Environmental sustainable value in agriculture revisited: How does Common Agricultural Policy contribute to eco-efficiency?

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Abstract

The conflict between capital-intensive agriculture, often called industrial agriculture, and sustainable farming is ongoing, and not because of Western European countries, where intensification is increasingly sustainable. It is caused by several million small farms in Central and Eastern Europe that must choose a long-term development path. This is also a dilemma for agricultural policy: Are small farms so environmentally friendly that they should play the role of ‘landscape guardians’ at the expense of public support and economic vegetation, or should they strive to improve productivity through investments? This study offers a methodological contribution to the value-based sustainability approach by computing indicators of environmental sustainable value (ESV). The authors have attempted to combine the value-oriented approach with frontier benchmarking. They then tested how the European Union Common Agricultural Policy (CAP) schemes contribute to ESV using a long-term panel of regionally representative farms from Farm Accountancy Data Network (FADN) with regard to factor endowments, for the years 2004–2017. The seminal within-between specification was employed to control the time variant and time invariant space heterogeneity of European regions. The main finding is that higher investment support is beneficial to ESV. Regarding factor endowment influence, there was a positive impact of the capital–labour ratio. Except the cross-sectional impact of environmental subsidies, the payments exert a negative effect on ESV.

Keywords Sustainable agriculture · Environmental sustainable value · Eco-efficiency · Agricultural policy · CAP

Introduction

Within the Treaty on the Functioning of the European Union, one of the main objectives of Common Agricultural Policy (CAP) is to increase agricultural productivity by ensuring technical progress, the rational development of agricultural production and the optimum utilisation of the factors of production (particularly labour) (Czyżewski et al. 2019a). The ‘Agenda 2000’ reform introduced the European Union’s (EU) rural development policy, the overarching priorities of which include fostering agricultural competitiveness, ensuring the sustainable management of natural resources and promoting climate action. As of 2003 Luxemburg reform,

one of the new objectives was to better meet society’s new demands regarding environmental conservation and product quality. Sustainable development, which is currently one of the most important objectives of the EU’s CAP (Fischler 2002), is the subject of many scientific papers (Glavic et al. 2007; Shearman 1990; Harris 2000; Connelly and Graham 2003; Waas et al. 2011). Achieving this status is possible, among other reasons, because of a set of CAP instruments that are key factors determining the eco-efficiency of agricultural activity.

In Western European countries, intensification in agricultural production is increasingly sustainable, but there are over six million small farms in the EU 27 (Davidova et al. 2013) that will have to make a difficult decision about which development path to take. This is also a dilemma for the new CAP perspective 2021–2027, in which the substantial reduction of investment funds is still an open question. Are small farms so environmentally friendly that they should act as ‘landscape guardians’ while being maintained by public support that condemns them to economic vegetation, or should they strive to improve productivity through

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investment support? This study has interdisciplinary value as it combines economic and environmental issues in agriculture which both contribute to the sustainable development. Measuring sustainability in agriculture, and especially estimating its drivers, encounters many methodological problems. This work provide an original contribution to the value-based approach on how environmental sustainable value (ESV) may be calculated and modelled based on farm accountancy panel data which are usually easily accessible. Widespread in the literature, microeconomic assessments of the impact of agricultural policy on the use of fertilisers and pesticides at the farm level only lead to indirect and hypothetical conclusions on the sustainability of European agriculture (Gocht et al. 2017). Common frontier efficiency estimation techniques that might measure the relative eco-efficiency of farms are hardly applicable for modelling determinants of a decision making unit's (DMU) score. Eco-efficiency scores received by nonparametric techniques such as the data envelopment analysis (DEA) and the free disposable hull analysis (FDH) require few-stage bootstrapping if they are to be used as dependent variables (see more in this article's 'Methods' section; Simar and Wilson 2007; Badunenko and Tauchmann 2018). The output of the parametric methods (i.e. the stochastic frontier approach), the thick frontier approach and the distribution-free approach also are hardly applicable for regression. For these reasons, this study has refreshed the basic approach of sustainable value (SV), improving its most questionable action of using sample averages as benchmarks. Instead this article proposes indicating benchmark units using the frontier estimation

technique. Further, SV generates results in monetary values that offer many interpretation opportunities.

Hence, the main objective of this paper is to estimate a long-term CAP subsidies impact on ESV, regarding factor endowments. The intermediate objective consists in addressing the eco-efficiency notion by the ESV measure (Kuosmanen and Kortelainen 2005). The concept of the study is depicted in Fig. 1 (see the 'Material and methods' section). From the findings of the authors quoted below we inferred the following research hypotheses, providing however that those findings concerned either production or environmental impact, rather than their mutual relationship as assumed in the eco-efficiency approach:

- H1. Investment subsidies and capital-intensive development of farms increase the eco-efficiency (Grovermann et al. 2019);
- H2. Subsidies for public goods provision and protection (including environmental and Less Favoured Area payments) increase eco-efficiency (Picazo-Tadeo et al. 2011; Chabe-Ferret and Subervie 2012; Liu et al. 2014; Pawłowska-Tyszko 2014);
- H3. Direct payments (i.e. decoupled subsidies) and labour-intensive development of farms decrease eco-efficiency (Rizov et al. 2013);
- H4. Production support reduces eco-efficiency (Rizov et al. 2013);

The justification for this research and the above hypotheses is the ambiguous impact of subsidies implemented under

Fig. 1 The concept of the research

the CAP on agricultural productivity in economic and environmental sense. The question of what effect CAP subsidies have on productivity of farms in the EU has been studied by many authors, but it has not yet been definitively answered (Olley and Pakes 1996; Hennessy 1998; Ciaian and Swinnen 2009; Rizova et al. 2013; Banga 2014). Researchers recognise that environmental subsidies contribute to the sustainable development of agriculture. The increase in capital expenditure is conducive to high economic efficiency in European agriculture (van Grinsven et al. 2019). In contrast, there is a concern that stimulating capital endowment under the CAP fosters industrial agriculture and may lead to excessive investment (Rizov et al. 2013). In this study, the authors attempt to verify whether these fears are not fully justified, and that subsidies under the CAP, depending on their type, affect the eco-efficiency of farms in various ways. Thus, the conducted research aims to confirm or refute Grovermann et al. (2019) conclusions, who argue that innovative systems in agriculture increase eco-efficiency. However, unlike studies by Moutinho et al. (2018), Bartová et al. (2018) and Rybaczewska-Błazejowska and Gierulski (2018), this study is not conducted on a national level but in a regional scale.

The results should therefore constitute guidelines for decision-makers in shaping agricultural policy instruments that are conducive to eco-efficiency (with the need to consider the diverse situation in this field in the EU Member States and their regions). The rest of the article is organised as follows: first, the state-of-the-art regarding techniques in the eco-efficiency approach as a measure of environmental sustainability are presented. Next, the methodology used to calculate ESV and to estimate the effects of policy on ESV is described. The results section presents main outcome of the modelling. In discussion part the study results are compared to other findings in this field. Finally, there are conclusions including recommendations for policymakers.

Eco-efficiency as a measure of environmental sustainability

The concept of eco-efficiency can be traced back to the 1970s as the concept of ‘environmental efficiency’ (Freeman et al. 1973). In the 1990s, Schaltegger and Sturm (1990) described eco-efficiency as a business link to sustainable development. The World Business Council for Sustainable Development (WBCSD 2000) popularised it around 1992. In the last decade, it has been applied more directly to agriculture (Keating et al. 2010). The Organisation for Economic Cooperation and Development (OECD 1998) has called eco-efficiency ‘the efficiency with which ecological resources are used to meet human needs’; it defines it as ratio of an output (i.e. the value of products and services produced by a firm, sector or economy as a whole) divided by an input (i.e. the

sum of environmental pressures generated by the firm, the sector or the economy).

In 2011, the European Commission (EC) stressed that an increased demand for certain resources will eventually lead to shortages and higher prices, inevitably affecting the EU’s economy. Thus, resources must be used more efficiently throughout their life cycle, from extraction, transport, recycling, consumption to waste disposal. That is why the EC urges resource efficiency. This means creating higher value with lower material costs. This would reduce the risk of scarcity, and the environmental impact would not go beyond the natural equilibrium of our planet. This all-encompassing idea touches on all natural resources, from food, wood and biodiversity to energy, metals, soil, minerals, the atmosphere and the earth. Although the transition to a green economy is inherently systemic and would have to involve the entire economy, three key sectors exist: (1) producing energy from clean and renewable sources (for instance, solar panels and wind turbines), (2) improving energy efficiency (especially in buildings and transport) and (3) conserving and the smart use of natural capital (sustainable agriculture, fishing, water, waste and other sectors) (Campiglio 2016). All of these questions have seen considerable research interest in the topic of eco-efficiency in many sectors (transport, energy, industry, construction, agriculture, etc.).

This article focuses on eco-efficiency in agriculture with a particular emphasis on the capital-intensive development path. Eco-efficiency in the simplest terms is about achieving more with less – more agricultural outputs in terms of quantity and quality for less input of land, water, nutrients, energy, labour or capital. Agricultural productivity represents a worldwide goal for agriculture research as a response to growing food, feed and energy demands (Bartolini et al. 2016); however, the effective use of resources is not only about the economic productivity growth at the farm level. The concept of eco-efficiency encompasses both the ecological and economic dimensions of sustainable agriculture (Caiado et al. 2017; Müller et al. 2014; Keating et al. 2010). Agriculture faces the pressure from both policy makers and consumers to adopt sustainability practices (Bartolini et al. 2016). The scientific question arises as to whether small farms with extensive farming practices are more eco-efficient than large capital-intensive farms. How small can farms contribute to the overall level of sustainable development in agriculture when their lack of capital and often outdated technology forces them to increase productivity at the farm level using more fertilisers, fuel and other inputs whilst also being more labour-intensive. Overall, there is a lack of answers on what factors affect eco-efficiency, especially eco-efficiency in small-scale farming.

Various studies have come to the same conclusion that the level of eco-efficiency varies between different countries (Czyżewski et al. 2019b; Grovermann et al. 2019; van

Grinsven et al. 2019; Staniszewski 2018; Moutinho et al. 2018). In the majority of studies, rich countries with an intensive agricultural sector are more eco-efficient and generate higher gross value added in their agricultural sectors with lower levels of input. At the same time, eco-efficient does not always mean environmentally sustainable in an absolute sense (Czyżewski et al. 2019b). For instance, the top 10 eco-efficient regions according to Czyżewski et al. (2019b) are several regions in France, the Netherlands, some regions in Italy and Spain, Denmark and the Vlaanderen region in Belgium. Some economists might have doubts whether those region are really environmentally sustainable. According the van Grinsven et al. (2019), the five EU Member States with the highest eco-efficiency level are also The Netherlands, Greece, Italy, France and Sweden; the bottom five are the Czech Republic, Estonia, Latvia, Ireland and Poland. Different rankings have been obtained depending on the chosen eco-efficiency assessment methodology. However, the above studies do show that higher eco-efficiency is obtained in these EU regions, which are strongly connected to international markets (The Netherlands, with its horticulture production; regions of France, Italy and Spain with well-known wine labels and other high-quality products, etc.). Staniszewski (2018) explained that for older Member States, sustainable intensification mainly means increasing environmental agriculture productivity without diminishing economic productivity. In contrast, in new Member States the sustainable intensification is more focused on improving economic productivity but without depleting natural resources. Changes that were not in line with the sustainable intensification concept occurred in the Benelux countries and in the United Kingdom (UK), where environmental productivity improved, diminishing economic productivity (Moutinho et al. 2018). The above inconsistent findings justify the need for the holistic approach of ESV focused on a broad regional cross-section of European agriculture.

The growth of eco-efficiency in the industrial sector has mainly been driven by technological progress; it was restricted by poor management level, which implies that policy makers should focus on improving the latter (Zhu et al. 2019). High levels of economic development, population density, market openness and industrial structure have had positive effects on eco-efficiency, whereas energy intensity and expenditure on science and technology have had negative impacts (Zhu et al. 2019). There are some specific factors emphasized, like the availability of an environmental management system, environmental knowledge, organisational culture and environmental monitoring and control (Vasquez et al. 2019). The results show that most small and medium enterprises are unaware of the existing sustainability strategies and environmental practices. The above observation may be common for the agricultural sector.

Regarding the determinants of eco-efficiency, the farmers benefiting from agri-environmental programmes as well as those with university educations are more eco-efficient. Concerning the policy implications of these results, public expenditures in agricultural extension and farmer training could be of some help to promote integration between farming and the environment (Grovermann et al. 2019; Picazo-Tadeo et al. 2011). Pawłowska-Tyszko (2014) claimed that environmental payments bring positive effects in the social dimension because, as a basis of remuneration for green services, they also play a profit-making role. This is of particular importance in small, extensive holdings being the main beneficiaries of these programmes. However, Chabe-Ferret and Subervie (2012) note that as a result of support for agri-environmental activities, two effects emerged: additional—value added generated by the implementation of an obligation and windfall—extraordinary, unexpected income. Therefore, the eco-compensation mechanism as a type of public institutional arrangements that internalises the economic externalities of ecological protection is one of the important ways to protect farmland ecosystems (Liu et al. 2014).

Research by Wrzaszcz and Prandecki (2015) showed that selected farm groups conducting pro-environmental activity were different in terms of production potential (expressed as volume of engaged factors of production including land, labour and capital). This means that one of the factors that can influence the level of eco-efficiency is farmers' participation in environmental schemes. The EKLIPSE Expert Working Group reported that farmers tended to adopt measures that required the least management change and that were most aligned to agricultural production—these were usually the measures with the least benefits for biodiversity (Brown et al. 2019). The agricultural producers highlighted the advantages of having multiple alternatives due to the changing market conditions—they were more predisposed to selecting the easiest one to implement (Angulo-Meza et al. 2019).

A group of scientists from The Netherlands suggested three major intervention routes to decrease resource demand and the adverse environmental and health impacts of the agri-food system: (1) increasing efficiency of agricultural production, (2) decreasing food waste and (3) adopting less resource-intensive and healthier diets (van Grinsven et al. 2019). The authors suggested implementing this joint approach for the whole EU, where environmental pressure must decrease in old Member States and gross value-added (GVA) in agriculture has to increase in the new Member States, all the while securing that total production satisfies the current and future demand for food, fibres, fuels, etc. in the EU. Czyżewski et al. 2019a made a similar deduction to the above sequence of the agricultural development of European farms: productivity => eco-efficiency => eco-

effectiveness => lowering absolute pressure on the environment. In this case, every country would have to implement different measures in order to improve eco-efficiency according to country specifics and specialisation in agriculture.

In summary, the most important potential factors affecting eco-efficiency in agriculture are (1) the capacity of the farm manager (education and knowledge, participation in trainings), (2) the level of government support and participation in environmental support schemes, (3) the extent of inputs and labour force and (4) the level of marketisation.

Material and methods

This research uses EU FADN data (FADN 2020) at the regional level for 25 EU member countries, excluding Cyprus and Malta, as they were outliers. The time range of the research is 2004–2017. The overall idea of the analysis is illustrated in Fig. 1.

In the first step, the ESV was calculated for the aforementioned scope as an alternative to the DMU scores obtained through the non-parametric frontier approach. An outcome of the latter may be biased due to the possible violation of normal distribution assumptions. A common two-stage approach can be found in the literature (e.g. Stanton 2002; Sexton et al. 1994; Chirkos and Sears 1994), in which censored (tobit-like) regression is used to determine the relationship between efficiency and explanatory variables. However, Simar and Wilson (2007) criticised this approach for ignoring that estimated DEA efficiency scores are calculated from a common sample of data. Due to serial correlation, treating them as if they are independent observations is not appropriate. Therefore, they proposed a two-stage estimation procedure that implies a truncated model and considers that the substantial share of fully efficient DMUs found in DEA is an artefact of the finite sample bias inherent in DEA but does not represent a feature of the true underlying data-generating process. Thus, they developed a parametric bootstrap procedure that is potentially less biased (Badunenko and Tauchmann 2018). In practice, however, this approach encounters a number of technical problems, such as negative DMU scores. It is also sensitive to excessive data variance and outlier observations. The ESV method originates from the value-oriented approach to sustainability. According to Liesen et al. (2009) and Burja and Burja (2016), SV is calculated in five steps: (1) defining resource efficiencies, (2) determining benchmark resource efficiencies, (3) calculating opportunity costs, (4) determining value contributions and (5) computing ESV. The indicators of the environmental pressure engaged in the present study follow the variables selection in Grzelak et al. (2019): stock density per ha, mineral fertilisers use, plant protection products, total use of energy and utilised agriculture area (UAA) minus

woodland area. As per the above-cited authors, this study uses a distance function to identify a benchmark unit for ESV (Grzelak et al. 2019):

$$ESV_i = \frac{1}{m} \sum_{j=1}^m r_{ij} \left(\frac{y_i}{r_{ij}} - \frac{yb_i}{rb_{ij}} \right) \quad (1)$$

where ESV is the sustainable value afferent to a region-representative farm i expressed in EUR; r_{ij} and rb_{ij} represent the input of polluting capital of type j and region-representative farm i and of the farm considered as the benchmark system identified in the input-oriented DEA analysis as an average of the inputs in farms located on the frontier, respectively; y_i and yb_i are the agricultural output of the analysed and benchmark farms; $j = 1 \dots m$ is the number of polluting inputs.

ESV can have both positive and negative values in monetary terms. If the ESV has a minus sign, it indicates a value of ‘clean production’, (obtained without the additional input of polluting capital) which a farm ought to provide in order to achieve the benchmark eco-efficiency level. If the ESV has a plus sign, it indicates clean production exceeding the average eco-efficiency of farms on the frontier (Grzelak et al. 2019). To account for the size effects and to visualise ESV for farms from various regions, the output to cost (OTC) ratio indicator was calculated: $OTC_i = \frac{y_i}{y_i - ESV_i}$. An OTC score exceeding one can be seen as a share of the output generated without polluting inputs.

In the second step we estimated a regression model. Here, the ESV (in real prices 2004 = 100, weighed by an exchange rate multiplier) stands for the dependent variable, CAP subsidies are the explanatory variables and factor endowments are the control variables. For the reason the study focuses on the effect of investment subsidies, we inserted different types of CAP subsidies and factor endowments into the model step-by-step to test whether the effect of the investment subsidies was robust regardless modifications in specification. The explanatory variables set includes (EUFADN database codes in brackets):

- Subsidies on investments (Inv; SE406);
- Decoupled payments (Dec; single area or farm payment SE630);
- Production payments (Prod) including: total subsidies on crops (SE610), other crops subsidies (SE613), total subsidies on livestock (SE615), subsidies dairying (SE616), subsidies other cattle (SE617), subsidies on sheep and goats (SE618), other livestock subsidies (SE619), subsidies on intermediate consumption (SE625);
- Environmental subsidies (Env; SE621);
- Less Favoured Areas subsidies (LFA; SE622);
- Control variables: total fixed assets (SE441) excluding land value (SE446) per ha of utilized agricultural area, UAA (SE025), total fixed assets excluding land value per

Fig. 2 Environmental sustainable value as the agricultural output to polluting cost ratio in regions of the European Union in the years 2004, 2007, 2014 and 2017. Source: as per Table 1

labour input (SE011), new Member States (the dummy variable referring to old Member States).

The study then compared the investment subsidies effect against other significant policy measures and factor endowments.

The specification on the left side of the model refers to the commonly used CES production function in agriculture (Dudu and Kristkova 2017); however, this study estimates the effect of policy and factors on ESV as the dependent variable which is a new approach. To be concise, in modelling, the study concentrates on two accomplished programming periods of CAP: 2004–2006 and 2007–2013 + 2 years, assuming that farmers were completing the investment and the agri-environmental agreements signed beforehand in the years 2014–2015. Such contracts are usually signed for 5 years.

Most panel data methods do not allow researchers to separately model the consequences of changes to the phenomenon over time or the effects of its heterogeneity in space. To account for this, the study used an approach called ‘the seminal within–between specification’, which Bell and Jones (2015) recently advocated for. The seminal within–between model makes it possible to solve the endogeneity problems found in random effect (RE) modelling. According to Wooldridge (2012), the RE model is consistent only if the within and between variances are equal. Otherwise, the estimation is biased because the unaccounted variance will be absorbed by the unit-specific error and will be correlated with the independent variables, violating the assumptions of the RE model. This type of endogeneity problem, inevitable in the present type of research, may be solved using the within–between approach (Asane-Otoo 2016; Tezcur 2016). Moreover, as standard errors in the estimation may be biased by heteroscedasticity and autocorrelation issues, the robust standard errors proposed by Arellano (2003) are used. The presence of autocorrelation was also tested for using the Born and Breitung test; autocorrelation was not present.

This specification written in the following general form was employed:

$$y_{c,t} = \alpha + \beta(x_{c,t} - \bar{x}_c) + \gamma\bar{x}_c + (\varepsilon_c + e_{c,t}) \quad (2)$$

where α is a constant term, $x_{c,t}$ is a set of time-variant variables and $\bar{x}_c$ consists of $x_{c,t}$ means calculated for each region-representative farm (which by definition are time-invariant). The error term presented in brackets consists of two parts: (1) a time-invariant element ε_c that reflects the unobserved

heterogeneity of units and (2) an idiosyncratic disturbance $e_{c,t}$ for each observation. The parameter β reflects the within effect, while γ captures the between effect; this can be interpreted as the impact of a unitary difference in $x_{c,t}$ among the region-representative farms on the dependent variable.

Results

The results of the OTC are presented in the form of maps for the years 2004, 2007, 2014 and 2017 (Fig. 2) and as descriptive statistics (means) in Table 1. The descriptive statistics and other technical issues for the explanatory variables are shown in Tables 2 and 3.

In the examined period (2004–2017), a moderate OTC upward trend was noted. This may indicate an improvement in the eco-efficiency of farms at the regional level. Thus, farms more efficiently used the environmental inputs. It can be concluded from the data (Table 1) that there are still significant reserves of OTC improvement, indicating the possibility of achieving higher production with the given environmental inputs. However, the processes of transforming inputs into production effects is heterogeneous, caused not only by significant differences in the scale of production resource use between regions but also resulting from their effectiveness as a consequence of the development of economic infrastructure, horizontal and vertical integration processes or the scope of implemented innovations. The relatively best situation can be seen in Western Europe, especially in the regions of The Netherlands, Belgium, Denmark, and northern France. The most difficult situation with regard to OTC takes place in the agriculture of the newly accessed countries (i.e. in regions in Central and Eastern Europe as well as in Greece, where the eco-efficiency scores are the lowest, c.f. Table 1). Meanwhile, the CAP support has remained stable, although one may notice slightly increasing trends for the investment subsidies, decoupled subsidies, and the payments for public goods (i.e. environmental and LFA subsidies), while the production support has been decreasing (Table 2).

The estimated within–between panel model (Table 4) is characterised by stability. This means that entering subsequent control variables has not significantly changed the signs of the regression coefficients. In addition, the regression coefficient values have fluctuated very little. Thus, the effects of various subsidies on ESV is robust to changes in time as well as to the addition of subsequent variables. The overall fit of the model amounts to $R^2 = 0.70$. The variables related to investment subsidies (with_inw), production (with_prod), LFA (betw_LFA) and environmental payments (betw_env) are statistically significant and robust throughout the estimation procedure. At the same time, the variance inflation factors (VIF) for the studied variables are

Table 1 Descriptive statistics: the environmental sustainable value according to average OTC ratios for the years 2004–2017 based on the EU FADN region-representative farms means

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2004–2017
Netherlands	1.390	1.371	1.407	1.322	1.283	1.276	1.337	1.329	1.353	1.381	1.552	1.554	1.545	1.578	1.405
Denmark	1.259	1.272	1.391	1.385	1.355	1.327	1.412	1.436	1.433	1.458	1.325	1.297	1.248	1.320	1.351
Belgium	1.193	1.191	1.254	1.233	1.115	1.171	1.210	1.186	1.185	1.189	1.232	1.248	1.206	1.211	1.202
France	1.078	1.063	1.111	1.090	1.018	1.026	1.099	1.097	1.081	1.064	1.099	1.123	1.033	1.083	1.076
Italy	1.047	1.055	1.176	1.182	1.041	1.074	0.978	0.960	0.952	0.959	1.123	1.131	1.102	1.022	1.057
Austria	1.025	1.000	1.052	1.081	1.038	0.989	0.997	1.059	1.045	1.059	1.065	1.113	1.109	1.145	1.055
Luxembourg	1.035	1.016	1.254	1.069	1.052	1.019	1.000	1.012	0.972	1.035	1.073	1.069	1.016	1.093	1.051
Germany	0.973	0.976	1.016	1.001	0.969	0.995	0.994	0.992	1.033	1.059	1.041	1.034	1.012	1.036	1.010
Sweden	0.924	0.935	0.967	0.948	0.931	0.884	0.923	0.997	1.030	1.051	1.078	1.040	1.026	1.050	0.985
UK	0.920	0.937	0.965	0.966	0.943	0.977	0.993	1.003	0.941	0.976	1.014	1.016	0.989	1.033	0.977
Spain	0.959	0.886	1.013	0.973	0.914	0.857	0.804	0.784	0.742	0.763	0.799	0.945	0.936	0.902	0.877
Czechia	0.953	0.935	0.913	0.897	0.856	0.807	0.811	0.867	0.837	0.863	0.880	0.441	0.836	0.870	0.840
Finland	0.790	0.780	0.837	0.846	0.792	0.783	0.809	0.819	0.856	0.878	0.925	0.896	0.855	0.846	0.837
Ireland	0.702	0.695	0.763	0.769	0.762	0.684	0.741	0.796	0.778	0.825	0.879	0.918	0.893	0.917	0.794
Slovenia	0.659	0.667	0.741	0.925	0.819	0.787	0.800	0.809	0.724	0.701	0.809	0.920	0.869	0.796	0.788
Estonia	0.723	0.786	0.774	0.804	0.729	0.728	0.708	0.740	0.731	0.745	0.760	0.781	0.707	0.805	0.752
Portugal	0.762	0.738	0.845	0.758	0.730	0.728	0.688	0.634	0.646	0.652	0.748	0.800	0.845	0.806	0.741
Slovakia	0.728	0.729	0.726	0.796	0.750	0.660	0.679	0.779	0.676	0.715	0.780	0.754	0.778	0.785	0.738
Latvia	0.700	0.746	0.755	0.744	0.727	0.656	0.613	0.645	0.685	0.694	0.701	0.737	0.698	0.751	0.704
Hungary	0.700	0.706	0.657	0.722	0.711	0.618	0.636	0.749	0.728	0.686	0.718	0.720	0.727	0.733	0.701
Lithuania	0.569	0.581	0.609	0.742	0.687	0.616	0.644	0.684	0.673	0.664	0.658	0.703	0.614	0.688	0.652
Poland	0.507	0.586	0.670	0.692	0.612	0.552	0.610	0.649	0.621	0.625	0.695	0.738	0.665	0.637	0.633
Bulgaria				0.526	0.513	0.567	0.638	0.640	0.654	0.625	0.656	0.687	0.635	0.711	0.623
Greece	0.239	0.331	0.425	0.343	0.300	0.376	0.391	0.558	0.537	0.556	0.714	0.773	0.707	0.624	0.491
Romania				0.518	0.436	0.375	0.464	0.441	0.382	0.381	0.561	0.519	0.561	0.512	0.468
EU 25 Mean	0.862	0.869	0.927	0.893	0.843	0.821	0.839	0.867	0.852	0.864	0.915	0.918	0.905	0.918	0.878

Illustrative interpretation: 1.39 means that 39% of the agricultural output was obtained without polluting inputs referring to the frontier (benchmark); 0.93 means that agricultural output requires an input-less increase by 7% referring to the frontier unit

Source: Own calculations based on the FADN data, which can be found at <https://europa.eu.int/comm/agriculture/rica/dwh>

below five, demonstrating the lack of extensive collinearity between the explanatory variables.

Special attention should be paid to the positive, stable impact of investment subsidies (with_inv) on ESV regardless of what kind of other variables were added to the model. Thus, this model primarily demonstrates the stable, positive relationship of ESV and investment subsidies which confirms the first hypothesis (H1). An increase in the value of these subsidies by 1 Euro in relation to the average from 2004–2015 for a given region resulted in an increase in the value of ESV by about 2.1 Euro in the ceteris paribus condition. This might be due to investments often serving environmental protection, for example, to meet cross-compliance requirements. Moreover, the new generation of machines and other means of production are getting less and less energy-consuming, which contributes to the eco-efficient transformation of investments into the value of production. The share of this group of subsidies in total subsidies was

relatively low (accounting for 3.8% of the total subsidies in the regions under study), that indicates significant possibilities of using this scheme to increase farms' eco-efficiency.

A positive impact on ESV formation was also noted for the cross-sectional variable bet_env that partially confirms the second hypothesis (H2) from the introduction. This phenomenon is not obvious, as obtaining environmental subsidies means meeting many requirements, which may hinder the transformation of environmental outlays on production effects. A higher average value of these subsidies results in a higher ESV value of 2.8 Euro per 1 Euro of the Env.

Other subsidies had a negative or insignificant impact. Negative values of regression coefficients were observed for subsidies to agricultural production (with_Prod) and for the decoupled payments (with_Dec) as it was hypothesised (H3 and H4), but also for LFA payments (bet_LFA). The latter finding partially denies the second hypothesis (H2). An increase in the average size of LFA subsidies by 1 Euro

Table 2 Descriptive statistics—the explanatory variables corrected with exchange rate multiplier for the years 2004–2017 (EU FADN region-representative farms means in € yearly)

Year	Inv	Dec	Prod	LFA	Env	Asset_UAA	Asset_labour
2004	630	523	23705	1675	1932	3114	32
2005	737	9955	12192	1831	2238	3137	34
2006	946	15576	6581	1883	2296	3142	35
2007	921	16315	6237	1945	2377	3044	31
2008	1071	16864	6733	1978	2457	3449	35
2009	1248	17003	6978	2016	2503	3430	38
2010	1155	17869	5657	2068	2726	3462	37
2011	1213	18261	5573	2080	2865	3548	39
2012	1135	18705	5130	2050	2975	3561	40
2013	1140	18500	5024	2066	3054	3511	41
2014	1122	18585	4848	1818	2925	3236	41
2015	1185	17633	6154	2101	2778	3172	42
2016	764	17415	5687	2408	2525	2856	39
2017	954	17829	6155	2483	2821	2844	38
Mean	1016	15788	7618	2029	2605	3251	37
Yearly av. Change* (2005–2017)	1.02	1.05	0.94	1.03	1.02	0.99	1.01

*Yearly average change was calculated according to geometric means. Trends should be analysed since 2005, as the CAP decoupled payments were not fully implemented in 2004

Source: as for Table 1

translates into a lower ESV by as much as 3.9 Euro. In practice, farms that receive LFA subsidies achieve production and economic results usually below the average. Further, LFA payments cannot compensate for the poorer farming conditions, especially in mountainous areas (Góral 2016).

Among the control variables, labour equipment with capital had a statistically significant positive effect on ESV both in terms of cross-sectional (between) and temporal (within) effects. This confirms previous observations related to the investment subsidies in Flemish dairy farms by Van Passel (2009), who pointed out that reducing labour intensity may improve eco-efficiency. In turn, the production intensity expressed by the time variant variable (with_AssetperUAA), as shown by the present model, had a negative impact, while the capital-labour ratio (with_Assetperlabor) is positive. This means that increasing the value of capital variously affects eco-efficiency depending on its relationship with other production factors like labour or land. From the perspective of the present model, the most favourable situation is when there is an increase in the technical labour equipment combined with an increase in the area of land. To conclude, the hypotheses stated in the introduction were answered as follows:

H1. It was confirmed that the investment subsidies and the capital-intensive development of farms increase the eco-efficiency.

H2. It was confirmed that the environmental subsidies increase the eco-efficiency but, on the other hand, it turned out that LFA payments have the reverse effect.

H3. There are premises to confirm that the decoupled subsidies decrease the eco-efficiency but this effect was unstable to some extent. The labour-intensive development of farms appeared to be unfavourable for the eco-efficiency, as it was proved that the higher asset to labour ratio fosters it.

H4. It was proved that the production support reduces the eco-efficiency.

Discussion

These results are to some extent in the line with other studies of eco-efficiency. There is evidence that farms' participation in agri-environmental schemes affects their sustainable and pro-ecological orientation (Bonfiglio et al. 2017). The presented model confirms that these subsidies are important in shaping eco-efficiency. This is also confirmed by the results of other studies. For example, Picazo-Tadeo's et al. (2011) show positive effect of agri-environmental schemes on eco-efficiency of arable farms. Gadanakis et al. (2015) and Czyżewski et al (2020) also emphasise that farmers' use of agri-environmental programmes can improve eco-efficiency. This is because environmental pressure is reduced

Table 3 Descriptive statistics—explanatory variables corrected with exchange rate multiplier in the EU countries cross-section (EU FADN region-representative farms means in € yearly)

Country	Regions N x t	Inv	Dec	Prod	LFA	Env	Assest per UAA	Assets per labor
Austria	14	1290	6797	3292	2730	5920	7913	72
Belgium	28	2194	16280	11348	538	2000	5648	55
Bulgaria	84	387	4434	1609	193	767	1043	8
Czech Republic	14	3412	34058	18366	6951	9780	1793	29
Denmark	14	406	31182	4946	38	1451	6932	196
Estonia	14	3314	10773	3459	1041	6357	1066	28
Finland	56	967	9910	34019	13914	9561	3315	64
France	308	1511	18788	12436	2081	1353	2069	58
Germany	182	1181	57370	10977	2368	6627	2517	46
Greece	56	52	4496	2830	486	306	3795	13
Hungary	38	814	9176	5290	40	2371	1277	19
Ireland	14	1065	12591	1858	2054	2615	2221	42
Italy	294	330	4654	1978	676	903	5527	26
Latvia	14	1908	4214	6314	1938	1779	868	14
Lithuania	14	2547	4599	2335	1099	304	1120	13
Luxembourg	14	15862	22328	2966	10961	10902	5857	122
Netherlands	14	616	13768	4312	15	2037	13075	79
Poland	56	232	3477	955	473	467	3061	15
Portugal	54	769	2755	5990	1025	1015	1894	11
Romania	111	120	1004	783	20	27	2434	8
Slovakia	14	10358	77942	38792	29562	16065	1333	25
Slovenia	14	1315	2570	2066	1236	1604	8281	31
Spain	238	382	5705	7293	446	549	3494	22
Sweden	42	117	21674	14767	7204	10788	2965	87
United Kingdom	84	1212	33016	5029	2499	6034	1554	46

Source: as for Table 1

due to higher standards in terms of environmental and animal welfare, including using lower and more diverse types of inputs (Bonfiglio et al. 2017). The issue of innovation and its impact on eco-efficiency raised by many authors (van Grinsven et al. 2019; Grovermann et al. 2019; Beltrán-Esteva and Picazo-Tadeo 2017) may also be relevant here. The point is that the use of agri-environmental programmes is likely to stimulate eco-innovation, which has a positive impact on eco-efficiency.

On the other hand, the impact of decoupled and production payments has proved to be negative. This may partly result from the fact that under the Single Payment Scheme (SPS) which is in force in EU15 (and in Slovenia) a structure of agricultural land remains quite constant that consequently promotes investment in other assets than land (Guyomard et al. 2004). Hence, this type of support may stimulate the demand for environmental input to a greater extent than increasing production, and, thus, has a negative impact on eco-efficiency. It is also worth noting that land in general is conducive to eco-efficiency as a larger utilised agricultural area facilitates the implementation of environmentally

friendly investments (through i.a. a ploughless cultivation system, use of precision fertilization etc.). However, some contradictory findings prove that direct payments can also be positively related to environmentally friendly production (Kleinhanß et al. 2007). It should be pointed out that there is a lack of research regarding the direct impact of investment subsidies on ESV or on the ecological effectiveness of farms. A such approach is, however, extremely important due to the upcoming challenges for agriculture with regard to increasing productivity of agricultural land in the line with growing demand for food and fibre (Keating 2010).

Burja and Burja (2016) examined Romanian farms, finding that environmental subsidies contribute to creating sustainable value as the environmental subsidies compensated for the additional costs incurred by agricultural producers to meet higher environmental standards for agricultural production. Therefore, the improvement of eco-efficiency is due more to the practices and techniques in connection with agri-environmental programmes than to the additional financial support itself (Picazo-Tadeo et al. 2011). Doubts have been raised regarding the balance of the costs and benefits of

Table 4 The effect of Common Agricultural Policy subsidies on environmental sustainable value ESV with regard to factor endowments (the results of within-between panel modelling)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	ROBUST(9)
Const	– 5078 (3981)	– 1480 (4278)	4796 (4501)	2939 (4620)	1425 (4592)	7105 (5509)	– 1.018e+04* (5260)	– 1724 (6408)	– 1724 (1.436e+04)
BetwInv	– 3.098* (1.800)	– 1.737 (1.887)	– 0.6746 (1.837)	1.581 (2.262)	1.676 (2.226)	2.016 (2.213)	0.1931 (1.895)	0.5703 (1.878)	0.5703 (1.662)
WithInv	1.893** (0.6741)	1.582** (0.6854)	2.264** (0.6841)	2.269** (0.6839)	1.980** (0.7177)	2.199** (0.7176)	2.060** (0.7118)	2.059** (0.7115)	2.059** (0.7783)
BetwDec		– 0.3245** (0.1530)	– 0.08174 (0.1642)	– 0.1377 (0.1671)	– 0.4816** (0.2214)	– 0.5754** (0.2257)	– 0.5922** (0.1916)	– 0.6253** (0.1897)	– 0.6253 (0.4525)
WithDec		0.1800** (0.07517)	– 0.7537** (0.1629)	– 0.7260** (0.1662)	– 0.7390** (0.1665)	– 0.7072** (0.1656)	– 0.6751** (0.1642)	– 0.6722** (0.1642)	– 0.6722 (0.4351)
BetwProd			– 1.396** (0.4228)	– 0.7666 (0.5614)	– 0.5825 (0.5580)	– 0.3702 (0.5680)	– 1.088** (0.4923)	– 1.213** (0.4891)	– 1.213 (1.116)
WithProd			– 0.9399** (0.1460)	– 0.9112** (0.1501)	– 0.9195** (0.1501)	– 0.8972** (0.1494)	– 0.7962** (0.1495)	– 0.7936** (0.1495)	– 0.7936** (0.3984)
BetwLFA				– 2.350* (1.383)	– 4.697** (1.696)	– 5.213** (1.707)	– 4.130** (1.457)	– 3.942** (1.440)	– 3.942** (1.999)
WithLFA				– 0.6269 (0.7666)	– 0.8860 (0.7910)	– 0.9167 (0.7859)	– 1.216 (0.7814)	– 1.218 (0.7811)	– 1.218 (1.288)
BetwEnv					3.808** (1.643)	4.000** (1.631)	2.687* (1.396)	2.828** (1.380)	2.828** (1.110)
WithEnv					0.7677 (0.5810)	0.7238 (0.5775)	0.2719 (0.5805)	0.2748 (0.5803)	0.2748 (0.5951)
BetwAssetpe- rUAA						– 1.681* (0.9764)	– 2.453** (0.8357)	– 2.714** (0.8330)	– 2.714 (2.730)
WithAssetpe- rUAA						– 3.693** (0.7410)	– 5.953** (0.8790)	– 5.953** (0.8787)	– 5.953** (2.267)
BetwAssetperla- bour							794.6** (110.3)	693.6** (117.8)	693.6** (182.4)
WithAssetperla- bour							457.7** (97.87)	457.7** (97.83)	457.7** (176.7)
NewMS2_2							– 1.742e+04**	– 1.742e+04**	– 1.742e+04**

Table 4 continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	ROBUST(9)
N	1492	1492	1492	1492	1492	1485	1485	(7743)	(8168)
lnL	- 1.82e+004	- 1.818e+004	- 1.813e+004	- 1.812e+004	- 1.81e+004	- 1.8e+004	- 1.783e+004	- 1.781e+004	- 1.781e+004

Inv subsidies on investments, *Dec* decoupled payments (single area or farm payment), *Prod* production payments (total subsidies on crops, other crops subsidies, total subsidies on livestock, subsidies dairying, subsidies other cattle, subsidies on sheep and goats, other livestock subsidies, subsidies on intermediate consumption), *LFA* less favoured areas subsidies, *Env* environmental subsidies, *AssetperUAA* total fixed assets excluding land value per ha utilised agricultural area, *Assetperlabour* total fixed assets excluding land value per labour input, Standard errors in parentheses

*Indicates significance at the 10 percent level

**Indicates significance at the 5 percent level

***Indicates significance at the 1 percent level

Source: Own calculations based on EU FADN and Eurostat data, presented at the XXVI PAAAE Congress (Czyżewski et al 2019a)

these programmes. There is primarily concern about farmers' high levels of ecological inefficiency, voluntariness, relatively low universality and increases in the conditionality of receiving CAP payments (Picazo-Tadeo et al. 2011).

In the case of LFA payments, as already indicated (Table 4), the impact is negative and statistically significant. This could result from the fact that in the areas where these payments are granted, farms achieve relatively low productivity, which is not fully compensated by the support. Negative impact of these subsidies is also confirmed by other studies: Ehrmann (2008) researched dairy farms in Germany, pointing out that increasing the share of LFA in the area of land used has a negative impact on sustainable value. This is consistent with the our results, although it referred here strictly to the environmental dimension of SV. However, it should not be forgotten that LFA subsidies support the vitality of rural areas, although it is debatable to what extent (Klepcka-Kołodziejska 2010).

This research also indirectly indicates that farms at the EU regional level are not overinvested. We recall that according to our model (Table 4), investment subsidies have the statistically significant effect on the eco-efficiency. However, this phenomenon might be more complex. Rizov et al. (2013) note that subsidies incentivise changes of the capital-labour ratio, leading to overinvestment. Lakner (2009) also reports that investment programmes have negative effects on the technical efficiency of organic dairy farms in Germany. Interesting observations are reported by Cíanan and Swinnen's (2009) and Hüttel et al.'s (2010): subsidies may function as a substitute for missing credit, stimulating capital investments and leading to a positive relationship between productivity and subsidy level.

As the present research shows that investment subsidies stimulate eco-efficiency, they allow a more efficient allocation of resources while integrating both economic and environmental dimensions. The improvement in eco-efficiency with an increase in investment subsidies is also linked to the fact that the agricultural materials industry is increasingly driven by pro-environmental requirements, including the reduction of energy consumption for its products (e.g. agricultural machines, harvesters). Thus, investment subsidies have tended to favour certain types of assets like plants and equipment (Gravelle 2010). Therefore, extending the objectives for using investment subsidies in CAP schemes (e.g. related to the thermo-modernisation of buildings) can further increase eco-efficiency of agricultural holdings.

Currently, the new generation of machines, their technologies (based on GPS) and other means of production are characterised by decreasing energy consumption, which favours the effective transformation of environmental expenditure into production value (Rodias et al. 2017). This may partly explain why in our model (Table 4) the impact of investment subsidies on the eco-efficiency is positive

including the effect of lowering greenhouse gas emissions (GHG) (Gómez-Calvet et al. 2016). As Beltrán-Estève et al. (2019) note, subsidising the use of green practices is required to boost attempts to catch up with environmental technologies in European agriculture. This could be done by promoting the use of environmentally friendlier vehicles or implementing recycling and recovery practices. Hence, there is a growing need to create new CAP incentives in the form of targeted subsidies for particular environmental investments.

In turn, the negative impact of the capital per UAA and, at the same time, the positive capital to labour ratio, as shown in our model (Table 4), means that increasing the value of capital variously affects eco-efficiency depending on the mutual relationship between the production factors that is affected by agricultural land market as well as by subsidies distribution system. These complex relationships result from trends of agricultural development, i.e. increasing capital intensity, land concentration and decreasing labour intensity (Grzelak et al. 2019). According to our model, among all the CAP measures, the subsidies for investments (with-Inv) have the strongest positive impact on the eco-efficiency. Thus, maintaining subsidies for investments in the next CAP perspective seems to be justified. Meanwhile, greater focus on green technologies may trigger multiplier effects in terms of environmental impact. Especially, the investment related to renewable energy should be supported (Moutinho et al. 2017), bearing in mind that market mechanism appears to be erroneous in providing by itself a such type of investment (European Commission 2014).

The results of our study may also indicate that there are significant reserves for the improvement of eco-efficiency, especially in regions in Central and Eastern Europe as well as in Greece (Table 1, Fig. 2). Other authors confirm that there occur new opportunities in the field of implementation of new technologies and eco-innovations (Beltrán-Estève and Picazo-Tadeo 2017).

The presented considerations with regard to our results bring clear implications for policy makers. Increasing the eco-efficiency of agricultural holdings may be achieved by a twin-track policy: (1) by increasing incentives for agricultural producers to participate in agri-environmental programmes (Bonfiglio et al. 2017) and (2) by maintaining investment support, especially in new Member States. The first track seems to be more effective when combined with payments for young farmers (Matthews 2013), which is already the case in the CAP instruments proposed for 2014–2020. In turn, investing in innovative and environmentally friendly technologies should contribute to reducing environmental pressure and increasing eco-efficiency (Garnett and Godfray 2012). In addition, support for advisory programmes would increase farmers' pro-environmental awareness and knowledge about production techniques that

limit environmental pressure (González and Cárcaba 2004; Ingram 2008).

Conclusions

The research carried out confirmed the hypotheses formulated at the beginning except the one which assumed the positive impact of LFA on ESV. Thus, the CAP and, more specifically, its instruments have a different impact on the ESV, depending on the type of support. Our study demonstrates that higher investment support and the cross-sectional impact of environmental subsidies are beneficial and statistically significant for ESV, whereas other payments have the negative effect. Environmental subsidies had the highest positive impact (for the 'betwEnv' variable the coefficient equals 2.8), while the largest negative impact was observed for the LFA payments (for the cross-sectional variable 'betwLFA' the coefficient equals -3.9). Positive impact of investment subsidies may be related to the fact that investments are increasingly environmentally friendly primarily by reducing energy consumption in agriculture. In turn, the negative impact of the LFA payments can be attributed to the low productivity of farms operating in a less favourable areas. It does not mean that this type of payments should be eliminated, as they play an important role in sustaining vitality of rural areas. When it comes to factor endowment influence, we proved the positive impact of the capital to labour ratio and negative impact of the capital to land ratio. The first one stimulates productivity, while the second one is related to the increasing pressure on natural resources. We have also noted an improvement in the eco-efficiency from the perspective of the OTC ratio. The most favourable situation was observed in the regions of the Netherlands, Belgium, Denmark and France. Least favourable situation was in Central and Eastern Europe, as well as in Greece. As we mentioned, there are significant reserves of improvements in the eco-efficiency.

In light of the above, this study recommends a two-track evolution of the CAP, which is not very popular in Western Europe, to maintain both strong pro-investment incentives and agri-environmental funds. The first type of subsidy should be particularly targeted at small- and medium-scale farms to increase their economic potential and accelerate the processes of capital concentration in agriculture, although paradoxically, this does not have to be at the expense of the environment. Both the currently dominant decoupled payments and the production support, which is gradually disappearing, are not effective solutions from the point of view of sustainable development. It remains an open question whether it would be worth additionally implementing instruments in the form of punishing producers for exceeding environmental standards (the 'polluter pays' principle)

(Picazo-Tadeo et al. 2012). Although reducing or removing CAP direct payments is out of the question for political reasons, some of the activities related to climate protection could be enhanced by linking the payment of those subsidies for example with meeting the requirements related to the use of pro-ecological sources of heat and fuel in farmers' households as well as in their farm infrastructure.

When it comes to future applications of the approach employed in the article, it makes a fruitful line for further research. The set of polluting inputs might be extended including such issues as GHG emissions, heavy metals contamination or soil erosion. On the other hand it is also possible to develop the output side by including for example different types of public goods beside the agricultural output, e.g. soil organic balance, permanent meadows or agricultural high nature value areas—AHNV (Sutkowska et al. 2013). The combination of the value-oriented approach with frontier benchmarking and the seminal within-between specification might be also applied for macro-level data to explore eco-efficiency in different sectors of national economy where interactions between time-varying and time-invariant variables are the case. There are however potential constraints related to this approach which concern evolution of the support schemes in the next CAP programming period which may reduce the comparability of data in long-term.

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