MEASURING THE EFFECT OF FIELD VIABILITY ON WHEAT YIELD

Sub theme: Knowledge and Information

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Abstract:

Agricultural Land fragmentation is a global problem in various magnitudes, but the disaggregated effect of field shape, size, and distance has not yet been established. Simple measures have been applied to estimate the aggregated effect of land fragmentation on farm performance. This paper contributes by introducing a new joint index for field shape and field size, field viability index (FVI), aiming at measuring the effect of land fragmentation on farm performance based on field characteristics. The index is calculated for Danish wheat fields and is tested on a large sample of Danish farmers showing a significant effect on yields. Further research may involve estimating the effect of field characteristics on the aggregated economic farm performance. The field viability index has multiple applications in e.g. benchmarking, leasing or buying arrangements, and for identifying potential land consolidation projects.

Keywords: *Land Fragmentation, Field shape, Field size, yield, Field Viability Index*

Introduction

Agricultural land fragmentation is a global problem and can basically be ascribed to two different causes. In an number of countries the laws on inheritance cause farms to be divided between heirs, thus, reducing the size of farms and farm plots; This is typically the case in less developed agricultural systems (King and Burton, 1982, Binns, 1950). The other reason is where the structural development has caused the farms to grow by acquisition of fragmented plots in order to obtain economies of scale through increased farm sizes. Analogously King and Burton (1982) refers to two definitions for land fragmentation, one in which farms are fragmented into too many plots. The second definition is where farms have many spatially dispersed plots.

Large farms with spatially dispersed plots typically have multiple plots with plots being small and/or oddly shaped resulting in relatively long field boundaries and large headland areas. This is expected to influence farm performance. There are, though, not comprehensive analyses of the value of having large and/or regular fields. The objective of the study is to estimate the joint effect of field size and field shape on performance measured as the yield of fields.

In the first section different measures of land fragmentation especially regarding field shape is reviewed and a new combined index of field shape and field size is proposed. The second section presents the materials and methods to empirically evaluate the effect of field viability on the yields. The final three sections contain the result of the analysis, the discussion, and the conclusion.

Measures of land fragmentation

The effect of land fragmentation has been investigated in a number of studies with different representation of fragmentation e.g. number of plots (Rahman and Rahman, 2009); number of plots, size of plots, and distance to fields (Tan et al., 2010). Latruffe and Piet (2014) take a more comprehensive approach and use five different descriptors with 11 different indices to analyse the effect of land fragmentation on farm performance. In Latruffe and Piet (op. cit.) field shape and size are two of the central descriptors but no significant effects were identified. Another rigorous land fragmentation index is tested in Gonzalez et al. (2004), (Gónzalez et al., 2007). Their combined index for size and shape also refer to the combined shape and size index as a measure of viability. This index is conceptually appealing as it uses estimated ploughing time as a proxy for the time allocated for all field operations. The ploughing pattern in a field is dependent on the precise shape of the field which makes it difficult to calculate for all fields in a large scale analysis because Gonzales (op. cit.) estimate tillage time for a sample of different standard field shapes and subjectively compared with actual field shapes to find an estimate of the tillage time for a field.

In a study by Demetriou *et al.* (2013a) a parcel index related to the combined shape and size effect is developed to evaluate land consolidation projects. In the index it is possible to ascribe subjective values to different parameters concerning the parcel shape. Subsequently these subjective weights are used on the attributes of the relevant fields, and the parcel shape index is defined, which is further developed into a land fragmentation index (Demetriou et al., 2013b).

Other measures of field shape exist in the literature (Latruffe and Piet, 2014) with the weighted average plot shape index and the average plot areal form factor[1], where:

- i is the subscript denoting the farm
- $k = 1,\ldots,K$ is subscript indicating the fields of farm i
- a_{ki} denotes the area of field k for farm i
- $A_i = \sum_{k=1}^{K_i} a$ denotes the total area of the farm i
- p_{ki} denotes the length of the perimeter of field k for farm i

Then the weighted average plot shape index is defined as:

$$a_{ki} \text{ weighted average plot shape index}_i = \frac{1}{A_i}\sum_{k=1}^{K_i} a_{ki} \frac{p_{ki}}{4\sqrt{a_{ki}}} \quad (1)$$

and the average plot areal form factor is defined as:

$$a_{ki} \text{ average plot areal form factor}_i = \frac{1}{K_i}\sum_{k=1}^{K_i} \frac{?}{a_{ki}} \quad (2)$$

[1] Another version of this index is found in Aslan et al. (2007) where the relation between the perimeter and area is used to define the Shape Index (SI) = $\frac{p_i}{2\sqrt{\pi a_i}}$ and the Fractal dimension (FD) = $\frac{2\log(p_i)}{\log(a_i)}$

Both of these indices basically represent a relation between the perimeter and the area of the field. This can be interpreted as a measure of compactness, and with the circle being the most compact shape this implies that the circle is the optimal shape of a field. Further, it does not comply with the intuitive understanding of the optimal shape of a field cropped using standard agricultural machinery. These indices are criticized for exactly that in Gonzalez et al. (2004) when indicating a good measure of farm fields.

Based on these considerations a new measure of field shape is proposed which to a large degree represents the same considerations as in Gonzalez et al. (2004). The main objective of the index is to reflect time consumed to till the fields. Also, it is expected that tillage time is positively related to the share of headland area to the total field area. With an increased share the yield per hectare is expected to decrease. This is due to traffic damage to the crop, poor growing conditions in the boundary of the field, and other issues related to headland cultivating.

The shape index proposed in this paper is called the minimum bounding rectangle area index (*mbrai*). Suppose $mbr(a_{ki})$ is the area of the minimum bounding rectangle of field a_{ki}, for farm *i*, i.e. the smallest possible rectangle which envelopes the field a_{ki}. Then the index for a whole farm can be defined as:

$$mbrai_i = \frac{\sum_{k=1}^{K} \frac{a_{ki}^2}{mbr(a_{ki})}}{A_i} \qquad (3)$$

which can be interpreted as the area of the field divided by the area of the smallest enveloping rectangle. The aggregated index at farm level is calculated as the area weighted index for all fields. The minimum bounding rectangle calculation is a feature in most GIS-software (Geographic Information System). If the index is calculated for a single field, then the index becomes: $\frac{a_{ki}}{mbr(a_{ki})}$ which is denoted minimum bounding rectangle field index (*mbrfi*). This is illustrated in Figure 1. The area of the field is 3.8 hectare which is the area with horizontal lines. The chequered rectangle is the minimum enveloping rectangle which has an area of 6.4 hectare. This results in *mbrfi* equalling 0.60.

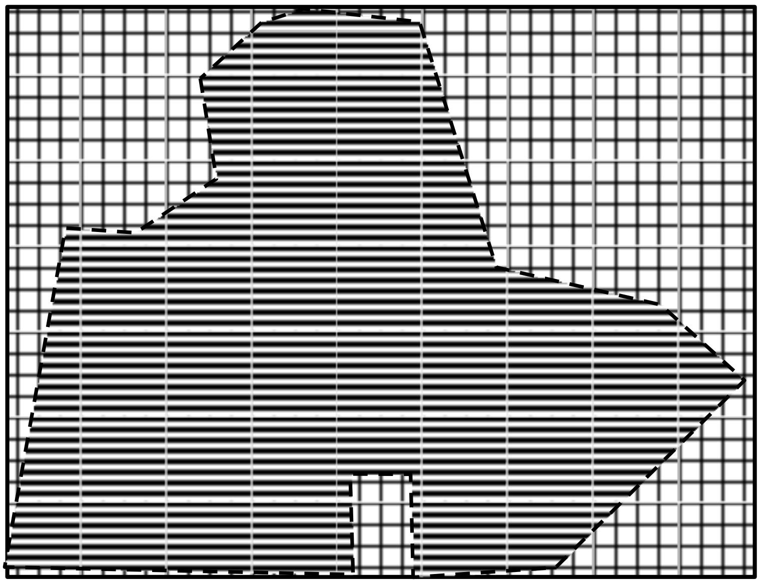


Figure 1. Illustration of the *mbrfi* as the ratio between the area with horizontal lines and the chequered area for a single field.

A rectangular field is considered having the optimal shape and *mbrfi* is attained a value of 1; an equilateral triangle is attained a value of 0.59; and a circle 0.79.

Plot shape is not alone defining whether a field is viable. To determine field viability the field size should be considered as well. The *mbrfi* can be combined with field size to yield a field viability index (FVI) which is the product of *mbrfi* and field size. The index is defined in equation (4):

$$FieldViabilityIndex = \frac{A_{ki}}{mbr(A_{ki})} \cdot A_{ki} \quad (4)$$

If the index is calculated for a farm it is transformed to a Farm field viability index (FFVI), which is the area weighed FVI and it is defined as:

$$FarmFieldViabilityIndex = \frac{\sum_{k=1}^{K} \left(\frac{A_{ki}}{mbr(A_{ki})} \cdot A_{ki} \right) \cdot A_{ki}}{A_i} \quad (5)$$

The interpretation of the shape index (*mbrfi*) is that a higher value is preferred and larger fields are preferred to smaller fields implying that high values of the FFVI are preferred as the two indices are multiplied. A high value of the FFVI is interpreted as high field viability. These indices seem consistent with the criteria in Wents' (2000) list of criteria where especially the computational ease and the compliance with human intuition of a good shape is better fulfilled than in the alternative indices.

Other field shape indices have been hypothesised to influence farm performance in e.g. Latruffe and Piet (2014). The FFVI is also expected to influence farm performance where the FFVI is expected to be positively related to yields, and negatively related to input use per hectare with respect to e.g. labour, seed, pesticides, and machinery and due to lower capacity utilisation of machinery with small or oddly shaped fields.

It is unlikely that oddly shaped fields are preferred to regular fields but studies indicate that land fragmentation may be advantageous to farmers (Blarel et al., 1992) (del Corral et al., 2011) due to reduced risks regarding natural disasters or drought, decreased seasonal bottlenecks in labour supply and increased flexibility regarding choice of crops. These factors are typically occurring at a larger geographical scale, and are, thus, not related to field shape and field size within a Danish farm structure.

Other issues related to land fragmentation are not considered in this paper as it focuses on the field shape and field size. To demonstrate features of the field shape index FFVI is calculated for fields grown with winter wheat on Danish farms. Further the index is regressed on the wheat yields per hectare to test the hypothesis that effects of field operations and consequently yields are dependent of field shape and size.

Materials and method

Yields from wheat fields are reported in farm accounts collected in a Database at SEGES (2015)[2]. The annual report is an account statement where the concepts, conventions, and information level are in line with the FADN farm accounts. The dataset comprise about half of the full-time farmers in Denmark.

The farm accounts are combined with Internet maps of the farm fields from Danish Agrifish Agency which is an agency under the Danish Ministry of Environment and Food. The databases are merged by use of a centrally administered unique number to

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

identify all business in Denmark including all farms organised as sole proprietorships, corporate entities, and other organisational forms and from these Internet maps of the farm fields the choice of crops for 2014 is known.

The effect of FFVI on yields is tested with a simple ordinary least squares (OLS) regression where the FFVI is interpreted as an interaction term between *mbrfi* and farm size with also the constituencies (*mbrai* is included as area weighed *mbrfi*) included in the regression. The specification of the linear regression is presented in equation (6):

$$\text{�h����i���}_i \sim \text{�}_i + \text{�}_1 FVI_i + \text{�}_2\text{����}_i + \text{�}_3\text{�i����i��}_i + \text{�}_4\text{�h���} \text{����}_i + \text{�}_5\text{�h������}_i + \text{�}_6\text{�h����h���}_i + \text{�}_k\text{�������h�}_i + \varepsilon_i, \quad (6)$$

$$\text{�} = 1 \ldots 6$$

Where subscript i indicates farm, $\text{�}_1$to �_3 parameters are the estimates for the relation between wheat yield and FVI and �_4 to �_6 are controlling for total wheat area, share of clay in the wheat area, and share of wheat in the utilised agricultural area. $\text{�}_1$to $\text{�}_6$is con- trolling for geographical variation in climatic conditions. $\varepsilon_i \sim (0, \sigma^2)$ is a random noise term which follow normal distribution with mean 0 and variance σ^2.

The descriptive statistics for the data used in the OLS-regression are shown in Table 1.

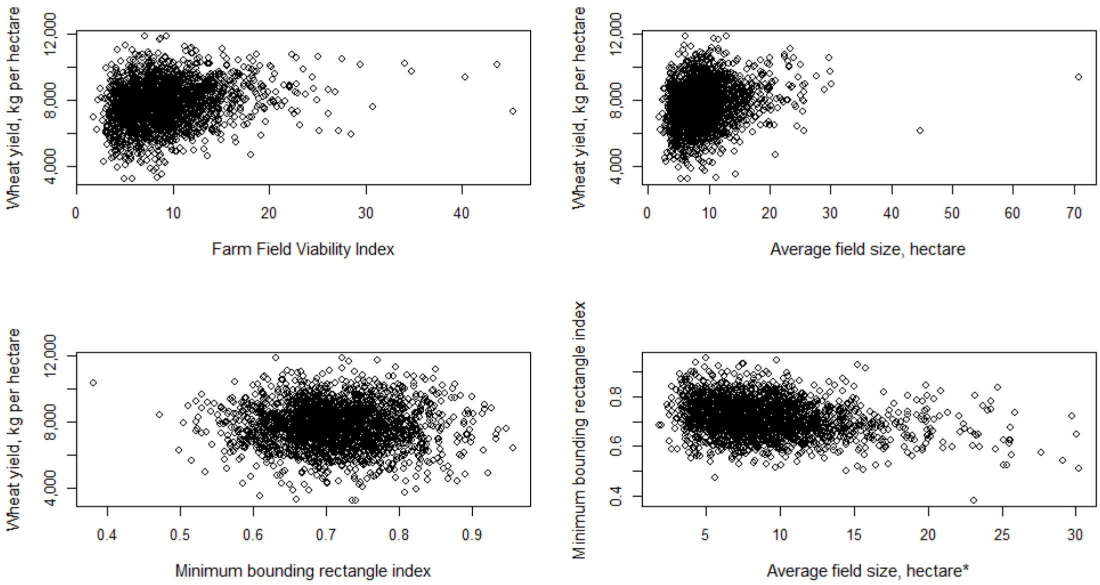
The total number of farms included in the analysis is 2,255. The farms chosen for the dataset all have more than 20 hectares with winter wheat and the share of wheat is above 20 percent of the total utilised agricultural area. Yields below 3,000 kg per hectare and above 12,000 kg per hectare are not included in the analysis in order to have farms with experience in growing wheat and with plausible yields in a Danish context.

Table 1. Descriptive statistics for wheat yield and dependent variables from Denmark

	Mean	Std.dev.
Wheat yield, kg per hectare	7,756	1,283
Field viability index	8.97	4.16
Minimum bounding rectangle area index	0.71	0.07
Average field size, hectare	9.0	4.2
Area with wheat, hectares	83.1	66.7
Share of wheat area, clay	0.50	0.40
Share of UAA, wheat	0.43	0.16
No. of farms in geographical region 1	78	
No. of farms in geographical region 2	467	
No. of farms in geographical region 3	301	
No. of farms in geographical region 4	346	
No. of farms in geographical region 5	358	
No. of farms in geographical region 6	238	
No. of farms in geographical region 7	467	

The geographical regions are defined with respect to the regional cultural development and settlement which in the Danish case influences shape and size of the fields.

Scatterplots of wheat yields, FFVI, average field size, and minimum bounding rectangle area index are presented in Figure 2.



* note: for readability are two observations with large average field sizes not shown

Figure 2. Scatterplots of wheat yield and indices

The minimum bounding rectangle index is below one, and the average field size for wheat fields is for the majority of farms between 3 and 15 hectares.

Results

The results from the OLS-regression are presented in Table 2. All the variables are significantly influencing wheat yield except for average field size and one of the geographical regions. Geographical region 3 is the dummy reference. The adjusted R^2 of the model is 0.32 and it is tested with at Likelihood Ratio test that the model is better than a model without the FFVI. The final model is also better than a model without the constituent variables.

Table 2. Results from OLS-regression of wheat yield with robust standard errors

	Estimate	Significance[1]
Intercept	6,889	***
Field viability index	46.9	***
Minimum bounding rectangle area index	819	*
Average field size, hectare	11.4	
Area with wheat, hectares	0.83	*
Share of wheat area, clay	708	***
Share of UAA, wheat	-664	***
Geographical region 1, dummy	-70.1	
Geographical region 2, dummy	314	***
Geographical region 4, dummy	-591	***
Geographical region 5, dummy	-252	**
Geographical region 6, dummy	-1,233	***
Geographical region 7, dummy	-828	***

1. Significance: p-values < 0.001: ***; p-values < 0.01: **; p-values < 0.05: *; p-values > 0.05:

The marginal effect at the mean of average field size (9 ha) is 12.4 kg per hectare with increase in *mbrai* of 1 percentage point, from e.g. 0.71 to 0.72.

The results implies that the field shape alone can explain a difference in yield of 260 kg per hectare or 3.8 percent between a 9 hectare rectangular shaped field compared to a circular shaped field of equal size.

Discussion

The results of the analysis of Danish farm level data shows that there is a correlation between Farm Field Viability Index developed in this paper and yields in wheat. The index is calculated for wheat fields only and is merged with crop level yield information from Danish farm accounts. The analysis shows that the combined index with both field shape and field size is significantly influencing wheat yields.

A squared index has been tested where the FFVI is calculated as the squared *mbrai* multiplied with the squared field size to follow the same type of logic which is inherently the reasoning behind the Januszewski[3] and Simpsons[4] indices. They both reflect that large values magnify when they are squared whereas small values (<1) are reduced more when square root is calculated. By using their logic the variation in the FFVI could increase by squaring the values, however an index based on squared values was inferior to the approach taken.

It could be argued that the field shape and field size is only interesting if it has an effect on the overall economic farm performance. This is though harder to investigate as there are no statistics that includes economic performance measures at the field level. Nonetheless, when the FFVI has an effect on the yield it is very likely to have an effect on the economic farm performance as oddly shaped and small fields are expected to influence input use, especially labour costs, as tillage time per hectare is higher for small and oddly shaped fields. Furthermore, effect of FFVI on the input use could be dependent on farm size. Low capacity utilisation for larger farms with bigger machinery could be more costly than low capacity utilisation for smaller farms. Hence, the relation between the FFVI and economic performance could be influenced by the farm size through its effect on input use.

However, as economic farm performance is not available on a field level the relation between FFVI and input use is not included in the analysis. On the other hand, geographical and climatic conditions are expected to influence the yields and therefore geographical dummies, soil quality and to some extent crop rotation (represented by the share of wheat in the crop rotation) are included in the regression. Last, it is likely that the influence of the field shape and size is determined also by management level of the farmer. However, no good proxy for this is available in the data.

The results from this analysis is somewhat analogous to the one presented in Latruffe and Piet (2014) except that Latruffe and Piet (op cit.) were not able to connect the shape

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[3] Januszewski's index is defined as:

$$\frac{\sqrt{A_i}}{\sum_{k=1}^{K_i} \sqrt{a_k}}$$

[4] Simpsons index is defined as:

$$1 - \frac{\sum_{k=1}^{K_i} a_k^2}{A_i^2}$$

indices to individual farmers. Further, in their study Latruffe and Piet (op cit.) did not identify an effect of plot shape on wheat yield. This may be because their analyses were at the more aggregated municipality level. Thus it is our understanding that the present study is the first to comprehensively analyse the effect at the field level on farm performance (yields) of field shape and size.

The measure is a believed to be a good representation of the CSSI developed in Gonzalez et al. (2004) even though the CSSI probably penalizes holes with a better approximation to the true annoyance of holes than the FFVI developed here. The FFVI outperforms the CSSI in a number of other dimensions, e.g. preparation of data, computation ease, and interpretation of results.

Conclusion

A new combined index of field shape and field size, termed the field viability index, is developed and tested on a unique dataset from Danish farmers. Further, the correlation between field viability index and yields from fields cropped with wheat is tested. The results show that there is a significant effect of the index on wheat yields. The index is easy to compute in GIS software and can be used to assess the value of single fields. Perspectives for using the index could apply to farmers' purchase or lease of new land as well as for supporting land consolidation processes (Schou et al., 2016)

Further, the index can be used in benchmarking where peers should be chosen not to have better production possibilities than the benchmarked farmer and should hence have same or lower FFVI. If this was not the case, then would an identified potential not reflect the true potential. Farms with high FFVI have higher potential performance than farms with low FFVI with respect to yield but also expectedly with respect to reducing input use and thereby cost.

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