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Does land fragmentation affect farm performance?

A French Breton case study

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Summary

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 correlation coefficients 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. 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 and lower crop yields where land fragmentation is more pronounced, but that this does not impede those farms from generating higher financial results. However, further investigations based on sound econometric estimations are needed before causal conclusions could be drawn.

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

JEL Classification codes: Q12, Q15, D24

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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. First, it takes time to travel from one parcel to the other when the labour force could be dedicated to more productive tasks. Second, it may require more equipment –in quantity and/or quality–, secondary farm buildings and/or external service expenses. Third, 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. Fourth, 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. First, greater LF may imply an increased diversity of land quality and therefore potentially higher yields. Second, 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 only 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 in Bulgaria affects farm profitability 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 of a hypothetical dataset.

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 3.65 hectares; 25% of the farms had 19 plots or more and 25% of these plots exhibited an average area of 0.91 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, yield, 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 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.

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 environmental vulnerable zones subject to zoning regulations

(Table 1). In 2007 the studied farms used on average 65.3 hectares (ha), which is greater than Brittany's farm population average of 47.3 hectares (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 average of 1.65 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 on average 76.8% of their utilised area, and employed 14.3% of hired labour force. They cultivated on average 4.6 different crops per year on their farm area.

Figure 1. Brittany NUTS3 regions and studied municipalities.

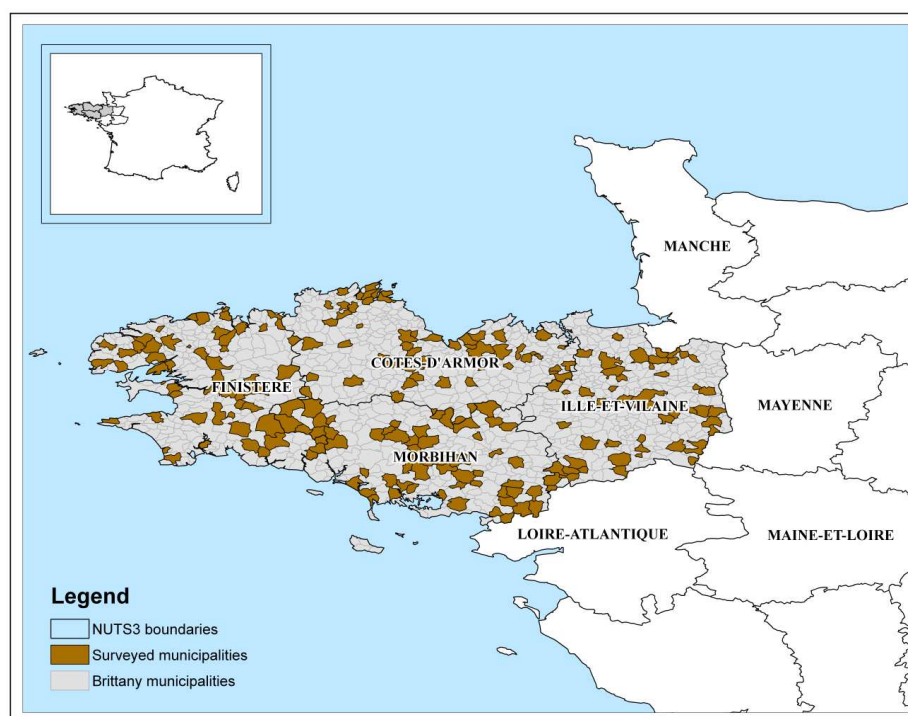
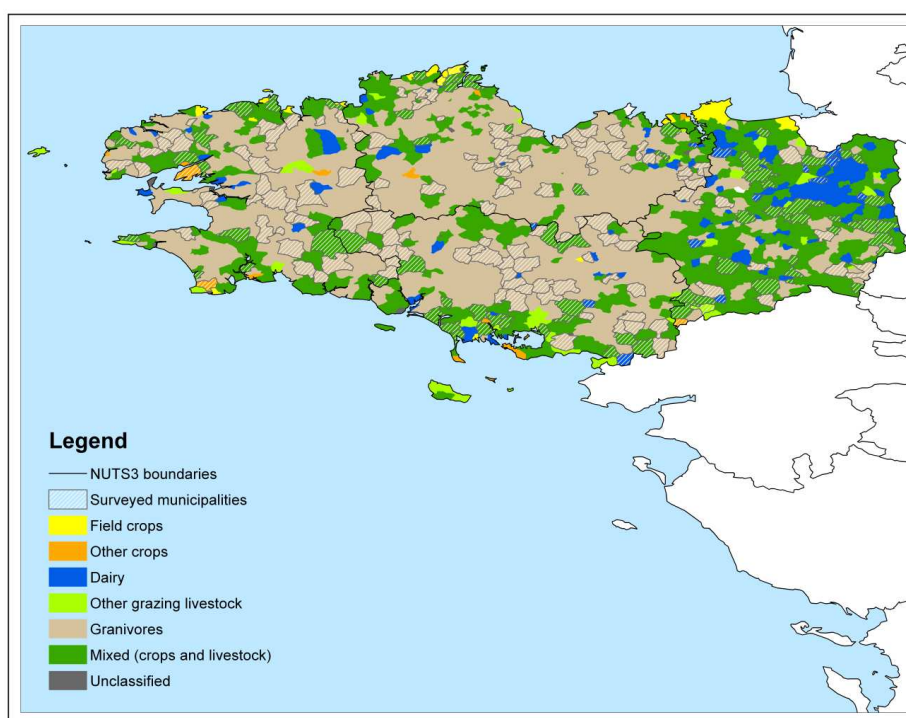


Table 1. Main characteristics of the farms in the FADN sample used (260 farms).

	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 environmental zoning			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

Figure 2. Main productions in Brittany's municipalities.

Source: Agricultural Census 2010 – authors' calculations

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, hired labour and outsourcing (*i.e.*, contract work). Secondly, two production yields were used: wheat yields in tons of wheat produced per hectare of wheat cultivated, and milk yields in litres of cow milk produced per cow. Thirdly, farm subsidies were investigated: farm subsidies excluding investment subsidies, and, within those subsidies, crop area payments, livestock area payments and environmental subsidies. Fourthly, 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; moreover, these four financial indicators were also 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 from 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 efficiency scores depend on the sample used, we did not construct the efficient frontier on the 260 farms only, but we used the whole Brittany FADN sample 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 2,856 Euros of pre-tax profit 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.

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
Outsourcing (contract work)	338
Yields	
Wheat yield (tons / hectare)	5.4
Milk yield (litres / cow)	7,092
Subsidies per area unit (Euros / hectare)	
Farm subsidies (outside investment subsidies)	577
Crop area payments	265
Livestock head payments	38
Environmental subsidies	6
Financial results per area unit (Euros / hectare)	
Gross product	24,784
Gross margin	11,163
Operating surplus	6,018
Pre-tax profit	2,856
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

2.2. Measuring land fragmentation

Land fragmentation was 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 'plots' which we will define for the rest of the paper as follows: a 'plot' is defined as 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.

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>).

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 Brittany and for which all plots were located inside Brittany; ii) farms registered inside Brittany but whose plots were partly located outside Brittany and; iii) farms registered outside Brittany but whose plots were totally or partly located inside Brittany. We considered all 30,234 farms and 428,260 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: in total we retained 386 farms from case ii) and 416 farms from case iii). For those 802 (386 + 416) farms, we considered not only their plots located in Brittany but also their plots located in the directly neighbouring NUTS3 regions outside Brittany. In the end, the database constructed for use in this paper consisted of 31,036 farms and 441,165 plots.

Four fragmentation descriptors were computed for each farm i : the number of plots, n_i ; the mean size of plots, h_i ; the grouping index, g_i ; and the structural index, s_i . Marie (2009) defines the grouping index g_i as the ratio of the distance from the most remote plot to the farmstead, d_i , to the radius of a hypothetical disc with the same area as the farm area ($g_i = \frac{d_i}{\sqrt{n_i h_i / \pi}}$); he further defines the structural index s_i as g_i divided by h_i . Hence, the grouping index captures the fragmentation dimension of plots’ distance, while the structural index accounts not only for plots’ distance but also for plots’ size. 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 of the farm plots being the plot’s area); we then replaced d_i in the above formula of the grouping index by \tilde{d}_i , the distance from the most remote centroid to the barycentre of the farm, leading to a new grouping index \tilde{g}_i ; we also modified the definition of the structural index accordingly, leading to \tilde{s}_i . Note that, for a given farm area, the number of plots, the grouping index and the structural index all increase with farmland fragmentation, while plot size mean decreases with farmland fragmentation.

Table 3 reports descriptive statistics for the 31,036 farms considered in our database. On average, the farms registered outside Brittany were the largest (their average area was 76.18 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). The four Breton NUTS3 regions ranked in the same order whatever the fragmentation descriptor considered, with ‘Côtes-d’Armor’ appearing as the most fragmented one (highest number of plots, lowest mean size of plots, highest grouping and structural indices), followed by ‘Finistère’, ‘Ille-et-Vilaine’ and finally ‘Morbihan’ (lowest number of plots, highest mean size of plots and lowest grouping and structural indices). The situation of farms registered outside Brittany was more contrasted: those farms were relatively fragmented when considering the number of plots or the grouping and structural indices, 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 small sample and, second, because when considered together they constituted a heterogeneous

category (the structure and production orientation of farms in the northern ‘Manche’ is quite different of these in ‘Loire-Atlantique’ in the South).

Table 3. Descriptive statistics of the fragmentation descriptors at the farm level.¹

NUTS3 where the farm is registered	Number of farms	Total farm area (ha)	Number of plots (n_i)	Mean size of plots (ha) (h_i)	Grouping index (\tilde{g}_i)	Structural index (\tilde{S}_i)
Côtes d’Armor	8,582	51.07 <i>(36.08)</i>	16.01 <i>(11.74)</i>	3.62 <i>(2.39)</i>	9.07 <i>(12.50)</i>	3.98 <i>(11.17)</i>
Finistère	6,490	56.10 <i>(42.53)</i>	15.20 <i>(11.66)</i>	4.34 <i>(3.47)</i>	9.14 <i>(13.35)</i>	3.51 <i>(7.71)</i>
Ille-et-Vilaine	9,057	48.72 <i>(37.18)</i>	12.87 <i>(10.63)</i>	4.33 <i>(3.60)</i>	8.80 <i>(13.17)</i>	3.18 <i>(7.70)</i>
Morbihan	6,491	53.81 <i>(40.18)</i>	12.66 <i>(9.88)</i>	4.87 <i>(3.61)</i>	6.88 <i>(10.32)</i>	2.20 <i>(5.19)</i>
Other ²	416	76.18 <i>(10.91)</i>	15.39 <i>(9.65)</i>	5.67 <i>(3.30)</i>	18.90 <i>(25.67)</i>	4.18 <i>(5.53)</i>
All	31,036	52.39 <i>(38.95)</i>	14.21 <i>(11.11)</i>	4.26 <i>(3.31)</i>	8.68 <i>(12.82)</i>	3.28 <i>(8.41)</i>

Source: “RPG anonyme ASP 2007” database – authors’ calculations

¹ Except for the number of farms, averages are presented and standard deviations are shown in brackets and italic font.

² 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.

Table 4. Correlation matrix of the fragmentation descriptors at the farm level.

	Number of plots (n_i)	Mean size of plots (ha) (h_i)	Grouping index (\tilde{g}_i)	Structural index (\tilde{S}_i)
Number of plots (n_i)	1.000			
Plot size mean (ha) (h_i)	-0.224	1.000		
Grouping index (\tilde{g}_i)	0.123	-0.088	1.000	
Structural index (\tilde{S}_i)	0.074	-0.191	0.741	1.000

Source: “RPG anonyme ASP 2007” database – authors’ calculations

Table 4 displays the correlation matrix of the four descriptors considered. It shows that the mean size of plots h_i is negatively correlated with the three other descriptors, confirming that, as expected, its relation with fragmentation is opposite to the relation of the other descriptors. The table also shows that the correlations are generally low, except between the grouping index \tilde{g}_i and the structural index \tilde{S}_i .

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 , each weight being the share of the farm area that was located in r . Formally, the fragmentation descriptor x in municipality r was given by:

$$x_r = \frac{1}{N_r} \sum_{i \in r} \frac{(S_i)_r}{S_i} x_i$$

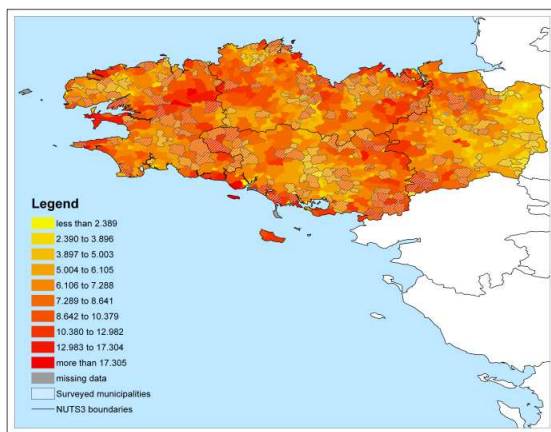
where x stands for one of the four fragmentation descriptors, N_r is the number of farms for which at least one of their exploited plots is located in r , $S_i = n_i h_i$ is the total area exploited by farm i and $(S_i)_r$ represents farm i exploited area that is located within municipality r . Note that, because we excluded

almost 3% of the farms (885 out of 31,921) from the initial field pattern registry 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.

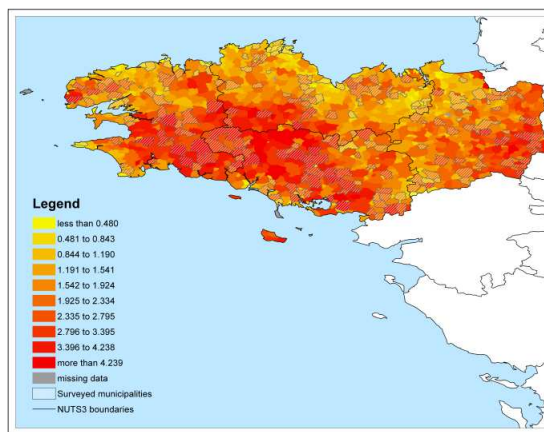
The four panels of Figure 3 map the descriptors computed at the municipality level. The opposite relationship between the number of plots and mean size of plots mentioned earlier is quite noticeable from the comparison of panels a) and b). No particularly striking spatial pattern arises for the grouping index on panel c). The spatial pattern of the structural index on panel d) corresponds to the one of the number of plots on panel a), but contrasts less with the spatial pattern of the mean size of plots on panel b). All in all, the maps show that the eastern part of ‘Ille-et-Vilaine’ and the area made up by the western part of ‘Morbihan’, the south-western part of ‘Côtes-d’Armor’ and the southern part of ‘Finistère’ seems to be less fragmented than the rest of Brittany.

Figure 3. Fragmentation descriptors at the municipality level.

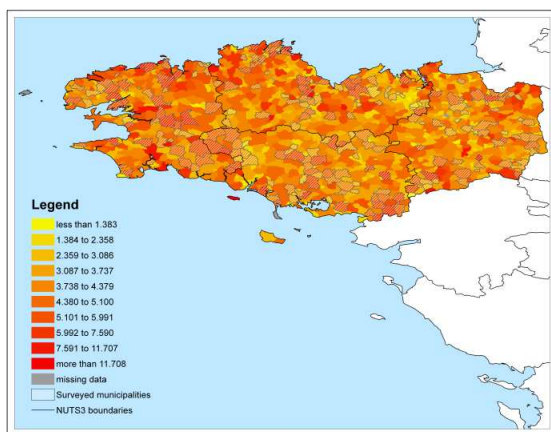
a) Number of plots (n_r)



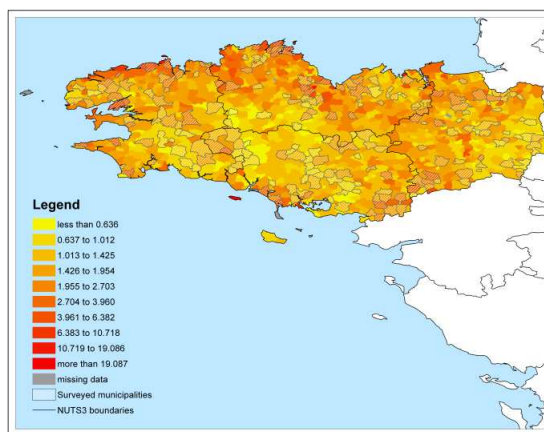
b) Mean size of plots (h_r)



c) Grouping index (\tilde{g}_r)



d) Structural index (\tilde{s}_r)



Source: ‘‘RPG anonyme ASP 2007’’ database – authors’ calculations

Finally, Table 5 and Figure 4 respectively report descriptive statistics and the corresponding distributions for the 215 municipalities which are used in the performance calculations with FADN, as well as for all the 1,255 Breton municipalities for which we had data. Both the table and the figure show that our sample is skewed toward higher values (of farm number, of area farmed and of fragmentation indices) but that the discrepancy is nevertheless very slight so that it can be regarded as representative of Brittany with good confidence.

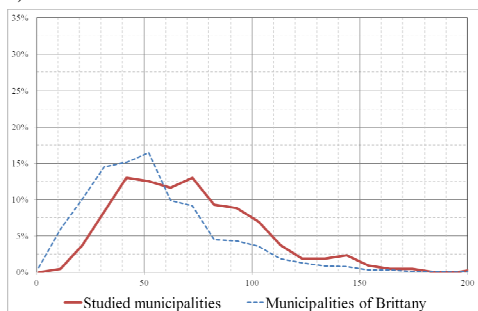
Table 5. Descriptive statistics at the municipality level.

	Mean	Std. deviation	Min	Max
Studied municipalities (215 observations)				
Number of farms	66.38	33.19	10.00	205.00
Farmed area (ha)	1,876.88	1,239.13	40.71	7,169.74
Number of plots (n_r)	7.31	2.21	2.91	14.96
Plot size mean (ha) (h_r)	2.30	1.08	0.25	6.15
Grouping index (\tilde{g}_r)	4.44	1.22	1.34	8.99
Structural index (\tilde{s}_r)	1.65	1.04	0.39	9.10
All municipalities in Brittany (1,255 observations)				
Number of farms	49.09	30.52	1.00	205.00
Farmed area (ha)	1,270.65	1,004.56	0.65	7,169.74
Number of plots (n_r)	6.90	2.84	0.18	31.51
Plot size mean (ha) (h_r)	1.88	1.03	0.01	6.15
Grouping index (\tilde{g}_r)	3.95	3.12	0.12	101.92
Structural index (\tilde{s}_r)	1.61	2.17	0.03	54.90

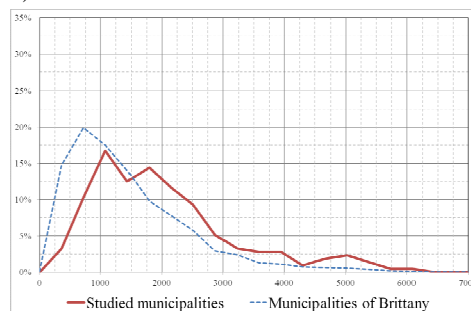
Source: “RPG anonyme ASP 2007” database – authors’ calculations

Figure 4. Distributions of the statistics reported in Table 5 for the studied municipalities (215 observations) and for all municipalities in Brittany (1,255 observations).

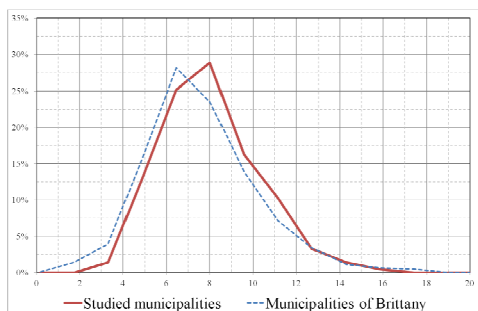
a) Number of farms



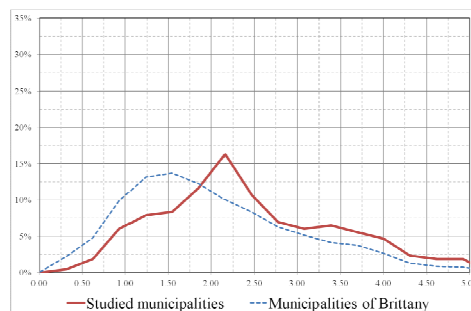
b) Farmed area



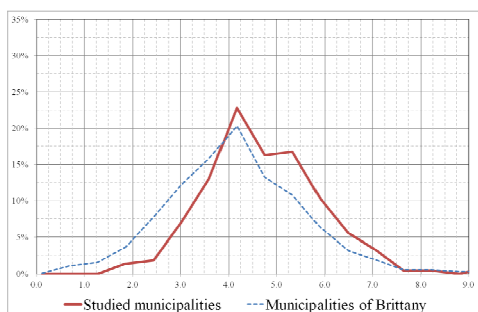
c) Number of plots (n_r)



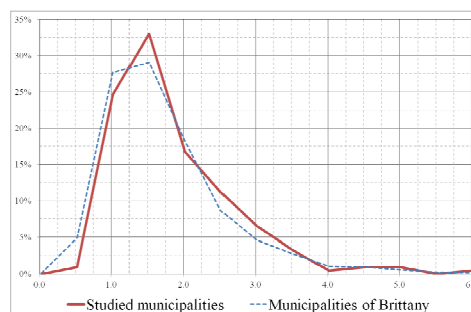
d) Average plot size (h_r)



e) Grouping index (\tilde{g}_r)



f) Structural index (\tilde{s}_r)



Source: “RPG anonyme ASP 2007” database – authors’ calculations

3. RESULTS

Table 6 shows how LF in FADN farms' municipality differs per farm depending on the farms' structure. Regarding the type of farming, there is no significant difference in terms of number of plots and mean size of plots. By contrast, the grouping and structural indices are higher (that is to say LF is more pronounced) on average in the municipalities where the farms of our FADN sub-sample which produce mainly other crops and mainly field crops are located. The average mean size of plots is higher in municipalities of farms located in areas without environmental zoning but no other significant difference exist for the other LF descriptors. Farms with larger utilised area are located in municipalities where the average mean size of plots is higher, and average grouping and structural indices are lower, that is to say LF is less pronounced. However, in such municipalities the average number of plots is also higher, which would indicate that LF is more pronounced. Farm labour per area unit is higher on farms located in municipalities where LF is more pronounced in terms of mean size of plots and grouping and structural indices. The same link is observed with respect to the number of crops per area unit and with respect to the equipment value per area unit. These findings suggest that LF requires more labour and equipment, may constrain farm enlargement, and that the production of crops is more adapted to a fragmented farm than livestock breeding does.

Table 6. Fragmentation descriptors and FADN farms' structure.¹

	Number of plots (n_r)	Mean size of plots (ha) (h_r)	Grouping index (\tilde{g}_r)	Structural index (\tilde{s}_r)
Mean descriptor per farm type				
Field crops	7.99	1.87	5.33	2.91
Dairy	7.17	2.28	4.18	1.49
Other grazing livestock	6.98	2.37	4.41	1.51
Granivores	7.21	2.46	4.67	1.56
Mixed (crops and livestock)	7.85	2.42	4.65	1.59
Other crops	7.84	2.00	5.17	3.18
Equality of the mean (t-test)			***	***
Mean descriptor in areas with/without environmental zoning				
Outside areas	7.35	2.34	4.56	1.73
Inside areas	7.82	1.48	4.87	2.90
Equality of the mean (t-test)		***		
Correlation coefficient with				
Utilised area	0.156 ***	0.120 **	-0.119 **	-0.238 ***
Labour used per area unit	0.060	-0.145 **	0.107 *	0.291 ***
Number of crops per area unit	-0.008	-0.131 **	0.094	0.274 ***
Value of equipment per area unit	0.077	-0.102 *	0.087	0.194 ***

Source: authors' calculations

*, **, ***: significance at the 1%, 5%, 10% level respectively

¹ The fragmentation descriptors (columns) are calculated at the municipality level (see text)

The correlation coefficients between FADN farms' performance and LF descriptors in their municipality are presented in Table 7. A first result worth noticing is that very few correlations with respect to the municipalities' average number of plots are significant, while almost all correlations with respect to the structural index are. Farms located in municipalities where the average number of plots per farm is higher (*i.e.*, LF is more pronounced), have significantly higher seed and pesticide costs per area unit and a lower wheat yield on average. This supports a negative relationship between LF and farm performance. Farms located in municipalities where the average mean size of plots is lower (*i.e.*, LF is more pronounced), have significantly higher pesticide, intermediate consumption and hired labour costs per area unit, and a lower scale efficiency, on average. This also supports a negative relationship between LF and farm performance.

However, those farms also have higher farm subsidies, including crop area payments and environmental subsidies, as well as higher gross product and gross margin, on average, supporting a positive relationship. The correlations with respect to the grouping index indicate a significant negative relationship between LF and farm performance when fertiliser, seed, pesticide and hired labour costs are considered (*i.e.*, the correlation coefficients are positive), but a positive relationship between LF when farm subsidies and pure technical efficiency are considered (*i.e.*, the correlation coefficients are positive). In turn, the structural index has a significant negative relationship with farm performance when all types of production cost (except for outsourcing cost), wheat yield and scale efficiency are considered. However, the relationship is significantly positive with farm subsidies, including crop area payments, and all financial result indicators. Finally, it is also worth noticing that the positive link between farms' financial results and LF in their municipality remains when farm subsidies are not accounted for in financial results indicators.

Table 7. Fragmentation descriptors and FADN farms' performance: correlations coefficients.¹

	Number of plots (n_r)	Mean size of plots (ha) (h_r)	Grouping index (\tilde{g}_r)	Structural index (\tilde{s}_r)
Production cost				
Fertilisers per area unit	0.087	-0.081	0.104 *	0.231 ***
Seeds per area unit	0.138 **	-0.083	0.108 *	0.278 ***
Pesticides per area unit	0.130 **	-0.130 **	0.194 ***	0.369 ***
Fuel cost per area unit	-0.037	-0.084	0.041	0.158 ***
Intermediate consumption per area unit	0.014	-0.114 *	0.067	0.187 ***
Hired labour cost	0.059	-0.147 ***	0.108 *	0.278 ***
Outsourcing (contract work) per area unit	-0.033	0.016	-0.010	0.001
Yields				
Wheat yield	-0.190 ***	0.052	-0.081	-0.131 *
Milk yield	0.071	0.082	0.007	-0.034
Subsidies				
Subsidies (not investment) per area unit	0.057	-0.156 ***	0.147 **	0.345 ***
Crop area payments per area unit	0.081	-0.167 ***	0.172 ***	0.381 ***
Livestock head payments per area unit	-0.105 *	0.004	-0.052	-0.083
Environmental subsidies per area unit	-0.069	-0.129 **	-0.037	0.017
Financial results				
Gross product per area unit	0.027	-0.122 **	0.081	0.224 ***
Gross margin per area unit	0.041	-0.127 ***	0.095	0.258 ***
Operating surplus per area unit	0.024	-0.100	0.076	0.225 ***
Pre-tax profit per area unit	-0.012	-0.054	0.037	0.149 **
Financial results without farm subsidies				
Gross product per area unit	0.026	-0.122 **	0.080	0.222 ***
Gross margin per area unit	0.040	-0.125 ***	0.093	0.255 ***
Operating surplus per area unit	0.022	-0.097	0.072	0.218 ***
Pre-tax profit per area unit	-0.016	-0.048	0.031	0.147 **
Efficiency scores				
Technical efficiency	-0.009	0.033	0.076	0.313
Pure technical efficiency	0.010	-0.009	0.103 *	0.094
Scale efficiency	-0.063	0.158 ***	-0.079	-0.209 ***

Source: authors' calculations

*, **, ***: significance at the 1%, 5%, 10% level respectively

¹ The fragmentation descriptors (columns) are calculated at the municipality level (see text)

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, subsidies, financial results and technical efficiency) calculated for a sub-sample of FADN farms were correlated with 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 two more complex indices, the grouping index and the structural index, in order to account for the distance between plots and farmsteads.

Comparing FADN farms' structure with LF in their municipality suggests, as expected from agronomic intuition, that fragmentation implies greater labour and equipment requirements for production, that it may constrain farm enlargement, and that greater fragmentation may be less suitable for livestock breeding than crop production.

Considering only the significant relationships, the analysis of farm performance and LF shows three main findings. Firstly, the traditional LF measure of the number of plots is related to very few performance indicators. By contrast, the structural index, which is the most complex index used here and which accounts both for the distance and for the mean size of plots, is the LF descriptor that is most strongly related to farm structure (in terms of area, labour and capital use) and to performance indicators. In other words, the number of plots *per se* does not seem to be sufficient to characterise finely the impact of LF on agricultural production systems. Secondly, whatever the LF descriptor considered, similar conclusions are reached. Thirdly, those conclusions are fivefold. 1) There is a positive relationship between LF and production cost (for seeds, fertilisers, pesticides, fuel, intermediate consumption and hired labour, but not for outsourcing), meaning that LF is likely to reduce cost performance. 2) There is a negative relationship between LF and wheat yield, but no significant relationship between LF and milk yield. This suggests that the impact of LF as reducing farms' productivity would be more pronounced in crop production than in livestock breeding. 3) There is a positive relationship between LF and farm subsidies, and in particular between LF and crop area payments. The relationship between LF and environmental subsidies is significantly positive only when the mean size of plots is considered. 4) There is a positive relationship between farm financial results and LF, whether farm subsidies are included or not, however only when considering both LF measures that account for plot size (*i.e.*, the mean size of plots and the structural index). 5) There is a positive relationship between pure technical efficiency and LF measured by the grouping index, and there is a negative relationship between scale efficiency and LF measured by descriptors accounting for plot size (the mean size of plots and the structural index).

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

Scale diseconomies could explain why farms located in municipalities with stronger LF exhibit higher production cost for crop and fuel cost and lower wheat yields. The latter finding could also reflect the common feature that yields are generally lower on field boundaries than in the central area of fields; finding a negative and significant correlation between the yield of wheat and the number of plots would therefore

conform to intuition. It is however more surprising to find that farms' subsidies and financial results increase with municipality's LF. The finding regarding subsidies reveals that crop area payments per area unit decrease with plot size. This unexpected result may be due to the type of farms exploiting land on the municipality for which LF descriptors are calculated, or to the type of crops cultivated by farms in the FADN sample used. A possible explanation for the positive relationship between LF and farm financial results is that LF enables or forces farms to diversify their productions, thus providing some risk mitigation and protecting eventual revenue loss from pest outburst or climate shocks.

However, 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 needed, especially before drawing any policy recommendations. In effect, the examination of simple linear correlations as we did here suffers several limitations that need to be overcome beforehand since, as usual, correlation does not mean causality. Firstly, drawing such 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. Secondly, 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. Thirdly, a better control of farm heterogeneity should prevent from spurious correlations. In particular, as our results show that LF (particularly distance) could be more problematic for cattle breeding than for crop cultivation, it would be necessary to control for the type of farming and, more generally, other structural characteristics of the farm. Finally, drawing conclusions for Brittany as a whole would remain difficult before checking the validity of such an extrapolation: the fact that each of our samples may be regarded as representative does not imply that they are jointly representative. In other words, generalizing our results would imply to first check that the studied farms are also representative in terms of their location. Alleviating this set of limitations calls for a sound econometric analysis which would help confirming or contradicting the results found in the present work.

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