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The relationship between agricultural land parcel size and cultivation costs

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ABSTRACT

Land fragmentation in agriculture is acknowledged as a problem that causes additional costs in cultivation and lowers productivity. Land consolidation programmes seek to alleviate the problem by influencing land ownership, with the aim to reduce travel distances and increase parcel sizes by connecting adjacent small land parcels. Decision making requires cost–benefit analysis of the costs of ownership changes compared to the potential benefits. Such analysis is based on before and after assessment, where the benefits of a larger parcel size and the costs caused by the distances travelled between land parcels and between parcels are the key determinants. This paper presents a method to analyse realized work efficiency at different parcels. The benefit from a larger parcel size appears to be greater than that reported in previous studies.

1. Introduction

Traditionally, agriculture in Western countries has operated in the form of family farms. Most of these countries are undergoing continuous structural development in which, for example, farms with low productivity or lacking a successor are exiting production, while continuing farms are seeking to expand their production subject to the available market opportunities and land resources. The availability of land is a particularly important factor, and the complex interactions between competing farms in local land markets affect farm size (Huettel, Margarian, 2009; Plogmann et al., 2022). As a result, the average size of farms has grown, but the growth has not always occurred in the optimal way in terms of distances between parcels and the integrity of the parcel structure.

Agricultural land in Finland is divided into very many parcels for geographical and historical reasons, and the average size of parcels is consequently relatively small and the structure of farm landholdings is often fragmented. Although farm exits increase the availability of land, an expanding farm may not acquire a uniform area attached to its current fields, but may have to include single parcels lying at a distance from the current fields. In the worst case, land parcels may be located across farms. This form of development not only hinders the working efficiency of farmers, but also has negative impacts on the climate (Hiironen and Niukkanen, 2014).

The resulting land fragmentation causes additional costs in cultivation and lowers productivity (e.g. Niskanen and Heikkilä, 2015; Orea et al., 2015; Looga et al., 2018). Since fragmentation is often associated with issues such as the hampering of agricultural mechanization and inefficiency in production (Latruffe and Piet, 2014; del Corral et al., 2011; Bradfield et al., 2021), farm profitability remains at a lower level than it would be with better structured landholdings. On the other hand, some studies have concluded that land fragmentation may also have beneficial side-effects and actually increase profits. Fragmentation can increase crop diversity which in turn can help to spread economic risk and increase biodiversity (Di Falco et al., 2010; Latruffe and Piet, 2014). However, these effects are likely to remain highly limited in the Finnish context. The northern climate limits the variety of economically viable crops and generally favours the cultivation of grass and animal husbandry.

Machinery traffic compacts the soil and, thus, negatively affects the soil structure. In particular, the parts of cultivated fields adjacent to the boundary, known as headland areas, are subject to contrasting stresses,

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primarily due machinery manoeuvres such as turns, which are executed on these areas (Ward et al., 2021). A small parcel size and irregular shape leads to headlands forming a greater share of the cultivated area, but these characteristics also induce relatively more overdrive when covering the potential triangles and edges, which may have negative effects on the average yield. Another relevant issue to consider for Finnish landscapes is shading from forested areas or shrubs, with effects on transpiration, temperature and soil moisture, which in turn affect the crop yield of the adjacent arable land. With an increasing distance from forest, solar irradiance and consequently the yield increase (Schmidt et al., 2019).

Land consolidation programmes seek to alleviate the problem of land fragmentation by influencing land ownership, with the aim to reduce distances ravelled between parcels and increase parcel sizes by connecting small adjacent parcels (Hiironen and Riekkinen, 2016). The objective of land consolidation is to increase the profitability of agriculture without changing the ownership structure of a land consolidation area, but rather reorganize the parcels. (Vitikainen, 2004). However, even though land consolidation activities are constantly carried out, average parcel sizes have not markedly increased. There may be several reasons for this, one being that participation in land consolidation is voluntary. As Çay and Ertunç (2018) note, the end result of reallocation of plots is dependable on the allocation process. In voluntary and negotiation-based allocation, the end result may not be as remarkable as allocating the plots without negotiating with the land owners. Participation in land consolidation is voluntary, and in practice, enough voluntarily participating farmers are needed in a certain area to make consolidation actions feasible. Motivating farmers to participate is sometimes a challenge, since farms differ from each other in their production and economic situation and have different development strategies.

Table 1 presents the average parcel sizes of completed land consolidation projects between 2018 and 2021 in Finland. Even though none of the project the average parcel size increased over 10 ha, there is still an average increase of 82.65% in the parcel size. This is quite well aligned compared to other countries, e.g. Lithuania 71.80% (Atkoceviciene et al., 2019), or Turkey 67.82% and 165.52% (Akdeniz et al., 2022). However, examples with extreme increase in parcel size exist. North Macedonia introduced land consolidation as a new tool and managed to increase the parcel size in different areas by 242.11 or even by 383.33% (Hartvigsen and Mitic-Arsova, 2022).

As in all European countries, land consolidation in Finland is based on legislation (Vitikainen, 2004). The main land consolidation act in Finland is the Real Property Formation Act (RPFA 554/1995). According to the RPFA, the implementation of land consolidation must always be profitable. Section 67 in the RPFA states that land consolidation may only be executed if the benefits exceed the costs. Analysis is based on before and after assessment, where the benefits of a larger parcel size and the costs caused by the distances travelled between land parcels and between parcels are the key determinants. As both voluntary decision making by farmers and mandatory legislative needs require cost–benefit analysis ownership changes, it is important that the analysis is based on up-to-date information regarding the benefits and costs. The average parcel size in Finland is similar (2.67 ha) to the areas, where land consolidation projects have been completed (Table 1). The projects are allocated to the areas where there is largest potential to increase the agricultural profitability. This may not always mean that the projects would be allocated to areas, where the average parcel size is the smallest before the land consolidation takes place. Actually, the majority of land consolidation projects are executed in the western part of Finland, even though the parcel size is above the average. (Hiironen and Riekkinen, 2016) The potential for improving the situation is still larger, compared to other areas.

Cost-benefit analysis is widely used in evaluating the feasibility of land consolidations. However, the attributes taken into consideration vary. Proposed models to measure the benefits of a land consolidation project include the increase of productivity due to investments such as drainage or irrigation during the project (Wojewodzic et al., 2021) or, for example, due to the resulting increase in the agricultural land area (Du et al., 2018), the reduced travel time due to decreased distance between the parcel and the farm compound (Hiironen and Riekkinen, 2016; Janus et al., 2016), the shape of the agricultural parcels (Demetriou et al., 2012), or the net present value index of the project investment (Wojewodzic et al., 2021). Harasimowicz et al. (2017) proposed an optimization model for parcel configuration that also includes estimates of the working time spent on the parcel as part of the model.

The objective of this study was to examine the increase in the working efficiency of farming due to changes in parcel structure. This paper presents a method to analyse realized work efficiency for different parcels and discusses the results in comparison with the previous efficiency models. Since a decrease in the time used for cultivating each parcel is one critical factor in determining agricultural efficiency and thus needs to be included in the cost–benefit analysis, this paper contributes to land consolidation research by presenting a method to analyse the realised cultivation time for different parcel sizes and discusses the results in comparison to previous efficiency models.

The rest of the paper is organised as follows. The next chapter describes the materials collected and the methods used in analysis, followed by showcasing of the modelling description and results, and discussion of the findings. Finally, chapter 4 concludes the paper.

Table 1
The average parcel size before and after land consolidation projects (LCP) in Finland 2018–2021 (data from The National Land Survey of Finland).

LCP	Av. before (ha)	Av. after (ha)
Akaa-Urjala	4.44	5.73
Isoniitty	4.05	6.18
Porre-Pesola	2.64	4.35
Luopa (kurikka)	3.67	8.23
Oravais-Österby	2.49	4.88
Komsi-Teerenpaikka	2.43	4.45
Lappi, Lumijoki	3.2	7.1
Sutela	3.69	6.77
Piipsjärvi	2.62	5.7

2. Materials and methods

Working efficiency for different parcel sizes is currently calculated based on a function that considers, for example, the arrangement time required to start working, the number of machinery turns in relation to the width of the equipment, the length of the parcel and the working speed (Hiironen, 2012). The work time data used in earlier Finnish studies were based on data collected from farms utilizing a standardized time measurement system for agricultural field work, with some extra time for pauses (coffee breaks, machinery maintenance, disturbances) added to measured work time. In Finland, studies on agricultural work are mainly conducted by the Work Efficiency Institute (TTS).

In land consolidation calculations, the computed execution times are standardized to a two-hectare parcel. The smaller the parcel is, the more inefficiency arises from starting the work, the number of machinery turns on the parcel, and so on. The direction of travel is standardized for long side travel and the driving technique for lane driving. In this study, we utilized the opportunities enabled by new technology implemented in tractors and working machinery, which included online measurement of several parameters such as transport time on the road and actual work time on the field. The collected data were saved in the Farm Management Information System (FMIS).

2.1. Data collection

AgriSmart software (Suonentieto Ltd., Finland) was utilized in the collection of empirical data. The software utilised the Valtra Connect service (AGCO Ltd.). This service is a small module that logs data from a tractor's computer and GPS device and saves the data in a cloud-based service. There is an application programming interface between the Valtra Connect service and AgriSmart software concerning the tractor location, field work time and fuel consumption. The software starts data logging, when the tractor enters a parcel. Data were read from a visualized route map and an Excel table generated by the AgriSmart software. An example of logged data from the ploughing of a field parcel visualized on an aerial map is presented in Fig. 1.

The data included measures for fuel consumption and the duration of field work, and these variables were used to approximate the cost per hectare. Fuel consumption and duration were multiplied by their respective price approximates. The tax-free price of fuel (€0.746/L) was obtained by calculating the 5-year average (2017–2021) price of light fuel oil divided by 1.24, i.e., the exclusion of 24% value-added tax. The data were obtained from Statistics Finland (2022). The cost of labour reflects the hourly wage of an agricultural worker (€15.94/h), and the 5-year average (2017–2021) was analogously used. The data for wages were obtained from the EconomyDoctor service (Luke, 2022). Three types of custom contracting existed: ploughing, mowing, and spraying. The data contained more crop protection sprayings than mowings and ploughings. Furthermore, smaller parcels were overrepresented, and the number of observations significantly decreased as the parcel size grew. However, no significant growth in the variance was observed; on the contrary, as the variance decreased as a function of increasing parcel size.

Automatic data collection also brought some corrupted observations. The system recorded some visits to parcels that the contractor did not actually visit but drove close to. This caused an unrealistically short distance driven on the field relative to the size of the parcel. An observation was removed if the distance driven divided by the parcel size was lower than 0.1. No fuel consumption was recorded in some cases, and these were respectively removed. Two parcels were recorded twice with different data, and these observations were also removed.

The data additionally included a few exceptionally small parcels. Very small parcels might actually form part of larger parcels but exist due to administrative reasons. However, these parcels were potential outliers, as the costs per hectare easily become extremely small or large depending on the number of turns required on the parcel. Because very small parcels were generally meaningless in the current analysis, they were removed from the data, and the minimum area of a parcel was set to 0.2 ha. The total number of observations was 459 on 385 different parcels. Some parcels were recorded twice, as the contractor re-visited the same parcel during the summer for a different working task. The representativeness of the data sample is described in Table 2. Data on the total number of parcels in Finland were obtained from the Integrated Administration and Control System (IACS) (Finnish Food Authority, 2022).

The collected data included three different work tasks operated on the fields: ploughing, mowing and spraying. The equipment included in ploughing comprised 4 and 5 mouldboard ploughs, while mowing was carried out using mowers with a working width of 6–9 m. Sprayers were towable and equipped with 3000- to 4000-litre tanks for spraying liquid and 24- and 28-m-wide booms. Table 3 presents summary statistics for the working tasks.

2.2. Model development

The precondition for model fitting is continuity, as the practical use of the results relates to the potential benefits of parcel consolidation. Based on previous studies, costs per hectare were assumed to decrease as a function of increasing parcel size. To generate a continuous general function to describe the relationship between parcel size and the cultivation costs, polynomials of different degrees with and without logarithmic transformation were considered. However, the functional form

Table 2
Observed field parcel data according to size class in comparison to the total in Finland.

Size class (ha)	Observed in the sample		Total in Finland 2021 (>0.2 ha)	
	N	Share	N	Share
0.2–0.5	23	0.06	118,796	0.14
0.5–1	57	0.15	166,607	0.19
1–2	78	0.20	216,586	0.25
2–5	158	0.41	247,452	0.29
5–10	53	0.14	90,322	0.10
> 10	16	0.04	29,596	0.03

Fig. 1. Example of recorded ploughing work carried out on a field parcel.

Table 3
Means and standard deviations of duration, distance, fuel consumption and costs in different work tasks conducted on field (standard deviations in parentheses; the final, cleansed data presented in the table).

Work task	N	Duration (min)	Distance (km)	Fuel consumption (L)	Costs[a] (€/ha)
Ploughing	31	282.35	24.56	67.4	34.32
		(286.39)	(25.16)	(71.1)	(6.35)
Mowing	168	37.15	4.45	12.8	7.38
		(30.38)	(3.87)	(11.3)	(2.24)
Spraying	260	21.98	2.33	2.86	2.90
		(18.54)	(2.14)	(2.71)	(2.22)
All combined	459	45.10	4.61	10.9	6.66
		(100.00)	(8.91)	(25.2)	(8.20)

[a] Costs determined as labour and fuel costs combined

had two strict preconditions. The function was not allowed to predict negative costs, at least not for any reasonable parcel size. Any linear model would have otherwise predicted negative costs at some point, so these were essentially ruled out. The second precondition was that the functional form has to allow costs to start increasing at some point, if supported by the data. This, however, was unlikely in the case of conventional sized parcels (<30 ha). Given the preconditions, a second order logarithmic polynomial function was considered the most preferable functional form.

To further verify this assumption, a nonparametric function was also estimated to examine whether it resembled the fitted logarithmic form. The imbalance between smaller and larger parcels in the data was another reason for estimating a nonparametric function. The shape of the cost function was assumed similar between different types of work, but the intercept was allowed to vary.

Parametric and semi-parametric methods were used to estimate the functions. For the fully parametric log-polynomial, SIZE was converted to a logarithmic form and was estimated using ordinary least squares. The estimated equation consisted of an intercept, dummy variables for ploughing and mowing, and the parcel size as an explanatory variable.

$$(1) \quad COST = \alpha + \delta_1 PLOUGHING + \delta_2 MOWING + \beta_1 \log(SIZE) + \beta_2 \log(SIZE)^2$$

The other model was semiparametric, as the dummy variables were entered into the model as fully parametric, but the functional form of SIZE was not predefined. The model was therefore a generalised additive model (Equation 2).

$$(2) \quad COST = \alpha + \delta_1 PLOUGHING + \delta_2 MOWING + f(SIZE)$$

Equation 2 is otherwise similar to 1, but SIZE is not converted to a logarithmic form and the equation has no predefined functional form. The term f indicates a flexible function of any form. The function was estimated using thin plate regression splines, and the resulting function is essentially a polynomial that best fits the data. The estimated function was a balance between the fit and the smoothness of the function, and generalised cross-validation was applied to find the optimal balance. The polynomial usually has a high degree, especially if the number of observations is low in some intervals of the exogenous variable. This was the case here, as small parcels were numerous, but increasingly fewer observations existed for larger-sized parcels. The model was estimated using maximum likelihood. Technical details regarding the regression splines and their estimation are fully described in Wood (2007).

To assess methodological differences and whether productivity has improved over the years due to larger and more advanced machinery, both estimated functions were compared to the estimates presented in Hiironen (2012). In that study, a so-called adjustment coefficient was calculated, which demonstrates costs as a function of parcel size. The coefficient is currently applied, although updated, in official land consolidations conducted by cadastral engineers. When exchanging parcels between farmers, differences between parcel sizes are compensated using the coefficient. Because the coefficient is an index, comparison between the current estimates and the coefficient was relatively straightforward. Some improvement was expected, implying a slightly steeper function compared to the estimates of Hiironen (2012). However, dramatic differences were not expected, because field work and machinery have not fundamentally changed, although development has presumably taken place. The comparison therefore enabled a reliability assessment of the obtained results.

2.3. Data analysis of parcel splits

A complementary analysis was implemented to assess when farmers have considered certain parcels so large that they have been sub-divided for different crops or other agricultural purposes. In Finland, a "base parcel" of land must have a declared usage, whether in cultivation or fallow, so if subdivided it has to include at least one agricultural parcel. Most parcels are small and for this reason have only one usage, but as the size grows, the area can be more efficiently used by dividing the parcel and allocating it to different crops. The field parcel data were obtained from IACS (Finnish Food Authority).

The list formed the raw data, which was further modified for statistical analysis. Only parcels above 0.2 ha were included. The reason for this was twofold. Firstly, very small parcels are numerous but often infeasible for the majority of arable crops. Secondly, many small parcels virtually belong to and in practise are cultivated together with another (larger) parcel, but are recorded as independent base parcels due to administrative or other reasons (such as a property line running towards a field) that are not related to directly to cultivation. To further prevent these parcels from entering the analysis, a divided base parcel had to include at least two parcels with a size representing at least 25% of the total parcels. Other limits were also tested to examine their impact on the results.

Parcels including more than three parcels were also excluded. Except for very large parcels, highly fragmented parcels are like to reflect some other aspect than an intention to improve productivity, and for this reason it was considered better to remove these observations. In many cases, only one crop was cultivated in a divided parcel. These parcels were not considered genuinely divided, and a divided parcel had to include at least two administratively different crops. Some agricultural parcels lacked data on the cultivated crops, and, if the base parcel was divided, it was not possible to determine whether the crops cultivated in a divided base parcel were different. These observations were also removed.

The statistical model was a logistic regression with a dummy indicating splitting as the dependent variable and parcel size as independent. The resulting model provided the likelihood of a parcel being divided given the size. R (2022) was used to estimate the models and produce the figures. The package mgcv (Wood, 2003, 2004, 2011, 2017; Wood, Pya, and Säfken, 2016) was used to estimate Equation 2. Functionalities from Tidyverse (Wickham et al., 2019) and sf (Pebesma, 2018) packages were applied in reading and handling the data.

3. Results

Table 4 presents the results from the logarithmic polynomial model. The estimated function fitted the data well, as the multiple R-squared value was as high as 0.91. It should be noted that the deviation was very large in the case of smaller parcels (Fig. 2). However, given the varying parcel shapes, driving styles, and other case-specific circumstances, the duration of work on a parcel was expected to vary. The variation was further magnified by rescaling the total costs to costs per hectare. Fig. 2 presents the estimated function and observations after multiplying mowing and ploughing by the respective coefficient values. Although the deviation was large in the case of smaller parcels, costs were found to vary relatively little in the case of larger parcels. This increases the reliability of the results for larger parcels, for which the number of observations was much lower.

Hectare costs, determined from working hours and fuel consumption, differ between work tasks. Spraying is carried out most efficiently, with a wide working width and relatively high driving speed, whereas ploughing requires a considerable amount of energy from the pulling tractor and the driving speed is low. However, the basic assumption of increased working efficiency due to fewer turns and a lower proportion of overdrive in larger field parcels was found in all tasks (Fig. 2).

Both fitted functions were compared with a previous adjustment coefficient estimated by Hiironen (2012). The numerical results are presented in Table 5, and these results are further visualised in Fig. 3. The current estimates were aligned with previous estimates, indicating the correct magnitude and reliability of the current results. As expected, the estimated log-polynomial function was slightly steeper than the previous estimates from Hiironen (2012). The current estimates suggest that, compared to earlier technology, a larger parcel size produces productivity gains up to approximately 15 ha. Neither the current nor previous estimates reveal an optimal size for a parcel. However, the estimated function indicated that the marginal gain from a larger size becomes negligible after 20 ha.

The estimated non-parametric function generally followed the log-polynomial function, which further justified the use of a log-polynomial (Fig. 3). It should be noted that the non-parametric estimation was sensitive to single observations, and, for this reason, the curve increasingly fluctuates as the number of observations decreases in the case of larger parcels. Especially for larger parcels, the log-polynomial was considered more reliable.

A sensitivity analysis was also implemented to assess changes in relative prices. Because fuel prices tend to fluctuate and the price of labour develops steadily, the costs per hectare were recalculated with a 50% increase in fuel prices and the model was re-estimated with the new cost estimates. Fig. 4 presents the difference between the baseline data and the data with 50% higher fuel prices. The two sets of estimates are presented as indices to better reveal the differences between them. The differences are quite small, but a relative increase in fuel costs appears to slightly decrease the advantage of a larger parcel size.

To examine what size is considered optimal in practice, the divisions of Finnish base parcels were analysed. The average size of base parcels in Finland is relatively small. Over half of the parcels above 0.2 ha were smaller than 2 ha (Table 6), the average size of these was 2.67 ha. Some modest differences between different regions existed, with the smallest parcels occurring in eastern parts and the largest in southern parts of the country. The difference between these two extremes, however, was only 0.73 ha.

Given the small average size of base parcels, only a minority of them were divided between different crops (Table 6). In absolute terms, most divided parcels were less than 5 ha, indicating there were various reasons for dividing the parcels. However, the relative frequency of divided parcels increased as a function of increasing parcel size, and larger parcels were more likely to be divided purely for productivity reasons. We also examined which crops were cultivated in divided parcels. Table 7 presents the most common combinations of crops. The crops and even the combinations were roughly the same when considering dairy and cereal farms only. Due to reasons related to the agricultural payment administration, several types of fallows and grass cultivation exist. The top five combinations, however, clearly demonstrate that cultivation mixes in divided parcels most commonly include grasses for feed, the two most common cereals (barley and oats) or some fallow.

The results from the logistic regression demonstrated the tendency of farmers to divide parcels as the size grows. However, the shape of the sigmoid was not steep, implying that divided parcels occurred in all size classes, but not all larger parcels were divided (Fig. 5). According to the results, a 27.8 ha parcel had a 50% probability of being divided. However, the smaller the minimum proportion of the total parcel area that a sub-division's size must exceed, the lower the 50% cut-off point. As demonstrated in Fig. 5, the point moves to 18.4 ha if a minimum of 1% of the total parcel size was allowed. This indicates that parcels are divided for various reasons, and the 25% limit more likely reflects divisions for productivity reasons than the 1% limit.

Regional differences also existed, as the parcel size related to the 50% probability limit was considerably larger in northern parts of the country, being 40 ha. In other parts of Finland, the cut-off point varied from 25.2 to 27.1 ha. This could reflect differences in farm characteristics, as the variety of feasible crops is very narrow in the north of Finland. This would reduce the incentive to divide parcels. The cut-off size was 24.3 ha for dairy farms and 25.2 ha for crop farms, implying practically no differences between the two main production types.

The results imply that the benefits of crop rotation, for example, start to have as large a weight as the marginal benefits from a larger parcel size when the parcel size approaches 30 ha. Then, parcels are more likely than not to be divided into smaller parcels below 20 ha. Although the cost function analysis provided no clearly defined optimal size, it appears that in terms of both production costs and practical use, the marginal gains from a larger parcel size become negligible after 20 ha.

Table 4
Results from the logarithmic polynomial model.

Term	Estimate	Std. Error	*P*-value
Intercept	3.83	0.2	< 0.001
MOWING	4.29	0.25	< 0.001
PLOUGHING	31.39	0.48	< 0.001
log (SIZE)	-1.29	0.2	< 0.001
$log\ (SIZE)^2$	0.13	0.1	0.2
Adjusted R^2:	0.91		

4. Discussion

Agricultural land in Finland is divided into very many parcels for historical and geographical reasons. Where possible, land consolidation may alleviate the inefficiency that arises from the fragmentation. The conducted study revised a previous calculation factor that is used in land consolidation projects to evaluate the benefits arising, for example, from merging adjacent land parcels through land ownership arrangements.

According to the cost function analysis, the largest marginal reductions occurred before 10 ha and the greatest potential from land consolidations exists for these parcels. It should be emphasised that no exact measure for a small but nevertheless significant reduction exists. No evidence was found for a turning point, after which costs per hectare would start to rise. Such a finding would have defined an ending point for cost reductions and furthermore a limit for an excessively large parcel. However, the difference between 10 and 20 ha was 0.7 index points, while that between 20 and 30 ha was only 0.2 points. This suggests that after 20 ha, at the largest, marginal gains become insignificant. To sum up, practically no further reductions in the marginal cultivation costs appear to exist for parcels over 20 ha.

The empirical analysis demonstrated that, in practice, parcels slightly below 28 ha had a 50% probability of being divided. At this

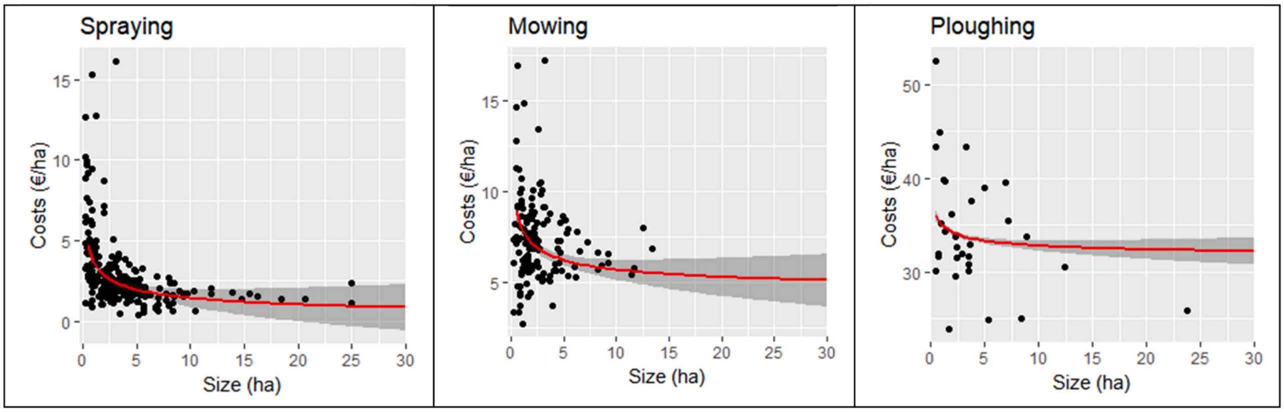

Fig. 2. Cultivation costs in relation to parcel size and the fitted log-polynomial function for spraying, mowing and ploughing.

Table 5
Numerical comparison between the previous correction factor (Hiironen, 2012), non-parametric estimation and a log-polynomial fitted function.

Parcel size (ha)	Hiironen (2012)	Non-parametric	Log-polynomial
0.5	1.33	1.31	1.27
1.0	1.12	1.17	1.12
1.5	1.04	1.06	1.05
2.0	1.00	1.00	1.00
2.5	0.96	0.98	0.96
5.0	0.90	0.90	0.87
10.0	0.86	0.77	0.79
20.0	0.83	0.63	0.72
30.0	0.82	0.62	0.70

point, it should be emphasised that the 50% limit implies that approximately half out of a large group of parcels are divided. Only a small fraction of all parcels actually exceeds 25 ha, and many of these parcels are not divided. Therefore, no pressure to divide parcels appears to exist, but the results clearly demonstrated the existence of benefits from splitting parcels. These benefits become increasingly apparent as the parcel size approaches 30 ha.

Generally, the results from the two analyses appear aligned. Marginal cost reductions were found to be very small between 20 and 30 ha, and the turning point concerning the practical tendency to divide parcels lies in this interval. Splitting a 25–30 ha parcel approximately in half creates two reasonably sized parcels in terms of significant cost reductions, as marginal cost reductions were noted to effectively end once the size exceeds 20 ha.

The estimated 50% cut-off point of this study significantly differs from the result of Myyrä and Pitkänen (2008), who conducted a similar analysis with a considerably smaller sample. According to their study, the 50% limit was at 8 ha for grain parcels and 6 ha for forage parcels. The difference probably reflects methodological differences between the studies, but may also reflect the change that has occurred in agricultural production over the years. Production technology has developed, making a larger parcel size an advantage.

The analysis demonstrated a need for further improvement in the farmland structure in Finland. Over half of the parcels were below 2 ha in size and over 80% of the parcels were below 5 ha. According to the results, significant reductions in production costs can be achieved above 5 ha, thus emphasising the need to increase the size of parcels. Structural change has enabled farms to exploit economies of size, and it continues to do so. However, small parcel sizes and land fragmentation more generally prevent farms from obtaining the full benefits from increasing in size. The improvement in the landholding structure should move in tandem with the growth in parcel size to reap the full advantage from a larger capacity. Thus, a lagging improvement in the landholding structure may even discourage farms from growing further, exploiting better machinery and so on. This would, in turn, have a negative impact on the competitiveness of Finnish farms.

A larger parcel size can also benefit soil quality. Enlarging the parcel size reduces the negative impacts that are faced by edge shadowing and soil compaction in headland areas resulting from machinery turns. This should, however, be considered together with other practical measures to prevent soil compaction, such as decreasing the axle load and/or increasing the contact area of wheels with the soil, as well as working soil at the optimal soil moisture content, and appropriate agronomical means, such as crop rotations that include plants with deep, strong taproots and soil health maintenance (Hamza and Anderson, 2005).

Two studies in the Finnish context have previously found a positive

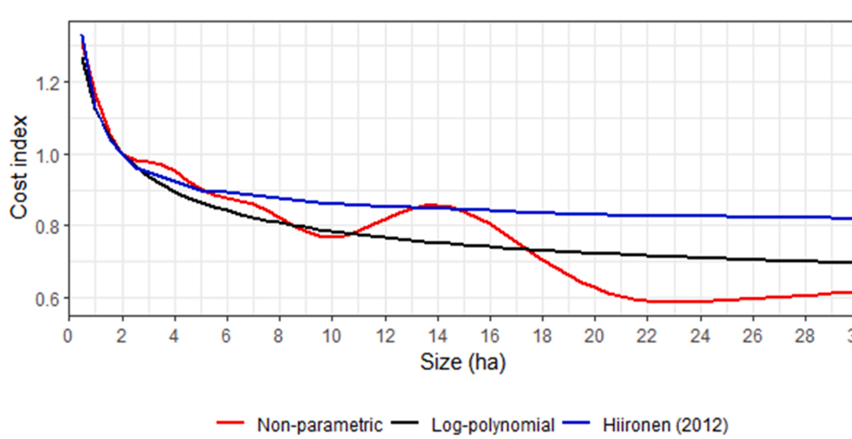

Fig. 3. A fitted log-polynomial function in comparison with a non-parametric function and the previous research estimate from Hiironen (2012).

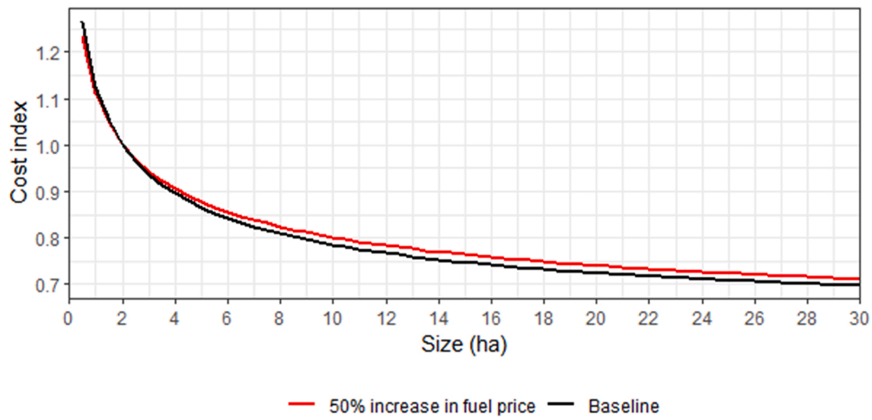

Fig. 4. Sensitivity analysis revealing the effect of a changes in the fuel/working hour cost ratio (results normalized to a 2-ha parcel).

Table 6
The number of parcels in different size categories and number of parcels divided, when the split is defined be at least 25% of the whole parcel size.

Size class (ha)	Number of parcels	Share	Cumulative share	Parcels divided
		(From all parcels >0.2 ha)		(At least two sub-divisions >25% of the whole parcel size)
< 0.2	57,339			
0.2–0.5	118,796	0.14	0.14	942
0.5–1	166,607	0.19	0.33	1741
1–2	216,586	0.25	0.58	4344
2–5	247,452	0.28	0.86	10,629
5–10	90,322	0.10	0.97	7218
10–25	27,692	0.03	0.99	3580
25–50	1747	0.00	0.99	286
> 50	157	0.00	1	8

Table 7
The most common combinations of crops in divided parcels in decreasing order (combinations with the same crop are excluded).

1.	Oat – Perennial grasses for feed
2.	Barley for feed – Perennial grasses for feed
3.	Oat – Barley for feed
4.	Perennial grasses for soil conservation – Perennial grasses for feed
5.	Pasture – Perennial grasses for feed

relationship between parcel sales prices and size (Valtiala et al., 2019; Peltola et al., 2006). Enlarging the parcel size thus increases the value of the parcel. The present analysis supports those results, as a higher price for a larger parcel could reflect lower production costs per hectare. However, while this result may generally hold, other factors, including local demand and natural productivity, affect the sales prices of parcels more than size. Ritter et al. (2020) concluded that the complex relationship between land price and parcel size is affected by several economic factors, such as economies of size, transaction costs, and financial constraints.

The empirical analysis revealed no indication of an excessive parcel size. However, the results clearly demonstrated that when the parcel size starts to approach and exceed 30 ha, it can be considered unnecessarily large. Greatly enlarging the parcel size also has environmental considerations, and, for this reason, the marginal benefits from a larger parcel size may become questionable at some point. Land consolidation arrangements have effects on the quality of the environment and the habitats of edge and yard species. Clough et al. (2020) stated that the diversity of plant and animal farmland species is usually lower where cropland has been aggregated into larger fields. Most field bird species use both edge zones (lowlands, protection strips, open drainage and ditches) and the field itself (Marja et al., 2013). There is also evidence that carabids, which have an important role in integrated pest management, benefit from increasing landscape heterogeneity (Jowett et al., 2022; Ekroos et al., 2009).

These findings suggest that when parcel enlargement no longer brings significant cost reductions, it might be wiser to abstain from the further enlargement for biodiversity and environmental reasons. It should be noted that the effect of a parcel enlargement is not only a

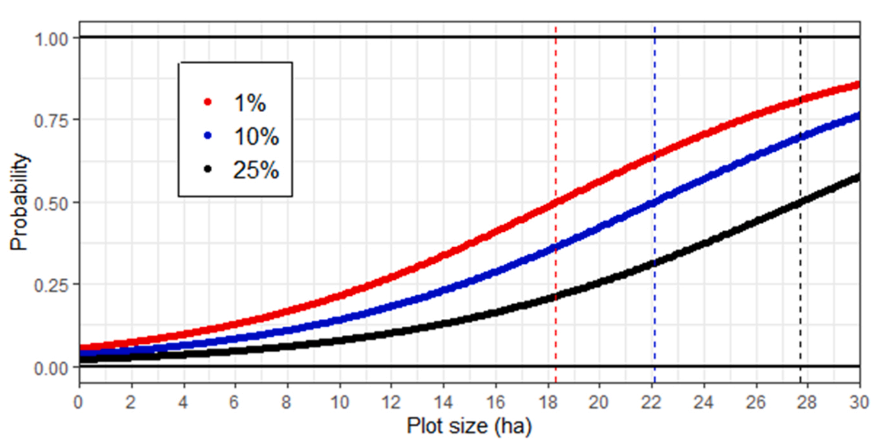

Fig. 5. Probability of a parcel being divided as function of total parcel size (different curves indicate the minimum proportion of the total parcel area that a sub-division's size must exceed).

matter is of a single parcel, but more about the agricultural landscape of the region. Finnish agricultural landscapes, however, differ from the European context, as agricultural land comprises less than 9% of the land area, and even in the most arable region in South–western Finland, the share is only 30%. Still, the fragmentation of agricultural land follows a similar pattern at least in parts of Central and Eastern Europe (Hartvigsen, 2014) and is considered as on-going phenomenon rather than something that can be abolished by a single land consolidation (King and Burton, 1982). This indicates that there is need to develop land consolidation instruments also in the future. A similar study could be implemented in other countries as long as the same data collection method is available. The results from this study may apply to other countries if the field work is carried out similarly as in this study. If, however, factors such as working width and driving speed considerably differ, the results from this study should be interpreted with caution in the context of another country.

5. Conclusions

Agricultural land in Finland is divided into very many parcels for geographical and historical reasons, and the resulting land fragmentation causes productivity losses to farmers. The conducted study revised previous results regarding the relationship between parcel size and working efficiency. The results indicate that there has been some development in working efficiency in the course of time, and technical benefits arising from a large parcel size have slightly grown. However, marginal benefits become increasingly negligible once the parcel size exceeds 20 ha. This result was supported by the tendency of farmers of dividing parcels in practice. The statistical analysis demonstrated that the probability of dividing a parcel between different crops is very low for smaller parcels, and that a parcel of size 27.8 ha has 50% probability of being divided.

There is a considerable potential for inefficiency related to small parcel sizes, and enlarging the parcel size could increase working efficiency. This study did not empirically measure the relationship between yield and parcel size, but it is generally known that machinery turns in headlands increase the risk of soil compaction and edge shadowing by forest and shrubs induces yield reduction. Thus, the results can be considered as a conservative estimate of the potential economic benefits arising from an increase in parcel size. Further parcel enlargement should be actively pursued. Currently, a considerable gap exists between the average parcel size and the more optimal size determined in this study. An apparent need to implement increasingly effective land consolidation projects clearly exists.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The authors do not have permission to share data.

References

Akdeniz, H.B., Çay, T., İnam, Ş. 2022. Evaluation of land consolidation impact criteria for rural development. 4th Intercontinental Geoinformation Days (IGD), 151–154, Tabriz, Iran.

Atkoceviciene, V., Jukneliene, D., Valciukiene, J., Orechovaite, D., 2019. Comparative analysis of the selected land consolidation projects. Balt. Surv. https://doi.org/10.22616/j.balticsurveying.2019.011.

Bradfield, T., Butler, R., Dillon, E., Hennessy, T., Kilgarriff, P., 2021. The effect of land fragmentation on the technical inefficiency of dairy farms. J. Agric. Econ. 72 (2), 486–499. https://doi.org/10.1111/1477-9552.12413.

Çay, T., Ertunç, E., 2018. Analysis of different reallocation results in land consolidation project. Int. J. Environ. Pollut. Environ. Model. Vol. 1 (1), 16–21 (2018).

Clough, Y., Kirchweger, S., Kantelhardt, J., 2020. Field sizes and the future of farmland biodiversity in European landscapes. Conserv. Lett. 13, 12752. https://doi.org/10.1111/conl.12752.

del Corral, J., Perez, J.A., Roibas, D., 2011. The impact of land fragmentation on milk production. J. Dairy Sci. 94 (1), 517–525. https://doi.org/10.3168/jds.2010-3377.

Demetriou, D., See, L., Stillwell, J., 2012. A parcel shape index for use in land consolidation planning. Trans. GIS. https://doi.org/10.1111/j.1467-9671.2012.01371.x.

Di Falco, S., Penov, I., Aleksiev, A., Van Rensburg, T.M., 2010. Agrobiodiversity, farm profits and land fragmentation: evidence from Bulgaria. Land Use Policy 27 (3), 763–771. https://doi.org/10.1016/j.landusepol.2009.10.007.

Du, X., Zhang, X., Jin, X., 2018. Assessing the effectiveness of land consolidation for improving agricultural productivity in China. ISSN 0264-8377 Land Use Policy Volume 70 (2018), 360–367. https://doi.org/10.1016/j.landusepol.2017.10.051.

Ekroos, J., Hyvönen, T., Tiainen, J., Tiira, M., 2009. Responses in plant and carabid communities to farming practises in boreallandscapes. Agric., Ecosyst. Environ. 135, 288–293. https://doi.org/10.1016/j.agee.2009.10.007.

Hamza, M., Anderson, W., 2005. Soil compaction in cropping systems. A review of the nature, causes and possible solutions. Soil Tillage Res. (82), 121–145. https://doi.org/10.1016/j.still.2004.08.009.

Harasimowicz, S., Janus, J., Bacior, S., Gniadek, J., 2017. Shape and size of parcels and transport costs as a mixed integer programming problem in optimization of land consolidation. Comput. Electron. Agric. Volume 140 (2017), 113–122. https://doi.org/10.1016/j.compag.2017.05.035. ISSN 0168-1699.

Hartvigsen, M., 2014. Land reform and land fragmentation in Central and Eastern Europe. Land Use Policy Volume 36 (2014), 330–341. https://doi.org/10.1016/j.landusepol.2013.08.016.

Hartvigsen, M., Mitic-Arsova, K., 2022. Note on lessons learned from the introduction of land consolidation in North Macedonia during 2014-22. Prep. Backgr. Doc. 13th Reg. LANDNET Workshop Organ. Skopje, North Maced. Hybrid. Event 25 – 27 May 2022.

Hiironen, J., 2012. Peltotilusjärjestelyn vaikutuksista ja kannattavuudesta (On the Impacts and Profitability of Farmland Consolidation—in Finnish, with English abstract). Aalto University publication series doctoral dissertations 21/2012. Aalto Univ. 251.

Hiironen, J., Niukkanen, K., 2014. On the structural development of arable land in Finland – how costly will it be for the climate? Land Use Policy Volume 36 (2014), 192–198. https://doi.org/10.1016/j.landusepol.2013.08.008. ISSN 0264-8377.

Hiironen, J., Riekkinen, K., 2016. Agricultural impacts and profitability of land consolidations. Land Use Policy 55, 309–317. https://doi.org/10.1016/j.landusepol.2016.04.018.

Huettel, S., Margarian, A., 2009. Structural change in the West German agricultural sector. Agric. Econ. 40, 759–772. https://doi.org/10.1111/j.1574-0862.2009.00413.x.

Janus, J., Glowacka, A., Bozek, P., 2016. Identification of areas with unfavorable agriculture development conditions in terms of shape and size of parcels with example of Southern Poland. Eng. Rural Dev. 1260–1265.

Jowett, K., Milne, A., Potts, S., Senapathi, D., Storkey, J., 2022. Communicating carabids: engaging farmers to encourage uptake of integrated pest management. Pest Manag. Sci. 78 (6), 2477–2491. https://doi.org/10.1002/ps.6878.

King, R., Burton, S., 1982. Land fragmentation: notes on a fundamental rural spatial problem. Prog. Hum. Geogr. 6 (4), 475–494. https://doi.org/10.1177/030913258200600401.

Latruffe, L., Piet, L., 2014. Does land fragmentation affect farm performance? A case study from Brittany, France. Agric. Syst. 129, 68–80. https://doi.org/10.1016/j.agsy.2014.05.005.

Looga, J., Jürgenson, E., Sikk, K., Matveev, E., Maasikamäe, S. , 2018. Land fragmentation and other determinants of agricultural farm productivity: The case of Estonia. Land Use Policy 79, 285–292. https://doi.org/10.1016/j.landusepol.2018.08.021.

Marja, R., Herzon, I., Rintala, J., Tiainen, J., Seimola, T., 2013. Type of agricultural drainage modifies the value of fields for farmland birds. Agric. Ecosyst. Environ. 165 (2013), 184–189. https://doi.org/10.1016/j.agee.2012.11.008.

Myyrä, S., Pitkänen, T. 2008. Farmer and landowner choices over drainage systems – profit maximisation and environment. Proceedings of the 10th International Drainage Workshop of ICID Working Group on Drainage, Helsinki/Tallinn 6–11. July 2008, Helsinki University of Technology, Water Resources Publications (TKK-VTR-16). Retrieved from: ⟨http://www.fincid.fi/idw2008/pdf/IDW2008_proceedings.pdf⟩.

Niskanen, O., Heikkilä, A.-M., 2015. The impact of parcel structure on the efficiency of finnish dairy farms. Agric. Resour. Econ. Rev. 44, 65–77. https://doi.org/10.22004/ag.econ.200996.

Orea, L., Perez, J.A., Roibas, D., 2015. Evaluating the double effect of land fragmentation on technology choice and dairy farm productivity: a latent class model approach. Land Use Policy 45, 189–198. https://doi.org/10.1016/j.landusepol.2015.01.016.

Pebesma, E., 2018. Simple features for R: standardized support for spatial vector data. R. J. 10 (1), 439–446. https://doi.org/10.32614/RJ-2018-009.

Peltola, R., Mattila, P., & Kasteenpohja, E. , 2006. Pellon arvo (Maanmittauslaitoksen julkaisuja nro 102). Maanmittauslaitos. ⟨https://www.maanmittauslaitos.fi/sites/maanmittauslaitos.fi/files/old/Nro_102_pellon_arvo.pdf⟩.

Plogmann, J., Mußhoff, O., Odening, M., Ritter, M., 2022. Farm growth and land concentration. Land Use Policy 115, 106036. https://doi.org/10.1016/j.landusepol.2022.106036.

REFA 554/1995. Real Estate Formation Act (554/1995). Ministry of Agriculture and Forestry, Finland. Unofficial translation available: ⟨https://www.finlex.fi/fi/laki/kaannokset/1995/en19950554_20030111.pdf⟩.

Ritter, M., Hüttel, S., Odening, M., Seifert, S., 2020. Revisiting the relationship between land price and parcel size in agriculture. Land Use Policy 97, 104771. https://doi.org/10.1016/j.landusepol.2020.104771.

Valtiala, J., Ovaska, S., & Sipiläinen, T. (2019, April). Investigating the Determinants of Finnish Agricultural Land Prices Using Generalised Additive Model. Paper presented at the 165. EAAE Seminar Agricultural Land Markets, Berlin, Germany. https://doi.org/10.22004/ag.econ.288447.

Vitikainen, A. 2004. An Overview of Land Consolidation in Europe. Nordic Journal of Surveying and Real Estate Research, 1(1). Retrieved from ⟨https://journal.fi/njs/article/view/41504⟩.

Ward, M., McDonnell, K., Metzger, K., Forristal, P., 2021. The effect of machine traffic zones associated with field headlands on soil structure in a survey of 41 tilled fields in a temperate maritime climate. Soil Tillage Res. 210, 104938 https://doi.org/10.1016/j.still.2021.104938.

Wickham, et al., 2019. Welcome to the tidyverse. J. Open Source Softw. 4 (43), 1686. https://doi.org/10.21105/joss.01686.

Wojewodzic, T., Janus, J., Dacko, M., Pijanowski, J., Taszakowski, J., 2021. Measuring the effectiveness of land consolidation: An economic approach based on selected case studies from Poland. Land Use Policy Volume 100 (2021), 104888. https://doi.org/10.1016/j.landusepol.2020.104888. ISSN 0264-8377.

Wood, S.N., 2003. Thin plate regression splines. J. R. Stat. Soc.: Ser. B (Stat. Methodol.) 65 (1), 95–114. https://doi.org/10.1111/1467-9868.00374.

Wood, S.N., 2004. Stable and efficient multiple smoothing parameter estimation for generalized additive models. J. Am. Stat. Assoc. 99 (467), 673–686. https://doi.org/10.1198/016214504000000980.

Wood, S.N., 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. J. R. Stat. Soc.: Ser. B (Stat. Methodol.) 73 (1), 3–36. https://doi.org/10.1111/j.1467-9868.2010.00749.x.

Wood, S.N. (2017). Generalized Additive Models: An Introduction with R (2nd edition). Chapman and Hall/CRC.

Wood, S.N., Pya, N., Säfken, B., 2016. Smoothing parameter and model selection for general smooth models. J. Am. Stat. Assoc. 111 (516), 1548–1563. https://doi.org/10.1080/01621459.2016.1180986.