Does land fragmentation affect farm performance?

A French Breton case study

Laure LATRUFFE

INRA, UMR1302 SMART, F-35000 Rennes, France
Agrocampus Ouest, UMR1302 SMART, F-35000 Rennes, France

Laurent PIET

INRA, UMR1302 SMART, F-35000 Rennes, France
Agrocampus Ouest, UMR1302 SMART, F-35000 Rennes, France

Paper presented at the 6èmes Journées de Recherches en Sciences Sociales
Toulouse (France), December 13-14, 2012

Acknowledgments
Financial support from FP7 project Factor Markets (Comparative Analysis of Factor Markets for Agriculture across the Member States) grant agreement n°245123-FP7-KBBE-2009-3 is acknowledged.

Corresponding author

Laurent Piet
INRA, UMR SMART
4 allée Adolphe Bobierre, CS 61103
35011 Rennes cedex, France
Email: laurent.piet@rennes.inra.fr
Téléphone / Phone: +33 (0)2 23 48 53 83
Fax: +33 (0)2 23 48 53 80

Does land fragmentation affect farm performance?
A French Breton case study

Abstract

Agricultural land fragmentation is widespread around the world and may affect farmers' decisions and therefore have an impact on the performance of farms, whether in a negative or in a positive way. In this paper we test whether the relationship is positive or negative for the French western region of Brittany in 2007. The relationship between land fragmentation and farm performance is investigated with econometric regressions applied to several performance indicators (production costs, yields, financial results and technical efficiency) calculated with Farm Accountancy Data Network (FADN) farm-level data, and several fragmentation descriptors calculated at the municipality level using data from the cartographic field pattern registry (RPG). The various fragmentation descriptors enable to account not only for the traditional number and mean size of plots, but also for their scattering in the geographical space. Our analysis highlights that the measures of land fragmentation usually used in the literature reveal less significant relationships with farm performance than more complex measures accounting for distance. Our results indicate that farms experience higher cost of production, lower crop yields and lower financial results where land fragmentation is more pronounced, and that technical efficiency is only loosely related to land fragmentation.

Keywords: agricultural land fragmentation, farm performance, financial results, technical efficiency, France

JEL classifications: Q12, Q15, D24

Does land fragmentation affect farm performance?
A French Breton case study

1 Introduction

Fragmentation of agricultural land is widespread around the world and originates from various institutional, policy, historical and sociological factors, such as inheritance laws, collectivisation and consolidation processes, transaction costs on land markets, urban development policies, and personal valuation of land ownership. Farm land fragmentation (LF) is a complex concept that encompasses five dimensions: i) in terms of number of plots farmed; ii) in terms of plot size; iii) in terms of plots' shape; iv) in terms of distance of the plots to the farm buildings; v) in terms of distance between the plots (or plot scattering). In a public economics perspective, LF may generate both positive and negative externalities: it may increase biodiversity and the society's economic value of landscape but, by contrast, it may induce additional trips by farmers which may result in extra roadwork, road safety issues, greenhouse gas emissions, etc. However, LF may first and foremost affect farmers' decisions and therefore have an impact on the performance of farms. On the one hand, the impact may be negative for several reasons. Firstly, it takes time to travel from one parcel to the other when the labour force could be dedicated to more productive tasks. Secondly, it may require more equipment –in quantity and/or quality–, secondary farm buildings and/or external service expenses. Thirdly, it may restrict the choice of productions and constrain the management practices, especially in terms of herd management. This could be particularly true for regions where dairy production prevails, such as the French western region Brittany. Fourthly, investments for soil quality improvement such as drainage may be reduced on remote plots. On the other hand, LF may contribute to farm performance, in two ways. Firstly, greater LF may imply an increased diversity of land quality and therefore potentially higher overall yields by optimizing which crop goes to which plot. Secondly, LF enables risk diversification, and production risk consequences at the farm level may be decreased with LF; for example, pest may spread on contiguous plots only so that merely part of a fragmented farm would be affected.

Several authors have tested empirically the effects of LF on the performance of farms. For example, Jabarin and Epplin (1994) study the impact of LF on the production cost of wheat in Jordan. In China, Nguyen *et al.* (1996) consider the effect of LF on the productivity of major crops, Wan and Cheng (2001) investigate how crop outputs produced by rural households are affected, while Tan *et al.* (2010) focus on the technical efficiency of rice producers in the South-East of the country. Kawasaki (2010) examines both the costs and benefits of LF in the case of rice production in Japan, similarly to Rahman and Rahman (2008) in Bangladesh. Parikh and Shah (1994) investigate the influence of land fragmentation on the technical efficiency of farms in the North-West Frontier Province of Pakistan. In Europe, di Falco *et al*. (2010) analyse how land fragmentation affects farm profitability in Bulgaria and del Corral *et al.* (2011) study the impact of LF on the profits of Spanish dairy farms.

However, with a few exceptions (e.g. Tan *et al.*, 2010, and Kawasaki, 2010 who consider, respectively, the average distance of the plots to the homestead and the Simpson Index), most of these papers define LF by two variables only, the number of plots and their average size, which do not account for all dimensions of LF and may not capture all the constraints that LF imposes on production systems. Gonzales *et al.* (2007) provide more elaborated measures of LF which account for the size, shape and dispersion of plots, but the authors apply such measures to study the productivity gains from land consolidation for a hypothetical dataset of farms.

The objective of the paper is to analyze the influence of LF on the performance of farms in the case of one French region, the Western region of Brittany. As in many other regions and countries, agricultural land is very fragmented in Brittany. For example, according to the cartographic field pattern registry (‘Registre Parcellaire Graphique’ or RPG) put in place in France since 2002 following the European Council Regulation No 1593/2000 (European Commission, 2000), Breton farms were composed on average of 14 plots in 2007 and the mean of plot sizes was 4.35 hectares; 25% of the farms had 18 plots or more and 25% of these plots exhibited an average area of 2.42 hectares or less. The relationship between land fragmentation and farm performance is investigated for the year 2007 with the help of several performance indicators (production costs, yields, financial results and technical efficiency) calculated from farm-level data, and several LF indicators calculated at the municipality level using data from the cartographic field pattern registry. The various fragmentation indicators enable to account not only for the traditional measures of plot number and mean size of plots, but also for the scattering of plots.

2. Data and methodology

2.1. Measuring farm performance

We investigated the relationship between farm performance calculated at farm level for a sample of farms, and LF in the municipality where the sample farms are located. The underlining assumption is that a farm's LF is positively correlated with the LF in the municipality where the farm is located. The studied farms are extracted from the French Farm Accountancy Data Network (FADN) 2007 database. The FADN database, managed by the French Ministry of Agriculture, contains bookkeeping information for a five-year rotating panel of professional farms. In 2007 480 farms of the FADN sample were located in Brittany. Among those 480 farms we could relate 266 farms to their municipality's LF situation, and among those 266 farms we excluded 6 farms which used zero land. Figure 1 shows the location of the municipality of the 260 FADN Breton farms we used.

(Insert Figure 1 around here)

Table 1 describes the sample of the 260 farms considered to analyse the relationship between farm performance and LF. It shows the distribution of these farms according to their main production, which is the one constituting at least two thirds of the farms' gross standard margin (see the definition of the type of farming in European Commission, 2010). The distribution reflects Brittany's agriculture where dairy, poultry and pig breeding prevail: 32% of the sample specialise in dairy production, and 24% in granivores production. Mixed crop and livestock farming (generally the production of cow milk and field crops) accounts for 14% of the sample, and breeding of other grazing livestock (goats and sheep) for 14%. Finally, 8% of the sample farms' main production is field crops, and for another 8% the main production is other crops than field crops (mainly vegetables). Figure 2 shows the distribution of Breton municipalities according to the main productions produced on each municipality based on the 2010 Agricultural Census. Granivores farms are located principally in central and eastern Brittany, while crops are mainly produced on the coast and grazing livestock breeding is mainly in the western part of the region. Four percent of the farms in the FADN sub-sample used are located in environmentally vulnerable zones ('areas with a structural nitrogen surplus') subject to zoning regulations (Table 1). In 2007 the studied farms used on average 65.3 hectares (ha), which is greater than Brittany's all farm population average of 47.3 hectares but close to the average of 60.0 hectares for Brittany's commercial farm sub-population (2010 Agricultural Census). They used on average 2.5 full time equivalents calculated as Annual Working Units (AWU; where 1 AWU corresponds to 1,200 hours of labour per year), also more than the region's all farm average of 1.65 AWU and close to the region's commercial farm average of 2.10 AWU (2010 Agricultural Census). The average number of livestock units (calculated with specific coefficients applied to each livestock type head) on the farms was 212.1. This relatively high figure is due to the numerous livestock specialised farms in Brittany, and in particular to the poultry and pig head numbers. Farms rented in 76.8% of their utilised area on average, and employed 14.3% of hired labour force. They cultivated on average 4.6 different crops per year on their farm area.

(Insert Table 1 and Figure 2 around here)

Farm performance was analysed with respect to several indicators. Firstly, various categories of production cost were calculated per unit of utilised area: cost of fertilisers, seeds, pesticides, fuel, intermediate consumption and hired labour. Secondly, two production yields were used: wheat yield in tons of wheat produced per hectare of wheat cultivated, and milk yield in litres of cow milk produced per cow. Thirdly, four financial results were considered, also related per unit of utilised area: the farm gross product made up from farm sales, subsidies, and insurance compensations; the farm gross margin calculated as the farm gross product minus variable cost specific to crop and livestock production; the farm operating surplus calculated as the farm gross margin minus land, labour and insurance costs; and the farm pre-tax profit calculated as the farm operating surplus minus depreciation and interest before taxes are deducted; note that these four financial indicators were calculated excluding subsidies. Finally, farm technical efficiency and scale efficiency were analysed. Technical efficiency assesses how far farms are located from the maximum production frontier for a given combination of inputs. It is a more complex measure than productivity as it relates all outputs produced to all inputs used. Technical efficiency has two components: one that arises from how farmers operate their farm, and one that arises from the scale of production. The former is called pure technical efficiency and the latter is called scale efficiency. Technical and scale efficiencies were calculated with the non-parametric method Data Envelopment

Analysis (DEA) which constructs with linear programming a frontier that envelops the data used (Charnes *et al.*, 1978). The FEAR package (Wilson, 2008, 2009) on R software was used (R Development Core Team, 2010). Efficiency scores obtained are between one –for a fully efficient farm (*i.e.*, a farm 'on the frontier')– and zero, and lower scores indicate lower efficiency. Because the efficient frontier depends on the sample used and the efficiency scores may be overestimated if the most performing farms of the population are not included, we did not construct the efficient frontier on the 260 farms only, but we used the whole Brittany FADN sample (480 farms) to calculate efficiency scores. The DEA model was output-oriented and had one single output, namely the farm output produced in Euros, and four inputs: the utilised area in hectares, the labour used in AWU, the intermediate consumption in Euros, and the capital value in Euros.

Table 2 presents the descriptive statistics of the performance indicators. Farms produced on average 5.4 tons of wheat per hectare and 7,092 litres of milk per cow. They generated on average 2,279 Euros of pre-tax profit without subsidies per hectare. Their technical efficiency score was 0.696 on average, indicating that they could increase their output by 30.4% without increasing their input use.

(Insert Table 2 around here)

2.2. Measuring land fragmentation

Land fragmentation was first measured at the farm level thanks to the cartographic field pattern registry ('Registre Parcellaire Graphique' or RPG) put in place in France since 2002 following the European Council Regulation No 1593/2000 (European Commission, 2000). This is a Geographic Information System (GIS) database which is maintained by the 'Agence de Service et de Paiement' (ASP), a public administration which gathers the field patterns declared by farmers who apply for support in the framework of the Common Agricultural Policy (CAP)[1] and which delivers subsidies to farmers based on these declarations. In fact, farmers are not requested to delineate each of their individual fields but rather each of their

[1] For more information on the RPG, see the dedicated pages on the website of the ASP. (http://www.asp-public.fr/?q=node/856).

‘plots’ which we will define for the rest of the paper as follows: a ‘plot’ is a set of contiguous fields cultivated under the same crop or under different crops, and it is delimited by easily identifiable landmarks (such as agricultural ways, roads, rivers, another plot, etc.) and stable from year to year.

We used the 2007 registry (‘RPG anonyme ASP 2007’) for the four NUTS3 regions (the ‘départements’) of Brittany (namely ‘Côtes-d’Armor’, ‘Finistère’, ‘Ille-et-Vilaine’ and ‘Morbihan’, see Figure 1), which identifies 450,787 plots exploited by 31,921 farms for these four regions. Among these farms, three situations arose: i) farms registered in one of the four Breton ‘département’ and whose plots were all located inside this ‘département’; ii) farms registered in one of the four Breton ‘département’ but whose plots were partly located outside this ‘département’ and; iii) farms registered outside Brittany but whose plots were totally or partly located inside one of the four Breton ‘département’. We considered all farms and plots corresponding to case i). As regards cases ii) and iii), we retained only the farms whose plots were located, or farms which were registered in, one of the four NUTS3 regions directly neighbouring Brittany (namely ‘Loire-Atlantique’, ‘Maine-et-Loire’, ‘Manche’ and ‘Mayenne’, see Figure 1), excluding farther NUTS3 regions. For those farms, we considered not only their plots located in Brittany but also their plots located in the directly neighbouring NUTS3 regions outside Brittany. Finally, we excluded those farms whose total area as declared by the farmer was above the sum of their plots area by at most 0.02 hectares, in order to assure that we dealt with ‘entire’ farms only. In the end, the database constructed for use in this paper consisted of 29,433 farms and 418,480 plots.

Ten fragmentation descriptors were computed for each farm i, which were each relating to one of the five dimensions of LF as described in the introduction (the formal definitions of the descriptors are given in the appendix):

1. LF descriptors relating to the number of plots; one descriptor was used, the number of plots on the farm ($nplot_i$);
2. LF descriptors relating to the shape of plots; two descriptors were used: the weighted average of the shape index of the plots ($wshsq_i$) and the average of the areal form factor ($aform_i$);

3. LF descriptors relating to the size of plots; three descriptors were used: the average plots size ($avpls_i$) and two more elaborate indices, the Simpson index ($simps_i$) and the Janusewski index ($janus_i$);

4. LF descriptors relating to the distance of plots to the farm; three descriptors were used: the average distance of an hectare ($avdha_i$) and two more elaborate indices, the grouping index ($grpgi_i$) and the structural index ($strui_i$) (Marie, 2009); and

5. LF descriptors relating to the scattering of plots (the distance between plots); one descriptor was used, the normalized average nearest neighbour distance ($nannd_i$).

As we did not have any information in the registry concerning the location of the farmsteads, we first computed the centroid of each plot (that is, its geometric centre) and deduced the barycentre of each farm (that is, its 'centre of mass', with the 'mass' associated to each plot of the farm being the plot's area); where relevant, we then replaced the distance to the farmstead by the distance to the barycentre of the farm.

Note that the relation between each LF descriptor and land fragmentation is as follows:

- descriptors positively related to LF (*i.e.*, for which a higher value indicates higher fragmentation): the number of plots, the weighted average of shape index, the Simpson index, descriptors relating to distance to the barycentre and the normalized average nearest neighbour distance;

- descriptors negatively related to LF (*i.e.*, for which a higher value indicates lower fragmentation): the average areal form factor, the Januszewski index and the average plots size.

Table 3 reports descriptive statistics for the 29,433 farms considered in our database. On average, the farms registered outside Brittany were the largest (their average area was 75.51 ha) and the farms registered within Brittany were relatively similar across NUTS3 regions in terms of average area (around 50 ha with a standard deviation of about 40 ha). Among the four Breton NUTS3 regions, 'Côtes-d'Armor' appears as the most fragmented one for most LF descriptors, followed by 'Finistère', 'Ille-et-Vilaine' and finally 'Morbihan'. The situation of farms registered outside Brittany was more contrasted: those farms were relatively fragmented when considering most descriptors, while, by contrast, their mean size of plots was higher than that of farms registered inside Brittany, suggesting a lower fragmentation level. This opposite picture may be explained, first, because these farms composed a smaller sample and, second, because when considered together they constituted a heterogeneous category (the structure and production orientation of farms in the northern ‘Manche’ are quite different of these in ‘Loire-Atlantique’ in the South).

(Insert Table 3 around here)

In order to derive the aggregated fragmentation descriptors at the level of each municipality r, we computed the weighted average of each descriptor considering all farms exploiting at least one plot in r, with each weight being the ratio of the farm area that was located in r to the total area operated in r, or, formally:

$$x_r = \frac{1}{A_r} \sum_{i \in r} A_{ir} x_i \quad (1)$$

where x stands for one of the ten fragmentation descriptors, A_{ir} represents farm i operated area that is located within municipality r and $A_r = \sum_{i \in r} A_{ir}$ is the total farmed area in municipality r. Note that, because the RPG only includes farms which apply to CAP payments and because we excluded almost 8% of the farms (2,488 out of 31,921) from the initial database during the sample selection process (see above), the descriptors calculated at the municipality level should be viewed only as proxies for the true farmland fragmentation of municipalities.

Table 4 reports descriptive statistics for the 215 municipalities which are used in the performance calculations with the FADN data, as well as for all the 1,255 Breton municipalities for which we had RPG data. It appears from this table and from a further examination of the distributions for all LF descriptors that our sample is skewed toward higher values but that the discrepancy is nevertheless very slight. Our sample can therefore be regarded as representative of Brittany with good confidence.

(Insert Table 4 around here)

2.3. Explaining farm performance with LF

The influence of LF on farm performance was investigated with econometric regressions (Ordinary Least Squares), where the dependent variables were, in turn, each of the performance indicators described above. Various explanatory variables were used: the farmer's age; a farm size dummy based on classes of economic size (the dummy is equal to 1 if the farm size is above 100 Economic Size Units (ESU), with 1 ESU equivalent to 2,200 Euros of standard gross margin; and 0 if the size is below 100 ESU); a farm legal status dummy (the dummy is equal to 1 if the farm is individual, and 0 if not); the share of rented land in total UAA; the share of hired labour in total labour used; the capital to labour ratio; a farm location dummy (the dummy is equal to 1 if the farm is located in an area with structural nitrogen surplus subject to pollution restrictions, and 0 if not); and farm specialisation dummies. The ratio of farm operational subsidies to farm output was also included, except in the regressions with the financial results per hectare as the dependent variables where the subsidies were included as subsidies per hectare of UAA.

All LF indicators were introduced in turn in the regressions as a supplementary explanatory variable. Therefore there were $15 \times 10 = 150$ regressions, differing by the dependent variable (each performance indicator) and the LF indicator considered.

3. Results

Due to the large number of regressions that were performed, we synthesize the results by only reporting in Table 5 the signs and significance levels of the regression coefficients obtained for each LF descriptors (detailed results for each regression are available from the author upon request).

(Insert Table 5 around here)

Our results first show that, from a methodological point of view, each LF descriptor relates to one or some performance indicators but not to all of them and that, reciprocally, each performance indicator is explained by one or some LF descriptors but not by all of them. This comforts our using a wide set of variables for both dimensions. However, if one had to retain only one LF descriptor, the optimal choice would certainly be the structural index ($strui_i$), as it is related to the highest number of farm performance indicators on all components but yields, and especially with financial results with a high level of significance. The more traditionally used LF descriptors, the number of plots ($nplot_r$) and the average size of plots ($avpls_r$), prove to be second best choices only since they relate to fewer performance indicators and either fail to relate to one important component (efficiency for the number of plots) or exhibit lower levels of significance (for the average plots size). Eventually, some LF descriptors appear to be poorly related to farm performance: the average distance of an hectare ($avdha_r$) shows no significant relation while the normalized average nearest neighbour distance ($nannd_r$), the grouping index ($grpgi_r$) and both plots shape descriptors ($wshsq_r$ and $aform_r$) only relate to very few performance indicators.

Most results regarding the detailed links between LF descriptors and performance indicators conform to agronomic and economic intuition. Production costs are positively related to the number of plots, to their shape and to their distance to the farm but decrease with plot size. LF seems to play no role in determining the yield of milk but the yield of wheat is negatively influenced by the shape of plots and their distance to the farm. All financial results significantly decrease with the distance to the farm and, as far as the pre-tax profit is concerned, are negatively related to the number of plots but positively related to the average size of plots. Finally, technical efficiency proves to be related to very few LF indicators but the average size of plots and the distance of plots to the farm do seem to play a role.

4. Conclusion

In this paper we investigated the relationship between agricultural land fragmentation (LF) and farm performance in 2007 in the French NUTS2 region Brittany. Various farm performance indicators (in terms of costs, yields, financial results and technical efficiency) calculated for a sub-sample of FADN farms were regressed on several explanatory variables, including average LF descriptors computed for the municipalities where those farms are located. Among the LF descriptors we used, we considered not only the number of plots and the mean size of plots which are traditionally used in the economic literature investigating the impact of LF on farm performance, but also other more complex indices, in order to account for the shape of plots, for (a proxy of) the distance between plots and farmsteads, and for the distance between plots themselves (or plots scattering).

In our view, our analysis first highlights that, from a methodological perspective, the measures of land fragmentation traditionally used in the literature, namely the number of plots and the average plots size, may not reveal alone the full set of significant relationships with farm performance because they do not capture all dimensions of land fragmentation. In particular they exclude distance considerations. In this respect, the structural index used here seems to be more powerful. However, circumventing the absence of information regarding the location of the farmsteads by computing distances relative to the farm barycentre, as we did in this paper, may introduce some bias that would be worth investigating.

Considering only the significant relationships, the analysis of farm performance and LF shows three main findings. Firstly, it appears that LF is only loosely related with technical efficiency as measured with the DEA method. Secondly, whatever the LF descriptor considered, similar conclusions are reached as regards the impact of land fragmentation on the various components of farm performance. Thirdly, those conclusions are fourfold: i) LF tends to increase production costs; ii) LF has a negative impact on crop yields; iii) LF tends to reduce financial results of the farm and; iv) technical and scale efficiency appear to be mainly influenced by the size of plots and their distance to the farm, while the other dimensions of LF (namely the number of plots, their shape and their scattering) seem to play only a marginal role. Such findings that land fragmentation is overall harmful to farm performance are consistent with those found in the previous literature on the subject.

Even though these results sound reasonable and conform to intuition, our analysis suffers two major limitations which should still prevent to consider them without due care. Firstly, endogeneity issues would have to be investigated carefully: although we can be relatively confident that the relationship between variables is mainly in one direction from a static point of view, namely that municipalities' LF influences performance of specific farms, it might be that, in a dynamic perspective, efficient farms are more likely to be in a position to decrease their fragmentation at the expense of neighbouring farms. Secondly, drawing any causal conclusions would mean assuming a direct link between the LF of the municipality where the considered farm is located, and the LF within the farm itself: though the approach adopted here –due to data limitation– indeed relies on the hypothesis that the higher the LF of the municipality, the higher the probability for the farm to be fragmented, it may happen that low (respectively highly) fragmented farms may be located in a highly (low) fragmented municipality. Finding a way to gain access to a measure of fragmentation at the individual level for the farms in our sample constitutes a major challenge for future work. Although our analysis sheds some light on the relationship between the performance of a farm and LF in the municipality where it is located, further investigation is therefore needed, especially before any policy recommendations could be drawn.

References

Charnes, A., Cooper, W. and Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research* 2:429-444.

Del Corral, J., Perez, J. A. and Roibas, D. (2011). The impact of land fragmentation on milk production. *Journal of Dairy Science* 94:517-525.

Di Falco, S., Penov, I., Aleksiev, A. and van Rensburg, T. (2010). Agrobiodiversity, farm profits and land fragmentation: Evidence from Bulgaria. *Land Use Policy* 27:763-771.

European Commission (2000). Council Regulation (EC) No 1593/2000 of 17 July 2000 amending Regulation (EEC) No 3508/92 establishing an integrated administration and control system for certain Community aid schemes. *Official Journal* L182:0004-0007.

European Commission (2010). *Farm Accounting Data Network - An A to Z of Methodology*. Version 04/10/2010. http://ec.europa.eu/agriculture/rica//pdf/site_en.pdf

Gónzalez, X., Marey, M. and Álvarez, C. (2007). Evaluation of productive rural land patterns with joint regard to the size, shape and dispersion of plots. *Agricultural Systems* 92:52-62.

Jabarin, A. S. and Epplin, F. M. (1994). Impacts of land fragmentation on the cost of producing wheat in the rain-fed region of northern Jordan. *Agricultural Economics* 11:191-196.

Kawasaki, K. (2010). The costs and benefits of land fragmentation of rice farms in Japan. *Australian Journal of Agricultural and Resource Economics* 54:509-526.

Marie, M. (2009). Des pratiques des agriculteurs à la production de paysage de bocage. Etude comparée des dynamiques et des logiques d'organisation spatiale des systèmes agricoles laitiers en Europe (Basse-Normandie, Galice, Sud de l'Angleterre). Ph-D dissertation of the University of Caen/Basse-Normandie, Caen (France), 513 p.

Parikh, A. and Shah, K. (1994). Measurement of technical efficiency in the northwest frontier province of Pakistan. *Journal of Agricultural Economics* 45(1):132-138.

Nguyen, T., Cheng, E. and Findlay, C. (1996). Land fragmentation and farm productivity in China in the 1990s. *China Economic Review* 7:169-180.

R Development Core Team (2010). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna.

Rahman, S. and Rahman, M. (2008). Impact of land fragmentation and resource ownership on productivity and efficiency: The case of rice producers in Bangladesh. *Land Use Policy* 26:95-103.

Tan, S., Heerink, N., Kuyvenhoven, A. and Qu, F. (2010). Impact of land fragmentation on rice producers' technical efficiency in South-East China. *NJAS - Wageningen Journal of Life Sciences* 57:117-123.

Wan, G. and Cheng, E. (2001). Effects of land fragmentation and returns to scale in the Chinese farming sector. *Applied Economics* 33(2):183-194.

Wilson, P. (2008). FEAR: a software package for frontier efficiency analysis with R. *Socio-Economic Planning Sciences* 42:247-254.

Wilson, P. (2009). *FEAR 1.12 Command Reference*. Working Paper, Department of Economics. Clemson University, Clemson, SC.

Table 1: Main characteristics of the farms in the FADN sample used (260 farms)

	Share of farms in the sample (%)			
According to their main production				
Field crops	8			
Dairy	32			
Other grazing livestock	14			
Granivores	24			
Mixed (crops and livestock)	14			
Other crops	8			
In areas with structural nitrogen surplus	4			
	Mean	**Std. deviation**	**Minimum**	**Maximum**
Utilised agricultural area (hectares)	65.3	45.2	0.12	242.0
Number of full time labour equivalents	2.5	2.6	1	21
Number of livestock units	212.1	279.4	0	2,083.3
Share of land rented in (%)	76.8	32.3	0	100
Share of hired labour (%)	14.3	24.5	0	92.8
Number of crops cultivated	4.6	1.9	0	10.0

Source: French FADN 2007 database – authors' calculations

Table 2: Performance of the farms in the FADN sub-sample used (average values)

Number of observations	260
Production costs per area unit (Euros / hectare)	
Fertilisers	288
Seeds	861
Pesticides	190
Fuel cost	156
Intermediate consumption	13,621
Hired labour cost	3,947
Yields	
Wheat yield (tons / hectare)	5.4
Milk yield (litres / cow)	7,092
Financial results without farm subsidies per area unit (Euros / hectare)	
Gross product	24,207
Gross margin	10,586
Operating surplus	5,441
Pre-tax profit	2,279
Efficiency scores	
Technical efficiency	0.696
Pure technical efficiency	0.727
Scale efficiency	0.959

Source: French FADN 2007 database – authors' calculations

Table 3: Descriptive statistics of the fragmentation descriptors at the farm level [a]

	22	29	35	56	Other [b]	**All**
Number of farms	7,942	6,149	8,653	6,298	391	**29,433**
Average farm area (ha)	49.13	54.85	47.49	52.92	75.51	**51.00**
	(34.98)	*(41.64)*	*(38.72)*	*(39.60)*	*(40.96)*	***(38.82)***
Number of plots ($nplot_i$)	15.11	14.55	12.24	12.32	14.93	**13.55**
	(11.10)	*(11.10)*	*(10.09)*	*(9.62)*	*(9.24)*	***(10.56)***
Weighted average plot shape index	1.34	1.32	1.31	1.33	1.37	**1.33**
($wshsq_i$)	*(0.19)*	*(0.17)*	*(0.18)*	*(0.19)*	*(0.18)*	***(0.19)***
Average plot areal form factor	0.044	0.044	0.044	0.044	0.042	**0.044**
($aform_i$)	*(0.006)*	*(0.006)*	*(0.006)*	*(0.006)*	*(0.005)*	***(0.006)***
Average plots size ($avpls_i$)	3.67	4.41	4.53	4.90	5.74	**4.37**
	(2.45)	*(3.53)*	*(14.58)*	*(3.65)*	*(3.32)*	***(8.36)***
Simpson index ($simps_i$)	0.77	0.77	0.72	0.73	0.80	**0.75**
	(0.22)	*(0.21)*	*(0.25)*	*(0.24)*	*(0.15)*	***(0.23)***
Januszewski index ($janus_i$)	0.37	0.37	0.42	0.41	0.34	**0.39**
	(0.19)	*(0.18)*	*(0.21)*	*(0.20)*	*(0.13)*	***(0.20)***
Average distance of an hectare	1,221	1,373	1,246	1,084	3,115	**1,256**
($avdha_i$)	*(1,823)*	*(1,917)*	*(1,844)*	*(1,392)*	*(3,452)*	***(1,814)***
Grouping index ($grpgi_i$)	8.93	8.92	8.74	6.84	18.01	**8.55**
	(12.68)	*(11.86)*	*(13.35)*	*(10.33)*	*(17.45)*	***(12.41)***
Structural index ($strui_i$)	3.93	3.42	3.15	2.19	4.13	**3.23**
	(11.52)	*(7.67)*	*(7.83)*	*(5.21)*	*(5.56)*	***(8.53)***
Normalized average nearest neighbor	1.47	1.32	1.66	1.40	2.18	**1.49**
distance ($nannd_i$)	*(3.90)*	*(3.76)*	*(4.89)*	*(3.53)*	*(5.23)*	***(4.14)***

[a] *Except for the number of farms, averages are presented and standard deviations are shown in brackets and italic font.*
[b] *Farms registered in NUTS3 regions directly neighbouring Brittany (namely 'Loire-Atlantique', 'Maine-et-Loire', 'Manche' and 'Mayenne', see Figure 1) and whose plots are at least partly located in one of Brittany's NUTS3 regions ("22" stands for 'Côtes-d'Armor', "29" stands for 'Finistère', "35" stands for 'Ille-et-Vilaine' and "56" stands for 'Morbihan').*

Source: 'RPG anonyme ASP 2007' database – authors' calculations

Table 4: Descriptive statistics at the municipality level

	Mean	Std. deviation	Min	Max
Studied municipalities (215 observations)				
Number of farms	62.29	31.45	9	200
Farmed area (ha)	3,718.58	1,988.61	359.36	11,811.04
Number of plots ($nplot_i$)	19.18	6.26	8.84	45.16
Weighted average plot shape index ($wshsq_i$)	1.345	0.062	1.213	1.542
Average plot areal form factor ($aform_i$)	0.043	0.002	0.038	0.049
Average plots size ($avpls_i$)	4.76	1.62	1.24	9.54
Simpson index ($simps_i$)	0.841	0.041	0.732	0.931
Januszewski index ($janus_i$)	0.302	0.045	0.187	0.416
Average distance of an hectare ($avdha_i$)	1,677	469	951	4,339
Grouping index ($grpgi_i$)	9.490	2.592	4.821	23.549
Structural index ($strui_i$)	2.971	2.208	0.901	23.938
Normalized average nearest neighbor distance ($nannd_i$)	0.982	0.263	0.557	2.181
All municipalities in Brittany (1,255 observations)				
Number of farms	45.67	28.72	1	200
Farmed area (ha)	2,781.25	1,704.15	9.01	11,811.04
Number of plots ($nplot_i$)	20.97	8.34	3.00	85.18
Weighted average plot shape index ($wshsq_i$)	1.347	0.075	1.084	1.848
Average plot areal form factor ($aform_i$)	0.043	0.002	0.026	0.056
Average plots size ($avpls_i$)	4.87	15.23	0.31	540.57
Simpson index ($simps_i$)	0.850	0.049	0.404	0.973
Januszewski index ($janus_i$)	0.290	0.052	0.124	0.668
Average distance of an hectare ($avdha_i$)	1,670	562	217	6,854
Grouping index ($grpgi_i$)	9.358	3.207	1.976	43.073
Structural index ($strui_i$)	3.075	2.620	0.582	47.152
Normalized average nearest neighbor distance ($nannd_i$)	0.937	0.350	0.289	5.344

Source: 'RPG anonyme ASP 2007' database – authors' calculations

Table 5: Fragmentation descriptors and FADN farms' performance: sign and significance of regression coefficients for LF indicators [a]

Performance indicator	Number of plots' indicators	Plots' shape indicators		Plot size's indicators		
	number of plots ($nplot_r$)	weighted average plot shape index ($wshsq_r$)	average plot areal form factor ($aform_r$)	average plots size (ha) ($avpls_r$)	Simpson index ($simps_r$)	Januszewski index ($janus_r$)
Production cost						
Fertilisers per area unit	+ **	– ns	+ ns	– ns	+ *	– *
Seeds per area unit	+ ns	+ ***	– ***	– ns	+ ns	– ns
Pesticides per area unit	+ ***	+ ns	+ ns	– *	+ ***	– ***
Fuel cost per area unit	– ns	+ ns	+ ns	– ns	– ns	+ ns
Intermediate consumption per area unit	+ ns	+ ns	+ ns	– ns	– ns	– ns
Hired labour cost	+ ns	+ ns	+ ns	– *	+ ns	– ns
Yields						
Wheat yield	– ns	– *	+ ns	+ ns	– ns	+ ns
Milk yield	+ ns	– ns	+ ns	+ ns	+ ns	– ns
Financial results without farm subsidies						
Gross product per area unit	+ ns	– ns	+ **	+ ns	– ns	+ ns
Gross margin per area unit	+ ns	– ns	+ *	+ ns	– ns	+ ns
Operating surplus per area unit	– ns	– ns	+ ns	+ ns	– ns	+ ns
Pre-tax profit per area unit	– **	– ns	+ ns	+ **	– ***	+ ***
Efficiency scores						
Technical efficiency	– ns	+ ns	+ ns	+ ns	– ns	+ ns
Pure technical efficiency	– ns	+ ns	+ ns	+ ns	+ ns	– ns
Scale efficiency	– ns	+ ns	– ns	+ **	– *	+ ns

[a] *The fragmentation descriptors (columns) are calculated at the municipality level (see text)*
, **, *: significance at the 1%, 5%, 10% level respectively. ns: not significant.*

Source: authors' calculations

Table 5 (continued): Fragmentation descriptors and FADN farms' performance: sign and significance of regression coefficients for LF indicators [a]

Performance indicator	Indicators of plots' distance to the farm			Indicators of plots' scattering
	average distance of an hectare $(avdha_r)$	grouping index $(grpgi_r)$	structural index $(strui_r)$	Normalized av. nearest neighbour distance $(nannd_r)$
Production cost				
Fertilisers per area unit	+ ns	+ ns	+ ns	– *
Seeds per area unit	– ns	– ns	+ ns	– ns
Pesticides per area unit	+ ns	+ ns	+ **	– ns
Fuel cost per area unit	+ ns	+ ns	+ ns	+ ns
Intermediate consumption per area unit	+ ns	+ ns	+ ns	+ ns
Hired labour cost	+ ns	+ ns	+ ns	– ns
Yields				
Wheat yield	– ns	– *	– ns	– ns
Milk yield	– ns	– ns	– ns	– ns
Financial results without farm subsidies				
Gross product per area unit	+ ns	– ns	– **	– ns
Gross margin per area unit	– ns	– ns	– ***	– ns
Operating surplus per area unit	– ns	– ns	– ***	– ns
Pre-tax profit per area unit	– ns	– *	– ***	+ ns
Efficiency scores				
Technical efficiency	+ ns	– ns	– *	– ns
Pure technical efficiency	+ ns	– ns	– ns	– ns
Scale efficiency	– ns	– ns	– ns	+ ns

[a] *The fragmentation descriptors (columns) are calculated at the municipality level (see text)*
, **, *: significance at the 1%, 5%, 10% level respectively. ns: not significant.*

Source: authors' calculations

Figure 1: Brittany NUTS3 regions and studied municipalities

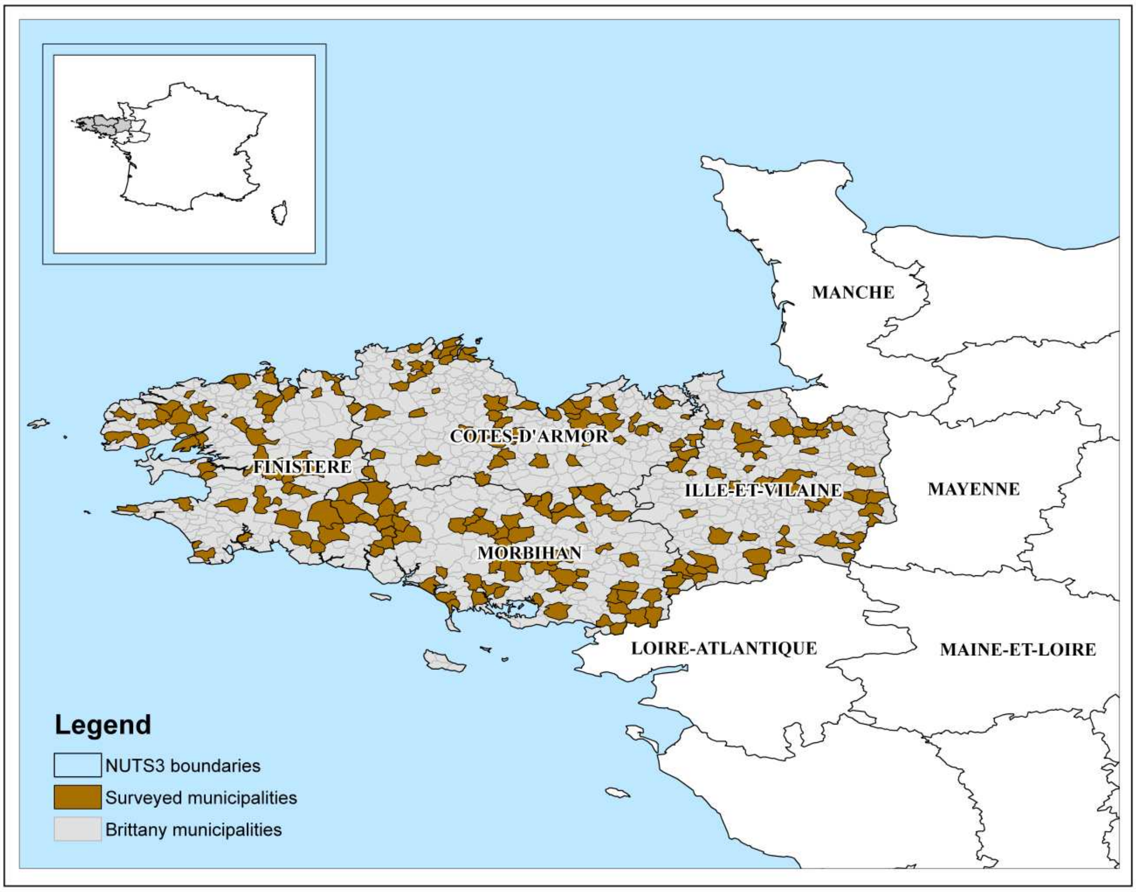
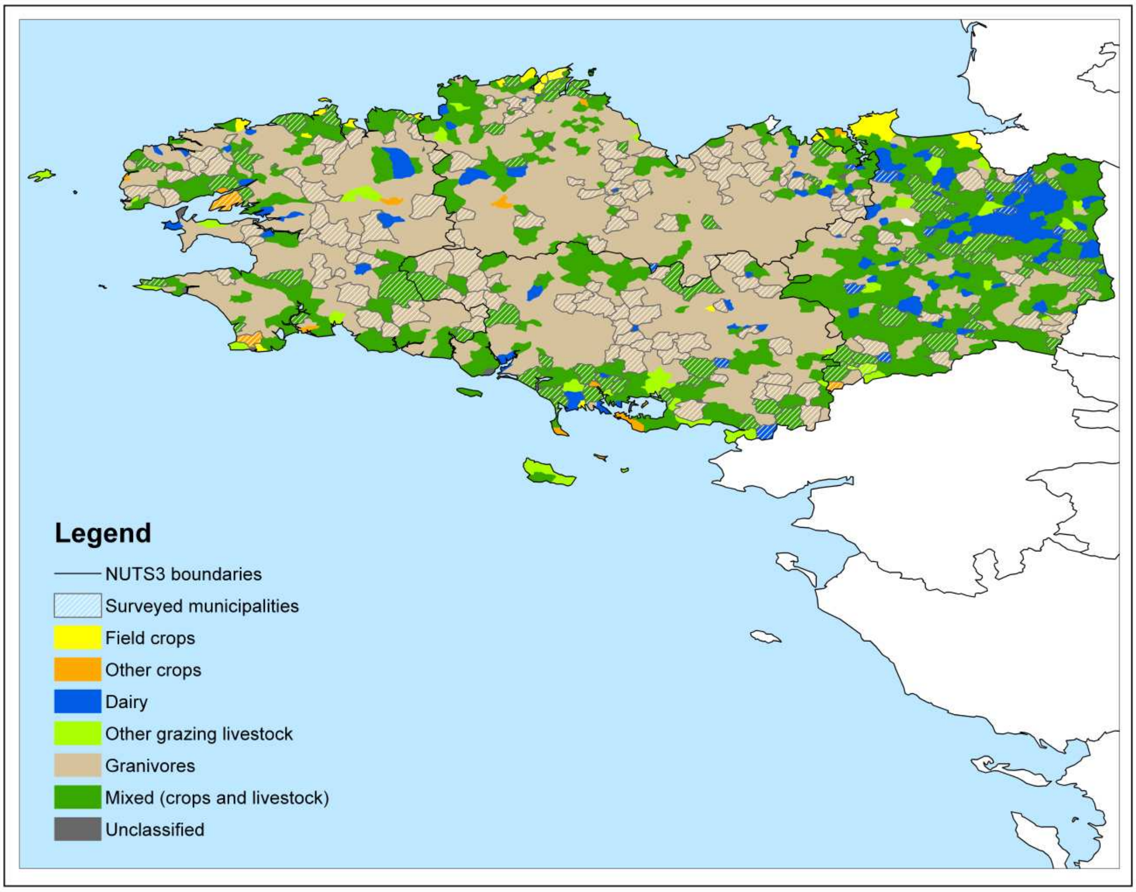


Figure 2: Main productions in Brittany's municipalities



Source: Agricultural Census 2010 – authors' calculations

Appendix. Formal definition of the LF descriptors used

Considering:

- i an index for the farms
- $k, l = 1, \dots, K_i$ an index for the plots of farm i
- (x_k, y_k) the plane coordinates of the centroid of plot k
- a_k the area of plot k and $A_i = \sum_{k=1}^{K_i} a_k$ the total area of farm i
- p_k the perimeter of plot k
- $(\bar{x}_i, \bar{y}_i) = \left(\frac{1}{A_i}\sum_{k=1}^{K_i} a_k x_k , \frac{1}{A_i}\sum_{k=1}^{K_i} a_k y_k\right)$ the plane coordinates of the barycentre of farm i

The LF descriptors are defined as follows:

1. LF descriptors relating to the number of plots

- number of plots: $nplot_i = K_i$

2. LF descriptors relating to the shape of plots

- weighted average plot shape index: $wshsq_i = \frac{1}{A_i}\sum_{k=1}^{K_i} a_k \frac{p_k}{4\sqrt{a_k}}$
- average plot areal form factor: $aform_i = \frac{1}{K}\sum_{k=1}^{K_i} \frac{a_k}{p_k^2}$

3. LF descriptors relating to the size of plots

- Average plots size: $avpls_i = \frac{A_i}{K_i}$
- Simpson index: $simps_i = 1 - \frac{\sum_{k=1}^{K_i} a_k^2}{A_i^2}$
- Januszewski index: $janus_i = \frac{\sqrt{A_i}}{\sum_{k=1}^{K_i} \sqrt{a_k}}$

4. LF descriptors relating to the distance of plots to the farm

- Average distance of an hectare:

$$avdha_i = \frac{1}{A_i}\sum_{k=1}^{K_i} a_k\sqrt{(x_k - \bar{x}_i)^2 + (y_k - \bar{y}_i)^2}$$

- Grouping index:

$$grpgi_i = \frac{argmax_{k=1}^{K_i}\left(\sqrt{(x_k - \bar{x}_i)^2 + (y_k - \bar{y}_i)^2}\right)}{\sqrt{A_i/\pi}}$$

- Structural index:

$$strui_i \equiv \frac{ngrpg_i}{avpls_i} = \frac{K_i . argmax_{k=1}^{K_i}\left(\sqrt{(x_k - \bar{x}_i)^2 + (y_k - \bar{y}_i)^2}\right)}{A_i\sqrt{A_i/\pi}}$$

5. LF descriptors relating to the scattering of plots

- Normalized average nearest neighbor distance:

$$nannd_i = \frac{\sum_{k=1}^{K_i} argmin_{l=1}^{K_i}\left(\sqrt{(x_k - x_l)^2 + (y_k - y_l)^2}\right)}{K_i\sqrt{A_i/\pi}}$$