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Assessing the efficiency of diversified farms in Slovakia using DEA metafrontier approach

Hodnotenie efektívnosti diverzifikovaných fariem na Slovensku pomocou metahraničného prístupu DEA

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ABSTRACT

The agricultural sector in Slovakia is characterized by low productivity and diversification. There is a substantial prospect of increasing agricultural productivity using the existing level of inputs and limited resources more efficiently. This study employed the metafrontier approach, which is a variation of the Data Envelopment Analysis technique to assess the technical efficiency of diversified farms that operate under different technological frontiers. A panel sample of 215 Slovak farms performing other gainful activities from 2014 to 2019 was constructed based on the Farm Accountancy Data Network database. Diversified farms were divided into three groups according to the type of specialization on farms specializing in crop, animal and mixed production. Results show that there are significant differences between farms using different technologies, specializing in crop, animal, and mixed production. The average technical efficiency of diversified farms that focus on crop production (0.72) and mixed production (0.71) generally has a high and stable level when compared to farms with animal production (0.65). In addition, this empirical analysis shows that specialization in livestock production is the least suitable from the point of view of technical efficiency in the case of farms that perform other income-generating activities. Finally, average technological gap ratio values indicate that diversified farms in crop production can compete efficiently with other farms and, on average, produce 89% of their potential outputs with their inputs. The existence of a technological gap between farms concerns the technology of resource utilization, therefore it would be necessary to rationally change resource utilization and support the improvement of management and organizational systems by improving the level of management.

Keywords: technical efficiency, agricultural, other gainful activities, FADN, technological frontier

ABSTRAKT

Poľnohospodársky sektor na Slovensku sa vyznačuje nízkou produktivitou a diverzifikáciou. Existuje značná perspektíva zvýšenia poľnohospodárskej produktivity efektívnejším využitím existujúcej úrovne vstupov a obmedzených zdrojov. V tejto štúdii sa použil metahraničný prístup, ktorý je variáciou techniky analýzy dátových obalov na posúdenie technickej efektívnosti diverzifikovaných fariem, ktoré fungujú pod rôznymi technologickými hranicami. Na základe databázy Informačná sieť poľnohospodárskeho účtovníctva bol zostavený panel údajov 215 slovenských fariem vykonávajúcich iné zárobkové činnosti v rokoch 2014-2019. Diverzifikované farmy boli rozdelené do troch skupín podľa druhu špecializácie na farmy špecializujúce sa na rastlinnú, živočíšnu a zmiešanú výrobu. Výsledky ukazujú, že existujú významné rozdiely medzi farmami využívajúcimi rôzne technológie špecializované na rastlinnú, živočíšnu a zmiešanú výrobu. Priemerná technická efektívnosť diverzifikovaných fariem so zameraním na rastlinnú výrobu (0.72) a zmiešanú výrobu (0.71) má vo všeobecnosti vysokú a stabilnú úroveň v porovnaní s farmami so živočíšnou výrobou (0.65). Táto empirická analýza navyše ukazuje, že špecializácia na živočíšnu výrobu je z hľadiska technickej efektívnosti najmenej vhodná v prípade fariem, ktoré vykonávajú iné zárobkové činnosti. Napokon, priemerné hodnoty pomeru technologických rozdielov naznačujú, že diverzifikované farmy v rastlinnej výrobe môžu konkurovať v efektívnosti ostatným farmám a v priemere produkujú 89% svojich potenciálnych výstupov svojimi vstupmi. Existencia technologickej priepasti medzi farmami sa týka technológie využívania zdrojov, preto by bolo potrebné racionálne meniť využívanie zdrojov a podporovať zlepšovanie systémov riadenia a organizácie zlepšením úrovne riadenia.

Kľúčové slová: technická efektívnosť, poľnohospodárstvo, ostatné zárobkové činností, FADN, technologická hranica

INTRODUCTION

Until recently the EU agricultural sector has been experiencing drastic changes (Shahzad et al., 2021). In order to address the challenges posed by the agricultural productivist model, the European Common Agricultural Policy has supported farm diversification to promote rural development (Meraner et al., 2015). The FAO (2020) emphasizes the need for support for a broader range of diverse economic opportunities for rural groups, including on-farm and off-farm diversification activities. Therefore, better production means investing in agriculture for sustainable, inclusive and resilient food systems. With a possible decrease in direct payments, EU agricultural policy continues to support other gainful activities (OGAs) at farm levels. This has an impact on the share of off-farm income in the total income of farms. The FAO (2022) emphasizes not only the connecting of smallholder markets but also takes into account primary production in order to increase diversification at the farm level. Sustainable agricultural production to the achievement of the Sustainable Development Goals (SDGs) should facilitate the availability of and access to diverse and nutritious food, not only through large-scale, specialized agriculture but also through diversified small-scale production at regional, national and local levels.

The diversity of agricultural diversification can be defined as the creation of any gainful activity that does not directly involve any agricultural work but is linked to the holding. This includes tourism, accommodation and other leisure activities, crafts, processing of agricultural products, wood processing, aquaculture, production of renewable energy for the market and contract work using holding facilities, and so on. Farm diversification triggers extensive processes with reference to core activities of the business, due to external pressures to stay in business and improve economic performance (De Rosa et al., 2019; Meraner et al., 2015; Krakowiak-Bal, 2009).

Diversification reduces the risk of fluctuations in farm yields by mitigating price risk and production volatility, as it reduces dependence on the single market and exposes it to price fluctuations (Robison and Barry, 1987). Given the risk structure of the market, it could be argued that from a farm perspective, the decision to diversify is a risk management strategy. Diversification is always assessed at the farm level and applies to all types of farms (Augère-Granie, 2016). A majority of the farms in the EU are still small farms where sole holders look to supplement their household income (Shahzad et al., 2021). One way to secure a non-agricultural income is to set up farm-diversified activities. Most of the agricultural enterprises are large competitive farms, and small farmers and family farms, whereas sole proprietors try to supplement their household income, are oppressed.

Thus, the diversification of agricultural activities involves mainly small and medium-sized farms, which are unable to compete with major large-scale farms (Forleo et al., 2021; Lupi et al., 2017; Salvioni et al., 2013). The EU emphasizes the integration of rural development policy with an agricultural system made up of young farmers and small farms (Shahzad et al., 2021). Diversification activities represent essential income opportunities, especially for small and medium farms, which would be unable to compete with the biggest farms on large-scale production. Understanding the trends and effectiveness of diversified farms is key to increasing the effectiveness of policies to support farm diversification.

Within this context of diversified activities, this study deals with the efficiency of farms through data envelopment analysis. Effectively use of available resources is one of the ways to increase competitiveness. Higher efficiency allows the farm to perform strategic activities better, which will also lead to gaining a competitive advantage. Measuring efficiency and identifying the causes of inefficiency are key factors for achieving competitiveness. The efficiency measure can be estimated using non-parametric and parametric approaches. Data envelopment analysis (DEA) is a non-parametric method. A non-parametric approach to the functional capacity to increase efficiency and does not require a functional form for production relations, and is therefore considered to calculate efficiency (Ray, 2004).

Technical efficiency using DEA models of any farm refers to input-oriented such as minimum use of inputs to produce a given level of output or output-oriented such as to produce maximum amount of output from a given set of resources (Coelli, 1996). Efficiency using DEA models can be investigated from the perspective of an input or an output-based model. In agriculture, input-oriented DEA models are used by some authors, because in this sector is very important the selection process of inputs is and in the end, outputs depend upon inputs (Toma et al., 2015; Imran et al., 2019; Zhang et al., 2016). If farmers have more control over the production outputs, then output-oriented DEA models for efficiency analysis are appropriate (Forleo et al., 2021; Romagnoli et al., 2021; Horvat et al., 2019; Kočišova, 2015; Bayyurt and Yılmaz, 2012).

Most EU countries could better rationalize the use of inputs to achieve more outputs and thus achieve production efficiency. Therefore, when planning policy, assessing the implications of the instruments of the CAP, but also when making management decisions, attention must always be paid not only to maximizing agricultural production but also to the excessive use of environmental resources (Toma et al., 2017; Martinho et al., 2022).

To enhance the accuracy when comparing this study with other research, the metafrontier approach with an output-oriented DEA model is used to estimate the technical efficiency of diversified Slovak Farms. Considering the literature mentioned above, the aim is to analyse the efficiency in the agriculture of the Slovak diversified farms during the years 2014-2019 divided according to some farm characteristics and provide recommendations for increasing the efficiency of inefficient.

MATERIALS AND METHODS

The DEA method is widely used in research to analyse the performance of the agricultural sector with different inputs and outputs. This technique is based on linear programming, as proposed and developed by Charnes et al. (1978). However, in agriculture, the process of selecting inputs is very important because the outputs depend on this consumption of inputs. It is essential to select enterprises with similar characteristics concerning agricultural systems when using this method. It is assumed that it is not correct to apply DEA to areas that are different from the point of view of agricultural practice, from the point of view of technology, therefore this study is focused only on specific farms, performing other gainful activities. In this article, the term “efficiency” refers to technical efficiency, which occurs when output cannot be increased without increasing input. However, there is also economic efficiency, which depends mainly on the prices of production factors, and to achieve it, it is necessary to achieve technical efficiency. In DEA, the efficiency of decision-making units (DMUs) is defined as technical efficiency, which is further decomposed into pure technical efficiency and scale efficiency. The technical efficiency of Slovak farms was examined according to specialisation using an output-oriented model, which considers multiple outputs and inputs. To analyse efficiency, output-oriented models with the assumption of a variable return to scale were used. A data panel of Slovak farms was created and used it to define a common efficiency frontier for every year. Technical efficiency is defined as the ratio between the weighted sum of its outputs and the weighted sum of its inputs.

The metafrontier approach is a method used to analyse the efficiency of different production technologies across different various types of specialization in diversified farms. It involves comparing the performance of three types of farm specialization against its own production frontier and then comparing these frontiers to a common metafrontier. The metafrontier represents the best possible production technology that could be achieved by farm specializations given the available resources and technology. This approach allows for a more accurate comparison of efficiency across diversified farms, as it takes into account differences in production technology and resources. Technical efficiency was quantified under the group frontiers (TEgroup) and metafrontier (TEmeta). By performing separate DEA efficiency analyses, the curves in Figure 1 are obtained, which lie below the metafrontier and represent technology-specific best practice frontiers. The entire metafrontier is obtained from all data, regardless of the technology used, and the DEA efficiency analysis is repeated.

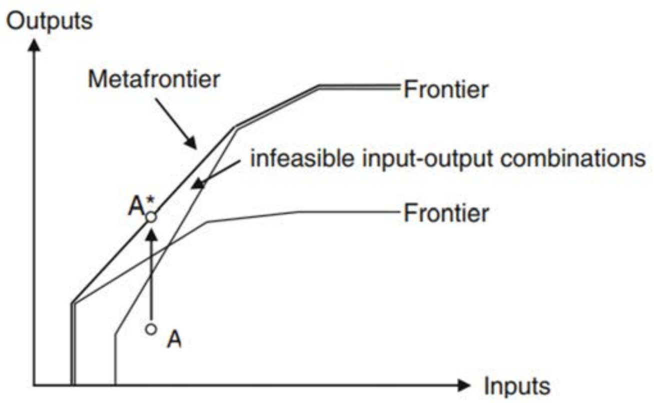


Figure 1. Concave metafrontier (Tiedemann et al., 2019)

Technical efficiency can be expressed using a dual linear programming model proposed by Charnes et al., (1978). This version of the CCR model aims to maximize outputs without requiring more of any of the observed input values. Technical efficiency reflects the ability of farms to obtain the maximum output from the given set of inputs. This is called the output-oriented model and is expressed as follows:

$$\begin{aligned} &\text{Max } \phi \\ &\text{s. t.} \\ &\textstyle\sum_{j=1}^{n} \lambda_j x_{ij} \geq x_{ij0}, \text{ i} = 1\ldots\text{m} \\ &\textstyle\sum_{j=1}^{n} \lambda_j y_{rj} \geq \phi y_{rj0}, \text{ r}=1\ldots\text{s} \\ &\textstyle\sum_{j=1}^{n} \lambda_j \geq 0, j = 1, \ldots n \end{aligned} \qquad (1)$$

where ϕ is the technical efficiency of j^{th} DMU. Each DMU has *m* inputs and produces *s* outputs. The variables *v* and *u* represent input and output weights, while *r* and *i* are the numbers of inputs and outputs. Equation (1) is known as the CCR DEA model, which assumes constant returns to scale (CRS). The technical efficiency for each group (TE_{group}) is lower than the technical efficiency with respect to the metatechnology (TE_{meta}), since the constraints of the problems of the different groups are subsets of the constraints of the metafrontier problem. The concept of the technological gap ratio (TGR) was used to predict the maximum output that is feasible by each farm given the input vector. Inequality between the group-k distance function and the distance function to the topic frontier was obtained as a measure of the proximity of the group frontier to the metafrontier, referred to as TGR (Battese et al., 2004) as:

$$TGR = TE_{meta} / TE_{group} \qquad (2)$$

An increase in TGR implies a narrowing of the gap between the group frontier and the metafrontier. Data used to measure technical efficiency were obtained from the Slovak section of the European Union's Farm Accountancy Data Network (FADN), which is collected annually. The Agricultural Accountancy Data Network (FADN) is the main information source on the real economic situation of agricultural enterprises in all the EU member countries. An important requirement of sampling surveys is just securing sample representativeness. In Slovakia, data collection from 562 selected agricultural enterprises takes place once a year (MARD SR, 2023). Our panel data sample comprised roughly half of the collected FADN data. The FADN database of Slovak farms does not represent the entire set of surveyed farms in a given area because only larger farms above ESU 6 are included in the FADN sample. Although FADN data is representative, it excludes very small farms, similar to agricultural censuses and other national statistics (Guiomar et al., 2018). The number and type of farms considered vary by region, technical and economic focus, and economic size categories.

Slovak agriculture has shown a significant preference for crop production, accounting for 65% of gross agricultural output, while the share of livestock production is declining (35%). Differences in the efficiency of farms are a result of the production structures with a preference for plant production over animal production and higher reduction of cost factors, especially personal costs. Therefore farmers primarily focused on crop production, which was less cost-intensive compared to livestock production. Revenues from crop production represented 52% of total income, with livestock production contributing only 6.6%. The increase in farmers' income was also influenced by diversifying services, particularly in agrotourism, and the adoption of ecological farming practices, both in crop and livestock production (MARD SR, 2022).

Data on Slovak farms are analysed over the period 2014-2019. All farms remain in the panel throughout the monitored period, so the panel is complete. In this study, farms that engage in other gainful activities are selected, and in the monitored period, they reached more than 10,000 euros in income from OGA. The total sample consists of 215 diversified farms after removing outliers that could affect the efficiency frontier. The most common activities, other than farm work, that had an economic impact on the farm were contractual farming (39%), crop processing (27%), animal products (10%), and energy production (10%). The variables were selected based on previous studies and the most commonly used variables in the application of DEA models in agriculture. Two main outputs were analysed, namely, total output (TCA) and output from other gainful activities (OGA) expressed in euros. The total output includes total crops, total livestock production, and animal production and services. For each category, the total specific output was calculated as the sum of total sales, total farmhouse consumption, total farm use, and the difference between closing and opening valuation minus total purchases. Inputs are divided into five groups. The first group is farming overheads and depreciation (FOD). The second group is total specific costs (SC), which is calculated as the sum of total specific livestock costs, specific crop inputs, and specific costs for other profitable activities. The third group is labour and machinery costs and inputs (LM).

These three groups of inputs represent the total input of the farm and are expressed in euros. Further input is labour as the sum of total work on holding, both unpaid and paid. Work on the holding includes agricultural work and work related to other gainful activities (OGA) directly related to the holding. By labour, we mean all persons who have been engaged in work on the farm during the year. Total employed work on the holding is converted into annual work units (AWU). The number of annual work units is not recorded for casual labour. The last input is land area expressed as total utilized agricultural area (UAA). The UAA is the total area occupied by arable land, permanent grassland, and permanent crops used by farms regardless of the type of tenure.

RESULTS AND DISCUSSION

Farms that receive income from sectors other than agriculture are analysed. As these diversified farms operate under different technologies, they have been divided into three groups based on their specialization in crop, animal, and mixed production, as classified by FADN. Table 1 provides descriptions of the average values of the variables used to measure efficiency over the years.

The highest value of production value was achieved by mixed farms. Although the total production value of all farms decreased in 2015, it maintained an increasing trend during the monitored years from 2014 to 2019. While the total production value of diversified farms specializing in crop production was the lowest on average, the total production value of these farms increased the most during the analysed period. In contrast to the total value of production, the output from other gainful activities (OGA) grew on all farms. The most significant increase, of over 40%, was observed in 2016.

Table 1. Endophytic isolates obtained from two soybean cultivars

Variables Unit	Description	Total sample mean								
		Specialization								
			2014	2015	2016	2017	2018	2019	% change	Mean
Outputs										
Tca	Total crops, livestock production and animal production	Crop farms	679	597	724	736	773	796	17	717
Thousand		Animal farms	860	747	777	772	805	879	2	807
EUR		Mixed farms	1969	1705	1734	1671	1891	1906	-3	1813
Oga	Output from other gainful activities	Crop farms	55	73	114	95	91	87	57	86
Thousand		Animal farms	214	239	288	236	223	294	38	249
EUR		Mixed farms	363	331	501	351	465	384	6	399
Inputs										
Uaa	Utilised agricultural area	Crop farms	609	638	694	818	779	793	30	722
Hectares		Animal farms	1022	984	928	910	872	925	-9	940
		Mixed farms	1621	1575	1552	1428	1528	1437	-11	1524
Awu	Total employed work	Crop farms	11	11	12	14	13	12	7	12
Count		Animal farms	27	26	24	23	22	23	-14	24
EUR		Mixed farms	37	38	36	35	38	36	-4	37
Fod	Farming overheads and depreciation	Crop farms	250	259	288	315	309	308	23	288
Thousand		Animal farms	322	348	339	306	302	351	9	328
EUR		Mixed farms	525	516	523	536	566	566	8	539
Lm	Labour and machinery cost	Crop farms	298	281	315	370	361	367	23	332
Thousand		Animal farms	517	446	476	488	485	542	5	492
EUR		Mixed farms	832	782	806	824	914	936	12	849
Sc	Total specific costs	Crop farms	321	315	351	383	337	422	31	355
Thousand		Animal farms	596	492	491	464	307	727	22	513
		Mixed farms	1229	1106	987	1010	824	1299	6	1076

Note: Tca – Total output; Oga – other gainful activities; Uaa – utilized agricultural area; Awu – annual work units; Fod – farming overheads and depreciation; Lm – labour and machinery costs; Sc – specific costs.

Diversified farms specializing in crop production showed the most significant increase in OGA, even though they had the lowest average value of OGA throughout the entire period.

The average area of diversified farms from our panel of data in the FADN database was 1000 hectares, and it exhibited a decreasing trend throughout the period. Interestingly, the average acreage of diversified farms focused on crop production was the lowest, and only these farms increased their acreage during the analysed period. In Slovakia, it is not true that small and medium-sized farms are the most diversified, where household members of these farms aim to increase their income from activities other than agriculture. The FADN database only selects larger farms in Slovakia, specifically those above ESU 6 in its sample. The average farm size in Slovakia is approximately 77.5 hectares (Eurostat, 2018), which is one of the largest areas among EU member countries. The development of the average work units in the six-year period was similar to that of the acreage. The highest average number of employees was found on farms focused on mixed production. The total number of employees only grew on diversified farms focused on crop production. The number of employees decreased the most in diversified farms focused on animal production since 2015, and it decreased by approximately 14% since the beginning of the analysed period. Farming overheads and depreciation grew sharply throughout the period, most notably in farms focused on crop production. Compared to diversified farms, farming overheads and depreciation in mixed farms were higher by more than 60%. Labour and machinery costs exhibited the same increasing trend for all farms. Farms focused on mixed production, which included both animal and crop production, had the highest value of labour and machinery costs. Total specific costs of farms focused on mixed and livestock production decreased until 2018 when there was the lowest decrease compared to 2014. Thanks to the sharp increase in specific costs in 2019, there was an overall increase in specific costs compared to 2014.

Before estimating efficiency, it was necessary to verify whether the observed differences between groups of diversified farms, divided by specialization, were statistically significant. In the case of observed differences, applying metafrontier analysis would be inappropriate, as it is a methodological solution for the analysis of heterogeneous groups of diversified farms (Battese et al., 2004). First, the normality of the analysed variables was tested using the Shapiro–Wilk W test for normal data. For all variables, the significance level was less than 0.001, indicating that the data do not have a normal distribution. Due to the non-parametric distribution of the analysed variables according to three groups of specialization, the Kruskal-Wallis non-parametric test was used for each year and for each input and output variable (TCA, OGA). The null hypothesis states that diversified farms, divided according to specialization, do not differ from each other, while the alternative hypothesis states that diversified farms, divided according to specialization, differ from each other the least in the technology used. As a result, the null hypothesis was rejected at a 1% significance level, indicating that the differences in all variables between diversified farms divided by specialization are statistically significant. The results indicate that there is considerable heterogeneity among diversified farms. This means that these diversified farms use different technologies, depending on their specialization in crop, animal, or mixed production. Furthermore, the technical efficiency was estimated with respect to the metafrontier for all diversified farms, the technical efficiency with respect to the technological frontier of each group of farm specializations, and the ratio of technological gap ratios (TGR) for each year separately using Eq. (1). Increasing the technical efficiency of the use of inputs can increase the profits of farms because such profits translate into an increase in the income of farmers. Technical efficiency scores are usually interpreted as the level of efficiency of individual farms in relation to their own technology, which is determined by the efficiency frontier.

The total number of selected diversified farms, according to specialization, and the percentage of the total number of diversified farms for each specialization are shown in Table 2. Additionally, the total number of efficient farms and the share of farms from the total number of farms within each specialization that lie on the border of efficiency, or whose technical efficiency score is equal to 1, are provided. If we focus on the percentage of efficient farms, representing best practices within their respective technology, our results indicate differences in technologies among the three types of diversified farms. Diversified farms specializing in crop production had the highest percentage of efficient diversified farms during the years 2014-2019, ranging from 27% to 43%. Similarly, diversified farms focused on mixed production, on average, have 31% efficiency (ranging from 27% to 37%). In contrast, for the observed period, 29% of diversified farms with animal production are efficient (ranging from 25% to 39%). In other words, 71% of diversified farms with animal production are inefficient and have the potential to improve their technological processes to match the efficiency of farms focused on animal production. When calculating technical efficiency using the metafrontier as the reference frontier for all diversified farms, the number of efficient diversified farms also decreases. However, this reduction in efficiency does not affect all technologies equally. For instance, the number of efficient farms using livestock production technology decreases by only 32% on average, while the number of efficient farms decreases by 39% for crop production farms and up to 54% for mixed farms.

First, the technical efficiency scores, calculated with respect to the three frontiers (TEgroup), for groups of diversified farms divided by specialization are explained and discussed (Table 3). The average technical efficiency score for the period 2014-2019 ranges from a minimum of 0.733 for diversified farms focused on animal production, 0.804 for diversified farms specializing in crop production, to a maximum efficiency level of 0.830 for diversified farms specializing in mixed production. This indicates that the output increases by about 83% of the potential relative to the frontier of the group of farms focused on mixed production. Furthermore, this means that diversified farms specializing in animal production are, on average, 27% below the technology frontier within their group, while mixed-production farms are, on average, 17% below the frontier of their group. In other words, the TEgroup technical efficiency score shows that the average difference between the best-performing farms and other farms within their technology is 20% in the case of farms specializing in crop production. To achieve a 100% level of technical efficiency, farmers will need to bridge the gap between the given level of performance and the maximum potential performance by optimally using the factors that cause inefficiency.

The second conclusion that can be drawn from the results in Table 3 concerns technical efficiency for the metafrontier. The technical efficiency calculated for all technologies (TEmeta) is lower than the efficiency calculated on the basis of individual frontiers.

Table 2. Characteristics of the analysed farms and number of efficiency farms

	Number (percentage)					
	2014	2015	2016	2017	2018	2019
Specialisation						
Crops	81 (38%)	79 (37%)	82 (38%)	89 (41%)	92 (43%)	94 (44%)
EFFgroup	31 (39%)	33 (42%)	34 (43%)	27 (34%)	25 (32%)	21 (27%)
EFFmeta	21 (27%)	20 (25%)	18 (23%)	14 (18%)	14 (18%)	17 (22%)
Animal	76 (35%)	78 (36%)	76 (35%)	73 (34%)	71 (33%)	74 (34%)
EFFgroup	28 (33%)	33 (39%)	22 (26%)	21 (25%)	23 (27%)	21 (25%)
EFFmeta	16 (19%)	23 (26%)	16 (19%)	18 (21%)	15 (18%)	14 (17%)
Mixed	58 (27%)	58 (27%)	57 (27%)	53 (25%)	52 (24%)	47 (22%)
EFFgroup	17 (33%)	14 (27%)	19 (37%)	14 (27%)	17 (33%)	16 (31 %)
EFFmeta	12 (23%)	10 (19%)	9 (17%)	4 (8%)	4 (8%)	6 (12%)

Note: EFFgroup – number of efficiency farms under group frontier; EFFmeta – number of efficiency farms under metafrontier

Table 3. Technical efficiency scores and technology gap

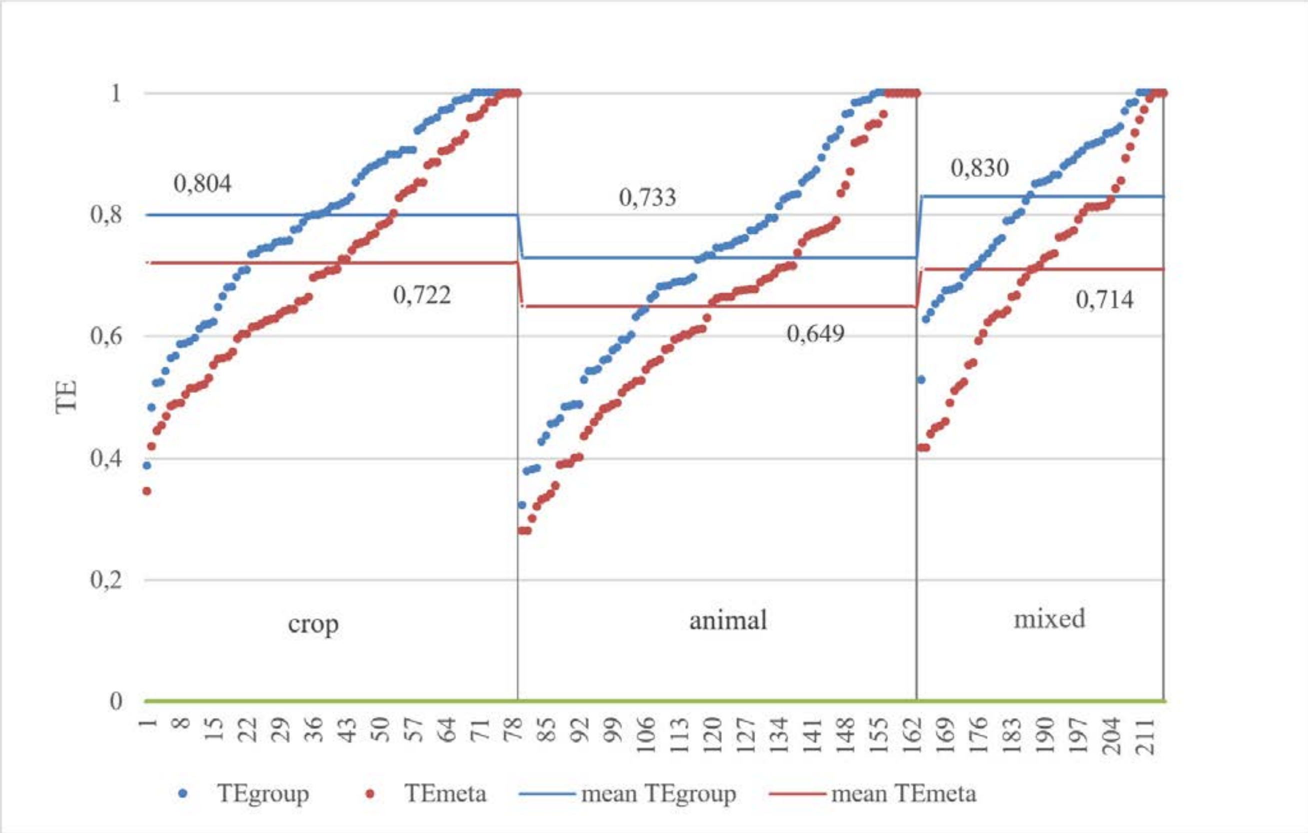
	Farming	2014	2015	2016	2017	2018	2019	Mean
TE_{group}								
	Crop	0.851	0.811	0.844	0.818	0.781	0.722	0.804
	Animal	0.753	0.763	0.690	0.700	0.725	0.768	0.733
	Mixed	0.816	0.830	0.843	0.820	0.840	0.833	0.830
TE_{meta}								
	Crop	0.766	0.724	0.762	0.718	0.698	0.670	0.722
	Animal	0.664	0.676	0.600	0.613	0.627	0.611	0.649
	Mixed	0.763	0.733	0.724	0.707	0.709	0.715	0.714
TGR								
	Crop	0.900	0.893	0.903	0.877	0.894	0.928	0.894
	Animal	0.882	0.886	0.876	0.876	0.864	0.795	0.876
	Mixed	0.935	0.883	0.862	0.862	0.844	0.857	0.850

Note: TEgroup – technical efficiency under group frontier; TEmeta – technical efficiency under metafrontier; TGR – technology gap ratio

The reason for this is that the metafrontier applies to all farms regardless of specialization. Thus, the calculation assumes the highest technological level within all diversified frontiers, while the group frontier contains only the top technological level within a given specialization. The results of the overall efficiency (meta) show that in this case, the harvest achieves an average technical efficiency (0.722), with the most inefficient farm among the various technological groups having an average score of 0.649. This suggests that livestock farmers must improve their understanding of the use of different inputs to match crop farms. This result emphasizes the importance of model specifications for diversified farms operating under different technological frontiers. The mean technical efficiency across all technologies was 0.691, indicating that the output vector was 69% of the maximum output that diversified farms could produce on average with current inputs.

In other words, the relative efficiency measure suggests that using the same input level, the diversified farms evaluated in the current study could produce an average of 31% more output if they operated at the frontier. Finally, Table 3 shows the calculated technological difference ratio of technical efficiency. The term TGR is interpreted as a difference between the technologies of different groups (metafrontier and group technologies) in our case, specialization. The calculated frontier and metafrontier production times for each technology can also be used to calculate the technology gap ratio (TGR) using Eq. (2). TGR measures the proximity of the group frontier to the metafrontier, which represents the current state of knowledge. The higher the TGR, the smaller the difference between the group frontier and the metafrontier, as shown in the picture. Figure 2 displays the average efficiency scores of TEgroup and TEmeta for diversified farms grouped into 3 types of specializations in the years 2014-2019.

Both crop and animal technology show low differences in the efficiency scores obtained, indicating a high degree of homogeneity within each group. As shown in Table 3, the average TGR values range from 0.850 in the case of diversified farms with mixed production, 0.876 for farms with animal production, and 0.894 for farms with crop production.



Note: TEgroup – technical efficiency under group frontier; TEmeta – technical efficiency under metafrontier

Figure 2. Group and metafrontier technical efficiency of diversified farms grouped in three types of specialisations (mean 2014-2019)

If these farms operated at peak efficiency, they could increase production by eliminating the gap by 15% for mixed production, and 12% for both animal and crop production. It is clear that the ratio of technological differences for farms with crop production during the period is, on average, the highest at 0.894, and this average TGR value is closest to the maximum value.

Thus, farms specializing in crop production work with the most efficient resource utilization technology and produce 90% of their potential output with respect to the current level of inputs. This result was expected because the crop technology group has a larger number of farms than the other diversified farms, resulting in higher variability in outputs and inputs for this technology. Additionally, crop production has been growing in the monitored years, and output from other gainful activities (OGA) is also increasing. Furthermore, this means that if all inputs remain unchanged, farms specializing in crop production will reach their maximum potential output faster compared to those specializing in animal and mixed production. For all diversified farms, regardless of specialization, the average TGR value is 0.877, indicating that the potential for improvement is estimated at 12.3% on average.

In summary, diversified farms with mixed production achieved the highest technical efficiency within the group frontiers, while diversified farms focused on crop production achieved the highest efficiency within the metafrontier. In both frontiers, diversified farms focused on animal production achieved the lowest efficiency. Surprisingly, farms specializing in crop production are more efficient compared to those with mixed production, even though the efficiency of farms within metafrontiers is higher for the mixed ones. Crop farms have the highest number of efficient farms, while mixed farms have the lowest number of efficient farms.

This result is also supported by the findings of other authors. Forleo et al. (2021) argued that there is a significant scope for improving the performance of diversified Italian farms, even after accounting for the observed variability between farms. Factors such as farm location and performance are related to efficiency performance. In the case of policies aimed at promoting farm diversification activities, the government needs to improve local farm structures and the income situation of agricultural enterprises to ensure that regional food supplies are not threatened (Shahzad et al., 2021). The social and economic importance of other gainful activities is much higher in the countries of Central and Northern Europe (Trnková, 2021). Salvioni et al. (2020) found that diversification activities have a significant and positive impact on the financial performance of farms, as well as increasing the efficiency gains in agriculture. At the level of technical efficiency, farmers with small land sizes should carry out improvements in agricultural activities using family labour (Han and Zhang, 2020) to improve their yield levels. Some authors found that farm size has a positive effect on technical efficiency. This means that larger farms are technically more efficient (Abate et al., 2019; Mussa et al., 2012; Tchale, 2009). According to Tenaye (2020), excess labour could be used for off-farm activities. Given the large average size of Slovak farms, improving the efficiency of input resource utilization could be achieved by transferring farm size. Resource inefficiency can be attributed to very small operating land, better activities producing off-farm income, fluctuations in agricultural product prices, the traditional mindset of older farmers, and the low degree of involvement of farmers in cooperative bodies (Pradhan, 2018). Fluctuations in the prices of agricultural products erode farmers' profits, so they tend to use opportunity costs of labour from agricultural activities. However, several authors agree that other income-generating activities from farms lack technical efficiency. Agricultural enterprises with no off-farm income are more efficient in their use of resources. The authors stated that participation in other farms comes at the expense of agricultural activities, possibly meaning less time for farming activities and, due to the gain of non-farm income, motivation to use resources wisely and efficiently (Tenaye, 2020; Razzaq et al., 2019; Mussa et al., 2012; Tipi et al., 2009; Twumasi et al., 2018; Lin et al., 2019). However, it is consistent with the results of other studies that show the positive impact of off-farm income on agricultural production (Kilic et al., 2009; Pfeiffer et al., 2009; Bojnec and Fertő, 2013; Ma et al., 2018). Other gainful activities can have a significant impact on the technical efficiency of farms, both positive and negative. One positive impact of other gainful activities on technical efficiency is that they can provide additional sources of income for the farm, which can be used to purchase better inputs, improve infrastructure and equipment, and invest in new technologies. This, in turn, can increase the farm's productivity and overall efficiency. If a farmer is too heavily engaged in other gainful activities outside of the farm, it can take away time and resources that could be devoted to improving the farm's productivity and efficiency. This can result in a decline in the quality and quantity of the farm's output and can negatively impact its technical efficiency. Moreover, if a farmer engages in off-farm activities that are not aligned with their core skills and competencies, they may not be able to fully leverage their knowledge and experience to maximize the efficiency of their farm. This can result in sub-optimal decisions, wasted resources, and lower overall productivity.

CONCLUSIONS

With the gradual shift towards sustainable rural development, farm diversification has gained importance in EU policy. This empirical study applies the metafrontier technique of the output-oriented DEA model to calculate the technical efficiency of diversified farms that engage in other gainful activities using different technologies in Slovakia. The study reveals significant differences between farms using various technologies, specializing in crop, animal, and mixed production. Technical efficiency at the group frontier considers technological differences and reflects the potential for efficiency improvement under existing technological circumstances. The results demonstrate that diversified farms focused on crop and mixed production consistently maintain a high level of average technical efficiency compared to farms with animal production. Specialization in livestock production appears to be the least suitable from a technical efficiency perspective for farms engaged in other income-generating activities. Based on the reviewed literature, the inefficiency of farms can result from incorrectly chosen sizes or inefficient input utilization. Therefore, reducing the scale of farms by reducing the agricultural land area may help improve efficiency, compared to previous years. Average TGR values indicate how these diversified farms can compete in terms of efficiency with farms of other specializations. Diversified farms specializing in crop production, in particular, exhibit an average output level of 89% of their potential with their inputs. The presence of a technological gap among farms highlights the need for rational resource utilization and support for improved management and organizational systems.

This study also reveals several policy implications. The observation that diversified farms specializing in livestock production exhibit technical inefficiency underscores the need for a national strategy for livestock production with adequate funding. Enhancing the efficiency of animal production farms can also be achieved by reducing agricultural land area. Efficiency can be further increased by supporting diversification in agricultural production and other income-generating activities. Investment in rural tourism development, particularly in small and medium-sized agricultural enterprises, can be encouraged through policies. The government should focus on enhancing farm income and supporting the stability of diversified farms. It's important to note that these conclusions pertain to diversified Slovak farms during the observed period, so careful consideration is necessary when interpreting and making decisions. The ultimate contribution of this research lies in identifying efficiency disparities among farms, which can inform efforts to optimize resource utilization and bolster the competitiveness of Slovak agriculture. Future research should expand its scope to investigate farm efficiency and productivity by analysing a larger sample of diversified farms while considering factors such as specific landforms, regions and economic size.

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