

## INTERDEPENDENCE OF ECONOMIC AND ENVIRONMENTAL EFFICIENCY IN AGRICULTURE IN THE EUROPEAN UNION

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### ABSTRACT

The aim of the study was to identify the most important determinants of economic and environmental efficiency of agricultural production in the EU countries in 2005, 2007, 2010 and 2013, with particular emphasis on structural conditions. The paper presents the results of modelling with the use of Eurostat data and methods of data envelopment analysis (DEA) and panel regression. In the case of economic efficiency, the importance of production concentration, understood as economic strength of farms, associated with an even distribution of production, was identified. In the case of eco-efficiency, its limiting factor turned out to be specialisation towards animal production. These results allow us to conclude that it is possible to achieve economic and environmental objectives at the same time, as none of the identified determinants was repeated in both models with the opposite sign. The results of the research are also a premise for the implementation of an active structural policy under the CAP after 2020.

**Key words:** economic efficiency, ecoefficiency, agriculture, DEA, panel regression

### INTRODUCTION

The draft regulations defining the shape of the Common Agricultural Policy (CAP) after 2020 propose far-reaching changes in the model of its implementation. The reform is based on making the policy more flexible by transferring the majority of powers to the level of Member States. At the same time, the new CAP is to be more goal-oriented, thanks to the creation of a system of indicators and methods of their evaluation [Regulation of the European Parliament and of the Council COM/2018/392]. In this situation, decision-makers in the Member States face the challenge of increasing the macroeconomic efficiency of agriculture (at the scale of the agricultural sector). This process should be based on maintaining the cur-

rent production potential, while at the same time reducing engaged inputs, not only in economic, but also environmental terms. However, there are a number of doubts related to this process. To what extent is it dependent on structural factors, which change in the short term is difficult? Are the objectives of improving economic and environmental efficiency (eco-efficiency) not mutually exclusive? Which of the broad set of factors determine the level of efficiency to the greatest extent? The answers to these questions are provided by the analysis carried out in this study. In line with the new approach to evaluation of the CAP, comparisons have been made at Member State level. Taking into account the special role of structural factors [Kukuła 2010], the following hypothesis will be verified in the study: Structural conditions are an

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important determinant of the level of economic and environmental efficiency of the agricultural sector of the EU countries, however, different dimensions of the structure affect other dimensions of efficiency. At the same time, on the basis of the literature review [Fuglie and Rada 2012, Wrzaszcz 2012, OECD 2013] a number of non-structural efficiency factors of exogenous, endogenous and institutional nature can be identified. Their impact will also be taken into account in the constructed models. The study was conducted on the basis of Eurostat data for the EU-25 (excluding Cyprus and Malta) in the years 2005–2013. The method of data envelope analysis (DEA) was used to measure the efficiency level, and panel regression to identify the dependencies.

## MATERIAL AND METHODS

Data describing the shape of production structures in agriculture in the EU come from the farm structure survey (FSS), which was carried out in 2005, 2007, 2010 and 2013. Therefore, all other variables have been recalculated in order to be consistent with the methodology of this survey. A detailed description of the structural variables used in the survey is presented in Table 1. The concentration level was measured by the standard concentration index [O'Donnell et al. 2016] (variables UAA\_SO, SO\_SO, AWU\_SO, LSU\_SO). To measure specialisation we used Hirschman-Herfindahl index (UAA\_TYPE, AWU\_TYPE, LSU\_TYPE, ABS\_SPEC) and Krugman index (REL\_SPEC) [Palan 2010].

**Table 1.** Structure measures used in the research

Feature	Code	Description
Concentration	AVG_UAA	average farm area (UAA)
	AVG_SO	average economic size of the holding (SO)
	AVG_AWU	average labour input (AWU)
	AVG_LSU	average number of livestock on the holding keeping the animals (FT45, 46, 47, 48, 51, 52, 53, 73, 74, 83, 84) (LSU)
	UAA_SO	distribution of the land factor among holdings of different economic size (UAA/SO)
	SO_SO	distribution of production among holdings of different economic size (SO/SO)
	AWU_SO	distribution of the labour factor between farms of different economic size (AWU/SO)
	LSU_SO	distribution of livestock between holdings of different economic size, which were keeping animals (LSU/SO)
Specialisation	SELF_CONS	share of farms using more than 50% of production for self-consumption
	MIXED	share of holdings of the type mixed production in production (SO)
	UAA_TYPE	distribution of the land between holdings of different types (UAA)
	AWU_TYPE	distribution of the labour between holdings of different types (AWU)
	LSU_TYPE	distribution of livestock between holdings of different types (LSU)
	ABS_SPEC	absolute specialisation – distribution of production among different types of farms (SO)
Orientation	REL_SPEC	relative specialisation – distribution of production among different types of farms (SO)
	ANIMAL	the share of the value of animal production (ANIMAL OUTPUT) in the total value of agricultural production (AGRICULTURAL GOODS OUTPUT), in base, 2005 constant prices

Source: Own study based on Eurostat [accessed: 11.12.2017].

The efficiency of agricultural production in the EU Member States in economic and environmental terms has been estimated using the DEA method. It allows to define the production function (production frontier) by means of linear programming methods, and then to determine the measure of efficiency as the distance of a given decision making unit (in this case Member State) from this frontier. A detailed description of this method can be found in Färe et al. [1994]. The DEAP 2.1 program was used for the estimations. Certain inputs and outputs used for calculations are described in Table 2.

Panel regression was used to study the dependencies between structural variables and efficiency. A detailed description of this method can be found in studies by Dańska-Borusiak [2011] and Park [2011]. Estimates were made in the Gretl. In order to test the robustness of the proposed models, a number of control variables have been introduced to control for the other determinants of agricultural productivity. They are listed in Table 3.

In order to verify the hypothesis contained in the introduction, two main models of panel regression

were constructed, where as an explanatory variable were used: (1) economic efficiency of the agricultural sector; and (2) eco-efficiency of the agricultural sector. Due to the wide range of potential determinants, the basic difficulty of the study lied in narrowing down this spectrum. For this purpose, the following procedures were applied:

- for all explanatory variables coefficients of variation were calculated, and those regression factors for which their value was lower than 10 were excluded from the study;
- considering the fact that the key group are structural variables, in the first place models describing each of the dimensions of efficiency by concentration of production, land, labour, or livestock were generated. To describe the degree of concentration in each of the dimensions, five variants of the model were constructed with the following explanatory variables: (1) average value (AVG\_XX); (2) concentration index (XX\_SO); (3) average value and concentration index; (4) interactional variable (int\_xx)<sup>1</sup>; (5) all these variables. The model with the highest value of  $R^2$  was adopted for further testing;

**Table 2.** Economic and environmental inputs and outputs of agricultural activity

Category	Metrics	Description
Economic inputs	labour	total agricultural labour input (40 000 AWU)
	capital	value of intermediate consumption (EUR 19 000) depreciation (EUR 21 000) at 2005 constant prices
	land	total utilised agricultural area in ha
Environmental inputs	GHG emission	CO <sub>2</sub> emission, in tonnes N <sub>2</sub> O, CH <sub>4</sub> , HFC, PFC, SF <sub>6</sub> , NF <sub>3</sub> , in tonnes of CO <sub>2</sub> equivalent
	nutrient balance	nutrient balance (N) in tonnes
	ammonia emission	annual NH <sub>3</sub> emissions of agricultural origin, in tonnes
	livestock density	number of LSU per 1 ha of UAA
Output	production	value of plant and animal output (EUR 14 000), at basic prices (including subsidies for production) at constant 2005 prices

Source: Own study based on Eurostat [accessed: 07.07.2017].

<sup>1</sup> An interaction variable is created by multiplying two variables that are suspected of interaction, i.e. the impact of one variable depends on the value of the other variable.

**Table 3.** Determinants of agricultural efficiency – overview of metrics

	Category	Metrics	Code	Description
Endogenic	technology	capital/labour ratio	C/W	capital (intermediate consumption + depreciation) per 1 AWU
		capital/land ratio	C/L	capital (intermediate consumption + depreciation) per 1 ha UAA
		irrigation	IRRIG	share of irrigated UAA
	human capital	farmer's education	EDU_HOLD	share of UAA managed by farmers with basic or full agricultural training
		farmer's age	MED_AGE	median of the farmer's age
Egzogenic	infrastructure	internet	INTERNET	households on low population density areas (less than 100 people per km <sup>2</sup> ) with broadband access
	environmental conditions	less favoured areas	LFA	share of LFA in total UAA
	macroeconomic conditions	price scissors	PRICE_SC	the ratio of dynamics of average prices of food products to average prices of inputs used in agriculture
		economic growth	GDP	GDP growth in constant 2005 prices
		interest rates	INT_R	Maastricht criterion interest rates
		budget deficit	GG_DEF	general government deficit/surplus, expressed as a percentage of GDP
	Institutional	market orientation	other gainful activities	OGA
factors ownership		land rental	L_LEASE	share of leased land in the total UAA
		non-family labour	NON_FAM	share of labour (AWU) provided by non-family members, employed on the holding on a permanent basis
		loans	LOANS	share of interest costs in the total amount of capital costs (intermediate consumption + depreciation + investment expenditures)
agricultural policy		general subsidies	CAP_GEN	the total value of the subsidies per 1 000 SO
		investment subsidies	CAP_INV	the total value of the investment subsidies per 1 000 SO

Source: Own study based on Eurostat and FADN [accessed: 17.11.2017].

- then, on the basis of the correlation matrix, structural variables not significantly correlated with the explanatory variables identified earlier were found and the impact of their inclusion in the model on its quality was tested. If quality increased, they could be included in the model;
- for the models estimated in this way, the adequacy of the estimator of the panel model (Hausman, Breusch–Pagan, F test) was tested. At this point, two models explaining the economic and environmental performance of the agricultural sector were selected for further research;

- in cases when the change of the estimator affected the significance of the previously selected regressors, the impact of their removal on the quality of the model was tested. In justified cases, insignificant variables were removed;
- for the models developed in this way, a robustness tests were carried out, consisting of the introduction of regressors representing non-structural efficiency factors into the model.

Due to the limited volume of work, only the models finally accepted for the research will be presented in the following section. All calculations are made using the Arellano robust errors (HAC) method. As a result of the described procedures, the following models were identified (Table 4).

Nine procedures were carried out for two dimensions of efficiency and four dimensions of agricultural production concentration. On the basis of these proce-

dures, two panel models explaining the variability of efficiency were constructed. In the case of economic efficiency, in all models, apart from those based on production concentration, the explanatory variables lost their significance after variables representing influence of individual factors characteristic for countries and periods were introduced into the model. For the model accepted for further calculations, the random effects estimator turned out to be the most adequate. This means that specific effects are not correlated with the explanatory variables of the model (as demonstrated by the Hausman test). In the case of models testing the impact of the concentration level on eco-efficiency, in the case of production and livestock, they were not significant even at the level of regression using the OLS method (pooled). In the case of the labour factor, although its average level in farms, initially turned out to be statistically significant, it lost its relevance

**Table 4.** Selection of structural factors for models – results

Economic efficiency				Ecoefficiency				
SO	UAA	AWU	LSU	SO	UAA	AWU	LSU	ad hoc
int_SO	UAA_SO	AVG_AWU, int_AWU	AVG_LSU	x	AVG_UAA, UAA_SO	AVG_AWU	x	AVG_SO, int_SO, int_AWU,
int_SO, AWU_SO, AWU_ TYPE, UAA_TYPE	UAA_SO, ABS_SPEC	int_AWU, SO_SO, AWU_ TYPE, LSU_TYPE, ABS_SPEC	AVG_LSU, AWU_ TYPE		AVG_UAA, UAA_SO, SO_SO, REL_SPEC	x		SELF- CONS, REL_SPEC, ANIMAL
int_SO, AWU_SO, AWU_ TYPE	x	x	x	x				ANIMAL, SELFCONS
random eff.								fixed eff.

row 1 – basic model; row 2 – model with additional structural variables; row 3 – panel model variables; row 4 – panel model estimator.

AVG\_UAA – average utilised agricultural area; AVG\_SO – average standard output.; AVG\_AWU – average labour input; AVG\_LSU – average livestock; UAA\_SO – land distribution; SO\_SO – standard output distribution; AWU\_SO – labour input distribution; LSU\_SO – distribution of livestock; SELFCONS – share of self-consumption; MIXED – share of mixed production; UAA\_TYPE – distribution of UAA between different types of production; AWU\_TYPE – distribution of labour between different types of production; LSU\_TYPE – distribution of livestock between different types of production; ABS\_SPEC – specialisation in absolute terms; REL\_SPEC – specialisation in relative terms; ANIMAL – share of animal production.

Source: Own study based on Eurostat.

when other structural variables were introduced into the model. The model estimated for the concentration of labour factor was no longer valid after the use of panel estimators. In this case, an alternative method was applied, which consisted in a stepwise elimination of structural variables from the panel model with fixed effects. As a result, we obtained model explaining the differentiation of eco-efficiency by means of structural variables describing specialisation.

In addition, a binary variables were introduced to the models. In random effects model it describes whether the country joined EU after 2004 (EU-12). In fixed effects model binary variables represent country-specific effects. In order to eliminate the risk of burdening the estimation results with heteroskedasticity of variance or autocorrelation of a random component, a robust Arellano estimator has been used. The co-linearity of the finally included regressors was also verified by means of the variance inflation factor (VIF).

## RESULTS

After receiving the basic versions of the models, robustness tests were carried out. First, the results obtained for economic efficiency will be discussed. Variables for robustness testing were selected with the method of backward stepwise regression, by removing from the model subsequent non-structural variables according to the key of their significance. Six variables which are strongly related to the economic efficiency of the agricultural sector have been identified. The impact of their control is shown in Table 5. According to the data presented there, the model showed significant robustness. The basic variable *int\_SO*, showing the mixed impact of deconcentration and average economic farm size, proved significance at the level of  $\alpha = 0.01$  in all models. Similarly, the *EU\_12* binary variable describing the non-modelled characteristics differentiating EU-12 and EU-15 countries. The other variables representing concentration (*AWU\_SO*) and specialisation (*AWU\_TYPE*) of labour factor use lost relevance at the level of  $\alpha = 0.01$  only after the *INT\_R* variable representing interest rates was introduced. In the case of models (2) and (7), the Hausman test showed a higher adequacy of the model with fixed effects. The change in the estimator substantially affected the results of

the estimates, but in both cases the *int\_SO* variable remained significant ( $p = 0.011$  and  $p = 0.025$ , respectively). Out of the estimated models, only in case (2) the addition of a control variable improved the quality of the estimate (lower AIC, BIC and HQC values). At the same time, however, the model no longer required the GLS estimator, and after changing the estimator, it lost its predictive power.

As for the identified significant structural variables, the main one is *int\_SO*, which illustrates the interaction between the average economic size of farm and concentration of production. It was constructed in such a way that it indicates that a positive impact on the economic efficiency of the agricultural sector is due to the high economic strength of farms, related to relatively even distribution of production. This means that the increase in the average size of farms through the enlargement of the largest units is less favourable than the enlargement of medium-sized farms. This variable may also be interpreted as an indication that the increase in average size of holdings will not significantly improve economic efficiency when agricultural production is too concentrated or that an even distribution will not be favourable if it concerns a sector with a fragmented production structure.

The other two structural variables concern the labour factor and their impact is negative. The variable *AWU\_SO* illustrates the labour factor concentration. Negative sign means that, similarly as in the case of production, it is more advantageous, from the point of view of economic efficiency, for work to be distributed evenly among farms. If we assume that with use of modern technologies 1 AWU per holding is enough to handle production, high concentration may mean that in farms with above-average labour input, the labour-intensive production model dominates and it is unfavourable from the point of view of economic efficiency. The high value of the *AWU\_TYPE* indicator informs about the specialisation of the use of the labour factor in farms of a certain type, which also turned out to be unfavourable for economic efficiency. Therefore, it turns out that specialisation, clearly positively assessed from the microeconomic perspective, from the macro point of view, may have the character of a destimulant. This effect may also be related to over-representation (in relation to other factors) of

**Table 5.** Robustness of the model for structural determinants of economic efficiency of agriculture (random effects, GLS, robust standard errors HAC)

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
cons.	<b>1.4***</b> (0.2)	1.34*** (0.2)	1.33*** (0.2)	1.33*** (0.19)	1.27*** (0.18)	1.39*** (0.19)	1.41*** (0.21)
int_SO	<b>1.88e<sup>-6***</sup></b> (4.9e <sup>-7</sup> )	2.33e <sup>-6***</sup> (5.15e <sup>-7</sup> )	2.49e <sup>-6***</sup> (7.48e <sup>-7</sup> )	1.02e <sup>-6***</sup> (4.18e <sup>-7</sup> )	2.08e <sup>-6***</sup> (4.66e <sup>-7</sup> )	2.68e <sup>-6***</sup> (5.33e <sup>-7</sup> )	1.87e <sup>-6***</sup> (4.85e <sup>-7</sup> )
AWU_SO	<b>-0.66**</b> (0.27)	-0.67*** (0.24)	-0.59** (0.28)	-0.45* (0.25)	-0.52** (0.26)	-0.65*** (0.23)	-0.66** (0.27)
AWU_TYPE	<b>-0.53**</b> (0.23)	-0.51** (0.21)	-0.49** (0.22)	-0.43* (0.23)	-0.40** (0.18)	-0.61** (0.25)	-0.54** (0.25)
EU_12	<b>-0.18***</b> (0.04)	-0.16*** (0.5)	-0.18*** (0.04)	-0.17*** (0.048)	-0.18*** (0.043)	-0.22*** (0.043)	-0.19*** (0.043)
IRRIG		0.42** (0.17)					
INTERNET			-0.0003 (0.0004)				
INT_R				-0.02*** (0.003)			
GG_DEF					0.007*** (0.001)		
OGA						0.38*** (0.12)	
LOANS							-0.28 (0.82)
SE	<b>0.1</b>	0.093	0.1	0.111	0.108	0.108	0.106
AIC	<b>-161.7</b>	-184.1	-161.1	-148	-153.6	-152.8	-156.4
BIC	<b>-148.7</b>	-168.5	-145.5	-132.3	-138	-137.2	-140.75
HQC	<b>-156.43</b>	-177.8	-154.8	-141.6	-147.3	-146.5	-150.1
between	<b>0.0113</b>	0.006	0.0118	0.0113	0.012	0.012	0.01
within	<b>0.0011</b>	0.0011	0.0011	0.0007	0.0008	0.0009	0.0011
theta	<b>0.84</b>	0.79	0.85	0.88	0.87	0.86	0.84
Breush–Pagan	<b>118.6</b> (1.28e <sup>-27</sup> )	78.53 (7.9e <sup>-19</sup> )	119.04 (1.02e <sup>-27</sup> )	117.6 (2.12e <sup>-27</sup> )	121.6 (2.8e <sup>-28</sup> )	120.6 (4.8e <sup>-28</sup> )	111 (5.86e <sup>-26</sup> )
Hausman	<b>1.92</b> (0.59)	21.2 (0.0003)	2.11 (0.71)	8.53 (0.062)	9.4 (0.052)	5.4 (0.25)	10.64 (0.031)

int\_SO – interaction of deconcentration and average farm output; AWU\_SO – labour factor concentration; AWU\_TYPE – specialisation of the labour factor; EU\_12 – country joining the EU after 2004 (binary variable); IRRIG – irrigation; INTERNET – broadband internet availability in rural areas; INT\_R – interest rates; GG\_DEF – budget deficit; OGA – additional income sources; LOANS – credits widespread; AIC – Akaike information criterion; BIC – Bayesian information criterion; HQC – Hannan–Quinn information criterion.

\*Significant at  $\alpha = 0.1$ ; \*\* $\alpha = 0.05$ ; \*\*\* $\alpha = 0.01$ . In brackets for the coefficients of the standard errors values, in brackets for the tests the  $p$ -value.

Source: Own study based on Eurostat.

labour in specific types of agricultural activity, which may imply labour-intensive production methods, and thus lower efficiency of the sector. In the context of both variables, it should also be noted that their occurrence in the model is a premise of great importance of the structure of the labour factor.

As for the second of the analysed efficiency dimensions – eco-efficiency, the search for its determi-

nants among the variables describing the concentration of production was unsuccessful, which resulted in the need to use an alternative method of selecting variables for the model. The procedure of backward stepwise regression was used, where by reducing subsequent insignificant variables, the model in version (1) was finally obtained (6). Diagnostic tests of the panel indicated that in such situation the estimator of

**Table 6.** Robustness of the model for structural determinants of eco-efficiency of agriculture (fixed effects, robust standard errors HAC)

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
cons.	0.91*** (0.11)	0.92*** (0.11)	0.88*** (0.12)	0.97*** (0.11)	0.93*** (0.10)	0.94*** (0.11)	0.93*** (0.1)
ANIMAL	-0.52** (0.23)	-0.52** (0.24)	-0.45* (0.25)	-0.57** (0.23)	-0.57** (0.21)	-0.48** (0.23)	-0.36* (0.2)
SELFCONS	0.11** (0.5)	0.11** (0.5)	0.11** (0.5)	0.09 (0.5)	0.12** (0.5)	0.08 (0.5)	
C/L		-2.26e <sup>-6</sup> (1.6e <sup>-5</sup> )					
INTERNET			0.0001 (0.0002)			0.0004* (0.0002)	0.0005** (0.0002)
NON_FAMILY				-0.1 (0.07)		-0.27** (0.1)	-0.36** (0.08)
CAP_INV					0.0004 (0.0002)	0.0004 (0.0002)	0.0004 (0.0003)
SE	0.026	0.026	0.026	0.026	0.026	0.025	0.026
AIC	-421.6	-419.6	-420.4	-421.1	-424.8	-428.1	-426.26
BIC	-351.28	-346.7	-347.5	-348.1	-351.85	-349.9	-350.7
HQC	-393.15	-390.11	-390.9	-391.5	-395.3	-396.42	-395.7
LSDV R <sup>2</sup>	0.991	0.991	0.991	0.991	0.991	0.992	0.992
within R <sup>2</sup>	0.131	0.131	0.138	0.144	0.175	0.233	0.203
F test	371.323 (4.49e <sup>-28</sup> )	732.15 (2.5e <sup>-31</sup> )	200.11 (2.17e <sup>-24</sup> )	223.3 (4e <sup>-25</sup> )	186.75 (3.9e <sup>-24</sup> )	230.3 (2e <sup>-25</sup> )	55.6 (2.7e <sup>-6</sup> )
Durbin-Watsons	1.48 (0.013)	1.49 (0.002)	1.52 (0.006)	1.49 (0.004)	1.54 (0.006)	1.7 (0.003)	1.64 (0.017)

ANIMAL – share of animal production; SELFCONS – share of farms with dominating self-consumption; C/L – capital/land ratio; INTERNET – availability of broadband Internet in rural areas; NON\_FAMILY – share of non-family labour input; CAP\_INV – CAP investment support.

\*Significant at  $\alpha = 0.1$ ; \*\* $\alpha = 0.05$ ; \*\*\* $\alpha = 0.01$ . In brackets for the coefficients of the standard errors values, in brackets for the tests the  $p$ -value.

Source: Own study based on Eurostat.

fixed effects is the most adequate. Such a construction makes it impossible to introduce to the model binary variables other than those describing individual effects (the problem of strict collinearity). The remaining control variables were subjected to a procedure analogous to that concerning structural variables. On this basis, four control variables were identified, which are characterised by a particularly high correlation with the eco-efficiency of agriculture. With the use of this set of regressors, model robustness tests were carried out, as illustrated in Table 6. Their results indicate that among structural variables the highest robustness was shown by the share of animal production (ANIMAL), which in all models was characterized by a significant, at least at the level of  $\alpha = 0.1$ , and a negative impact on eco-efficiency. The second of the studied structural variables, describing widespread of self-consumption (SELFCONS), turned out to be less robust and in two models (4) and (6) it lost its significance due to the introduction of the variable share in employment people not from the farmer's family (NON-FAMILY). Finally, this variable was also introduced into the model (6) which was of the highest quality (lowest values of AIC, BIC and HQC) and was adopted for the final conclusion. It includes insignificant variable (SELFCONS), due to the fact that its removal worsened the quality of the model, as evidenced by the estimation (7). For the same reasons variable CAP\_INV, describing investment support under the Common Agricultural Policy, remained in the model. The impact of capital/land ratio (C/L) was also tested, but it did not prove to be significant in any of the configurations.

The correlations revealed between the variables lead to the following observations. Firstly, the most important variable for building eco-efficiency was the share of animal production. In countries where it was higher, the eco-efficiency was significantly smaller. This is in line with theoretical considerations and indicates a greater environmental footprint of this type of production. On the other hand, it should be taken into account that the eco-efficiency was estimated on the basis of statistics (GHG emissions, stocking densities, ammonia emissions) arising to a large extent from the size of the animal population, hence the negative impact of this type of production may be

over-represented in the eco-efficiency index. However, this flaw results mainly from the lack of other measures of the impact of agriculture on the environment, available in a sufficiently long time horizon. This leads to the conclusion of a technical nature, that in order to better investigate the relationship between eco-efficiency and agricultural structure, a more complete set of data describing the development of the eco-efficiency is necessary. Secondly, the negative impact of livestock production becomes more important under conditions of controlling the impact of self-supply production (inclusion of the SELFCONS variable in the model). This may mean that the maintenance and production of livestock on such farms is less burdensome for the environment than on specialised farms. The SELFCONS variable becomes irrelevant due to the control of the level of employment in the holding of people not from the farmer's family (inclusion of the NON\_FAMILY variable in the model), which turns out to have a significant negative impact on eco-efficiency.

## SUMMARY

The estimated model of panel regression with random effects (RE), as the most important determinant of the economic efficiency of the agricultural sector indicated a large average economic size of farms, connected with a relatively even distribution of production (lack of polarisation). Apart from them, the relation with specialization in the use of labour factor (concentration of factor in one type of farms) was also important, as a destimulant. The model additionally indicated that even after excluding the impact of the above variables in the EU-12 countries, economic efficiency still remained significantly lower. The estimated panel regression model with constant effects (FE) indicated, as the most important determinant of eco-efficiency, the higher share of animal production, which had a negative impact. The other tested structural and control variables did not show a permanently significant relationship. However, the best of the estimated models indicated a positive impact of Internet availability and negative impact of non-family employment. At the same time, individual effects of particular countries were

distinguished in this model, which in the vast majority were significant. It means that the level of eco-efficiency depends to a larger extent on individual, immeasurable features of the agricultural sector in particular EU countries.

The obtained results of the research correspond only moderately to the conclusions of similar studies. As far as the relationship between economic efficiency and concentration is concerned, earlier studies have rather indicated a positive impact of the production scale [Huffman and Evenson 2001, Bojnec et al. 2014] on efficiency or lack of a statistically significant relation [Vollrath 2007, Nowak et al. 2015]. Differences in results may come from differences in the temporal and spatial range of research and different ways of defining concentration. In this study, it is broadly understood and takes into account the distribution of resources, not only their average level. In terms of eco-efficiency, earlier works indicated rather a positive correlation with animal production [Wrzaszcz 2012, Cupo and Di Cerbo 2017]. However, these analyses were conducted at the farm level, which may explain the discrepancies.

Comparing the results of the research on determinants of economic efficiency and eco-efficiency, the following conclusions can be drawn. Firstly, the differentiation of panel regression estimators for both types of efficiency allows us to state that in the case of eco-efficiency, estimated with the use of the constant effects estimator (FE), individual, unmeasurable features of the agricultural sector in individual countries were much more significant. Secondly, it can be noted that economic and environmental efficiency was stimulated by different features. In this situation, striving for efficiency in one dimension does not have to take place at the expense of the other, as none of the identified determinants was repeated in both models with the opposite sign. Therefore, the hypothesis stated earlier can be accepted. Thirdly, the explanatory variables identified in both models indicate that the economic efficiency of the sector is more closely related to the degree of concentration, while eco-efficiency to the direction of specialisation. All these conclusions justify the implementation of tools for restructuring the agricultural sector under the CAP after 2020.

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## **WSPÓŁZALEŻNOŚĆ EFEKTYWNOŚCI EKONOMICZNEJ I ŚRODOWISKOWEJ W ROLNICTWIE UNII EUROPEJSKIEJ**

### **STRESZCZENIE**

Celem badania było zidentyfikowanie najistotniejszych determinant ekonomicznej i środowiskowej efektywności produkcji rolnej w krajach UE w latach 2005, 2007, 2010 i 2013, ze szczególnym uwzględnieniem uwarunkowań strukturalnych. W opracowaniu przedstawiono wyniki modelowania z wykorzystaniem danych Eurostat i metod analizy obwiedni danych (DEA) oraz regresji panelowej. W przypadku efektywności ekonomicznej zidentyfikowano znaczenie koncentracji produkcji, rozumianej jako duża siła ekonomiczna gospodarstw, powiązana z równomiernym rozkładem produkcji. Czynnikiem ograniczającym efektywność okazała się specjalizacja w kierunku produkcji zwierzęcej. Wyniki te pozwalają wnioskować, że możliwa jest jednoczesna realizacja celów ekonomicznych i środowiskowych, gdyż żadna ze zidentyfikowanych determinant nie powtarzała się w obydwu modelach z przeciwnym znakiem. Wyniki badań stanowią też przesłankę do realizacji w ramach WPR po 2020 roku aktywnej polityki strukturalnej.

**Słowa kluczowe:** efektywność ekonomiczna, efektywność, rolnictwo, DEA, regresja panelowa