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The Effect of Land Fragmentation on Farm Performance: A Comprehensive Farm-Level Study from Denmark

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Abstract

This paper analyses the effect of land fragmentation on the performance of Danish farms based on a cross-sectional farm-level data set from 2014. Our measures of land fragmentation indicate the size and shape of the fields as well as inter-field distances and distances between farm buildings and fields. Fragmented land is expected to increase costs and reduce production and, thus, decrease the performance of farms. Preliminary results based on two methodological approaches both indicate no statistically significant effect of the shape of the fields, while smaller field sizes and longer distances significantly reduce performance.

Keywords: Land Fragmentation, Output distance function, Productivity, Denmark

JEL Classification: D24, Q12, Q15

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Author contributions:
Jakob Vesterlund Olsen and Jesper Sølver Schou initiated the research and developed the general idea of the study. The literature review was mainly conducted and the theoretical model was mainly developed by Jakob Vesterlund Olsen. The preparation, handling, and analysis of the data was conducted by Jakob Vesterlund Olsen, Tomasz Gerard Czekaj, and Arne Henningsen. The article was written by Jakob Vesterlund Olsen, Tomasz Gerard Czekaj, Jesper Sølver Schou, and Arne Henningsen. All authors participated in the revision of the article.

1 Introduction

Due to a rapid development of the mechanisation and automation of agricultural production processes, farm sizes in Denmark and in the rest of Western Europe have rapidly increased in recent decades, while the number of full-time farms has rapidly decreased. Although many farmers ceased their production and sold or leased their land to other farms, farms that wanted to increase their land area frequently did not find land close to their farm that was available for purchase or lease and, thus, bought or leased land that was further away from their farm. Furthermore, variation in climate or land quality can make the purchase or lease of distant fields attractive (Hung, Macaulay and Marsh 2007). Consequently, many farms have dispersed fields that are quite far away from each other and/or from their farm. Furthermore, sizes and shapes of the fields vary considerably, whereas some farms predominantly cultivate fields with favourable sizes and shapes, while other farms predominantly cultivate fields with unfavourable sizes and shapes, e.g. due to regional differences in legal and physical boundaries in the landscape. All together these elements lead to land fragmentation (LF), which is generally considered as a factor that influences costs and level of agricultural production and, thus, farm productivity and performance (Latruffe and Piet 2014).

Based on a unique farm-level dataset that combines farm-level accountancy data with various plot-level LF indicators as well as information about slurry production and soil quality, this paper empirically estimates the effect of LF on the performance of Danish farms. LF is measured in terms of size and shape of the fields as well as in inter-field distances and distances between farm buildings and fields. Information on the effects of LF can help farmers to make more informed decisions regarding buying or leasing of land. Furthermore, our results could help to assess the importance of reducing LF and to foster institutional innovations and to design policies that address those aspects of LF that have the most negative effects on performance.

The next section provides background information and theoretical considerations on land fragmentation. Sections 3 and 4 describe the data and methods used in this study, respectively. Sections 5 and 6 present and discuss, respectively, the results. Finally, section 7 concludes.

2 Background

Land fragmentation is used ambiguously in the literature (King and Burton 1982). The predominant interpretation of LF in the literature is that each farm becomes very small. This is often related to the division of farms into several separate farms when farms are inherited, which often also leads to the division of fields because heirs are supposed to share different qualities of land (Jabarin and Epplin 1994).

However, this is not relevant in the Danish case. Therefore, we use an alternative interpretation of LF in this paper: size and shape of the fields as well as inter-field distances and distances between farm buildings and fields. In the literature, it is argued that this type of LF can be associated both with gains and losses (Blarel et al. 1992, Jabarin and Epplin 1994). Gains from LF could be caused by variation in climatic conditions and soil quality, which is not included in the definition of LF in our study. Climate variation is minimal within Denmark and we control for soil quality in the estimation.[1] Higher variation in crop choice is also mentioned as a benefit from small plot sizes but this is a pseudo-argument because nothing hinders farmers from dividing their fields into several parts and planting a different crop on each part if this is optimal.

Table 1 presents some reasons for negative impacts of LF on farm performance. For instance, shape and size of a field affect the complexity of field operations and, thus, the associated costs. Furthermore, the longer inter-field distances and distances between farm buildings and fields, the more time is spend on transport leading to increased labour and machinery costs.

[1] We use the share of loamy soils in total farm land as indicator of soil quality. If variation in soil quality is an advantage, farms with around 50% of loamy soils should *ceteris paribus* have a higher performance than farms with a very small or a very high proportion of loamy soils, resulting in a strictly concave relationship between the proportion of loamy soils and performance.

Table 1: Reasons for negative impacts of LF on farm performance

LF Dimension	Mechanism behind the effect on farm performance	Effect on farm performance
Low plot size		
	Higher organising and controling cost	-
	Harvest loss along field boundaries and living fences	-
	Machinery capacity utilisation low due to machinery transfer between working and transportation mode	-
	Cost of cleaning dirt from public roads after transportation tasks	-
	Risk of traffic accidents increases	-
Irregular plot shape		
	Reduced capacity utilisation of machinery	-
	Harvest loss along field boundaries and in corners	-
	Higher input factor use in wedge-shaped parts of the field	-
Long distances		
	Increased cost for transportation of inputs, workers, outputs, equipment and grazing livestock	-
	Less labour dedicated to productive tasks and conflicts in labour allocation	-
	Difficult water management	-

Source: Based on Østergaard (1987) and Latruffe and Piet (2014)

The type of LF that we analyse in our study can be caused by various factors such as urban development, evolution of infrastructure, or farm consolidation (Jabarin and Epplin 1994). In Denmark, shapes and sizes of the fields are usually a reminiscence of the 18th century farm technology. Improving shapes and sizes of fields usually requires the relocation or destruction of streets, hedges, trees, or streams, which would be costly or is restricted by environmental regulations.

Many studies have shown that agricultural production usually exhibits increasing returns to scale (e.g. Heshmati and Kumbhakar 1997, Rasmussen 2010, Latruffe and Sauer 2010, Kumbhakar and Lien 2010, Zhu and Lansink 2010, for crop farms in Europe). With increasing returns to scale and technology evolving over time, optimal farm size has increased and is expected to increase even further in the future. In order to benefit from increasing returns to scale and mechanisation, many young farmers have acquired land from older farmers and successful farmers have acquired land from less successful farmers. The high demand for agricultural land resulted in extreme land scarcity so that farmers who wanted to exploit economies of scale by increasing their land size were frequently unable to buy or lease land from neighbouring farms but had to accept any land available (Blarel et al. 1992). This increased the inter-field distances and distances between farm buildings and fields. Furthermore, the inter-field distances and the distances between farm buildings and fields have increased simply because of the increase in farm size. Farmers accepted additional costs of transportation that occurred due to increased distances when expanding their farms because of the substantial gains from economies of scale, while in the absence of economies of scale, farms would have maintained their farm size (Krugman 1998).

Several studies have analysed the effects of LF (e.g. Jabarin and Epplin 1994, Wan and Cheng 2001, Hung, Macaulay and Marsh 2007, Tan et al. 2010, Manjunatha et al. 2013, Latruffe and Piet 2014). The study that is most similar to our study is the one of Latruffe and Piet (2014) who found that in Brittany (France), LF in a municipality was negatively associated with performance and productivity of farms in the respective municipality. In contrast to Latruffe and Piet (2014), our study analyses effects of LF on performance at individual farm level.

3 Data and variables

3.1 Data sources

The farm-level economic data used in our analysis are based on farm accounts for the year 2014 collected in a database at SEGES (2015)[2]. The information level, conventions, and concepts of these farm accounts are in line with those of the FADN data. This dataset includes accountancy data from about half of the full-time farms in Denmark.

The field-level geographical data used in our analysis are based on Geographical Information System (GIS) data from the Danish Agrifish Agency that administers farmer' application for support under the Common Agricultural Policy (CAP). This database covers 604,000 fields and 2.67 million hectares of agricultural land, which corresponds to roughly 99% of the agricultural land in Denmark.

These two data sets were merged based on the farms' unique id numbers in the Danish Central Business Register (*Det Centrale Virksomhedsregister*, CVR) that identify all business in Denmark including all farms organised as sole proprietorships, corporate entities, or other organisational forms.

The farms in our economic dataset and fields in our geographical dataset do not comprise random samples of all farms and all fields, respectively, in Denmark. However, given that our merged database is based upon about half of all full-time farms and 99% of all fields in Denmark, we expect that farms in our merged dataset represent a large proportion of farms in Denmark, particularly of full-time farms.

3.2 Farm performance

Our analysis of farm performance is based on the farms' annual accounts. These annual accounts are not used for tax purposes but have been prepared to support the respective farmer's decision making and, thus, should give realistic information about the farm's performance. Depreciation of investments is usually done by the straight-line method.

One indicator of farm performance that we use in our analysis is the Ricardian land rent. We calculate the Ricardian land rent by adding a remuneration for unpaid work (usually the farmer and eventually some family members) to farm profit (including subsidies) before interest payments and taxes and dividing this by the farm's agricultural land area.

Furthermore, we aggregate the production data from farm accounts into five inputs and two outputs that we can use to assess farm performance based on an output distance function (see below).

3.3 Land Fragmentation (LF)

LF is often quantified with simple measures, e.g. Jabarin and Epplin (1994) use the field size, Wan and Cheng (2001) use the number of plots and the average plot size, Hung, Macaulay and Marsh (2007) use the number of plots and the Simpsons index, Tan et al. (2010) use the number of plots combined with the average plot size and the average distance from the homestead to the plots, and Manjunatha et al. (2013) use the number of plots. However, when estimating the effects of LF on performance, one needs to use suitable indicators of LF that make sure that the effects of LF are not conflated with the effects of economics of scale.

In a recent study of land fragmentation, Latruffe and Piet (2014) use five different measures of LF that take into account the scattering of the fields, the distance to fields, and the number of plots. However, Latruffe and Piet (2014) observed the LF indicators at the municipality level and not for each individual farm due to lack of identification of farms across databases. Hence, the relationship between LF and performance could only be established at the municipality level, thus, disregarding individual effects at the farm level. In contrast to Latruffe and Piet (2014), our data sources allow us to identify LF indicators for each individual farm so that we can identify the effect of LF on performance at individual farm level.

[2] SEGES is a branch of the Danish Agriculture and Food Council (owned by Danish farmers).

The indicators of LF that we use in our analysis are based on the indices used by Latruffe and Piet (2014). Their indices have been tested and slight modifications of the indices combined with a new index are used to assess the LF in this paper.

We will use the following symbols to describe and explain the LF indicators that we use in our analysis:

- i is the subscript denoting the farm,
- P_i is total number of fields of farm i,
- $r, q = 1, \ldots, P_i$ are subscripts indicating the individual fields of farm i,
- (x_{ir}, y_{ir}) indicates the coordinates of the centroid for field r of farm i,
- a_{ir} denotes the area of field r for farm i,
- $A_i = \sum_{r=1}^{K_i} a_{ir}$ denotes the area in crop rotation of the farm i,
- p_{ir} denotes the length of the perimeter of field r for farm i,
- $(\bar{x_i}, \bar{y_i})$ denotes the coordinates for the farm, i.e. the address point,
- $mbr_{a_{ir}}$ is the area of the minimum bounding rectangle of field r for farm i, i.e. the smallest possible rectangle which envelopes the field r for farm i.

The Minimum Bounding Rectangle Area Index ($mbrai$) is then defined as:

$$mbrai_i = \frac{\sum_{r=1}^{P_i} \frac{a_{ir}^2}{mbr_{a_{ir}}}}{A_i} \tag{1}$$

This is the new index, which is a measure of how rectangular the field is. A rectangle has the value 1 and a circle has a value of 0.79. This index is assessed to outperform the average plot areal form factor and the the weighted average plot shape index from Latruffe and Piet (2014). Gonzalez, Alvarez and Crecente (2004) used the ploughing time for different land parcel shapes to calculate an index of shape. This measure is for large surveys hard to manage as the ploughing time is not easily calculated but the minimum bounding rectangle area index and the average field size together is expected to capture the same aspects as the ploughing index because regular large fields are faster to plough.

The average field size ($avfs$) is simply the agricultural area in rotation divided by the number of fields in rotation for a given farm

$$avfs_i = \frac{A_i}{P_i} \tag{2}$$

The distance to fields normalized by the farm size is denoted the average grouping index ($agrpgi$) and it is a modified version of the grouping index in Latruffe and Piet (2014). It is the average distance to the fields instead of the distance to the most distant of the fields as in Latruffe and Piet (2014).

$$agrpgi_i = \frac{\sum_{r=1}^{P_i} a_{ir} \cdot \text{network distance}((x_{ir}, y_{ir}); (\bar{x_i}, \bar{y_i}))}{A_i \sqrt{A_i/\pi}} \tag{3}$$

The average grouping index can be interpreted as the average distance to the hectare divided by the radius to the circle of the same size as the whole farm area.

The distance between the fields is referred to as the scattering of plots and denoted and calculated as Normalised Nearest Neighbour Index ($nannd$). This index is calculated at another level than the other indices, as the distance to other fields in most instances would be too small. In applied terminology of fields it is another field if a wet spot in a field with winter crop is sown with a spring crop. The plot level is potentially multiple fields bounded by physical barriers which for this purpose is considered to be a more suitable level. The normalized nearest neighbour index is calculated as in equation (4).

$$nannd_i = \frac{\sum_{r=1}^{P_i} \arg\min_{q=1}^{P_i} \left(\sqrt{(x_{ir} - \bar{x_q})^2 + (y_{ir} - \bar{y_q})^2} \right)}{P_i \sqrt{A_i/\pi}} \tag{4}$$

Descriptive statistics for farms used in both methodological approaches is presented in Table 2.

Table 2: Descriptive statistics of variables

	Mean		**Std. dev.**
Slurry, ton kilometre per hectare	15,571.4		24,481.5
log(UAA)*, hectare	187.4		120.5
Livestock units per hectare	1.773		0.879
Share of UAA*, forage	0.254		0.337
Share of UAA, clay	0.393		0.373
Farm type, No. of crop farms		352	
Farm type, No. of dairy farms		1849	
Farm type, No. of pig farms		1102	
Farm type, No. of mixed farms		160	
y_1, crop output, thousand DKK	2,075.8		1,451.6
y_2, animal and other output, thousand DKK	5,439.7		4,549.8
x_1, labour, hours	4,967.1		4,140.1
x_2, land, hectares	187.4		120.5
x_3, intermediate crop input, thousand DKK	408.1		300.7
x_4, intermediate non-crop input, thousand DKK	4,313.5		3,051.0
x_5, capital, thousand DKK	2,819.6		1,939.9
$log(mbrai)$ Minimum bounding rectangle index	0.725		0.055
$log(avpls)$ Average plot size, hectare	5.611		2.152
$log(agrpgi)$ Average grouping index	3.463		2.129
$log(nannd)$ Nearest neighbour index	3.091		1.015

* UAA - Utilised agricultural area

In the non-parametric estimations of the LF-indicators on land rent the full 3,463 farms are included but in the output distance function only farms which have animals are included as the logarithm is taken to the slurry production variable excluding farms without production of slurry from the analysis. 3,228 farms are utilised in the output distance function.

3.4 Slurry transportation

One component of the cost of LF is the transportation of slurry. Due to the European Commission directive on nitrate leaching and general environmental concerns, there is a limit to the maximum applicable slurry quantity on the land. The structure of the farms is heterogeneous and this component of costs is not necessarily captured in the distance between farm buildings and fields because more than 30 percent of the farms in the study have more than one herd and hence multiple sites where slurry is produced. It is assumed that the slurry is equally distributed to all fields that a livestock farmer cultivates and for that the farmer has slurry transfer agreements. The shortest necessary distance to spread the slurry from all slurry production sites to all the fields is calculated and the average distance is multiplied by the quantity of slurry produced, which gives a measure of slurry transport (in ton kilometres). This variable is used as a control variable in the estimations.

4 Method

We use two different approaches for analysing the effects of LF on farm performance. First, we use nonparametric local-linear kernel regression to estimate the effect of LF on the Ricardian land rent. Second, we use a Translog output distance function to estimate the effects of LF on technical efficiency.

4.1 Nonparametric regression

As argued earlier, it is expected that land fragmentation increases costs and reduces revenues (see Table 1) and, thus, reduces the Ricardian land rent. We regress the Ricardian land rent on various LF indicators as well as several control variables that may also affect the Ricardian land rent: soil quality, crop choice, farm type, farm size (economies of scale), livestock density, and costs of slurry transport. Due to possibly highly nonlinear relationships between the LF-indicators and the land rent, we use nonparametric local-linear kernel regression for our analysis because this avoids misspecification errors of the functional form.

Nonparametric local-linear kernel regression is basically a set of weighted linear regressions, where a linear regression is performed at each observation and the weights of the other observations decrease with the distance from the respective observation. The weights are determined by a kernel function and a set of bandwidths. The smaller the bandwidth, the faster the weight decreases with the distance from the respective observation.

We used local-linear kernel regression with Gaussian kernel functions used for continuous regressors and the Li and Racine (2004) kernel used for categorical regressor, and we selected the bandwidths based on the expected Kullback-Leibler criterion.

While the choice of the kernel function is usually of less importance (Silverman 1986), the choice of the bandwidths is the most crucial decision in nonparametric regression (Racine 2008). There are different ways to obtain the bandwidths (Racine 2008), namely Silverman's (1986) rule-of-thumb, plug-in methods, and data driven bandwidth selection methods. Currently two data driven methods, i.e. bandwidth selection according to the expected Kullback-Leibler criterion (Hurvich, Simonoff and Tsai 1998) and least-squares cross validation, are most often used in empirical applications of kernel regression.

The significance of an explanatory variables in a nonparametric regression setting (analogous to a simple t-test in a parametric regression setting) can be obtained using bootstrap methods proposed by Racine (1997).

4.2 Output distance function

We use the stochastic frontier framework (Aigner, Lovell and Schmidt 1977, Meeusen and van den Broeck 1977) to investigate how land fragmentation is related to farm technical efficiency. Because analysed farms produce more than one output, e.g. farms specialized in crop production can also produce animal output and provide agricultural services to other farms, farms specialized in animal production often produce also crops, etc. To avoid aggregation of these outputs to one output we distinguish two main output categories, namely crop output, y_1 and non-crop output y_2 which consists of animal output and other output (e.g. services). In order to account for multiple outputs in our model we use the multiple-output generalization of a frontier production function: the output distance function (Shephard 1970).

In our model we account for five inputs: labour, land, intermediate crop inputs, intermediate non-crop input, and capital. Labour input, x_1, expressed in hours is derived from cost of hired labour and proxy of family labour. Land input, x_2, equals utilised agricultural area in hectares. Intermediate crop input (e.g. seed, fertilizers etc.), x_3, and intermediate non-crop input (e.g. feed, veterinary, miscellaneous costs etc.), x_4, and capital input, x_5, measured using weighted average cost of capital are expressed in thousands DKK. We control for possible differences in production technologies among different farm types (FT) (e.g. crop farms, dairy/cattle farms, pig farms, other farms) using FT categorical variable based on share of crop output, dairy output and pig output in total output produced at the given farm.

We formulate our output distance function is the Translog functional form:

$$-\log(y_{1i}) = \beta_0 + \alpha_2 \log(y_{2i}/y_{1i}) + \frac{1}{2}\alpha_{22} \log(y_{2i}/y_{1i}) \log(y_{2i}/y_{1i}) + \sum_{m=1}^{5} \beta_m \log(x_{mi}) \tag{5}$$

$$+ \frac{1}{2} \sum_{m=1}^{5} \sum_{n=1}^{5} \beta_{mn} \log(x_{mi}) \log(x_{ni}) + \sum_{m=1}^{5} \theta_{m2} \log(x_{mi}) \log(y_{2i}/y_{1i})$$

$$+ \sum_{f=1}^{3} \psi_f FT_{fi} + u_i + v_i,$$

where subscript i indicates the farm, $\beta_m; m = 0, \ldots, 5$, $\beta_{mn}; m, n = 1, \ldots, 5$, α_2, α_{22}, $\theta_{m2}; m = 1, \ldots, 5$ and $\psi_f; f = 0, 1, 2, 3$ are parameters to be estimated, $u_i \sim N^+(\mu_i, \sigma_u^2)$ accounts for inefficiency, and $v_i \sim N(0, \sigma_v^2)$ is a random noise term which follows normal distribution with mean 0 and variance σ_v^2.

Furthermore, we account for land fragmentation using the same four indicators as we use in the non-parametric estimation of land rent model: $mbrai$, z_1, $avfs$, z_2, $agrpgi$, z_3, and $nannd$, z_4 and finally we control for the slurry transportation, sumsltonkm z_5.

We use Battese and Coelli (1995) approach, assuming that z-variables affect the location parameter of the technical inefficiency term, μ_i, as follows:

$$\mu_i = \delta_0 + \sum_{j=1}^{5} \delta_j log(z_j) \tag{6}$$

where subscript i indicates the farm and $\delta_j; j = 0, \ldots, 5$ are parameters to be estimated.

Therefore we obtain consistent estimates of all model parameters by joint estimation of stochastic frontier output distance function (5) and the inefficiency effects model (6) using maximum likelihood method. Marginal effects of the z-variables on technical efficiency are obtained using the method proposed by Olsen and Henningsen (2011).

5 Results

5.1 Ricardian land rent

The median values of gradients from the non-parametric estimation, optimal bandwidths and P-values indicating statistical significance of regressors are presented in Table 3. We found that the control variables: slurry transportation, utilised agricultural area, the soil quality, share of UAA used for forage production, and farm type have a significant effect on land rent. Among the LF-indicators only logarithm of scattering of plots is significantly affecting land rent.

Table 3: Results for the non-parametric estimation of LF-indicators on farm performance

	Bandwith	**Gradient**	**P-value**
Slurry, ton kilometre per hectare	318.4	2.7	< 0.001
$log(UAA)^*$, hectare	0.473	-1,279.0	< 0.001
Livestock units per hectare	0.886	2,830.0	0.481
Share of UAA^*, forage	5.124	2,530.0	0.023
Share of UAA^*, clay	11.72	1,175.0	< 0.001
Farm type:	0.004		0.025
Other		4,387.6	
Cattle		305.5	
Pig		-87.4	
$log(mbrai)$ Minimum bounding rectangle index	0.081	746.5	0.965
$log(avpls)$ Average plot size, hectare	0.208	1,156.6	0.193
$log(grpgi)$ Average grouping index	0.694	-405.4	0.536
$log(nannd)$ Nearest Neighbour index	6.025	-428.6	< 0.001

* UAA - Utilised agricultural area

The non-significant LF-indicators have the expected signs, i.e. higher value of minimum bounding rectangle and increasing field size positively affect the land rent, and higher value of the average grouping index negatively affects the land rent.

The nearest neighbour index being significant and of the expected sign, suggests that scattering of the plots is the important LF-indicator. The bandwidth for Farm type is small indicating different influence of control variables and LF-indicators on land rent for different farm types.

5.2 Output distance function

The output distance function is estimated as a parametric stochastic frontier analysis (SFA) estimated by using the frontier package in R (Coelli and Henningsen 2013) with a Translog functional form. The z-variables in this specification are explaining the inefficiency in the model as an efficiency effects frontier (Battese and Coelli 1995). The results from the output distance function are presented in Table 4 and the marginal effects of the z-variables on the technical efficiency are provided in Table 5.

The γ parameter, ($\gamma = 0.855$) indicates that both the inefficiency and the statistical noise is present in the data. The inputs and outputs in the output distance function are highly significant except for a smaller share of the interaction terms. Farm type is significant which is in line with the non-parametric estimation from Table 3 where farm type was also significant. The z-variables explaining inefficiency are significant except for the minimum bounding rectangle area index ($mbrai$). The significant LF-indicators have the expected sign where average field size ($avfs$) is negatively affecting inefficiency with the interpretation that larger field size is positively influencing efficiency of the farm. The average grouping index ($agrpgi$) and nearest neighbour index ($nannd$) are both significant and the longer distances the more inefficient is the farm. Slurry transportation ($sumsltonkm$) is negatively affecting inefficiency which is interpreted as the longer distances travelled with slurry the more efficient the farm is.

The counter intuitive sign of the slurry transportation needs to be investigated further in a future version of the paper and could potentially be related to a misspecification of the model with respect to the animals as slurry transportation is only relevant for the farms with farm animals. It could also be attributed to fertilizing effect of slurry.

6 Discussion

This comprehensive study of LF in Danish agriculture is built upon a rich dataset which on the farm level relates the distances to fields to economic performance of the farm with two methodological approaches which both indicate an effect of LF on farm performance. The approaches do not yield unidimensional results regarding which LF-indicators being significant. Further analyses are planned to assess a more robust relation between the LF-indicators and farm performance. Assessing the distances between farm and fields as network distances using public roads might induce noise because some inter-farm transport is done on private dirt roads etc. Therefore further analysis is also analysing the effects of LF by using Euclidean distances instead of network distances.

The model specification and functional form of the output distance function will be scrutinized and—if necessary—improved in future research.

Assuming the model specification and functional form are "right" then multiple inherent causes could be at play for the multidimensional effects found in this analysis. Results from Latruffe and Piet (2014) suggests that there is no systematic relation between LF and different farm performance measures on regional level. Even though there are variations in cost of cropping the land and this is not unidimensionally related to LF then the results of this study still points to significant cost of LF.

There is a lot of variation in land rents of many reasons, which not all are specified in the model. Choice of crops grown in the relevant year has been tested for and other crop choices but forage is insignificant. There is the management level of the farmer and ability to harvest high quantities which are not controlled for. Farmers having fields located distant from farms may be more driven by necessity to reduce their costs of cropping the land whereas farmers with closer proximity to the fields could be motivated to buy a bigger or newer tractor than necessary because he or she does not waste money on fuel to drive a long way on the roads. This is analogously to saying that if we controlled for management level, then we could find larger adverse effects of farm performance, which is relevant in future research. On the other hand, it might be possible that LF is not a good barrier to farm performance and farmers are good at dealing with the adverse effects of fragmented land by e.g. placing crops with low transportation requirement at more distant fields and using contractor or collaborates with other farmers to crop fields with long distances.

Table 4: Result for output distance function for all farms in 2014

	Estimate	P-value	sign. code†
Intercept	-0.004	0.771	
$log(y_2/y_1)$	0.587	< 0.001	***
$log(x_1)$	-0.094	< 0.001	***
$log(x_2)$	-0.226	< 0.001	***
$log(x_3)$	-0.090	< 0.001	***
$log(x_4)$	-0.553	< 0.001	***
$log(x_5)$	-0.067	< 0.001	***
$I(0.5 * log(x_1) * log(x_1))$	-0.063	< 0.001	***
$I(0.5 * log(x_2) * log(x_2))$	0.046	0.343	
$I(0.5 * log(x_3) * log(x_3))$	-0.040	0.028	*
$I(0.5 * log(x_4) * log(x_4))$	-0.104	< 0.001	***
$I(0.5 * log(x_5) * log(x_5))$	-0.025	0.064	.
$I(0.5 * log(y_2/y_1) * log(y_2/y_1))$	0.196	< 0.001	***
Farm type: Other	-0.065	< 0.001	***
Farm type: Cattle	-0.114	< 0.001	***
Farm type: Pig	0.051	< 0.001	***
$log(x_1) : log(x_2)$	-0.024	0.200	
$log(x_1) : log(x_3)$	0.025	0.038	*
$log(x_1) : log(x_4)$	0.063	< 0.001	***
$log(x_1) : log(x_5)$	-0.040	< 0.001	***
$log(x_2) : log(x_3)$	0.011	0.630	
$log(x_2) : log(x_4)$	-0.067	0.013	*
$log(x_2) : log(x_5)$	0.050	0.020	*
$log(x_3) : log(x_4)$	0.010	0.611	
$log(x_3) : log(x_5)$	-0.018	0.316	
$log(x_4) : log(x_5)$	0.093	< 0.001	***
$log(y_2/y_1) : log(x_1)$	-0.026	< 0.001	**
$log(y_2/y_1) : log(x_2)$	0.108	< 0.001	***
$log(y_2/y_1) : log(x_3)$	0.024	0.067	.
$log(y_2/y_1) : log(x_4)$	-0.056	0.000	***
$(z_0)Intercept$	-0.578	< 0.001	***
$(z_1)log(sumsltonkm)$	-0.151	< 0.001	***
$(z_2)log(mbrai)$	0.075	0.281	
$(z_3)log(avpls)$	-0.244	< 0.001	***
$(z_4)log(agrpgi)$	0.129	< 0.001	***
$(z_5)log(nannd)$	0.054	< 0.001	***
σ^2	0.039	< 0.001	***
γ	0.855	< 0.001	***

† Significance levels are indicated as follows: "***" = 0.001, "**" = 0.01, "*" = 0.05, "."= 0.1.

Table 5: Marginal effects of the z-variables on the technical efficiency

Variable	Mean	Median
$(z_1)log(sumsltonkm)$	0.007	0.008
$(z_2)log(mbrai)$	-0.003	-0.004
$(z_3)log(avpls)$	0.011	0.013
$(z_4)log(agrpgi)$	-0.006	-0.007
$(z_5)log(nannd)$	-0.002	-0.003

7 Conclusion and perspectives

Depending on the methodological approach different aspects of LF affects farm performance in the preliminary results with unique Danish data where farm performance on farm level is merged with farm level information about LF and slurry production. A non-parametric estimation of LF-indicators with Ricardian land rent shows a significant effect for scattering of plots but no effects of other LF-indices. This is somewhat in line with a study of LF in Brittany, France where Latruffe and Piet (2014) found various effects of the land fragmentation depending on the chosen depending variable.

The output distance function shows significant results on the LF-indices relating to distance and field size but counter-intuitive sign for the transportation of slurry. Further analyses are expected to shed light on this issue. The distances from farm to fields are based on the network distance between the farm and the fields. The distances for farms with high dependence on private roads is too high with this approach but chosen because it is expected that the majority of farms are using public roads for a large fraction of distances driven between farm and fields. Further estimations using the Euclidean distances are made in the coming months and the results are compared to results from the model with network distances.

First step to reduce the LF in agriculture is to know the full costs of LF as this knowledge then would be more integrated into the farmer's decision processes when strategic decision of future land acquisitions or leasings are undertaken.

Over the years several land consolidation programs have been put into place to reduce the LF locally. It has not, though, been applied on a large scale without government intervention. This is likely related to transaction costs in the land market with stamp tax on land transfers.

Cultural barriers in the agricultural community might also cause hesitation to farmers entering into consolidation programs e.g. based on leasing arrangements which does not include taxes in Denmark. Blarel et al. (1992) focus on the causes of fragmentation which is closely linked to inefficiencies in the land, credit and food markets. If the family have been cropping the land for decades, then there might be barriers to swap land with other farmers to have a consolidation program clear. The land leasing market is, though, an inefficient market with only a limited number of lessors and lessees in the geographically bounded marketplace, as well as limited information of buyers and sellers.

Societal costs of LF have not been included in this analysis, as they by definition are not included in farm accounts. Societal costs most noticeable in the traffic with increased risk of traffic accidents and by increased carbon emissions are related to LF in the dimension of distance to farms.

Often costs of LF e.g. in terms of extra costs of transport between farm buildings and the fields are assessed by simple static comparative calculations of the cost per km. However, when facing extra costs farmers should be expected to respond by adjusting their farm management in order to mitigate the cost increases. This effect is captured in our analysis as it is based on observed farm economic behavior. Therefore, we should a priori expect the identified economic effects of LF to be less that those based on static comparative calculations. Possible dynamic adjustments in farm management to mitigate costs of LF may occur in terms of the choice of crops and crop rotation so that distant fields or fields with unfavourable shapes are cultivated with crops that require rather few field operations or they might be cultivated in collaboration with farmers located adjacent to the fields. Although it is not possible to quantify the dynamic adjustments of the farmers, this may be an explanation for why effects of LF are difficult to identify.

References

Aigner, D., Lovell, C. A. K. and Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics* 6: 21–37.

Battese, G. E. and Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics* 20: 325–332.

Blarel, B., Hazell, P., Place, F. and Quiggin, J. (1992). The economics of farm fragmentation: Evidence from ghana and rwanda. *The World Bank Economic Review* 6: 233–254.

Coelli, T. and Henningsen, A. (2013). frontier: Stochastic Frontier Analysis. R package version 1.1, *http://CRAN.R-project.org/package=frontier*.

Gonzalez, X., Alvarez, C. and Crecente, R. (2004). Evaluation of land distributions with joint regard to plot size and shape. *Agricultural Systems* 82: 31 – 43.

Heshmati, A. and Kumbhakar, S. C. (1997). Estimation of technical efficiency in swedish crop farms: A pseudo panel data approach. *Journal of Agricultural Economics* 48: 22–37.

Hung, P. V., Macaulay, G. T. and Marsh, S. P. (2007). The economics of land fragmentation in the north of vietnam. *Australien Journal of Agricultural and Resouce Economics* 51: 195–211.

Hurvich, C. M., Simonoff, J. S. and Tsai, C. L. (1998). Smoothing parameter selection in nonparametric regression using an improved Akaike information criterion. *Journal of the Royal Statistical Society Series B* 60: 271–293.

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.

King, R. and Burton, S. (1982). Land fragmentation: Notes on a fundamental rural spatial problem. *Progress in Human Geography* 6: 475–494.

Krugman, P. R. (1998). Space: The final frontier. *The journal of economic perspectives* 12: 161–174.

Kumbhakar, S. C. and Lien, G. (2010). Impact of subsidies on farm productivity and efficiency. In Ball, V. E., Fanfani, R. and Gutierrez, L. (eds), *The Economic Impact of Public Support to Agriculture: An International Perspective*. Springer Verlag, *7*, 109–124.

Latruffe, L. and Piet, L. (2014). Does land fragmentation affect farm performance? a case study from brittany, france. *Agricultural Systems* 129: 68 – 80.

Latruffe, L. and Sauer, J. (2010). Subsidies, Production Structure and Technical Change: A Cross-Country Comparison. In *2010 Annual Meeting, July 25-27, 2010, Denver, Colorado*. Agricultural and Applied Economics Association.

Li, Q. and Racine, J. S. (2004). Cross-validated local linear nonparametric regression. *Statistica Sinica* 14: 485–512.

Manjunatha, A., Anik, A. R., Speelman, S. and Nuppenau, E. (2013). Impact of land fragmentation, farm size, land ownership and crop diversity on profit and efficiency of irrigated farms in india. *Land Use Policy* 31: 397 – 405, themed Issue 1-Guest Editor Romy GreinerThemed Issue 2- Guest Editor Davide Viaggi.

Meeusen, W. and Broeck, J. van den (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review* 18: 435–444.

Olsen, J. V. and Henningsen, A. (2011). Investment Utilization and Farm Efficiency in Danish Agriculture. FOI Working Paper 2011/13, Institute of Food and Resource Economics, University of Copenhagen.

Østergaard, F. (1987). Jordfordeling ved vejanlæg. *Landinspektøren, tidsskrift for kortlægning og arealforvaltning* 33: 537–543.

Racine, J. S. (1997). Consistent significance testing for nonparametric regression. *Journal of Business and Economic Statistics* 15: 369–379.

Racine, J. S. (2008). Nonparametric econometrics: A primer. *Foundations and Trends in Econometrics* 3: 1–88.

Rasmussen, S. (2010). Scale efficiency in Danish agriculture: An input distance–function approach. *European Review of Agricultural Economics* 37: 335–367.

SEGES (2015). Economoics database. Withdraw from the farm accounts database, "Economics database".

Shephard, R. W. (1970). *The Theory of Cost and Production Functions*. Princeton University Press.

Silverman, B. (1986). *Density Estimation for Statistics and Data Analysis*. London and New York: Chapman and Hall.

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

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

Zhu, X. and Lansink, A. O. (2010). Impact of CAP subsidies on technical efficiency of crop farms in Germany, the Netherlands and Sweden. *Journal of Agricultural Economics* 61: 545–564.