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The Effect of Land Fragmentation on the Technical Inefficiency of Dairy Farms

Tracy Bradfield, Robert Butler, Emma Dillon, Thia Hennessy and Paul Kilgarriff[1]

Abstract

Exploiting the link between land identification and farm accountancy data, we use a uniquely detailed database to conduct a robust analysis of land fragmentation and its effect on technical inefficiency on dairy farms in Ireland. Using a Stochastic Production Frontier model, our results show that the number of parcels, the average distance between parcels and the main farm, and the portion of land separate from the main farm all increase technical inefficiency. Such inefficiency can be reduced through increased parcel area, reduced travel distances, advisory services contact, intensive practices and hired labour. Our findings support the need for policy to improve land and labour mobility, providing evidence to support incentives to promote the transfer and long-term leasing of agricultural land.

Keywords: land fragmentation, technical efficiency, dairy, agricultural policy

JEL Classifications: *Q15, Q18*

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[1] Tracy Bradfield (contact author: t.bradfield@umail.ucc.ie) and Robert Butler are both in the Department of Economics, Cork University Business School, University College Cork, Ireland. Emma Dillon is with the Agricultural Economics and Farm Surveys Dept, Teagasc, Athenry, Co. Galway, Ireland. Thia Hennessy is in the Dept. of Food Business & Development, Cork University Business School, University College Cork, Ireland. Paul Kilgarriff is in the Luxembourg Institute of Socio-Economic Research, Luxembourg. This research was supported by the Teagasc Walsh Scholarship Programme. The authors gratefully acknowledge anonymous referees and the Editor for their helpful comments on previous drafts.

1. Introduction

Climate change will limit the area of the world where farming can remain economically viable and environmentally sustainable (Levy and Patz, 2015). Simultaneously, rising global population calls for a 70% increase in food production by the year 2050 (Looga et al., 2018). Technical efficiency and agricultural productivity must improve to ensure global food security. Moreover, efficient and effective land management is a key element of a more productive and environmentally sustainable pastoral livestock sector. We use a unique dataset to explore the effect of land structure, and in particular land fragmentation (LF), on the technical efficiency of dairy production in Ireland.

LF is the division of land holdings into discrete parcels that are dispersed over a wide area (Binns, 1950). Four types of LF are distinguished in the existing literature: fragmentation of land ownership; land use; internal fragmentation within a farm; and separation of ownership and use (Van Dijk, 2003). Although the degree of LF is high in some of the main milk producers of the EU (Saint-Cyr et al., 2016), there is a lack of empirical research analysing this issue in the context of milk production since the work of Orea et al. (2015) which examines data between 1999 and 2011. We focus on internal fragmentation and its effect on technical efficiency in the Irish dairy industry. Ireland presents an interesting case study as it has the highest proportion of land, of countries within the EU, dedicated to agriculture at 70 percent (Eurostat, 2020). Furthermore, agricultural land in Ireland is fragmented[2] and there is rapid expansion of the dairy sector, which is largely pasture based and, therefore, sensitive to land availability and structure. Ireland experiences notably low levels of agricultural land sales each year[3]. In recognition of the importance of land management to the overall productivity of the dairy sector, the

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[2] Including all farm types, Ireland has a mean of 12.51 land parcels with a mean area of 10 hectares, compared to a mean of 24.11 parcels and 5 hectares across nine European countries. Ireland possesses an average distance of 10.89 km between plots compared to the study's average of 3.74km. The study within the FLINT project assesses LF in Germany, Spain, Finland, France, Greece, Hungary, Ireland, Netherlands and Poland (Saint-Cyr et al., 2016).

[3] Ireland experiences low levels of sales each year, reflecting high sentiment for family land. Agricultural land sold in 2018 was 0.3% of all the available agricultural land in Ireland (CSO.ie, 2019).

Irish Department of Agriculture offers tax relief for land consolidation[4] and long-term land leasing.[5]

The technical efficiency of dairy farming has implications for the environment, in terms of the efficient use of natural resources and farm inputs, and also for the economy and rural development, in terms of the productivity of the sector and the multiplier effect, with further implications for global food security. Our motivation is to establish whether land fragmentation is detrimental to the overall technical efficiency of the dairy sector and whether there is evidence to support specific policy measures to tackle land fragmentation.

We contribute to existing knowledge of farm efficiency by applying the Simpson index to dairy farms for the first time[6] and by examining LF in more detail that has been examined previously. Specifically, the impact of the number of parcels, average parcel area, the distance between parcels, and the portion of land on the main farm are all assessed. We contribute to previous work that examines the technical efficiency of dairy farms in Ireland (Kelly et al., 2013; Kelly et al., 2012; Carroll et al., 2007) by also examining the impact of land fragmentation on technical efficiency. We combine data from the Irish National Farm Survey and the national farm boundary spatial database SLIDE (Spatial Land Identification Database for Éire) which has not previously been used to assess LF. The paper is organised as follows. In Section 2 the background and conceptual framework are discussed. Section 3 describes the data and Section 4 details the empirical specification. This is followed by the empirical results and discussion in Section 5 and Section 6. Section 7 concludes.

2. Background & Conceptual Framework

2.1 Background

[4] Capital gains tax relief is available for land consolidated by sale, purchase or exchange (Revenue, 2020). Stamp duty of 1%, reduced from 6%, is applied to the excess value of land acquired over the value of the land disposed of. The exchange must occur within a 24-month period (Revenue, 2019).

[5] From 2015, up to €40,000 of income tax relief can be obtained on a 15 year lease (Revenue.ie, 2019).

[6] Latruffe and Piet (2014) apply the Simpson index to farms in France. However, only 29% of the sample engage in mainly dairy production.

Because cows have to travel to the milking parlour, land fragmentation deters herd expansion and frequent milking. Increased travelling time between fields reduces the efficiency of machines and labour (Buller and Bruning, 1979; Del Corral et al., 2011). Also, land is lost to plot boundaries and access routes (Orea et al., 2015). As noted by Sauer et al. (2012), LF also influences farmers' decisions to leave land fallow or idle.

Existing studies on the effect of LF on farm performance give differing results. Looga et al. (2018) note that the relationship may be positive or negative depending on the specific unit of analysis, and productivity and fragmentation indicators, which may be calculated at farm or region level data. We test the hypothesis that LF contributes to technical inefficiency on dairy farms in Ireland.

2.2 Factors Affecting Technical Inefficiency

A farm is considered technically inefficient if it could potentially increase its output level without increasing its input level, or, reduce its input level without reducing its output level (Carroll et al., 2007). Del Corral et al. (2011) is one of the first studies to assess the effect of LF on technical inefficiency in the dairy industry, using data from Spain. Their results show that the number of land parcels increases technical inefficiency, albeit at a decreasing rate. Also, the greater the farm size, the higher the technical inefficiency. Consequently, a decrease in land parcels increases profits by 9.4 to 14 percent. These authors find that intensive farming practices reduce technical inefficiency while the greater proportions of family labour increase technical inefficiency.

Orea et al. (2015) extend the work of Del Corral et al. (2011) by studying the technical inefficiency of dairy farms in Northwest Spain. Orea et al. (2015) find that, among extensive farms[7], the number of plots has a positive relationship with technical inefficiency. The family to total labour ratio is not found to be significant. Both Del Corral et al. (2011) and Orea et al. (2015) use owned land as a proxy variable to assess how the location of plots affects technical inefficiency, on the basis that farmers tend to own the land closest to the main farm. Their analyses ignore the performance differences

[7] Extensive farms are those considered to have low stocking rates and low use of purchased feeds.

between rented and owned land, which is driven by high opportunity costs and self-selection, as outlined by Bradfield et al. (2020) for the Irish dairy industry.

Niskanen and Heikkilä (2015) look at the effects of parcel size and parcel distance on technical inefficiency on dairy farms in Finland. The results show that increased parcel area reduces technical inefficiency and increased parcel distance increases technical inefficiency. However, they do not consider how the number of parcels or farm demographics may alter the relationship. Looga et al. (2018) have since noted that studies often lack empirical testing of whether the impact of LF on productivity remains positive or negative if other control variables, which are not related to LF, are included in the model.

Although technical inefficiency has been previously studied in Ireland, the important issue of LF has not been considered. In Ireland, agricultural land is an important area of research as O'Donnell et al. (2008) show that land is under-utilised. Läpple and Hennessy (2012) note that the land area around the milking platform is a key factor limiting expansion of milk output, while Kelly et al. (2013) note that increased land availability is required to improve dairy farm performance. Irish dairy farms exhibit technical inefficiency, with Kelly et al. (2013) showing that technical efficiency is on average 0.76 under constant returns to scale. Within their study, only 12% of the sample studied are operating at their optimum scale. Kelly et al. (2012) note that technically efficient dairy farms produce 27 percent higher levels of milk solids per hectare compared to inefficient farms[8], with more efficient farms receiving €1,500 higher milk bonuses[9] on average. Evidence from both Carroll et al. (2007) and Kelly et al. (2013) suggests that stocking rates have a negative effect on Irish dairy farm technical inefficiency. Carroll et al. (2007) find that engagement with extension/advisory services reduces technical inefficiency. Martinez Cillero et al. (2018) find that older farmers are less efficient at cattle rearing.

[8] Mean technical efficiency score of 0.78 for inefficient producers compared to a mean score of 1 for efficient producers.
[9] Milk bonuses are financial rewards for better quality milk.

3. Data

We use data from the 2014 Irish Teagasc National Farm Survey (NFS) of 900 farms. The survey is operated as part of the EU Farm Accountancy Data Network (FADN). It includes a representative sample of farms in the Republic of Ireland with a standard output of greater than €8,000 per annum, selected in conjunction with the Central Statistics Office (CSO).[10] The Teagasc NFS collects data from a stratified random sample of farms annually, with each farm in the survey assigned a weighting factor (Teagasc, 2015) to obtain estimates for all dairy farms in the Republic of Ireland. There were approximately 15,654 representative specialised dairy farms[11] with an average farm family income[12] of €67,598 in 2014 (Teagasc, 2015). Milk production per farm rose by 3 percent in 2014, supported by higher yields and a 2 percent rise in the average dairy herd size (Teagasc, 2015). The sample includes similar specialist dairy farms, that operate the typical spring calving system. We include farm characteristics to account for unobserved heterogeneity, while multicollinearity, assessed using Variance Inflation Factors and a correlation matrix, was not deemed problematic.

GIS methods are used to create the Irish national farm boundary spatial database SLIDE (Spatial Land Identification Database for Éire), utilising national administrative data (Land Parcel Identification System) and a spatial data storage model (Ordnance Survey Ireland Prime 2 data) (Kilgarriff et al., 2020). For the first time, we use data on the land structure of 293 nationally representative dairy farms.[13] These farms match to 96% of the representative sample of farms within the NFS.[14] Definitions of variables used in the analysis of technical inefficiency, and their means, are shown in Table 1.

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[10] The CSO classifies farms into size groups on the basis of their standard output by applying a standard output coefficient to each animal on the farm. Only farms with a standard output of €8,000 or more, the equivalent of 6 dairy cows, are included in the sample (Teagasc, 2015).
[11] Farms with a majority of output derived from dairy farming.
[12] This represents the total return to the family labour, management and capital investment in the farm business.
[13] 2014 is the only year for which this matched data is available.
[14] The mean litres of milk produced by the 293 farms is 99.5% of the total mean. No sampling bias is expected, given the near perfect matching of the two datasets.

Table 1. Variable Definitions

Variable	*Definition*	*Mean*	*Std. Dev.*
Milk Produced (,000s)	Litres of milk produced by the farm enterprise.	351.90	195.21
Dairy forage area (ha)	The total area under grass (including rough grazing) plus adjusted commonage for dairy enterprise.	33.72	16.37
Dairy direct costs (€,000s)	Costs that are readily allocated to the dairy enterprise e.g. purchased feeds, winter forage, vet, AI, casual labour. Lime usage and machinery operating costs are apportioned to the dairy enterprise.	50.09	31.30
Labour (€,000s)	The sum of the values of hired and family labour. The value of family labour is calculated as family labour units multiplied by the minimum agri. wage.	29.30	12.64
Capital (€,000s)	The value of land, buildings and machinery.	266.88	169.06
Parcels	The number of separate parcels of land within the farm.	6.08	3.43
Parcel area (ha)	Utilised agricultural area size divided by the number of parcels.	11.47	9.38
Distance to yard (km)	The average distance of land parcels to the main farm. This is a linear measurement.[15]	1.33	1.19
Main farm portion	Land on the main farm divided by total land farmed.	0.42	0.26
U.A.A. size	The utilised agricultural area, or farm area, in hectares.	57.14	29.20
Hired to family labour ratio	Paid units of labour (ie. hired) divided by unpaid labour units (ie. family). A labour unit is 1800 hours of work.	0.15	0.28

[15] The average distance is 1.65km. This variable is capped at 4km under the assumption that land far away from the main farm is not used in the daily running of the dairy enterprise. 90% of the sample have parcels within 4km from the main farm. Some farmers may have land away from the homestead that is used to reduce average nitrates per hectare, to satisfy government regulations.

Table 1. Variable Definitions (continued)

Variable	Definition	Mean	Std. Dev.
Owned land Ratio	Owned land divided by total land farmed.	0.78	0.21
Stocking rate	The herd size divided by the feed area (in hectares).	2.06	0.52
Farmer's age	The age of the farm holder.	53.09	10.13
Advisory services	= 1 if services are used, 0 otherwise.	0.83*	

*The proportion of farms that engage in advisory services.

The mean and median number of land parcels on dairy farms in Ireland is 6. 59% of farms have 6 or less parcels and 41% have between 7 and 22 distinct parcels of land. The percentage of dairy farms containing differing numbers of parcels is shown in Table 2.

Table 2. The Breakdown of Land Parcels on Dairy Farms

Number of Land Parcels	Percentage of Farms
1	2.0%
2 – 4	33.4%
5 – 7	34.8%
8 – 10	17.7%
11 – 13	8.2%
>13	3.8%

Source: Authors' computation

Preliminary assessment of the data shows that farms with a high degree of LF differ from farms with a fewer number of parcels, as illustrated in Table 3.

Table 3. Parcel Analysis (mean figures)

	1 to 4 Parcels	5 to 8 Parcels	> 8 Parcels
Parcel area (ha)	18.73	9.26	6.42
Distance between parcels & yard (km)	0.70	1.65	1.86
Main farm portion	0.58	0.35	0.22
Milk produced per ha (litres)	6,964.62	6,604.23	5,552.45
Dairy net margin per ha (€)	899.05	848.76	735.25
U.A.A/Farm size (ha)	49.26	57.62	74.64
Dairy forage hectares	30.38	34.17	41.09
Stocking rate	2.14	2.05	1.94

Source: NFS (2014)

T-tests[16] show that highly fragmented farms (with more than 8 land parcels) have a significantly lower mean average parcel size than all other farms, while their mean average distance between parcels and the main farm is also significantly greater. Both the average milk produced per utilised agricultural area (UAA) hectare and the dairy net margin per UAA hectare, are significantly lower for highly fragmented farms, suggesting negative effects of fragmentation. Both the number of parcels and the average distance between parcels and the main farm are divided by UAA hectares in our subsequent econometric analysis. We use interaction analysis to test for a significant linear relationship between these variables and farm size.

We add to existing research by Del Corral (2011) and Orea et al. (2015) by including the average distance to the main farm and land ownership as two separate variables, and we also consider the proportion of land on the main farm. A correlation matrix between the percentage of land owned and the average distance between parcels and the main farm, reveals only a weak relationship of 0.22. Given Ireland's policy to promote land leasing, we also investigate how land rental affects technical inefficiency,

[16] Details of t-tests are provided in the Appendix 1(on-line).

as land rental has been found to increase land consolidation and farmers' profits (Li et al., 2017).

4. Empirical Approach

We use a Stochastic Production Frontier (SPF) model (Aigner et al., 1977), to estimate technical inefficiency. This approach was also used by Del Corral et al., (2011), Orea et al., (2015), Niskanen and Heikkilä (2015) and Mehmood et al. (2018). Specifically,

$$\mathrm{y} = f(x).\exp(\varepsilon): \varepsilon = v - u \tag{1}$$

where: y is output, measured in our case as litres of milk produced, and
x is a vector of inputs
ε is a composed error term.
v captures statistical noise and other stochastic shocks, such as weather, and it is assumed to follow a normal distribution centered at zero.
u reflects farm technical inefficiency.

Although farms in the dataset are specialised in dairy production, the majority of farms are also involved in other farming activities. Therefore, capital and labour are allocated according to the farm's level of specialisation in dairy production[17]. On average, this figure is 81% in the dataset.

A translog functional form is the chosen specification for the SPF, since it provides a flexible representation of the production technology and does not assume perfect substitution between production factors (Klacek, et al., 2007). The specification involves, firstly, dividing input variables by their geometric mean in order to determine elasticities for the first-order coefficients. Following this, the SPF model in translog functional form is estimated by maximum likelihood;

$$lny = \beta_0 + \sum_{n=1}^{N} \beta_n \, lnx_n + \frac{1}{2}\sum_{n=1}^{N} \sum_{n=1}^{N} \beta_{nm} \, lnx_n lnx_m + \varepsilon \tag{2}$$

[17] This is the level of dairy gross output (€) divided by total farm output (€).

$$\epsilon = v - u$$

where *n* and *m* are farm inputs (direct costs, capital, herd size and labour). The model specification controls for heteroskedasticity within the technical inefficiency component. The estimation of the stochastic frontier translog production function makes it possible to verify whether the deviation in technical efficiencies from frontier output is due to farm specific factors or due to exogenous stochastic factors.

To examine LF, many papers, including Wu et al. (2005), Verschelde et al. (2011) and Kompas et al. (2012), use the Simpson index (Simpson, 1949) to measure LF. The index is derived as follows:

$$SI = 1 - \frac{\Sigma_n^n a_n^2}{(\Sigma_n^n a_n)^2} \quad (3)$$

where: n is the number of parcels and a_n is their size in square metres.

The formula contains three properties: the index increases with the number of plots; it increases when the size of plots tends to be similar, and it decreases when the plot size increases, and is 0 with no LF. However, it does not account for the scattering of parcels over space, which Kompas et al. (2012) note is a limitation of their study. We further explore the characteristics of LF by also including the number of farm plots, average area of the plots, the portion of land not on the main farm, and the average distance between the plots and the main farm.

5. Empirical Results

Firstly, the presence of technical inefficiency is tested using a SPF containing the log functional form of dairy direct costs, herd size, capital and labour, divided by their geometric mean, to create a production frontier. Lambda (λ) of greater than 1 is reported, which justifies the use of the SPF in determining milk production. Explanatory variables for the technical inefficiency term are subsequently included[18]. Both Cobb-Douglas and translog functional forms of the SFP are run and a log-likelihood ratio test confirms that

[18] Appendix 2, on-line, shows the stepwise addition of independent variables to the SPF, to ensure robustness of results.

the translog functional form offers a better fitted model. Full results of the translog SPF are shown in Table 4. All first order coefficients are positive and significant at the 99 percent confidence level.

Table 4. Stochastic Production Frontier Model

Milk Produced	**Coef.**	**Std. Err.**
Direct dairy costs (€)	0.39***	0.00
Capital (€)	0.03***	0.00
Labour (€)	0.04***	0.00
Herd size	0.58***	0.01
0.5(Direct dairy costs)^2	0.19***	0.02
0.5(Capital)^2	0.22***	0.02
0.5(Labour)^2	-0.05**	0.02
0.5(Herd size)^2	-0.67***	0.04
Direct dairy costs*Capital	-0.05**	0.02
Direct dairy costs*Labour	-0.15***	0.01
Direct dairy costs*Herd size	-0.01	0.02
Capital*Labour	-0.17***	0.01
Capital*Herd size	-0.01	0.02
Labour*Herd size	0.56***	0.02
Constant	5.88***	0.00

Statistically significant: ***at 1% level; **at 5% level; *at 10% level.
All variables are in log format.

Table 4. Stochastic Production Frontier Model (continued)

Technical Inefficiency	**Coef.**	**Std. Err.**
Parcels per ha	-14.82***	1.60
Parcels per ha^2	22.23***	2.41
UAA size	-0.06***	0.00
UAA size^2	0.00***	0.00
Distance to yard per ha	-64.49***	5.66
Distance to yard per ha^2	246.42***	24.88
UAA Size*Parcels per ha	0.12***	0.02
UAA Size*Distance to yard	0.48***	0.07
Main farm ratio	-2.27***	0.31
Main farm ratio^2	0.92***	0.30
Stocking rate	-0.45**	0.21
Stocking rate^2	0.21***	0.04
Owned land ratio	2.00***	0.64
Owned land ratio (sq)	-1.18***	0.44
Hired to family labour ratio	-2.19***	0.23
Hired to family labour ratio^2	1.42***	0.16
Advisory services	-0.47***	0.15
Age	-0.03**	0.02
Age^2	0.00***	0.00
Constant	0.87	0.61
σ_u	0.10	0.00
σ_v	0.09	0.00
λ	1.11	
$\sigma_u^2/(\sigma_u^2+\sigma_v^2)$	0.55	
Observations	292	

Statistically significant: ***at 1% level; **at 5% level; *at 10% level. Prob>chi2=0.00

Post-estimation analysis shows that an average technical efficiency score of 91% is achieved and no farm achieves complete technically efficiency. A breakdown of the mean characteristics of farms which operate below and above the average level of technical efficiency is outlined in Table 5. More efficient farms are considerably larger and more consolidated in terms of parcel numbers but have higher mean travel distances. However, as highlighted by the statistical significance of interaction effects in Table 4, farm size is influencing this relationship. Highly efficient farms tend to have a greater portion of land on the main farm and a lower portion of owned land.

Table 5. A Comparison of Means - Low and High Technical Efficiency Farms

	Low Efficiency	High Efficiency
Variable	Mean	Mean
Parcels per ha	0.12	0.11*
Parcel area (ha)	10.52	12.89**
Distance to yard (km) per ha	0.02	0.03*
Main farm portion	0.35	0.43***
UAA size (ha)	58.47	65.69**
Dairy forage area (ha)	33.64	38.42**
Owned land ratio	0.80	0.76*
Observations	105	187

Statistical significance of t-tests: ***at 1%; **at 5%; *at 10% level.

6. Discussion

6.1 Input elasticities

The results of the SPF in Table 4 show that direct dairy inputs, capital, labour and herd size have a positive effect[19] on milk production. The sum of their elasticities shows the existence of increasing returns to scale, with an output elasticity of 1.04. This is a slight decrease on the figure of 1.05 between 1996 and 2005, reported by Carroll et al. (2007). Similar to Del Corral (2011) and Carroll et al. (2007), herd size is the input with the highest output elasticity with an elasticity figure of 0.58[20]. Further research is required to assess how this has changed over time, following the elimination of the EU milk quota.

6.2 Land fragmentation

[19] The elasticity of each input has been calculated for individual farms. All elasticities are positive, satisfying the condition of monotonicity.
[20] Del Corral et al. (2011) and Carroll et al. (2007) report herd size elasticities of 0.68 and 0.67 respectively.

6.2.1 Economic benefits for farmers

The results show that an increase in the number of land parcels initially causes technical inefficiency to decrease, followed by a strong increase in technical inefficiency ($p<0.01$). A large average parcel size, the inverse of the number of parcels per hectare, helps to reduce technical inefficiency.[21] As shown in Table 3, highly fragmented farms tend to be larger. Farm size, in isolation, has a negative effect on technical inefficiency which provides motivation for farm expansion[22]. However, interaction analysis shows that when farm size is increasing, more land parcels increase technical inefficiency.

The relationship between the average distance between land parcels and technical inefficiency follows a similar trend in which increased distances initially reduce technical inefficiency, followed by a strong increasing relationship.[23] Again, a significant relationship is found between distance and farm size. Interaction analysis shows that the benefits of increased farm size are reversed when the land parcels are far from the main farm, as expected This is supported by the finding that the greater the portion of land on the main farm, the greater the reduction in technical inefficiency[24]. Farmers should expand their farms through the expansion of existing parcels, ideally close to the main farm where possible. The results share similarities with other European countries with Del Corral (2011) finding that the number of parcels increases technical inefficiency, at a declining rate. Del Corral et al. (2011) find that larger farm sizes lead to increased technical inefficiency, but interaction effects are not considered. Niskanen and Heikkilä (2015) note that increasing parcel size reduces technical inefficiency while parcel distance increases technical inefficiency.

The SPF in translog functional form is also estimated using a Simpson index instead of details of land parcels, with the results confirming that high levels of LF

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[21] Post estimation analysis finds that farms with greater than 0.33 parcels per hectare experience increased technical inefficiency. This implies that land parcels of less than 3 hectares increase technical inefficiency. However, farm size must be considered as interaction analysis in Table 4 shows that the effect of the number of parcels on technical inefficiency increases when farm size is also increasing.

[22] A negative relationship exists between farm size and technical inefficiency on 98 percent of farms. These farms consist of up to 158 hectares. However, interaction effects should be considered.

[23] Technical inefficiency increases when farms consist of parcels that are more than an average of 0.13km from the main farm, on a per hectare basis. However, interaction effects must be considered.

[24] 55 percent of farms experience reduced technical inefficiency due to farming land of which at least 25 percent is rented.

positively affects technical inefficiency (Appendix 3, on-line). However, the model in Table 4 provides more detailed conclusions for farm managers and policymakers by looking at LF variables in isolation and by assessing their interactions.

6.2.2 Policy implications

The higher the percentage of land that is owned, the greater the technical inefficiency ($p<0.01$), albeit at a declining rate. This finding is contrary to the results of Del Corral et al. (2011). This finding suggests that farmers can reduce the negative effects of LF by increasing the area of their land parcels with rented land. This positive effect of leased land builds on the benefits of land leasing noted by Bradfield et al. (2020) who discuss how farmers who rent in land seek to make a return that compensates for the costs of additional land. In 2014, rental agreements were predominately short-term conacre agreements, which meant that farmers had little incentive to invest in rented land, though the increase in tax incentives in 2015 may encourage more land rental.

An increased stocking rate, or level of farming intensity (Kelly et al., 2013), decreases technical efficiency, at a declining rate ($p<0.01$), Table 4, similar to the results of Carroll et al. (2007) and Kelly et al. (2013).

6.2.3 Employment and rural development

We find that hired labour has a negative effect on technical inefficiency, encouraging expansion beyond current family labour resources, which benefits rural employment. For countries such as Ireland, which are net exporters of milk, increased production generates revenue injections into the economy. Hennessy et al. (2018) calculate an output multiplier of agriculture in Ireland at 1.44. Furthermore, growth in dairy production is particularly important to the prosperity of rural regions as Hennessy et al. (2018) highlight the benefit of agriculture to regions outside of the main urban areas in particular.

Older farmers experience lower technical inefficiency, which may reflect increased experience. Further research is required to assess how young farmers can gain the skills of older farmers and advisory services are one way in which this can be achieved. Engagement with advisory services also helps to reduce technical inefficiency ($p<0.01$).

7. Conclusion

We find that land fragmentation (LF) clearly increases technical inefficiency, with the findings being more robust and complex than either a count of parcels or a Simpson index can represent. LF is a widespread issue and if farmers can obtain land adjoining their existing land holdings or increase their overall farm size, technical efficiencies may be achieved.

From a policy perspective, our results confirm that incentives to encourage land leasing and consolidation are justified to improve the technical efficiency of dairy farming, especially in the context of extremely low level of land sales. With tax relief in place for leasing out or transferring land, landowners are encouraged to lease or transfer under-utilised land. These policies benefit farmers, the aggregate Irish economy and, more generally, food security through increased milk production. Additional policy implications lie in the advantages hired labour offers to individual farms and the overall economy. Therefore, the promotion of job creation in the dairy sector, along with secure employment contracts, will improve farm performance and boost the economy through the multiplier effect. This is important to the retention of employment in agriculture and rural areas. The use of advisory services should also be encouraged due to the benefits they provide in reducing technical inefficiency.

Although milk production in Ireland has increased by 30 percent since the removal of the milk quota (Läpple, 2019), it would be interesting to consider the impact of land fragmentation on the efficiency levels of expanding farms. Unfortunately, due to the matched GIS and farm data only being available for 2014, this has not been possible here. More frequent matching of spatial datasets to farm performance data, such as FADN, would facilitate richer policy analysis.

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The Effect of Land Fragmentation on the Technical Inefficiency of Dairy Farms

Tracy Bradfield, Robert Butler, Emma Dillon, Thia Hennessy and Paul Kilgarriff

On-Line Appendices.

Appendix 1

T-Test Results

Difference = mean(farms with >8 parcels) - mean(farms with 1-8 parcels)

Variable	Difference
Parcel area (ha)	-6.61***
Distance between parcels and main farm (km)	0.65***
Milk produced per ha (litres)	-10,595.7***
Dairy net margin per ha (€)	-156.50**
Farm size (ha)	20.75***

Statistically significant: ***at 1% level; **at 5% level; *at 10% level.

Appendix 2

Stochastic Production Frontier

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
Milk Produced	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**
Direct costs (€)	0.40***	0.40***	0.40***	0.39***	0.39***	0.39***	0.39***	0.39***	0.39***	0.39***
	(0.00)	(0.00)	(0.00)	(0.00)	0.00	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Capital (€)	0.05***	0.04***	0.04***	0.04***	0.04***	0.04***	0.04***	0.04***	0.04***	0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Labour (€)	0.03***	0.03***	0.04***	0.04***	0.04***	0.04***	0.04***	0.04***	0.04***	0.04***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Herd size	0.57***	0.55***	0.56***	0.56***	0.56***	0.57***	0.57***	0.58***	0.58***	0.58***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$0.5(\text{Direct costs})^2$	0.01	0.18***	0.18***	0.17***	0.18***	0.19***	0.20***	0.19***	0.19***	0.19***
	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
$0.5(\text{Capital})^2$	0.21***	0.22***	0.19***	0.18***	0.18***	0.23***	0.23***	0.23***	0.23***	0.22***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
$0.5(\text{Labour})^2$	-0.10***	-0.09***	-0.10***	-0.09***	-0.10***	-0.08***	-0.08***	-0.05**	-0.05**	-0.05**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
$0.5(\text{Herd size})^2$	-0.61***	-0.55***	-0.59***	-0.64***	-0.66***	-0.64***	-0.63***	-0.66***	-0.68***	-0.67***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Direct costs*Capital	0.04**	-0.03	-0.02	-0.02	-0.02	-0.04**	-0.04**	-0.05***	-0.05***	-0.05***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Direct costs*Labour	-0.18***	-0.21***	-0.18***	-0.17***	-0.17***	-0.18***	-0.18***	-0.16***	-0.15***	-0.15***
	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Direct costs*Herdsize	0.04	-0.06**	-0.08	-0.05**	-0.05**	-0.03	-0.04**	-0.02	-0.01	-0.01
	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Capital*Labour	-0.15***	-0.13***	-0.15***	-0.15***	-0.17***	-0.16***	-0.17***	-0.18***	-0.17***	-0.17***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Capital*Herd size	-0.08***	-0.04**	0.00***	0.02	0.02	-0.02	-0.02	-0.02	-0.01	-0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Labour*Herd size	0.58***	0.60***	0.60***	0.57***	0.60***	0.60***	0.60***	0.58***	0.56***	0.56***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Constant	5.91***	5.90***	5.89***	5.89***	5.89***	5.89***	5.88***	5.88***	5.88***	5.88***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Ln(sigma v)^2	-4.93***	-4.86***	-4.82***	-4.82***	-4.81***	-4.82***	-4.82***	-4.79***	-4.79***	-4.79***
	(0.03)	(0.03)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)

Statistically significant: ***at 1% level; **at 5% level; *at 10% level.

All variables are in log format. Standard errors are in parentheses.

Stochastic Production Frontier (continued)

Technical inefficiency (Ln(sigma u)^2)	V1 Coef.	V2 Coef.	V3 Coef.	V4 Coef.	V5 Coef.	V6 Coef.	V7 Coef.	V8 Coef.	V9 Coef.	V10 Coef.
Parcels per ha	-2.39***	-5.41***	-2.00***	-5.85***	-11.55***	-13.32***	-14.31***	-14.25***	-13.90***	-14.82***
	(0.60)	(0.67)	(0.73)	(1.25)	(1.46)	(1.43)	(1.51)	(1.53)	(1.52)	(1.60)
Parcels per ha (sq)	4.83***	8.63***	5.39***	10.16***	18.88***	22.11***	23.95***	22.90***	21.52***	22.23***
	(1.37)	(1.46)	(1.64)	(1.94)	(2.22)	(2.22)	(2.34)	(2.36)	(2.33)	(2.41)
UAA size		-0.03***	-0.03***	-0.05***	-0.06***	-0.06***	-0.06***	-0.06***	-0.06***	-0.06***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
UAA size (sq)		0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Distance to yard per ha			-25.96***	-50.48***	-61.90***	-64.30***	-63.32***	-60.99***	-68.41***	-64.49***
			(2.29)	(4.41)	(4.95)	(4.97)	(4.88)	(5.57)	(5.69)	(5.66)
Distance to yard per ha (sq)			94.46***	184.77***	235.63***	236.91***	233.02***	226.33***	259.92***	246.42***
			(15.69)	(20.19)	(22.27)	(22.46)	(22.24)	(24.69)	(25.00)	(24.88)
UAA size*Parcels				0.06***	0.05***	0.06***	0.08***	0.09***	0.11***	0.12***
				(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
UAA size*Distance to yard				0.38***	0.50***	0.53***	0.52***	0.46***	0.53***	0.48***
				(0.05)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)	(0.07)
Main farm ratio					-2.96***	-2.62***	-2.45***	-2.59***	-2.24***	-2.27***
					(0.28)	(0.28)	(0.29)	(0.30)	(0.30)	(0.31)
Main farm ratio (sq)					1.49***	0.97***	0.81***	1.01***	0.84***	0.92***
					(0.27)	(0.27)	(0.28)	(0.29)	(0.28)	(0.30)
Stocking rate						-0.69***	-0.65***	-0.43**	-0.47**	-0.45**
						(0.20)	(0.20)	(0.21)	(0.21)	(0.21)
Stocking rate (sq)						0.24***	0.23***	0.21***	0.22***	0.21***
						(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Owned land ratio							1.27**	1.31**	2.10***	2.00***
							(0.60)	(0.62)	(0.64)	(0.64)
Owned land ratio (sq)							-0.64	-0.60	-1.27***	-1.18***
							(0.41)	(0.43)	(0.44)	(0.44)
Hired to family labour ratio								-2.04***	-2.02***	-2.19***
								(0.23)	(0.22)	(0.23)
Hired to family labour ratio (sq)								1.31***	1.32***	1.42***
								(0.16)	(0.15)	(0.16)

Stochastic Production Frontier (continued)

Technical inefficiency	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
Ln(sigma u)^2										
Advisory services									-0.46***	-0.47***
									(0.05)	(0.05)
Age										-0.03**
										(0.02)
Age (sq)										0.00***
										(0.00)
Constant	-3.48***	0.09***	-2.04***	-1.30***	0.85***	1.17***	0.49	0.02	0.16	0.87
	(0.05)	(0.00)	(0.09)	(0.14)	(0.23)	(0.33)	(0.38)	(0.40)	(0.40)	(0.61)
Sigma_v	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Statistically significant: ***at 1% level; **at 5% level; *at 10% level.
Prob>chi2= 0.00 Standard errors are in parentheses.

Appendix 3

Stochastic Production Frontier using a Simpson Index

Milk Produced	**Coef.**
Direct costs (€)	0.38***
	(0.00)
Capital (€)	0.03***
	(0.00)
Labour (€)	0.04***
	(0.00)
Herd size	0.58***
	(0.01)
$0.5(\text{Direct costs})^2$	0.21***
	(0.03)
$0.5(\text{Capital})^2$	0.22***
	(0.02)
$0.5(\text{Labour})^2$	-0.09***
	(0.02)
$0.5(\text{Herd size})^2$	-0.63***
	(0.04)
Direct costs*Capital	-0.05***
	(0.02)
Direct costs*Labour	-0.15***
	(0.01)
Direct costs*Herd size	-0.05*
	(0.02)
Capital*Labour	-0.15***
	(0.01)
Capital*Herd size	-0.01
	(0.02)
Labour*Herd size	0.56***
	(0.02)
Constant	5.88***
	(0.00)
$\text{Lnsigma}(v)^2$	-4.77***
	(0.04)

Statistically significant: ***at 1% level; **at 5% level; *at 10% level.

All variables are in log format. Standard errors are in parentheses.

Stochastic Production Frontier using a Simpson Index (continued)

Technical inefficiency (Lnsigma(u)^2)	**Coef.**
Simpson index	-2.68***
	(0.40)
Simpson index (sq)	3.08***
	(0.39)
UAA size	-0.04***
	(0.00)
UAA size (sq)	0.00***
	(0.00)
Distance to yard per ha	-63.99***
	(5.70)
Distance to yard per ha (sq)	242.99***
	(25.01)
UAA size*Simpson index	0.01**
	(0.00)
UAA size*Distance to yard	0.45***
	(0.06)
Stocking rate	-0.14
	(0.21)
Stocking rate (sq)	0.14***
	(0.05)
Owned land ratio	2.19***
	(0.68)
Owned land ratio (sq)	-1.30***
	(0.47)
Hired to family labour ratio	-2.50***
	(0.24)
Hired to family labour ratio (sq)	1.74***
	(0.18)
Advisory services	-0.65***
	(0.06)
Age	-0.05***
	(0.02)
Age (sq)	0.00***
	(0.00)
Constant	-1.19**
	(0.57)
Sigma_v	0.09***
	(0.00)

Statistically significant: ***at 1% level; **at 5% level; *at 10% level. Prob>chi2= 0.00