Skalicky, R., Rogalska, E., Pietrzak, M.B., Zinecker, M., Meluzinova, J. (2021), "Optimal Farm Size and Effectiveness of Agriculture in the EU: The Case of Wheat Yields", *Transformations in Business & Economics*, Vol. 20, No 3C (54C), pp.653-669.

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BUSINESS & ECONOMICS

OPTIMAL FARM SIZE AND EFFECTIVENESS OF AGRICULTURE IN THE EU: THE CASE OF WHEAT YIELDS

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Received: April, 2021
1st Revision: September, 2021
2nd Revision: November, 2021
Accepted: November, 2021

ABSTRACT*. *The article concentrates on the relationship between the size of a farm and its efficiency in relation to wheat production in the European Union (EU). The issue is not new, however fundamental from the point of view of the agricultural policy, as the appropriate shape of the agrarian structure affects the economic rationality in agriculture and significantly improves the productivity. We analysed data for the period between 2004 to 2016 while using the Farm Accountancy Data Network. The fixed effects model was used to identify the explanatory variables for farm size and wheat yields. We calculate the yields per hectare as the ratio of the sum of input costs per hectare to the cost of producing a unit of yield per hectare. Using the 1st derivative, we then estimate the marginal cost of the inputs for each of the farm size categories. Our main conclusion is that with the growing size of a farm, there is a continuous increase in yields of wheat per hectare. This result is achieved by increasing the specific crop costs, a significant part of which are fertilizers and crop protection products, both with respect to the cultivated area and the production achieved. When evaluating the efficiency of production, the optimal size of the economic unit (according to the FADN categorization) is 5. Up to the size category 5, there is an increase in production with respect to the monetary value of production inputs. In the case of larger farms, the ratio is declining.

KEYWORDS: farm efficiency, farm size, farming intensity, production input, productivity, wheat yields, the EU agriculture.

JEL classification: O12, Q18, Q13.

Introduction

The relationship between the size of a farm and its efficiency has been an issue in the academic literature and agricultural policy for decades. Researchers observed declining yields per hectare with a growing farm size in a number of countries in the second half of the 20th century. There are many empirical studies delivering empirical evidence on this phenomenon, see, e.g., Sen (1962) in India, Moghadam (1982) in Iran, Cortes (1995) in Japan, Sial *et al*. (2012) in Pakistan, Bell (2011) in Brazil, Demir (2016) in Turkey and many others. The explanations are based on market imperfections and the limited time capacity of owners, in particular in terms of hired workforce management due to the moral hazard problem (Eswaran, Kotwal, 1986). Henderson (2015) and Chen *et al*. (2011) considered hypotheses based on decreasing returns to scale, land quality heterogeneity, and different attitudes to uncertainty. Another important direction to explain the phenomenon consists in the technical efficiency of production depending on the size of a farm (Bravo-Ureta, Pinheire, 1997).

Another strand of literature argues that the relationship between the size of a farm and its efficiency is positive. For example, in the U.S., the median area for corn cultivation increased from 200 to 600 acres between 1987 and 2007, and at the same time, yields per hectare grew as well (Sumner, 2014). The number of “mega” farms farmed on hundreds of thousands of hectares has increased in recent decades (Hermans *et al*., 2017). In the last years, agriculture technology has seen an immense growth in investment in technology (Weersink, Tauer, 1991). Sheng *et al*. (2016) found that a higher productivity of larger farms in Australia cannot be explained by increasing returns to scale, but by the returns to size, which make it easier to use technologies that are not available for smaller producers. The ability to adapt new technologies and changes in relative prices mean additional income for the farm (Sheng *et al*., 2015). This explanation is consistent with the idea of the insignificance of returns to scale in agriculture, expressed by, e.g., Hallam (1991), who assumed that the costs in the agricultural sector in relation to the production range match the L-shaped curve.

A positive relationship between the yields and the cultivated area could be also observed in developing countries like Nepal (Poudel *et al*., 2017) or inland areas of Argentina (Sawers, 1998). In these cases, the explanation for the positive relationship consists in education, ability to manage the farm and in capital endowment and access to it. The ability to accept new technologies (along with other factors) is considered by Mundlak (2005). This aspect is an important determinant of long-term growth of the agricultural sector in the US. On the other hand, insufficient investments in agriculture technologies may lead to slow growth, which can even cumulate to reginal level growth, as it could be verified in some developing countries (Kostiukevych *et al*., 2020). Additionally, it must be remembered that the ability to follow technological changes can differ between small and large farms. Kalirajan and Shand (2001) documented delays in adopting new technologies by farmers in India.

Bojnec, Latruffe (2013) identified a positive relationship between the yields and the cultivated area at the level of technical efficiency in Slovenia; however, the relationship is ambiguous at the level of allocation efficiency. The authors assess the influence of the subsidy policy. Naglova, Gurtler (2016) document the influence of the Common Agricultural Policy (CAP) on entities, which differ in size. Davidova *et al*. (2005) found that smaller farms are rather less efficient in terms of organizational structure in Central and Eastern European countries. Czyżewski, Majchrzak (2018) point out the different behaviour of small and large farms and their productivity during the economic downturn in Poland. Ryś-Jurek (2008) assessed the profitability of specific farms in Poland and in the EU in terms of their size. Dachin (2016) concludes that the cost of production of Romanian farms are the lowest in the size category 5. Bartolini and Viaggi (2013) discuss the influence of common agricultural policy on farm size. They conclude that the intention to increase the cultivated area is significantly (positively) influenced by the existence of the CAP.

The above literature review suggests that the relationship between the size of a farm and its yields per hectare is ambiguous. From the agricultural policy point of view, the issue which kind of agricultural units achieve the highest efficiency is however essential. Therefore, in this paper, we aim at exploring the relationship between the size of a farm and its wheat yields per hectare in the EU. We are focused on farms growing wheat as this agricultural crop has been produced in most of the EU countries. In the first step, we address the issue how do small and large agricultural units differ in the use of production inputs? Next, we are focused on hectare yields modelling based on the production inputs. The last issue concerns the estimation of an optimal size category of a wheat farm in terms of hectare yields in relation to the costs incurred.

We used data from the European Commission Farm Accountancy Data Network/FADN (2018) from the period between 2004 and 2016. This period includes not only different stages of the business cycle but also different climate conditions affecting agricultural production. The length of the time series thus ensures that the results of the study are not affected by random phenomena related to, for example, one season (climatic phenomena, pests, economic development).

Panel data are categorized by country and farm size. Due to the different external conditions in individual countries (climatic, soil, socio-economic, etc.), we use the model of fixed effects (Greene, 2018; Kruk, 2019) to identify the main determinants of production on the level of inputs (labour, direct specific crop costs, depreciation and overheads). These inputs in respect of the cultivated area are then used to explain the total production costs per unit of produced wheat related to a unit of the cultivated area. Next, the estimated coefficients are applied to calculate the marginal effects of the change in individual inputs on the wheat production per hectare for the individual size categories of farms. The research results indicate that the highest increase in production is achieved by farms in the size category 5 according to the FADN categorization.

To our knowledge, empirical results on the topic are currently not available, as prior academic studies have not documented the relationship between farm size and yield per hectare in wheat production representing a substantial part of the CAP application area.

1. Data and Methodology

The dataset of the European Commission Farm Accountancy Data Network/FADN (2018) is used here to examine the relationship between farm size and yield per hectare in wheat production. For analytical purposes, a standard report YEAR.COUNTRY.SIZ6.TF14.zip was used. The report captures a range of indicators on farming from the period between 2004 and 2016 in 28 European countries. The categorization of farms is based on the European Commission Decision 2003/369/EC, amending the former Decision 85/377/EEC. For our calculations, only farms from the category "Specialist COP" have been selected as these are focused on the production of cereals, oilseeds, and protein crops. The reason for this choice is the widespread existence of this type of farm and the capturing of indicator wheat yield per hectare (SE110), as it is a widespread crop in this farm category. The data are reported for six size categories of farms based on their Standard Output (SO) as defined by Commission Decision 85/377/EEC in the last amendment 2003/369/EC.

The comprehensive data for "Specialist COP" farms growing wheat is available only for a limited number of 28 member states. The countries with a low representation of "Specialist COP" (less than 4 size categories) and those with insignificant data on wheat cultivation were excluded from our calculations. A comprehensive list of included and excluded countries is shown in *Table 1*.

Table 1. Countries included in (yes) and excluded from (no) calculations

Country		Country		Country		Country	
(BEL) Belgium	no	(ESP) Spain	yes	(LTU) Lithuania	yes	(POR) Portugal	no
(BGR) Bulgaria	yes	(EST) Estonia	yes	(LUX) Luxembourg	no	(ROU) Romania	yes
(CYP) Cyprus	no	(FRA) France	no	(LVA) Latvia	yes	(SUO) Finland	no
(CZE) Czech Rep.	yes	(HRV) Croatia	no	(MLT) Malta	no	(SVE) Sweden	yes
(DAN) Denmark	no	(HUN) Hungary	yes	(NL) Netherlands	no	(SVK) Slovakia	yes
(DEU) Germany	yes	(IRE) Ireland	no	(OST) Austria	yes	(SVN) Slovenia	no
(ELL) Greece	yes	(ITA) Italy	yes	(POL) Poland	yes	(UKI) United Kingdom	yes

Source: own research based on FADN database.

European Commission Farm Accountancy Data Network/FADN (2018) monitors and reports on a variety of indicators. In addition to the wheat yield per hectare (SE110), the area where wheat is grown (SE110D), the total cultivated area (SE025), and various types of production inputs are included in the database. One of the monitored inputs is represented by total specific costs (SE281) concerning plant production (crop specific inputs). These include seed and planting costs (SE285), fertilisers (SE295), crop protection products (SE300), and other crop specific costs (SE305). Other cost categories are represented by nonspecific farming overheads (SE336) directly related to production (e.g., maintenance of vehicles, buildings, land, insurance, energy, costs linked to work carried out by contractors, machine rentals, and other direct inputs like water). The next cost category covers depreciations (SE360) and estimated labour costs (for both paid and unpaid labour. Furthermore, we used spent labour (SE010), which is expressed (unlike other cost categories) not in Euros but in AWU (annual work unit = full-time person equivalent). In addition, the data on the area where cereals are grown (SE035) and the rented area (SE030) are used.

To capture the quantitative and qualitative differences (e.g., the level of economic development, wages, and natural conditions) affecting wheat yields per hectare in the individual countries, the fixed effect model was used (Greene, 2018). The wheat yields per hectare are estimated while using the following model:

$$y_{ik} = \alpha_i + \boldsymbol{x}'_{ik}\boldsymbol{\beta} + \varepsilon_{ik} \tag{1}$$

Where y_{ik} are yields per hectare in the country (i) (i =1,…,16), k is the farm size category (k=1,…, 6), x_{ik} is the common variable affecting the yields per hectare in observed countries (e.g. farm size in hectares), α_i is the level constant corresponding to the effect of local factors in the country i not included in x_{ik} and ε_{ik} is the error term. The variable y_{ik} and the corresponding explanatory variables x_{ik} are obtained as mean values for the period 2004-2016 for entities (*ik*) (*i*-country, *k*-size category).

To capture the change in the way a farm is managed in connection with the change in the size of a farm, we use a model where the response variable is the cultivated area and the explanatory variables are represented by production input factors. This approach helps us to identify how the management of small and large units differs at the level of inputs. Schwarz criterion (Schwarz, 1978) and Akaike criterion (Arnold, 2010) were used to evaluate the suitability of the model. Furthermore, a fixed effect model based on Greene (2018) was applied here to explain the hectare yields of wheat regardless of the farm size based on inputs. Next, we calculated how the amount of change in individual inputs corresponds to the change of unit costs of wheat produced. In a fixed effects model, we estimated the production costs per unit of wheat per hectare (c_{ik}) based on the amount of individual costs according to the equation as follows:

$$\mathrm{c_{ik}} = \alpha_i + \boldsymbol{x}'_{ik}\boldsymbol{\beta} + \varepsilon_i \qquad (2)$$

Where:

$$\mathrm{c_{ik}} = \sum_{j=1}^{n} x_{ik_j} \Big/ y_{ik} \qquad (3)$$

y_{ik} is the yield per hectare in the country (i) (i =1,…,16), (k) is the farm size category (k=1,…, 6), xik_j are the individual categories of farm costs per hectare of cultivated area, and n is the number of cost categories. The estimation of production per hectare is calculated as a combination of cost inputs and estimated parameters a_i and b:

$$\hat{y}_{ik} = \frac{\sum_{j=1}^{n} x_{ik_j}}{\alpha_i + \boldsymbol{x}'_{ik}\boldsymbol{b}} \qquad (4)$$

Next, according to Mas-Colell *et al*. (1995), we calculate partial derivatives to determine the marginal rate of cost input transformation:

$$\frac{\partial \mathrm{y}}{\partial \mathrm{x_j}}\left(\frac{\sum_{j=1}^{n} x_{ik_j}}{\alpha_i + \boldsymbol{x}'_{ik}\boldsymbol{\beta}}\right) \qquad (5)$$

If we substitute the average values for individual farm size categories, we can determine which size units reach the highest values.

2. Research Findings

2.1 The Relationship between the Size of a Farm and Inputs Used per Hectare

Our calculations show that with the growing size of a farm the use of resources transforms. The size of the cultivated area in logarithms of hectares can be expressed as a combination of (decreased) labour cost inputs per hectare and increased specific crop costs (crop protection costs in particular). Thus, overheads do not contribute to the explanation of the size of the cultivated area, and the contribution of depreciations is limited (negative) with a lower level of statistical significance. The closest relationship is achieved by specific crop costs, in particular crop protection and fertilizers.

We have evaluated several combinations of explanatory variables reflecting the production mix in fixed effects models based on equation (1) to explain the size of a farm. The model with the explanatory variables labour per hectare and crop protection per hectare delivers the best results (according to Schwarz and Akaike criteria). The model specification is as follows:

$$size_{ik} = country_i + labour_{ik}\beta_1 + protect_{ik}\beta_2 + \varepsilon_{ik} \quad (6)$$

Where $size_{ik}$ is the logarithm of the cultivated area in hectares in the country i; k is the size category of the country; $country_i$ is the country-specific level of farm size; $labour_{ik}$ is the yearly amount of labour in time units per hectare; and $protect_{ik}$ is the monetary value of crop protection per cultivated hectare in the country i and the size category k.

The growing size of a farm producing wheat in the EU can be described through the change in the volume of production inputs; it is as a combination of a slowdown of labour (in time units) per hectare of cultivated area and an increase of plant protection expenditure (in monetary units) per hectare of cultivated area. For calculation results, see *Table 2*.

Table 2. Fixed effect model – calculation results

Model parameters estimation results			
Variable	Estimate	Std. error	p-value
Labour (SE010) in AWU/ ha	-34.53	3.70	1.8e-013
Crop protection (SE010) in 1 000 Eur/ha	34.36	4.55	2.24e-010
Model fit measures			
Within R-squared	0.80	Schwarz criterion	221.49
Log-likelihood	-71.20	Akaike criterion	178.39

Notes: dependent variable expressed as logarithm of cultivated area, 16 countries involved, 6 categories of farm size, 81 observations); robust (HAC) standard errors.

Source: own calculations based on FADN database.

2.2 Wheat Hectare Yields and Production Inputs

Next, we are focused on the relationship between wheat hectare yields and production inputs. Fixed effects models are used to explain the relationship. Different combinations of production inputs, e.g., the size of the cultivated area, labour, and various types of incurred costs serve as explanatory variables.

If we apply (Schwarz, 1978) and Akaike criterion (Arnold, 2010), our results suggest that hectare yields of wheat can be best explained by the energy consumption per cultivated area and the ratio of the protection cost to the energy cost. This fixed effects model can be described as follows:

$$yield_{ik} = country_i + frequency_{ik}\beta_1 + dose_{ik}\beta_2 + \varepsilon_{ik} \quad (7)$$

Where $yield_{ik}$ stands for the yields of wheat per hectare in the country (i) and the size category (k); $frequency_{ik}$ is the monetary value of energy used per hectare and $dose_{ik}$ is the ratio of protective products used to energy consumed in monetary units per hectare in the country (*i*) and the category size (*k*).

An adjustment can be achieved by including the ratio of specific crop costs to the sum of depreciations and overheads. This ratio can be understood as an expression of the facilities necessary for land cultivation. The negative coefficient (however, on the border of significance) can be interpreted as the need to keep some fixed facilities given the scale of production. This fixed effect model is specified as follows:

$$yield_{ik} = country_i + frequency_{ik}\beta_1 + dose_{ik}\,\beta_2 + leverage_{ik}\beta_3 + \varepsilon_{ik} \qquad (8)$$

The variables are the same as in equation (7), the variable $leverage_{ik}$ is the ratio of specific crop costs to depreciations and overheads.

The coefficient estimates of this fixed effect model are shown in *Table 3*.

Table 3. Fixed effect model – calculation results

Model parameters estimation results			
Variable	Estimate	Std. error	p-value
Frequency (Energy (SE345) in Eur/ha)	0.13	0.03	7.06e-05
Dose (Crop protection to energy (SE300/SE281))	22.16	2.52	1.58e-012
Leverage (Specific crop costs to depreciations and overheads (SE381/(SE336+360))	-6.21	3.48	0.0792
Model fit measures			
Within R-squared	0.80	Schwarz criterion	423.64
Log-likelihood	-170.07	Akaike criterion	378.14

Notes: dependent variable expressed as wheat yield per hectare, 16 countries involved, 6 categories of farm size, 81 observations); robust (HAC) standard errors.

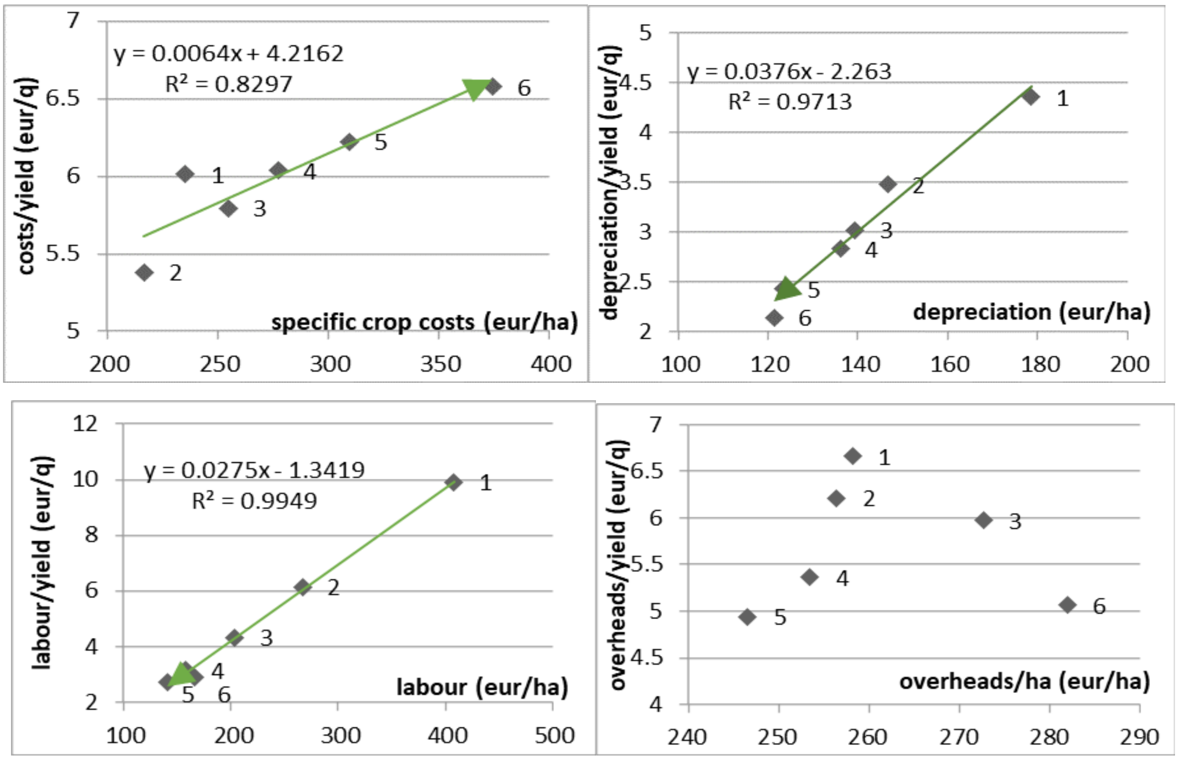
Source: own calculations.

Our calculations suggest that yields per hectare are positively affected by the energy consumption per hectare and the amount of fertilizers and crop protection related to the energy consumed. Other cost inputs (depreciations, overhead, and labour) are insignificant in these models (also due to mutual correlation). We interpret both variables as a reflection of the intensification of agricultural production. The energy consumed per hectare is a variable expressing the frequency (more frequent use of machinery ≈ higher energy consumption per hectare). The ratio of crop protection costs to energy per hectare represents another variable. It can be interpreted as the size of dose per application (higher dose or more valuable protection per application ≈ higher protection / energy ratio). A model replacing the crop protection variable with fertilizers can explain wheat yields per hectare as well, however, the variable crop protection delivers more robust results. The last variable – the leverage - can be interpreted as evidence that specific crop costs have limits. Producers have to keep on a certain level base (approximated by overheads and depreciations).

The question why a more intensive production method (with higher specific crop costs) is mainly associated with larger farm units remains nevertheless unanswered. In the case of crop protection and fertilizers, the effect on the production decreases with increasing the amount of input per hectare. The effects of specific crop costs on wheat yields is shown in graphs 1c and 1d (*Appendix 1*). In contrast, larger farms reduce the amount of labour and depreciations per hectare. This is accompanied by a lower proportional decrease in yields related to these costs (graphs 1e–1j). The relation between the size category of a farm and overheads remains unclear (graph 1k), however, due to the increasing yields per hectare with a growing farm size (graphs1a, 1b) a decrease in overhead to the yield (graph 2k) could be indicated.

The *Figure 1A* (*Appendix 1*) shows that with the growing size category (and the total cultivated area) yields per hectare increase (an exception represents the second size category) The efficiency in relation to production is gradually decreasing. Production intensity of long-term assets (depreciations) relative to the cultivated area decreases with a growing farm size. The use of labour (in temporal as well as monetary units) lowers with a growing farm size. Work consumption increases only in the largest size category. The development of overheads per hectare is not simple. When expressed in relation to the unit produced, the results suggest a decreasing trend (the largest size category represent an exception). The development of labour costs, specific crop costs and depreciations per production unit to the cultivated area corresponds to the idea of decreasing marginal products (like in other areas of agricultural production, see, for example, Macdonald *et al*., 2017).

Shifts of size category in the intensity of using the individual types of resources and their corresponding average production costs are shown in *Figure 2* (a, b, c, d), based on *Figures 1A* c–1h, 1k, 1l.



Source: own calculations based on FADN database.

Figure 2. **Average Cost per Hectare and Average Wheat Production Costs per Hectare Based on the Farm Size Category**

The main conclusion here is that farms classified as large are more successful in choosing a more appropriate combination of inputs compared to their smaller peers.

2.3 Optimal Size of a Farm

The last issue concerns the estimation of an optimal size category of a farm producing wheat in terms of hectare yields achieved. To gain a more comprehensive idea of the effects incurred by the cost inputs and the effects of specific crop costs on production, we expand the approach applied in graphs 2a–2d (*Figure 1A*). The relationship between the average input costs per produced unit and the level of this input per hectare related to the level of all monitored production inputs at the same time can be calculated as follows:

$$\frac{x_1+x_2+x_3+x_4}{Y} = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 \tag{9}$$

Where Y is wheat production per hectare (in *q*), x_1 are specific crop costs per hectare, x_2 are depreciations per hectare, x_3 are labour costs per hectare, and x_4 represent overheads per hectare. Coefficients *α*, *β1*, *β2*, *β3*, and *β4* are estimated by the model of fixed effects.

When we modify the equation (4) and, subsequently, partial derivations of cost inputs are conducted, the marginal rate of transformation of cost inputs per product is obtained (Mas-Colell *et al*., 1995). The formula for the first cost input is as follows:

$$\frac{\partial Y}{\partial x_1} = \frac{\partial}{\partial x_1}\left(\frac{x_1+x_2+x_3+x_4}{a+b_1x_1+b_2x_2+b_3x_3+b_4x_4}\right) = \frac{a+b_2x_2+b_3x_3+b_4x_4-b_1(x_2+x_3+x_4)}{(a+b_1x_1+b_2x_2+b_3x_3+b_4x_4)^2} \tag{10}$$

The estimation of coefficients b_1 to b_4 and the subsequent calculations of the marginal product growth rates are shown in *Table 4*.

Table 4. Calculation results – the fixed effect model

Model parameters estimation results			
Variable	Estimate	Std. error	p-value
Specific crop cost (SE281) in 1 000 Eur/ha	5.05	1.57	0.0020
Depreciations (SE360) in 1 000 Eur/ha	13.38	4.58	0.0049
Labour in 1 000 Eur/ha	26.83	2.26	1.62e-017
Overheads (SE336) in 1 000 Eur/ha	13.92	4.32	0.0020
Model fit measures			
Within R-squared	0.94	Schwarz criterion	309.19
Log-likelihood	-110.65	Akaike criterion	261.30

Notes: the dependent variable is represented by the production costs of a unit of wheat; 16 countries involved, 6 farm size categories, 81 observations; robust (HAC) standard errors.

Source: own calculations based on FADN database.

The coefficients show that an increase in specific crop costs leads to the lowest overall increase in cost per unit of production. Values of marginal rate of transformation cost inputs per product related to individual input category and farm size category are shown in *Table 5*. The main conclusion is that the productivity of specific crop costs remains the highest across all farm size categories. The largest farms on the one hand and the smallest farms on the other hand have the smallest marginal productivity of all cost inputs. The overheads do not have a direct relationship with production, so they can be considered as fixed costs associated with the existence of a farm. Farms of size categories 4 and 5 reach the highest values.

Table 5. Marginal productivity of production factors by farm size

Farm size category	1	2	3	4	5	6
Mean costs incurred per hectare						
X_1: Specific crop costs (Eur/ha)	236	217	256	278	310	375
X_2: Depreciations (Eur/ha)	179	147	140	136	124	122
X_2: Labour (Eur/ha)	409	268	205	159	142	167
X_3: Overheads (Eur/ha)	258	254	266	251	244	282
Marginal impact on wheat production when increasing the input by equation (4) with the estimated parameters (b1 to b4) based on Table 4 in points (X_1 to X_4) for individual farm size categories						
$\partial Y/\partial X_1$ (Specific crop costs)	0.033	0.039	0.039	0.041	0.042	0.038
$\partial Y/\partial X_1$ (Depreciations)	0.016	0.020	0.021	0.022	0.022	0.018
$\partial Y/\partial X_1$ (Labour)	0.015	0.019	0.020	0.021	0.021	0.017
$\partial Y/\partial X_1$ (Overheads)	-0.012	-0.009	-0.009	-0.009	-0.011	-0.013

Source: own calculations based on FADN database.

3. Discussion

Our first main finding is that the increasing size of a wheat growing farm in the EU can be best based on production inputs, estimated through decreasing labour inputs per cultivated area and increasing crop protection products per cultivated area. Hectare yields of wheat can then be best estimated as a combination of “frequency” (energy consumption per cultivated area), “dose” (the ratio of crop protection products to energy) and “leverage” (the ratio of variable to fixed cost of a unit).

With the increasing size of the agricultural unit, there is a steady increase in specific production costs per area and an increase in yields per hectare. At the same time, there is a steady decrease in depreciations per cultivated area and up to the 5th size category there is a decrease in labour costs per cultivated area. Only in the 6th size category, the labour costs per cultivated area are on the rise.

Our main results are consistent with prior studies. Based on U.S. data, Sumner (2014) indicates that a gradual increase in the size of the cultivated area contributes at the same time to an increase in wheat yields per hectare. Our results do not contradict the theory that larger units perform better due to increasing returns to scale (Sheng *et al.*, 2016) and higher flexibility in adopting new technologies (Mundlak, 2005; Kalirajan, Shand, 2001). Our findings are also consistent with empirical results from other EU-countries (see, e.g., Bojnec, Latrutte, 2013; Davidova *et al.*, 2005). A negative relationship between yields per hectare and the extent of cultivated area observed in a number of other countries for a variety of crops could not be indicated for wheat production in the EU.

The factor that encourages larger farms to use specific crop costs instead of labour can be explained by a high proportion of unpaid labour in the case of smaller agricultural units. In smaller farms, the work is performed by the owners and their family members. Using own work means substantial tax benefits and avoiding the transaction costs of hiring and supervision. These costs are considered a source of declining yields per hectare in developing countries (e.g., Henderson, 2015). Because small farms within the EU (size categories 1 and

2) use mostly unpaid labour from their own resources, we suggest that this effect might be also valid in this region. However, it should be emphasized that small farms in developing countries are mostly cultivating units of hectares, rarely tens of hectares.

When evaluating the impact of farm size on wheat yields per hectare, we found that all monitored inputs (labour, specific crop costs, depreciations) per hectare decrease if we take into account the shift from the size category "the smallest farm" (up to 14 ha) to the next size category (up to 37 ha). This result is in accordance with the findings reported by Sen (1962). The farms in the second size category use similar farming approaches as the smallest farms (i.e., labour represents the main production factor to minimize the use of capital). The limited labour capacity and a larger cultivated area can, however, lead to lower intensity of farming. A lower farming activity in this regard was also documented by Eswaran, Kotwal (1986) and Bell (2011). On the other hand, what may prevent smaller farms from more intensive farming, i.e., the application of more expensive or larger amounts of crop protection, fertilizers and their combinations, is probably knowledge of and experience with these procedures. The process of learning new technologies is incremental and this leads to a lag behind the technical potential (Kalirajan, Shand, 2001). In smaller farms, the lag can be more pronounced in particular. Different conditions of small and large units can promote their different behaviour.

Small farms use more labour and record higher depreciation per cultivated area than their large peers. They use less fertilizers and crop protection products. These inputs are essential for large farms, which use these inputs to achieve increasing hectare yields. The increase of these inputs as well as the increase of hectare yields can be observed from the second to the sixth size category.

However, increasing the farm size and yields per hectare has its limits given by the rising production costs in the 6th farm size category. Our results show that in terms of the cost per unit of wheat produced, the optimal farm size is represented by the categories 4 and 5 within the EU. These units achieve the largest production related to labour costs, specific crop costs (fertilizers and crop protection products), and depreciations. This result is consistent with empirical findings from Romania (Dachin, 2016), where farms in the size category 5 achieve the lowest production costs. Our results are also in accordance with Bartolini and Viaggi (2013) who showed that the CAP supports establishing larger farms. Hermans *et al*. (2017), however, concludes that establishing of mega-farms is not common in the EU in comparison to other parts of the world. Our findings also contradict the idea of Hallam (1991) and Chavas (2008) that the production costs have an L-shaped curve when the production grows. Our results suggest a rather U shaped curve with minima at the level of size categories 4 and 5.

Conclusions

The summarized key conclusions of our research are as follows.

We found a positive relationship between the size of a farm and the wheat yields per hectare. This is achieved by increasing the amounts of specific crop products (fertilizers and crop protection products), which replace labour and lead to higher yields per hectare. Farms in the larger size categories use fertilizers and crop protection more intensively compared to their smaller peers, but with declining efficiency. The largest farms (up to thousands of hectares) have to face increased labour costs and overheads, which means, that the marginal rate of transformation of cost inputs per hectare tends to decrease. Thus, we can conclude that the cost curve is U shaped for farms producing wheat in the UE with values that reach their minimum in the case of the size categories 4 and 5.

The main limitation of this study consists in the fact that we employed data only for farms producing wheat. In reality, farms produce other crops and may be focused on a variety of entrepreneurial activities. This must be reflected while interpreting our conclusions. Wheat production is also of different importance in the context of CAP; in some areas it is even missing and thus cannot be evaluated. From the methodological point of view, it can be problematic to deal with the data as it is based on average values. Additionally, differences in the importance of wheat production in individual EU member states might lead to biased results. Partial improvements could be achieved if we employed data for individual agricultural areas, not for countries.

We use only financial data reflecting the production technologies used. We do not, however, know the differences in terms of applied technologies (the data does not cover them). This let us to assume that larger farms are encouraged to use more intensive farming methods in a form, which is not available for smaller farms.

Further research of the relationship between farm size and its productivity should be focused on identifying the most important farm activities in individual agricultural areas and assessing their characteristics when evaluating the relationship between size and cost productivity. Unanswered remains also the issue of dynamics of the here presented differences and production characteristics of small and large farms over time. This study shows that specific crop costs (fertilizers and crop protection products) are the most important production inputs. A deeper research focused on the relationship between this input category and production outputs seems promising to us in terms of delivering new research results.

References

Arnold, T.W. (2010), "Uninformative Parameters and Model Selection Using Akaike's Information Criterion", *Journal of Wildlife Management*, Vol. 74, No 6, pp.1175-1178, https://doi.org/10.2193/2009-367.

Bartolini, F., Viaggi, D. (2013), "The common agricultural policy and the determinants of changes in EU farm size", *Land use policy*, Vol. 31, March, pp.126-135, https://doi.org/10.1016/j.landusepol.2011.10.007.

Bell, A.R. (2011), "Highly Optimized Tolerant (HOT) Farms in Rondônia Productivity and Farm Size, and Implications for Environmental Licensing", *Ecology and Society*, Vol. 16, No 2, https://doi.org/10.5751/ES-04098-160207.

Bojnec, Š., Latruffe, L. (2013), "Farm size, agricultural subsidies and farm performance in Slovenia", *Land use policy*, Vol. 32, May, pp.207-217, https://doi.org/10.1016/j.landusepol.2012.09.016.

Bravo-Ureta, B.E., Pinheiro, A.E. (1997), "Technical, Economic, And Allocative Efficiency In Peasant Farming: Evidence From The Dominican Republic", *Developing Economies*, Vol. 35, No 1, pp.48-67, https://doi.org/10.1111/j.1746-1049.1997.tb01186.x.

Chavas, J. -Paul. (2008), "On the economics of agricultural production", *Australian Journal of Agricultural and Resource Economics*, Vol. 52, No 4, pp.365-380, https://doi.org/10.1111/j.1467-8489.2008.00442.x.

Chen, Z., Huffman, W.E., Rozelle, S. (2011), „Inverse Relationship Between Productivity and Farm Size: The Case of China", *Contemporary Economic Policy*, Vol. 29, No 4, pp.580-592, https://doi.org/10.1111/j.1465-7287.2010.00236.x.

Cortes, B. (1995), "Government regulation, productivity, and farm size in Japan's rice market", *International Advances in Economic Research*, Vol. 1, No 2, pp.104-109, https://doi.org/10.1007/BF02295964.

Czyżewski, B., Majchrzak, A. (2018), "Market versus agriculture in Poland – macroeconomic relations of incomes, prices and productivity in terms of the sustainable development paradigm", *Technological and Economic Development of Economy*, Vol. 24, No 2, pp.318-334, https://doi.org/10.3846/20294913.2016.1212743.

Dachin, A. (2016), "Production Costs of Field Crops by Economic Size of Farms in Romania", *Scientific Papers*

Series Management, Economic Engineering in Agriculture and Rural Development, Vol. 16, No 3, pp.103-106, https:// http://managementjournal.usamv.ro/pdf/vol.16_3/Art14.pdf.

Davidova, S., Gorton, M., Ratinger, T., Zawalinska, K., Iraizoz, B. (2005), "Farm Productivity and Profitability: A Comparative Analysis of Selected New and Existing EU Member States", *Comparative Economic Studies*, Vol. 47, No 4, https://doi.org/10.1057/palgrave.ces.8100066.

Demir, I. (2016), "The firm size, farm size, and transaction costs: the case of hazelnut farms in Turkey", *Agricultural Economics*, Vol. 47, No 1, pp.81-90, https://doi.org/10.1111/agec.12211.

Eswaran, M., Kotwal, A. (1986), "Access to Capital and Agrarian Production Organisation", *The Economic Journal*, Vol. 96, No 382, https://doi.org/10.2307/2233128.

European Commission (2018), *Standard Reports: YEAR.COUNTRY.SIZE6.TF14.ZIP*, Farm Accountancy Data Network, Database (Brussels, Belgium, 2018), available at, http://ec.europa.eu/agriculture/rica/database/consult_std_reports_en.cfm, referred on 20/06/2018.

Greene, W.H. (2018), *Econometric Analysis*, New York: Pearson.

Hallam, A. (1991), "Economies of Size and Scale in Agriculture: An Interpretive Review of Empirical Measurement", *Review of Agricultural Economics, Agricultural and Applied Economics Association*, Vol. 13, No 1, pp.155-172, https://ideas.repec.org/a/oup/revage/v13y1991i1p155-172..html.

Henderson, H. (2015), "Considering Technical and Allocative Efficiency in the Inverse Farm Size–Productivity Relationship", *Journal of Agricultural Economics*, Vol. 66, No 2, pp.442-469, https://doi.org/10.1111/1477-9552.12086.

Hermans, F.L.P., Chaddad, F.R., Gagalyuk, T., Senesi, S., Balmann, A. (2017), "The emergence and proliferation of agroholdings and mega farms in a global context", *International Food and Agribusiness Management Review*, Vol. 20, No 2, pp.175-186, https://doi.org/10.22434/IFAMR2016.0173.

Kalirajan, K.P., Shand, R.T. (2001), "Technology and farm performance: paths of productive efficiencies over time", *Agricultural economics*, Vol. 24, No 3, pp.297-306, https://doi.org/10.1016/S0169-5150(00)00077-3.

Kostiukevych, R., Mishchuk, H., Zhidebekkyzy, A., Nakonieczny, J., Akimov, O. (2020), „The impact of European integration processes on the investment potential and institutional maturity of rural communities", *Economics and Sociology*, Vol. 13, No 3, pp.46-63, https://doi.org/10.14254/2071-789X.2020/13-3/3.

Kruk, D. (2019), „Productivity or the External Environment: Which is More Important for Growth in Emerging Markets?", *Entrepreneurial Business and Economics Review*, Vol. 7, No 2, pp.119-139, https://doi.org/10.15678/EBER.2019.070207.

Macdonald, K.A., Penno, J.W., Lancaster, J.A.S., Bryant, A.M., Kidd, J.M., Roche, J.R. (2017), "Production and economic responses to intensification of pasture-based dairy production systems", *Journal of dairy science*, Vol. 100, No 8, pp.6602-6619, https://doi.org/10.3168/jds.2016-12497.

Mas-Colell, A., Whinston, M.D., Green, J.R. (1995), *Microeconomic Theory*, New York: Oxford University Press.

Moghadam, F.E. (1982), "Farm Size, Management and Productivity: A Study of Four Iranian Villages", *Oxford Bulletin of Economics and Statistics*, Vol. 44, No 4, pp.357-379, https://doi.org/10.1111/j.1468-0084.1982.mp44004005.x.

Mundlak, Y. (2005), "Economic Growth: Lessons from two countries of American agriculture", *Journal of Economic Literature*, Vol. 43, No 4, https://doi.org/10.1257/002205105775362005.

Naglova, Z., Gurtler, M. (2016), "Consequences of supports to the economic situation of farms with respect to their size", *Agricultural Economics* (Czech), Vol. 62, No 7, pp.311-323, https://doi.org/10.17221/191/2015-AGRICECON.

Poudel, K.L., Yamamoto, N., Sugimoto, Y., Nishiwaki, A., Kano, H. (2010), „Estimation of Production Function and Resource use Condition of Organic Coffee Cultivation in Different Farm Size and Altitude Categories in the Hill Region of Nepal", *European Journal of Scientific Research*, Vol. 45, No 3, pp.438-449, http://hdl.handle.net/10458/4344.

Ryś-Jurek, R. (2008), "The output of the average individual farm in Poland and in the European Union countries. An attempt of defining similarity of structures in 2005", *Journal of Agribusiness and Rural Development*, Vol. 8, No 2, pp.119-133, https://doaj.org/article/e3c3aec7340f4bca9a90cf1f85ea233f.

Sawers, L. (1998), "Farm Size, Productivity, and Public Policy in the Argentine Interior", *The Journal of Developing Areas*, Vol. 33, No 1, pp.121-150.

Sen, A.K. (1962), "An aspect of Indian agriculture", *The Economic Weekly*, Vol. 14, February, pp.243-246.

Sheng, Y., Zhao, S., Nossal, K., Zhang, D. (2015), "Productivity and farm size in Australian agriculture:

reinvestigating the returns to scale", *Australian Journal of Agricultural and Resource Economics*, Vol. 59, No 1, pp.16-38, https://doi.org/10.1111/1467-8489.12063.
Sheng, Y., Davidson, A., Fuglie, K., Zhang, D. (2016), „Input Substitution, Productivity Performance and Farm Size", *Australian Journal of Agricultural and Resource Economics*, Vol. 60, No 3, pp.327-347, https://doi.org/10.1111/1467-8489.12136.
Sial, M.H., Iqbal, S., Sheikh, A.D. (2012), "Farm Size – Productivity' Relationship: Recent Evidence from Central Punjab", *Pakistan Economic and Social Review*, Vol. 50, No 2, pp.139-162.
Sumner, D.A. (2014), "American Farms Keep Growing: Size, Productivity, and Policy", *The Journal of Economic Perspectives*, Vol. 28, No 1, pp.147-166, https://doi.org/10.1257/jep.28.1.147.
Schwarz, G. (1978), "Estimating the Dimension of a Model", *The Annals of Statistics*, Vol. 6, No 2, pp.461-464.
Weersink, A., Tauer, L. (1991), "Causality Between Dairy Farm Size and Productivity", *American Journal of Agricultural Economics*, Vol. 73, No 4, http://search.proquest.com/docview/1296594884/.

OPTIMALUS ŪKIO DYDIS IR ŽEMĖS ŪKIO EFEKTYVUMAS ES: KVIEČIŲ DERLIAUS ATVEJO ANALIZĖ

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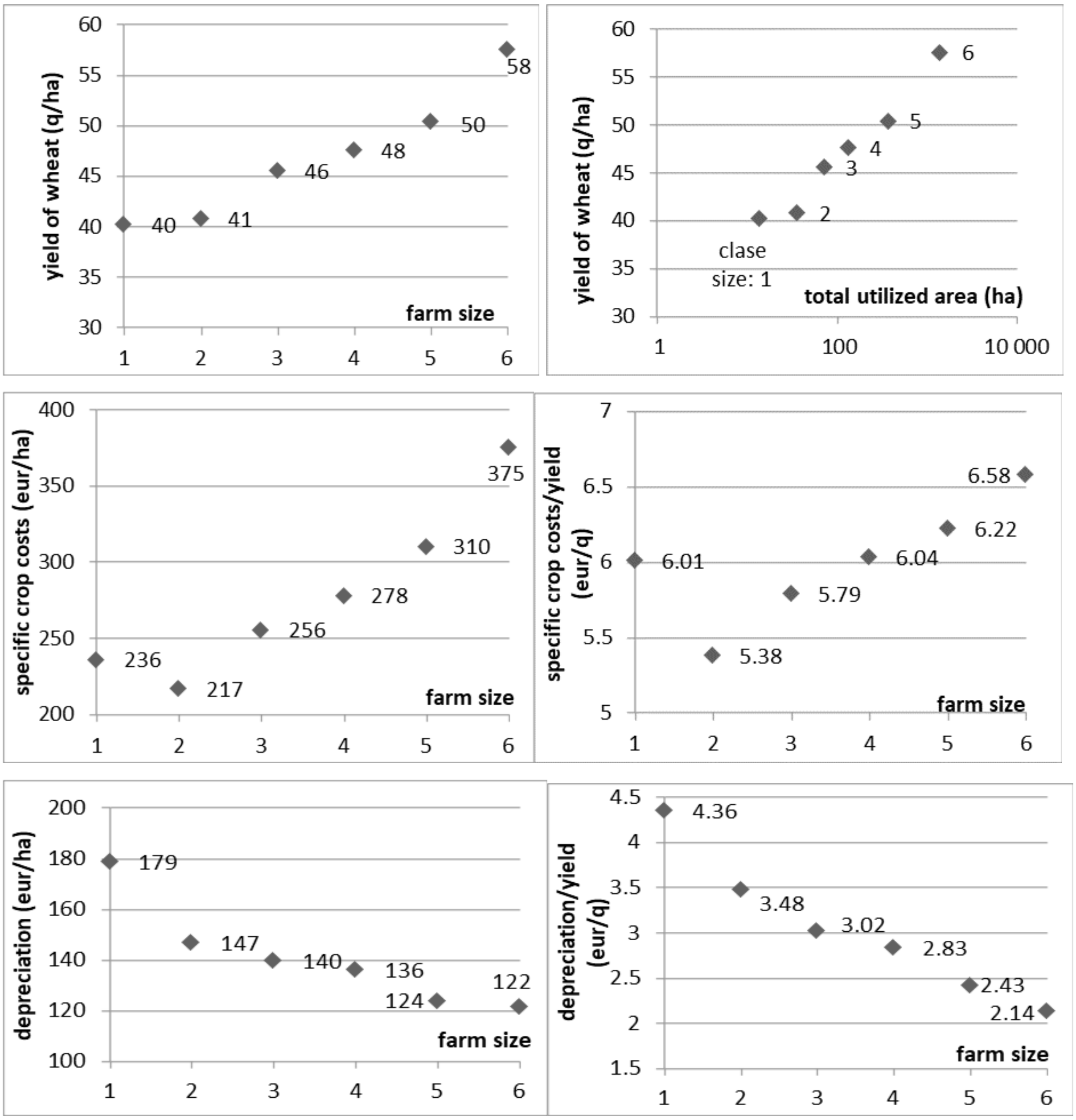
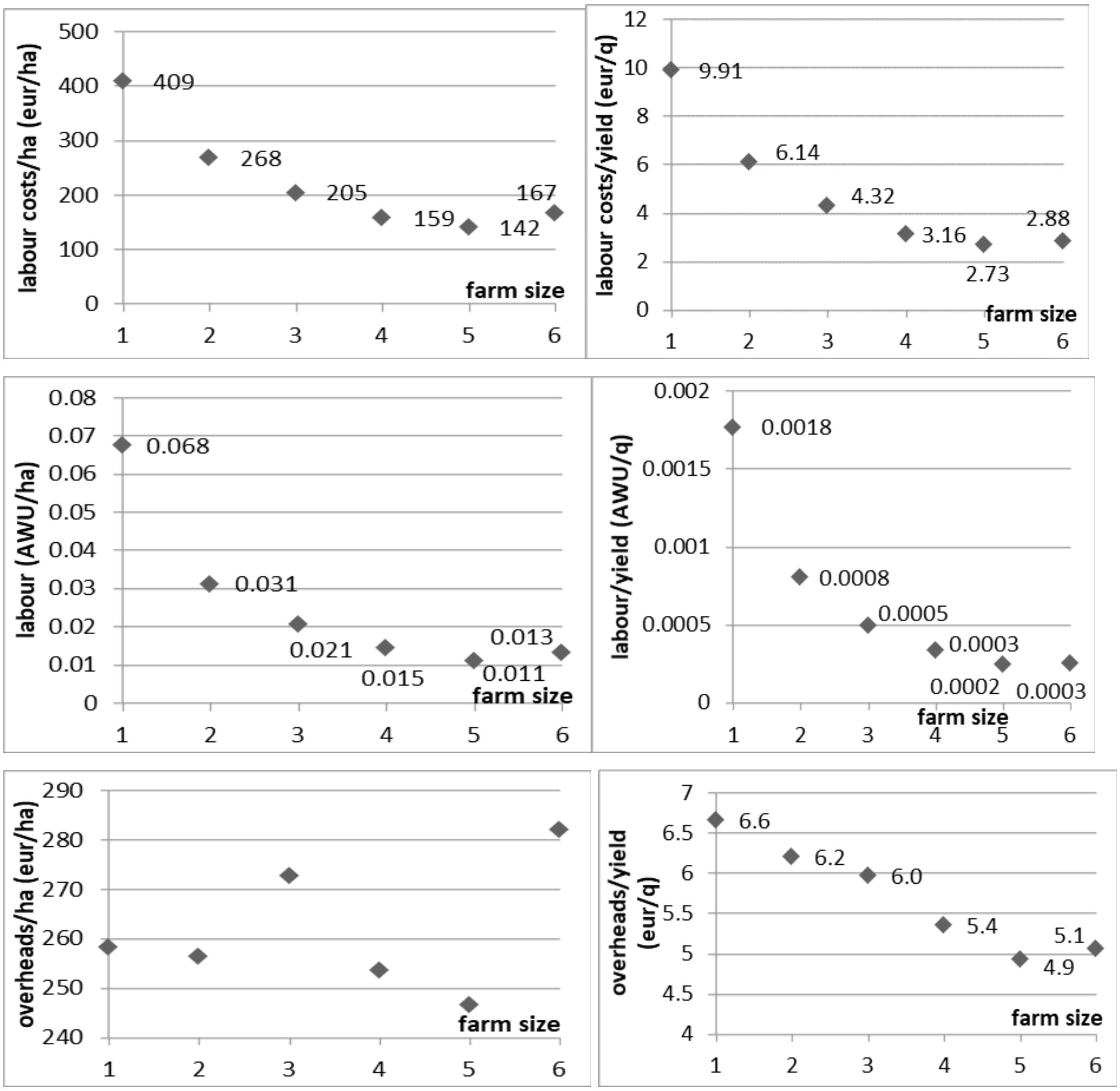
SANTRAUKA

Straipsnyje nagrinėjamas ūkio dydžio ir jo efektyvumo ryšys, vertinant kviečių auginimą Europos Sąjungoje (ES). Šis klausimas nėra naujas, tačiau esminis žemės ūkio politikos požiūriu, nes tinkama agrarinės struktūra turi įtakos ekonominiam racionalumui žemės ūkyje ir gerokai padidina produktyvumą. Naudojantis Ūkių apskaitos duomenų tinklu buvo analizuoti 2004–2016 m. laikotarpio duomenys. Fiksuotų efektų modelis taikytas siekiant nustatyti ūkio dydį ir kviečių derlių aiškinantiems kintamiesiems. Vieno hektaro derlingumas apskaičiuotas kaip vienam hektarui tenkančių sąnaudų sumos ir vieno hektaro derliaus vieneto pagaminimo sąnaudų santykis. Remiantis pirmąja išvestine, apskaičiuotos ribinės sąnaudos kiekvienai ūkių dydžio kategorijai. Pagrindinė išvada yra ta, kad didėjant ūkio dydžiui nuolat didėja kviečių derlius iš hektaro. Šis rezultatas pasiekiamas didinant specifines pasėlių sąnaudas, kurių didelę dalį sudaro trąšos ir augalų apsaugos produktai, atsižvelgiant tiek į pasėlių plotą, tiek į gautą produkciją. Vertinant gamybos efektyvumą, optimalus ekonominio vieneto dydis (pagal Ūkių apskaitos duomenų tinklo kategorizaciją) yra 5. Iki 5 dydžio kategorijos gamybos apimtis didėja gamybos sąnaudų piniginės vertės atžvilgiu. Didesniuose ūkiuose šis santykis mažėja.

REIKŠMINIAI ŽODŽIAI: ūkio efektyvumas, ūkio dydis, ūkininkavimo intensyvumas, gamybos sąnaudos, našumas, kviečių derlius, ES žemės ūkis.

Appendix 1


yield of wheat (q/ha)
farm size
40
41
46
48
50
58
yield of wheat (q/ha)
total utilized area (ha)
clase size: 1
2
3
4
5
6
specific crop costs (eur/ha)
farm size
236
217
256
278
310
375
specific crop costs/yield (eur/q)
farm size
6.01
5.38
5.79
6.04
6.22
6.58
depreciation (eur/ha)
farm size
179
147
140
136
124
122
depreciation/yield (eur/q)
farm size
4.36
3.48
3.02
2.83
2.43
2.14



Source: Own calculations based on FADN database

Figure 1A. **Yields and Costs of Wheat Growing Farms Depending on Size**