farm employment (Central Statistics Office, 2012). Most beef farms are also subsidised by government direct payments (Hennessy *et al.*, 2012). Over half of all beef produced in Ireland originates from the 'suckler' (beef cow) herd of 1.1 million cows. The remaining beef is produced from the culls and un-bred progeny of dairy herds. Irish suckler farms are typically small scale, (average of 14 breeding suckler cows) and located on the least productive soils in the wettest climatic regions of Ireland (west and north-west) (Central Statistics Office, 2012). The Irish agri-food industry have set strategic targets for increased output from the primary agriculture sector including an increase of beef output value by 20% from current values of €1.55 billion per annum (Food Harvest 2020; DAFF, 2010). To achieve this, an increase in the number of 'market oriented' beef producers is proposed. Given the high dependence on direct payment subsidies on cattle rearing farms (202% of family farm income in 2010 (Hennessy *et al.*, 2011)) increased output from Irish beef farms can only be economically sustainable in the medium to long-term if accompanied by increased farm level efficiency.

This article aims to 1) describe a model of efficiency for alternative Irish beef production systems, 2) to identify management related drivers of efficiency and to 3) identify farm scale, intensity and structural characteristics likely to facilitate profitable expansion of Irish suckler beef production.

2. Methodology

Productivity and efficiency

Fried *et al.* (2008) defined productivity as a ratio of aggregated outputs to aggregated inputs and efficiency as the ratio of measured productivity to potential productivity. Data Envelopment Analysis (DEA) is non-parametric method of efficiency calculation devised by Charnes *et al.* (1978). It is a non-parametric in that the modeller does not specify the functional form, but rather it is specified by the decision-making units (DMUs) or farms comprising the modelled dataset. The production frontier is the isoquant connecting the most efficient (i.e. 'best observed practice') DMUs in the dataset (see Figure 1). These farms exhibit an efficiency score of one and the convex isoquant created by joining their production functions 'envelops' farms below the frontier which have an efficiency score of less than one (Shephard, 1970). Efficiency models can be either output oriented (output maximising) or input oriented (input minimising). Figure 1 illustrates output oriented efficiency calculation under models of variable returns to scale (VRS) and constant returns to scale (CRS). Efficiency measured to the VRS frontier assumes that all farms are operating at optimal scale, while if measured to the CRS frontier it is assumed that all farms can achieve the scale of the most scale efficient farm in the sample. In this example of a single input, single output production system, points C, F and D are fully efficient farms represented by points on the convex VRS production frontier. However under the assumption of CRS only farm F is fully efficient. Points A and B represent inefficient farms, where the distance from the x axis to point A or B divided by the distance from the x axis to point A' or B' indicates their efficiency scores. The output oriented efficiency score of farm A (ES_A) under VRS can be calculated as:

$$ES_A = pA/pA' \tag{1}$$

This study employed an output oriented DEA model using the FEAR software package in the R language (Wilson, 2009). The efficiency scores calculated by this model therefore imply that an individual farm can improve its efficiency (where efficiency < 1) by employing the existing resource set in a more favourable manner so as to increase output value, while maintaining current input levels. An output oriented model was deemed appropriate given that farmers are more likely to reduce production rather than improve production system efficiency when faced with a constraint on inputs (Tauer, 1993).

Farrell (1957) decomposed economic efficiency into the sub-components of technical and allocative efficiency. However this approach was not feasible for an efficiency analysis of Irish beef farms due to the dearth of recorded common measures of physical output by which to calculate technical efficiency. This is due to the considerable heterogeneity of the physical nature of output both within and between farms. The highly diverse distribution of age, gender, breed, and marketing strategy variables for cattle sold from beef farms contrasts with the relatively homogenous milk output of dairy farms. Consequently, this study calculates income efficiency using whole-farm financial rather than physical data. While this constraint prohibits calculation of technical efficiency it avoids the potential pitfall of making subjective judgements and assumptions around the nature, quantity and quality of physical outputs in the absence of standardised empirical data.

The DEA model was preferred to parametric models such as stochastic frontier analysis for three main reasons:

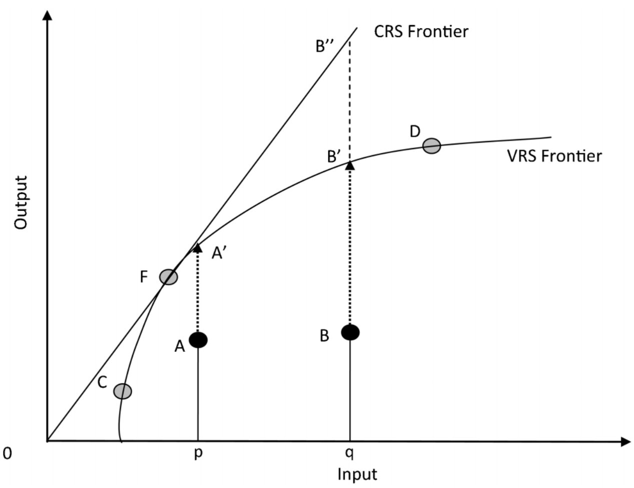

Figure 1: Illustration of output oriented efficiency under assumptions of variable returns to scale (VRS) and constant returns to scale (CRS)

Table 1: Efficiency model inputs, outputs and intensity indicators for two beef farm systems for 2009 and 2010

	Cattle Rearing				Cattle Other			
	2009		2010		2009		2010	
	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
Sample size	228		218		187		249	
Inputs (all per farm)								
Utilised agricultural area - ha	41	(25)	42	(30)	44	(31)	48	(33)
Livestock units [1]	40	(31)	41	(40)	57	(48)	55	(47)
Labour units [2]	1.05	(0.35)	1.06	(0.40)	1.09	(0.48)	1.08	(0.50)
Concentrates - € [3]	4,126	(4,737)	4,350	(5,632)	6,194	(8,100)	7,641	(9,757)
Fertiliser - €	2,389	(1,977)	2,680	(3,153)	3,579	(3,985)	3,493	(3,468)
Other variable costs - €	5,921	(4,073)	6,110	(6,324)	7,304	(6,327)	8,340	(14,038)
Overhead costs - €	13,092	(10,454)	15,100	(13,754)	16,168	(13,071)	18,182	(15,369)
Direct payments - €	17,942	(12,198)	18,552	(14,763)	22,121	(18,057)	22,326	(18,712)
Outputs								
Family farm income - €	9,164	(11,415)	9,808	(11,641)	14,218	(17,509)	15,454	(20,579)
Intensity indicators								
Stocking rate	1.15	(0.47)	1.12	(0.47)	1.36	(0.48)	1.31	(0.52)
Market gross output/livestock unit - €	378	(135)	449	(176)	421	(194)	509	(266)

[1]1 suckler cow = 0.9 livestock units. 1 lowland ewe = 0.2 livestock units
[2]Labour units = the total paid and unpaid labour units employed annually on the farm
[3]€1.00 = $1.32 US Dollars = £0.82 GBP (January 2013)

1) It enables consideration of inputs with differing units of measurement;
2) It permits both income and scale efficiency to be easily measured;
3) Specification of production system functional from is not required in DEA in contrast to parametric efficiency models (Latruffe *et al.*, 2005).

Point 3 is especially important given the considerable heterogeneity of production systems prevailing on Irish beef farms. Table 1 lists the inputs and outputs used in calculation of the efficiency model. Note that whole-farm output was net income or family farm income (FFI measured in Euros/farm). FFI includes income from subsidiary enterprises such as sheep as well as market derived income from cattle and farm direct payments or subsidies. "Other variable costs" refers to all direct costs allocated to the farm livestock enterprise excluding fertiliser and purchased concentrate expenditure. "Overhead costs" refers to all farm fixed costs in addition to direct costs such as fuel and lubes which are not directly allocated to a livestock enterprise. All income efficiency scores referred to in the paper should be interpreted as output-oriented VRS income efficiency scores unless stated otherwise.

Data and model specification

Farm input and output data from the Teagasc National Farm Survey (NFS; Hennessey *et al.*, 2012) was used. The NFS is an annual voluntary survey of approximately 1,100 farms representative of 100,000 farms, providing data to the Farm Accountancy Data Network (FADN). For this study 'specialist beef' farms were analysed using 2009 and 2010 data. Specialist beef farms were defined as those farms which earned 66% or greater gross output from their beef enterprises. These farms were subdivided into 'cattle rearing' (CR) and 'cattle other' (CO) categories. Cattle rearing farms are primarily suckler (beef cow) farms while CO farms are primarily beef finishing farms. Table 1 shows the sample size and main farm characteristics for each farm category for 2009 and 2010.

Efficiency score bootstrapping

Because the statistical estimators of the efficiency frontier were taken from a finite sample, a form of sampling bias may exist in the derived efficiency scores (Efron, 1979; Banker *et al.*, 1984). To correct for this bias, a re-sampling procedure known as 'bootstrapping' was applied to the dataset as described by Simar and Wilson (1998). By generating 10,000 Monte Carlo pseudo-samples from the dataset, a bootstrap bias term was calculated for each farm. This bias term was then subtracted from the corresponding efficiency score to give a bias-corrected income efficiency score (BCES). It should be noted that all efficiency sample induced bias is negative, in effect a one-sided error term as explained by Fried *et al.* (2008). All further reference to 'income efficiency score' of a farm or DMU in this paper is BCES.

Analysis of explanatory variables

Following calculation of BCES, farms were divided into terciles ranked on BCES and statistical differences in explanatory variables between these income efficiency ranked groups were identified using a Mann-Whitney test (Table 4). The effect of some explanatory variables of particular interest on BCES were further analysed by ranking and grouping farms in quintiles based on the value of the continuous explanatory variable of interest. Statistically significant differences in BCES between these quintiles are denoted in Figure 2 for six variables. Significant differences for the explanatory variable quintile analysis were determined using the confidence interval method described by Latruffe *et al.*, (2005). If the 95% confidence interval BCES value for one data-point was less than the 5% confidence interval BCES of another data-point within a system and year these data-points were identified as significantly different.

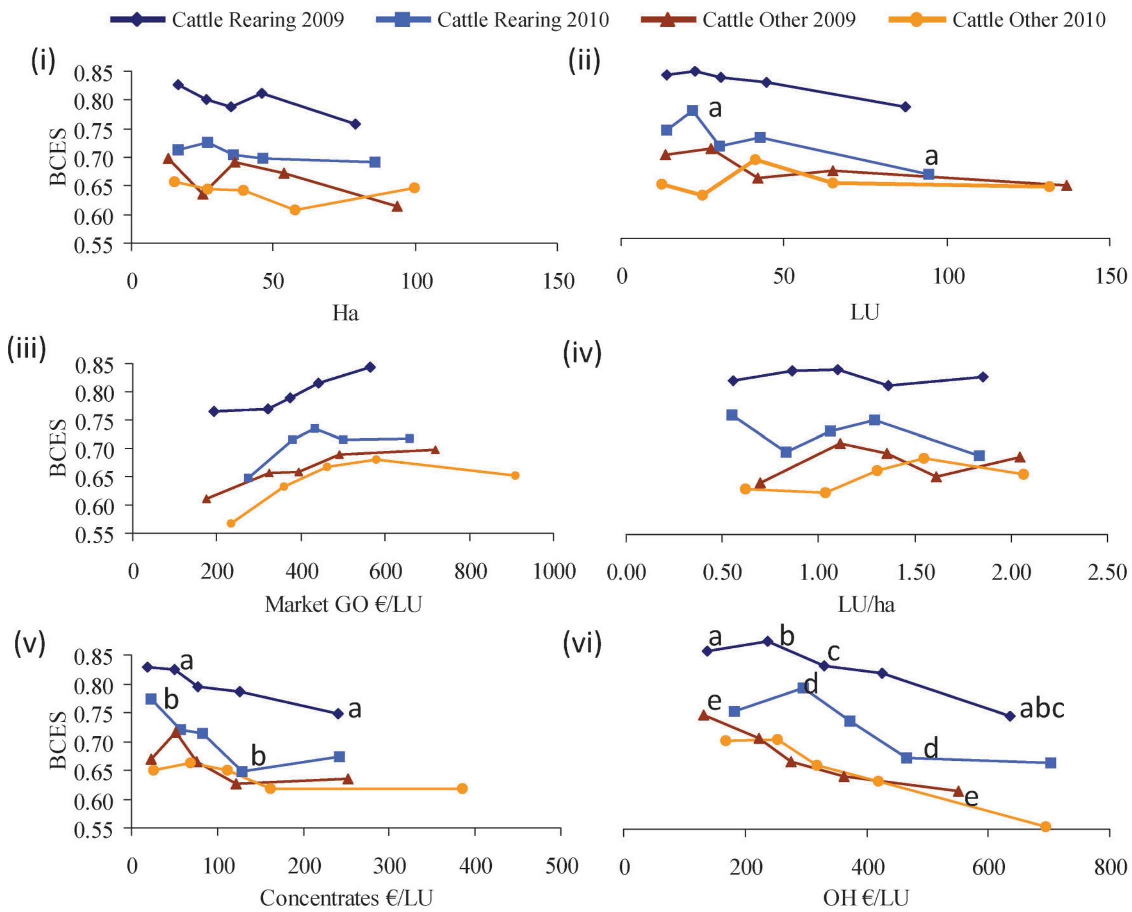

Figure 2: Effect of six quintile-ranked explanatory variables on bias corrected income efficiency scores (BCES) for two cattle systems and two years
Ha = hectares; LU = Livestock units; GO = Gross output - €; OH = Overhead costs - €
Data-points with common subscripts are significantly different within year and system ($P < 0.05$)

Scale efficiency

Chavas *et al.* (2005) defined a scale efficient farm as one for which output or earnings could not be improved by increasing or decreasing the size of the input/output mix. Bias corrected scale efficiency score (SES) was calculated for each DMU in the dataset using the calculation of Fried *et al.* (2008) and substituting BCES for efficiency score:

$$SES\ DMU_i = BCES_{CRS}\ DMU_i / BCES_{VRS}\ DMU_i \qquad (2)$$

Where $BCES_{CRS}$ is the constant returns to scale bias-corrected efficiency score and $BCES_{VRS}$ is the variable returns to scale efficiency score.

Scale efficient farms have a scale efficiency score of unity, meaning that these farms are equally efficient under models assuming constant and variable returns to scale (farm F in Figure 1). Such farms may be said to be operating at optimal scale and productivity cannot be increased on these farms by changing scale. Scale inefficient farms were then classified as operating at either 'increasing returns to scale' (IRS) or 'decreasing returns to scale' (DRS). IRS farms could increase income efficiency by increasing scale while income efficiency would decline on DRS farms if scale increased. Farms were subsequently classified into evenly sized terciles ranked on bias-corrected scale efficiency score. Characteristics of each scale efficiency tercile were compared to determine management or demographic factors associated with scale efficiency.

3. Results

Income efficiency scores

The mean deterministic income efficiency scores ranged from 0.76 (CO 2010) to 0.86 (CR 2009). The proportion of farms exhibiting a deterministic income efficiency score of unity ranged from 17 to 21% (CO 2010 and CO 2009 respectively) (Table 2). Input slacks for each input variable are presented in Table 3. These input slacks are quantified using an input oriented model and are presented to indicate the inherent sources of input inefficiency within each beef production system. The mean input slack is the extent of over-supply of a given input on the average farm relative to farms on the efficiency frontier. The slack of 5 ha for CR 2009 indicates that the average farm in that sample would need to reduce area farmed by 5 ha to achieve income efficiency under an input minimising model. A ratio of input slack to input variable mean is shown as an indicator of the relative importance of that input to efficiency. Variables exhibiting high slack to input mean ratios indicate that that particular input is of greater importance in determining farm level income efficiency, therefore direct payments, a relatively fixed input, exhibits the lowest slack. Conversely, the slack results indicate that reducing overhead costs and

Table 2: Sample mean income efficiency scores and bootstrapping results under assumptions of both variable and constant returns to scale for two beef farm systems for 2009 and 2010

	Cattle Rearing		Cattle Other	
	2009	2010	2009	2010
Variable returns to scale				
Deterministic mean efficiency score	0.86	0.81	0.78	0.76
Proportion of sample efficient [1]	0.19	0.21	0.21	0.17
Bias corrected mean efficiency score	0.80	0.71	0.66	0.64
Bias [2]	0.06	0.10	0.12	0.12
5% confidence interval	0.76	0.68	0.64	0.63
95% confidence interval	0.85	0.80	0.78	0.75
Constant returns to scale				
Deterministic mean efficiency score	0.58	0.60	0.50	0.45
Proportion of sample efficient	0.10	0.11	0.13	0.11
Bias corrected mean efficiency score	0.45	0.45	0.39	0.35
Bias	0.14	0.15	0.11	0.10
5% confidence interval	0.46	0.47	0.36	0.32
95% confidence interval	0.57	0.59	0.59	0.43

[1]Proportion of sample with efficiency score equal to one in the deterministic income efficiency model
[2]Bias and confidence intervals calculated from 10,000 bootstrap replications (Simar and Wilson, 1998)

concentrate feed costs provide the greatest potential to achieve increased efficiency. Greater slacks were also observed on the CO farms than on the CR farms, highlighting greater potential for cattle finishing farms to improve their income efficiency.

Explanatory variable differences

Table 4 shows differences in size, system, intensity, environmental and demographic variables between the top and bottom thirds ranked on income efficiency score. Six key variables were further analysed to identify their effect on BCES. These variables were ranked in quintiles and plotted against BCES in Figure 2.

Size

The top and bottom thirds ranked on income efficiency were of similar size in terms of livestock units and hectares. However, the top third of CR farms had significantly less hectares in 2009 and significantly less livestock units in 2010. The top third of farms tended to have greater farm gross output than the bottom third. However differences were slight and non-significant. Figure 2 shows a peak efficiency score for CR farms at 22 LU and at 28 and 41 LU for CO farms in 2009 and 2010, respectively. In LU terms, both larger and smaller CO farms were less efficient than those with intermediate cattle numbers. For CR farms, although intermediate size farms were most efficient, smaller farms tended to be more efficient than the largest quintile (Figure 2). The top third of CR farms received greater farm direct payments than the bottom third, however any differences within the CO group were non-significant.

System and intensity

There were no significant differences in labour input, or AI usage between high and low efficiency groups. There was generally no significant effect of stocking rate on efficiency except for a slight positive effect for CO 2010. Concentrate expenditure had a significantly negative impact for the CR farms and was much less negative for the CO farms, indicating a return to concentrate feeding on some CO farms but not on CR farms. Gross output value/LU was strongly positive for cattle rearing farms and somewhat less so for CO farms. Market gross output/LU (i.e. output value excluding subsidies) appeared to reach an optimum at about €400 for CR and €580 for CO farms in 2010 (Figure 2). Increased market gross output above those levels in that year were achieved at the expense of declining income efficiency. There was a tendency towards a lower proportion of land rented for the top third of farms, although only significant in CR 2009. The more efficient CO farms were less specialised in terms of LU species. Overhead costs per LU had a significantly negative effect on BCES in all systems and years, as did depreciation and interest repayments.

While not significant, there was a repeated tendency for the higher income efficiency CR farms to market cattle as weanlings and for the low income efficiency CR farms to market cattle directly for slaughter. Direct payments/LU were significantly greater for the higher income efficiency CR farms, but there was no significant difference in this measure between high and low income efficiency CO farms. High income efficiency farms had greater labour input, but not significantly greater for CR farms. Investment in machinery, buildings and livestock exhibited varying degrees of significance across systems and years but the tendency was for a negative effect of investment on income efficiency score.

Demographic variables

There was no significant difference in farmer age, proportion of family labour, soil type, off-farm employment or income or participation in an environmental stewardship programme (Rural Environmental Protection Scheme; REPS) between the top and bottom BCES thirds. Fragmentation had a negative effect on income efficiency but only significantly so in CR 2010 (Table 4). Although not generally significant, there was a tendency for the least income efficient farms to be situated in the eastern region of Ireland; Meath, Kildare, Wicklow, Dublin, and the most income efficient farms to be situated in the west, mid-west or south-west.

Table 3: Slacks for model input variables under an input oriented efficiency model

		Model Input	Land area	Labour	Fertiliser	Concentrates	Livestock units	Other variable costs	Overhead costs	Direct payments
		Units	*Ha*	*Labour units*	€	€	*LU*	€	€	€
Cattle Rearing	2009	Slack	5	0.10	733	1,295	6	1,808	6,000	427
		Slack/mean	0.12	0.09	0.31	0.40	0.14	0.31	0.46	0.02
	2010	Slack	3	0.12	1,011	1,373	5	1,634	4,543	577
		Slack/mean	0.08	0.12	0.38	0.38	0.13	0.27	0.30	0.03
Cattle Other	2009	Slack	11	0.20	1,175	1,865	15	1,603	7,703	1,433
		Slack/mean	0.26	0.19	0.33	0.31	0.26	0.22	0.48	0.06
	2010	Slack	7	0.34	551	3,033	12	1,882	6,158	848
		Slack/mean	0.16	0.32	0.16	0.47	0.23	0.23	0.34	0.04
CR mean slack/input mean			0.10	0.10	0.34	0.39	0.14	0.29	0.38	0.03
CO mean slack/input mean			0.21	0.25	0.24	0.39	0.24	0.22	0.41	0.05
Cross system mean slack/input mean			**0.15**	**0.18**	**0.29**	**0.39**	**0.19**	**0.25**	**0.39**	**0.04**

Scale efficiency

Table 5 shows mean scale efficiency scores and the number of farms exhibiting IRS, DRS and scale efficient. Farms with an SES of one lay on the production frontier and were efficient whether CRS or VRS was assumed in DEA efficiency calculation. 7% of all sample farms were scale efficient in 2009 and 2010. Of the remaining farms, just 1% and 4% of the CR farms exhibited increasing returns to scale in 2009 and 2010 respectively. No CO farms exhibited increasing returns to scale in either year. The top third SES farms were smaller, less intensive and retained more of their direct payments as income than the bottom third (Tables 6 and 7). The top third CO farms also rented proportionally less land, employed less non-family labour and held less fragmented farms. These traits were either weaker or not observed for CR farms. Overheads/LU were not significantly different for high and low scale efficiency farms, except for CO 2010 where overheads/LU were greater on the high scale efficient farms. High SES farms were significantly more specialised. While the larger, low SES farms were more intensive (LU/ha) (Table 7), market net margin and FFI per hectare were not significantly different to the smaller, low SES farms. No economies of scale with respect to fixed costs were observed, i.e. no advantage in terms of lower overhead costs/LU for the larger, lower SES farms (the exception being CO 2010).

4. Discussion

Scale and intensity

Non-linear relationships between scale and efficiency have been previously reported by Latruffe *et al.* (2005) in a study of Polish livestock farms and Hansson (2008) in a study of Swedish dairy farms. However the relationships reported in those studies were 'u' shaped (intermediate scale farms exhibiting lower efficiency than smaller and larger farms), rather than the 'n' shaped curves evident in Figure 2. In terms of both intensity and size, intermediate farms were more efficient, indicating an optimal scale and intensity close to the mean. Therefore only a small minority (<4%) of cattle rearing farms can increase efficiency by increasing scale (Table 5). There was little potential identified for cattle other farms to increase efficiency by increasing scale.

Furthermore, stocking rate appears to be a lesser determinant of income efficiency than either scale or market gross output per livestock unit. Similar to the scale effect, stocking rate exhibited a 'n' shaped relationship with efficiency (Figure 2iv). This is indicative of an optimal stocking rate close to the sample mean, between 1.0 and 1.5 LU/ha. This contrasts with an almost linear positive relationship of stocking rate with gross margin reported in a study of Irish suckler systems in 2010 (Teagasc Specialist Service, 2011). However, that analysis was partial rather than whole-farm in that farm fixed costs were allocated on an LU basis to the suckler enterprise. It appears that increasing stocking rates above optimal levels may reduce profitability due to increased expenditure on buildings and purchased concentrates. Therefore in order to improve income efficiency, increased stocking rates must be associated with increased utilisation of low cost grazed pasture rather than an

Table 4: Mann-Whitney test results for differences in explanatory variable means for beef farms ranked in income efficiency groups of top and bottom 1/3

System	Cattle Rearing						Cattle Other					
Year	2009			2010			2009			2010		
Income efficiency tercile	Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3	
Size variables												
Income efficiency score	0.89	0.69	***	0.84	0.57	***	0.82	0.50	***	0.79	0.47	***
Scale efficiency score	0.58	0.51	***	0.65	0.58	***	0.56	0.59	NS	0.50	0.57	NS
Total livestock units - LU	44	46	NS	43	46	**	52	54	NS	56	52	NS
Land area - ha	42	45	*	47	44	NS	42	44	NS	46	47	NS
Farm gross output - €	40,600	35,129	NS	41,745	38,508	NS	48,263	42,041	NS	54,545	41,712	NS
Farm direct payments - €	21,057	18,565	***	21,224	18,230	***	21,754	20,366	NS	22,943	18,774	NS
System and intensity variables												
Stocking rate - LU/ha	1.24	1.21	NS	1.11	1.23	NS	1.34	1.33	NS	1.35	1.23	*
LU/labour unit	32	29	NS	28	30	NS	33	31	NS	35	27	NS
Gross output - €/LU	978	772	***	1,058	864	***	918	790	**	992	976	*
Direct payments - €/LU	548	433	***	595	440	***	447	421	NS	443	496	NS
Concentrate costs - €/LU	74	123	***	82	125	***	103	123	*	143	181	NS
Fertiliser costs - €/LU	60	68	NS	58	69	***	57	63	NS	63	62	NS
Depreciation - €/LU	69	121	***	94	119	**	60	100	***	78	133	***
Interest payments - €/LU	18	24	***	11	15	**	9	18	**	9	15	NS
Other variable costs - €/LU	146	176	***	144	168	***	123	159	***	124	163	***
Overhead costs- €/LU	285	438	***	329	430	***	275	337	***	296	454	***
Machinery investment - €/LU	365	616	***	413	505	NS	400	510	NS	400	654	*
Buildings investment - €/LU	601	952	***	679	824	NS	432	741	***	476	857	***
Livestock investment - €/LU	910	938	NS	896	956	**	898	964	*	836	1,000	***
AI - € per cow[1]	8	7	NS	6	8	NS	–	–	–	–	–	–
Rented land[2]	0.10	0.17	**	0.14	0.14	NS	0.13	0.17	NS	0.14	0.12	NS
Specialisation[3]	0.97	0.96	NS	0.96	0.94	NS	0.95	0.96	NS	0.92	0.97	***
Environmental and demographic variables												
Age of holder - years	54	53	NS	54	52	NS	59	59	NS	59	59	NS
Family labour[4]	0.99	0.98	NS	0.99	0.97	NS	0.98	0.98	NS	0.99	0.97	NS
Fragmentation[5]	3.1	3.2	NS	2.9	3.4	*	2.9	3.2	NS	3.2	3.3	NS
Off-farm income[6]	–	–	NA	973	928	NS	–	–	NA	681	860	NS
Soil[7]	2	4	NS	5	3	NS	5	1	NS	5	3	NS
REPS participation[8]	54	59	NS	66	56	NS	55	45	NS	46	41	NS
Off-farm employed[9]	78	76	NS	82	71	NS	71	77	NS	69	76	NS

[1]Artificial insemination expenditure per cow or breeding heifer
[2]Rented land area as a proportion of total area farmed
[3]Cattle LU as a proportion of total LU
[4]Family labour employed as a proportion of total labour employed
[5]Number of land parcels
[6]Monthly off-farm income; not recorded in 2009
[7]Soil qualitatively classified from 1 to 6 on potential agricultural use; soils classified 1 have broadest use, soils classified 6 have limited use
[8]Rural Environmental Protection Scheme – percentage of farms participating
[9]Percentage of farms with holder or spouse in off-farm employment
Significance levels: *** P<0.01; *** P<0.05; * P<0.10; NS = Not significant

Table 5. Mean income and scale efficiency scores and number of farms exhibiting increasing, constant or decreasing returns to scale

System	Year	IRS[1]	CRS[2]	DRS[3]	IES[4]	Bias	SES[5]
Cattle Rearing	2009	3	5	220	0.80	0.06	0.56
	2010	9	5	204	0.71	0.10	0.63
Cattle Other	2009	0	24	163	0.66	0.12	0.55
	2010	0	29	220	0.64	0.12	0.52

[1]Increasing returns to scale
[2]Constant returns to scale; these farms are fully scale efficient (IES = 1)
[3]Decreasing returns to scale
[4]Income efficiency score (under variable returns to scale model)
[5]Scale efficiency score

increase in purchased inputs (Finneran *et al*., 2012). The observed positive relationship of market gross output per livestock unit (Figure 2iii) with efficiency observed has been previously highlighted by Helfand and Levine (2004) in a study of Brazilian farms. It is indicative of either improved genetic merit of livestock sold or an improved marketing strategy relative to the mean.

Although the bottom third farms ranked on SES were 1.8 to 4 times the scale of the bottom third in LU terms, overhead costs and FFI were not significantly different. This suggests that these larger farms were not taking advantage of economies of scale. This is because overhead costs and depreciation were rising almost linearly with rising livestock numbers. Thus, it appears that the more intensive (higher stocking rates) production systems employed by these larger farms are associated with increased fragmentation, land rental and machinery and livestock investment. The negative effects of fragmentation and associated travel between dispersed land parcels have been identified previously by O'Neill and Matthews (2001) and Del Corral *et al.* (2011).

Market net margin was negative across systems and years and not significantly different between low and high scale efficiency farms (Table 6). Therefore, the larger (low SES) farms suffered more negative farm market net margins, but earned significantly greater farm direct payments than the smaller, more scale efficient farms (Table 7). These larger farms received lower direct payments/LU, indicating a greater diversion of subsidies towards livestock and capital investment than on the smaller farms.

Therefore, it appears that there are two principal divergent strategies for maximising household income on cattle farms. Despite negative market net margins, larger farms appear to utilise the direct payments as a subsidy for increased scale and intensity of production, and a source of investment finance (supported by greater borrowings – Table 7), in addition to an income support. This tendency to use subsidies to support unprofitable production – despite the primary subsidy (the single farm payment) being fully decoupled from production – has been previously identified by Howley *et al.* (2012). Smaller farmers in contrast retain a greater proportion of the direct payments as FFI and supplement this with greater monthly off-farm income. Smaller farms thereby maintain a low scale, low intensity production strategy and consequently achieve greater farm scale efficiency.

Management, environmental and demographic effects

High concentrate feeding on cattle rearing farms was a significant impediment to income efficiency. This relationship has been identified and explored previously by Kelly (2000) and Crosson *et al*. (2007), with increased utilisation of grazed grass and home produced forages a recommended solution to this constraint (Finneran *et al*., 2012). Achieving increased grass utilisation while minimising capital and labour investment is a considerable challenge on low profit beef farms. However, given that the greatest input slacks were observed for concentrate feed and overhead expenditure (Table 3), reducing these inputs while maintaining or increasing output would appear to provide the greatest potential for efficiency increases.

Surprisingly, soil type was found to have no effect on income efficiency, however farms in the western regions of the country typically exhibited greater efficiency scores. This may be because soil and climate is more suited to dairy and cereal production in the east of the country and therefore the more profit oriented farmers are most likely to choose these more profitable enterprises over beef production in the east (Boyle, 2002).

The lack of any effect of labour input on income efficiency is striking. Greater labour input/LU was associated with greater scale efficiency (although not significant on CR farms). It is clear that the higher proportions of (generally unpaid) family labour utilised on smaller farms is a key component of the greater scale efficiency of these farms. This finding accords closely with the results presented by Latruffe *et al*. (2005).

Similar to the results of Carroll *et al.* (2007), Lien *et al.* (2010) and Kelly *et al.* (2012), off-farm employment had no effect on-farm income efficiency. This is likely due to smaller, part-time farmers implementing farm production strategies which permit most efficient allocation of resources between off and on-farm employment (Chavas *et al*., 2005; Lien *et al*., 2010).

Greater capital investment in a low profit enterprise such as beef production was associated with lower farm income efficiency in the short run. Longer term productivity analysis such as Malmquist Index modelling would be required to determine the long term effect of such investment. Such a model should ideally take account of increasing fixed asset values by including net worth change as a model output in addition to annual farm income.

Table 6: Mann-Whitney test results for differences in farm financial measures for beef farms ranked in scale efficiency groups of top and bottom 1/3

System	Cattle Rearing						Cattle Other					
Year	2009			2010			2009			2010		
Scale efficiency tercile	Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3	
Scale efficiency score	0.74	0.40	***	0.81	0.46	***	0.85	0.33	***	0.82	0.29	***
Gross margin - €/ha	542	529	NS	571	567	NS	577	680	**	694	713	NS
Market net margin - €/ha	−234	−216	NS	−197	−201	NS	−221	−185	NS	−182	−180	NS
Family farm income - €/ha	230	194	NS	232	205	NS	265	290	NS	338	278	NS
Off-farm income[1]	–	–	NA	1,168	915	NS	–	–	NA	1,053	720	**

[1]Monthly off-farm income; not recorded in 2009
Significance levels: *** P<0.01; *** P<0.05; * P<0.10; NS = Not significant

5. Conclusions

The highly heterogeneous nature of physical output from Irish beef farms, and the prevalence and diversity of complementary enterprises create impediments to efficiency modelling. Development of a whole-farm income efficiency DEA model has partially overcome these constraints, as well as providing more holistic solutions than could be derived from comparative analysis using partial measures of profit such as gross margin analysis. By including direct payment subsidies as both inputs and outputs (as a component of FFI) the model took consideration of the efficiency with which the farmer retained these direct payments as an income support or employed them as a production subsidy. While this whole-farm approach may provide a richer picture of efficiency drivers than partial analysis approaches, further studies including off-farm income and non-economic factors could provide even greater insights. Given that social and environmental factors can play as great a role as economic factors in farm decision-making (Macken-Walsh, 2010) they should be considered in any truly holistic family farm model.

Little opportunities exist to increase beef farm efficiency by way of increased scale, although this may be possible for a minority of the smaller, less intensive cattle rearing farms. Smaller, more scale efficient beef farms retained more direct payments as income and supplemented this with greater off-farm income. Larger, less scale efficient farms utilised direct payments to subsidise increased investment in rented land and additional livestock. These larger, more fragmented farms are not achieving economies of scale because overhead costs and investment are increasing linearly with livestock unit increases. This may be associated with greater stocking rates requiring greater machinery and building investment. Substituting capital inputs and paid labour for unpaid family labour is also contributing to reduced scale efficiency on larger farms.

Smaller farms with off-farm incomes are classified as "sustainable" by Hennessey *et al.* (2012), however, their existence is dependent on the continued availability of off-farm employment in rural areas. That the regions with the smallest farm size, (border and west) are also the regions experiencing the greatest unemployment rates nationally (Central Statistics Office, 2012b) is of concern. At the other end of the size scale, larger farms are more dependent on the continuity of direct payment subsidies. Prospects of increasing beef output by means of scale expansion are therefore negative in an external environment of declining subsidies and off-farm employment in rural areas.

Increased output from Irish beef farms must therefore come primarily from farm system structural changes rather than scale changes, otherwise farm income efficiency will decline. High overhead costs per livestock unit and high concentrate feeding on cattle rearing farms were identified as significant constraints to income efficiency. Maximising output from grazed forage on owned land is likely to result in the greatest income efficiency.

Prescriptive advice from a farm comparative analysis study may provide greater insight when conducted over a longer time period than two years. Long run farm efficiency analysis should include non-income benefits of the farming system such as accumulation of net worth. A

Table 7: Mann-Whitney test results for differences in explanatory variable means for beef farms ranked in scale efficiency groups of top and bottom 1/3

System	Cattle Rearing						Cattle Other					
Year	2009			2010			2009			2010		
Scale efficiency tercile	Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3	
Size variables												
Scale efficiency score	0.74	0.40	***	0.81	0.46	***	0.85	0.33	***	0.82	0.29	***
Income efficiency score	0.83	0.77	***	0.74	0.67	***	0.68	0.64	NS	0.64	0.62	NS
Total livestock units - LU	24	49	***	29	52	***	26	97	***	24	97	***
Land area - ha	30	49	***	38	48	***	27	68	***	29	75	***
Farm gross output - €	22,178	40,209	***	29,087	44,453	***	22,899	76,550	***	28,597	82,850	***
Farm direct payments - €	13,312	20,095	***	15,222	21,534	***	12,735	33,187	***	12,831	33,900	***
System and intensity variables												
Stocking rate - LU/ha	1.00	1.23	***	0.99	1.21	***	1.18	1.54	***	1.08	1.56	***
LU/labour unit	23	30	NS	26	28	NS	26	55	***	20	60	***
Gross output - €/LU	953	854	**	1059	889	**	858	807	NS	1173	863	***
Direct payments - €/LU	586	455	***	602	463	***	503	349	***	642	353	***
Concentrate costs - €/LU	108	98	NS	123	91	NS	80	127	***	164	143	NS
Fertiliser costs - €/LU	59	64	NS	61	64	NS	56	63	NS	62	68	*
Depreciation - €/LU	87	92	NS	128	95	**	67	73	NS	112	91	NS
Interest payments - €/LU	16	20	***	13	16	NS	5	16	***	7	18	***
Other variable costs - €/LU	167	158	NS	179	146	***	149	124	*	162	141	NS
Overhead costs- €/LU	377	342	NS	433	365	NS	292	285	NS	409	319	*
Machinery investment - €/LU	405	481	*	604	428	NS	434	398	NS	547	439	NS
Buildings investment - €/LU	734	706	NS	803	656	NS	528	562	NS	703	610	NS
Livestock investment - €/LU	890	912	NS	894	901	NS	876	910	NS	892	960	**
AI - € per cow[1]	11	8	NS	10	7	NS	–	–		–	–	
Rented land[2]	0.14	0.15	NS	0.15	0.14	NS	0.09	0.15	**	0.07	0.16	***
Specialisation[3]	0.97	0.96	**	0.96	0.95	**	0.97	0.92	***	0.97	0.92	***
Environmental and demographic variables												
Age of holder - years	53	54	NS	53	55	NS	59	57	NS	60	56	*
Family labour[4]	0.99	0.98	*	0.98	0.96	NS	1.00	0.95	***	1.00	0.96	***
Fragmentation[5]	3.1	2.9	NS	3.4	3.1	NS	2.5	3.5	***	2.7	3.9	***
Off-farm income[6]	0	0		1168	915	NS	0	0		1053	720	**
Soil[7]	3	2	**	5	2	NS	5	1	NS	3	1	NS
REPS participation[8]	42	61	***	63	51	NS	44	56	NS	36	40	***
Off-farm employed[9]	83	74	NS	84	73	NS	74	76	NS	76	70	NS

[1]Artificial insemination expenditure per cow or breeding heifer
[2]Rented land area as a proportion of total area farmed
[3]Cattle LU as a proportion of total LU
[4]Family labour employed as a proportion of total labour employed
[5]Number of land parcels
[6]Monthly off-farm income; not recorded in 2009
[7]Soil qualitatively classified from 1 to 6 on potential agricultural use; soils classified 1 have broadest use, soils classified 6 have limited use
[8]Rural Environmental Protection Scheme – percentage of farms participating
[9]Percentage of farms with holder or spouse in off-farm employment
Significance levels: *** P<0.01; *** P<0.05; * P<0.10; NS = Not significant

broader, multi-output model could more accurately reflect farmers likely long term behaviour under changing regulatory and macro-economic circumstances.

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