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Comparison of Technology and Technical Efficiency in Cereal Production among EU Countries

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Anotace

Článek prezentuje výsledky analýzy produkce obilovin v rámci jednotného trhu EU. Analýza je založena na odhadu multiple output distance (vzdálenostní) funkce pro jednotlivé členské země v prvním kroku a následném odhadu metafrontier multiple output distance funkce v druhém kroku. Komparativní analýza ukazuje na vysokou technickou efektivnost producentů obilovin v analyzovaných zemích. Z výsledků plyne, že mezi zeměmi EU neexistují výrazné rozdíly v technické efektivnosti, přestože značnou rozdílnost vykazují v produkčních technologiích i v determinantech technické efektivnosti.

Klíčová slova

Obiloviny, vzdálenostní funkce, technická efektivnost, technologie, metafrontier analýza, SFA.

Abstract

The paper presents the analysis of cereal production in the EU. The analysis provides the comparison of production technologies and technical efficiency among EU countries using the country specific multiple output distance function models in the first step and metafrontier approach in the second step to determine the level and development of technical efficiency. The results show the high technical efficiency of cereal producers in the analyzed countries. On average, the differences in technical efficiency among the analyzed countries are not pronounced; however, the technologies used as well as the determinants of technical efficiency differ significantly.

Key words

Cereal production, multiple output distance function, technical efficiency, technology, metafrontier analysis, SFA.

Introduction

Cereal production is one of the most important sectors of plant production in European agriculture as well as worldwide. The size of crop production is not substitutable in many European countries. The same holds true for the Czech Republic, where cereals are cultivated on around 50 % of arable land. The share of cereal production in plant production is about 45 % and in gross agricultural production about 20 % (MA-CZ, 2014). Production has been gradually increasing worldwide during the analysed period (2004–2011) and in subsequent years. European countries followed this trend as well (Jansson and Heckelei, 2011). According to FAO estimates, world cereal production increased by 9 % in the period 2004–2011 (AMIS database, 2015). However, this increasing trend can be changed by negative factors in important production regions (e. g. Ukraine).

As far as European cereal production is concerned, significant differences among the EU countries can be found not only in the volume of production but also in crop systems (extensive vs. intensive) (Tiffin and Renwick, 1996). In this regard, the paper aims to address two research questions. The first question deals with the production technology. Specifically, the paper provides a comparison of cereal production technologies among the EU countries. The second question is related to technical efficiency. The paper identifies the differences and developments in the efficiency of inputs use.

The technical efficiency of crop production has been analysed in a number of studies (e.g. Aciti and Podinovsky, 2015; Baráth and Ferto, 2015;

Dhehibi et al., 2014; Batten and Hossain, 2014; Blazejczyk-Majka et al., 2012; Skevas et al., 2012; Odeck, 2007; Hadley and Irz, 2007). Moreover, the studies focused on the analysis of technical efficiency of cereal production can be found (e.g. Wouterse, 2010; Baranyai, 2009). However, these studies usually analyzed technical efficiency of specific plant (e.g. wheat in Hussain et al. (2012), maize in Ndlovu et al. (2014)) in one country. Only a few studies compared the technical efficiency of cereal producers from more than one country. Latruffe et al. (2012) compared technical efficiency of farms in cereal sector in France and Hungary and found out that Hungarian technology is more productive. Barnes and Revoredo-Giha (2011) used matafrontier analysis to compare technical efficiency of specialized farms in 11 European Union countries, namely Belgium, Denmark, France, Germany, Hungary, Ireland, Italy, Netherlands, Poland, Spain and the UK. They found out that COP farms in France are the most technically efficient. On the other hand the lowest mean of technical efficiency was observed in Italy.

Since a systematic overall assessment of the EU cereal production is missing the paper tries to complement the research by conducting a metafrontier analysis of the comparative assessment of technology and technical efficiency differences among EU member countries.

The paper is organized as follows: the Materials and methods section presents the estimation strategy and describes the data set; the Results and discussion section presents the results of country-specific multiple output distance models and a stochastic metafrontier multiple output distance function, discusses and compares estimated technology and compares technical efficiency and its development; and the Conclusions section contains concluding remarks.

Materials and methods

The research questions will be addressed by: (1) estimation of a country-specific multiple output distance function, and (2) calculation of an efficient output level which will be used in a metafrontier approach to determine the technical efficiency level and development.

We assume that the production process can be well approximated by a translog multiple output distance function (ODF) (Coelli and Perelman, 1996):

$$-lny_{1it} = \alpha_0 + \sum_{m=2}^{3}\alpha_m ln\, y^*_{mit} + \frac{1}{2}\sum_{m=2}^{3}\sum_{n=2}^{3}\alpha_{mn} lny^*_{mit} lny^*_{nit} + \sum_{k=1}^{5}\beta_k ln\, x_{kit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{l=1}^{5}\beta_{kl} lnx_{kit} lnx_{lit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{m=2}^{3}\gamma_{km} lnx_{kit} lny^*_{mit} + \delta_t t + \frac{1}{2}\delta_{tt} t^2 + \sum_{m=2}^{3}\alpha_{mt} t lny^*_{mit} + \sum_{k}^{5}\beta_{kt} t ln\, x_{kit} + u_{it} + v_{it} \quad (1)$$

where we assume that $v_{it} \sim N(0,\sigma_v^2)$, $u_{it} \sim N^+(0,\sigma_u^2)$, and that they are distributed independently of each other, and of the regressors (Kumbhakar and Lovell, 2000).

Heterogeneity in technology is captured using a Fixed Management model. Álvarez et al. (2003 and 2004) specified the Fixed Management model as a special case of the Random Parameters model in the following form:

$$-lny_{1it} = \alpha_0 + \sum_{m=2}^{3}\alpha_m ln\, y^*_{mit} + \frac{1}{2}\sum_{m=2}^{3}\sum_{n=2}^{3}\alpha_{mn} lny^*_{mit} lny^*_{nit} + \sum_{k=1}^{5}\beta_k ln\, x_{kit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{l=1}^{5}\beta_{kl} lnx_{kit} lnx_{lit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{m=2}^{3}\gamma_{km} lnx_{kit} lny^*_{mit} + \delta_t t + \frac{1}{2}\delta_{tt} t^2 + \sum_{m=2}^{3}\alpha_{mt} t lny^*_{mit} + \sum_{k}^{5}\beta_{kt} t ln\, x_{kit} + \alpha_{m*} m^*_i + \frac{1}{2}\alpha_{m*m*} m^{*2}_i + \delta_{tm*} m^*_i t \quad (2)$$

Álvarez et al. (2004) showed that u_{it} can be estimated according to Jondrow et al. (1982) as (3) with simulated mi* according to the relation (4).

$$E\left[u_{it}\middle|\varepsilon_{it}, m^*_i\right] = \frac{\sigma\lambda}{(1+\lambda^2)}\left[\frac{\phi\left(-\left(\varepsilon_{it}\middle|m^*_i\right)\lambda/\sigma\right)}{\Phi\left(-\left(\varepsilon_{it}\middle|m^*_i\right)\lambda/\sigma\right)} - \frac{\left(\varepsilon_{it}\middle|m^*_i\right)\lambda}{\sigma}\right], \quad (3)$$

where $\lambda = \frac{\sigma_u}{\sigma_v}$, $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\varepsilon_{it} = v_{it} + u_{it}$.

$$\hat{E}\left[m^*_i\middle|\mathbf{y}_i, \mathbf{X}_i, \boldsymbol{\delta}\right] = \frac{\frac{1}{R}\sum_{r=1}^{R} m^*_{i,r}\hat{f}\left(\mathbf{y}_{1i}\middle|\mathbf{y}^*_{mit}, \mathbf{x}_{it}, t, m^*_{i,r}; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right)}{\frac{1}{R}\sum_{r=1}^{R}\hat{f}\left(\mathbf{y}_{1i}\middle|\mathbf{y}^*_{mit}, \mathbf{x}_{it}, t, m^*_{i}; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right)} \quad (4)$$

FMM is estimated using the maximum simulated likelihood method in the econometric software LIMDEP 9.0.

The metafrontier analysis will be conducted using the same model specification as for the individual countries. We will calculate the efficient output based on the parameter estimates of a country multiple output distance function and will use them in the estimation of a stochastic metafrontier multiple output distance function.

The ODF will be estimated on the basis of the panel data set drawn from the FADN database provided by the European Commission. The data set contains data on 24 EU member countries (Cyprus, Malta and Luxembourg are missing) and covers the period from 2004 to 2011, except for Austria (2005–2011), Bulgaria and Romania (2008–2011).

The following variables are used: y_1 cereal production, y_2 other plant production, y_3 animal production, x_1 labour, x_2 land, x_3 capital, x_4 specific material and x_5 other material. Labour is represented by the total labour measured in AWU. Land is the total utilised land. Capital is the sum of contract work and depreciation. Specific material in cereal production is represented by the costs of seeds, plants, fertilisers and crop protection. Outputs as well as inputs (except for labour and land) are deflated by country price indices on each individual output and input (2005 = 100). The country price indices are taken from the EUROSTAT database.

The multiple output distance function is estimated only for specialized producers. Specialisation is defined when cereal production accounts for at least 50 % of total plant production.

Results and discussion

1. Individual country estimates

Tables 1 and 2 provide selected first-order parameter estimates of the multiple output distance function (equation 2) for 24 EU member countries.

Instead of discussing each country estimate separately, we will evaluate and compare the results for all member countries together. This strategy helps us to better understand the common and individual specifics of cereal production in EU member countries, as far as technology, heterogeneity and efficiency are concerned.

Table 1 shows the estimated parameters conventionally discussed in the distance function, i.e. first-order parameters on outputs and inputs of the multiple output distance function. Almost all parameters are significant, even at a 1 % significance level. This also holds true for the majority of other fitted parameters. As far as theoretical consistency is concerned, the monotonicity requirements for outputs imply: $\beta_{y2} > 0$, $\beta_{y3} > 0$ and $\beta_{y2} + \beta_{y3} < 1$; and for inputs: $\beta_q < 0$ for q = x_1, x_2, x_3, x_4, x_5. Table 1 shows that these conditions are met. Moreover, convexity in inputs also holds true for almost all countries (evaluated on the sample mean), i.e. $\beta_{qq} + \beta_q^2 - \beta_q > 0$ for q = x_1, x_2, x_3, x_4, x_5.

Since all variables are normalised in logarithm by their sample mean, the first-order parameters of outputs represent the shares of outputs y_2 and y_3 in the total output, and parameters of inputs can be interpreted as elasticities of production on the sample mean. As far as the shares of outputs are concerned, the countries differ significantly in their production structure. Since we are analysing specialized cereal companies (i.e. with a share of cereal production in total plant production exceeding 50 %), the parameters on y_2 are lower than 0.5, except for the Netherlands, where we did not distinguish between specialized and non-specialized due to the low number of observations of specialized companies. The estimates show that agricultural companies in most member countries are highly specialized in cereal production, with a share exceeding 40 % of the total production. Austria, Belgium, Germany, France, the Netherlands, and Slovenia are exceptions. In these countries animal production is more pronounced. As far as the structure of plant production is concerned, specialized crop companies have a share of cereal production higher than 70% in most cases. Other production types play a more significant role in Bulgaria, the Czech Republic, Germany, the Netherlands and Romania.

The production elasticities of the individual countries share some common patterns. The highest elasticity is for material inputs, i.e. specific and other materials, and the lowest is for capital. However, the differences among the countries in the value of all elasticities are highly pronounced. The sum of the elasticity of material inputs is in the interval -0.4 to -0.9. The interval for labour elasticity is from -0.04 to -0.24. The lowest land elasticity is in Slovakia (-0.05) and the highest is in Denmark (-0.60). Capital elasticity in the majority of countries does not exceed -0.1. Moreover, the estimates of capital elasticity are quite low (lower than |0.05|) in some countries, which could be connected with capital market imperfections, including limited access to capital and the use of old machinery by many farmers in these countries. Thus, we can already

EU member country		Other plant production	Animal production	Labour	Land	Capital	Specific material	Other material	RTS
		y_2	y_3	x_1	x_2	x_3	x_4	x_5	
Austria	Coeff.	0.0862	0.6522	-0.0752	-0.1303	-0.0497	-0.1506	-0.6982	-1.1039
		***	***	***	***	***	***	***	
Belgium	Coeff.	0.1072	0.7871	-0.1413	-0.0001	-0.0489	-0.1246	-0.6471	-0.962
		***	***	***		***	***	***	
Bulgaria	Coeff.	0.334	0.1036	-0.0632	-0.2879	-0.0704	-0.3247	-0.2064	-0.9526
		***	***	***	***	***	***	***	
Czech Republic	Coeff.	0.3278	0.1769	-0.0923	-0.1369	-0.0302	-0.3891	-0.3673	-1.0159
		***	***	***	***	***	***	***	
Germany	Coeff.	0.2132	0.3979	-0.0489	-0.2032	-0.0471	-0.2012	-0.6076	-1.1081
		***	***	***	***	***	***	***	
Denmark	Coeff.	0.1909	0.2343	-0.0959	-0.5992	-0.0273	-0.0653	-0.3208	-1.1085
		***	***	***	***	**	***	***	
Estonia	Coeff.	0.2108	0.0895	-0.0625	-0.2843	-0.0673	-0.3188	-0.2648	-0.9976
		***	***	***	***	***	***	***	
Spain	Coeff.	0.0265	0.2152	-0.1453	-0.1308	-0.0269	-0.2686	-0.3644	-0.9361
		***	***	***	***	***	***	***	
Finland	Coeff.	0.0781	0.4491	-0.1436	-0.258	-0.0261	-0.1061	-0.6117	-1.1455
		***	***	***	***	***	***	***	
France	Coeff.	0.0775	0.5255	-0.097	-0.1494	-0.1148	-0.1766	-0.5538	-1.0916
		***	***	***	***	***	***	***	
Great Britain	Coeff.	0.1695	0.2661	-0.1924	-0.1202	-0.0335	-0.4099	-0.436	-1.192
		***	***	***	***	***	***	***	
Greece	Coeff.	0.0604	0.3934	-0.236	-0.0911	0.0333	-0.1994	-0.3078	-0.801
		***	***	***	***	***	***	***	
Hungary	Coeff.	0.2345	0.1174	-0.0416	-0.2732	-0.0542	-0.209	-0.3915	-0.9696
		***	***	***	***	***	***	***	
Ireland	Coeff.	0.1743	0.3398	-0.0355	-0.4049	-0.1057	-0.3256	-0.2745	-1.1462
		***	***	**	***	***	***	***	
Italy	Coeff.	0.2057	0.1199	-0.047	-0.3779	-0.0712	-0.214	-0.206	-0.9161
		***	***	***	***	***	***	***	
Lithuania	Coeff.	0.1915	0.1017	-0.0833	-0.2413	-0.0765	-0.3776	-0.2151	-0.9937
		***	***	***	***	***	***	***	
Latvia	Coeff.	0.1828	0.1362	-0.007	-0.2077	-0.0948	-0.2743	-0.4082	-0.992
		***	***		***	***	***	***	
Netherlands	Coeff.	0.6746	0.0754	-0.1216	-0.2544	-0.1066	-0.2947	-0.5124	-1.2898
		***	***	***	***	***	***	***	
Poland	Coeff.	0.1243	0.4206	-0.0597	-0.2655	-0.0485	-0.1469	-0.5359	-1.0565
		***	***	***	***	***	***	***	
Portugal	Coeff.	0.066	0.2362	-0.0626	-0.1225	-0.0372	-0.2416	-0.3481	-0.812
		***	***		***	**	***	***	
Romania	Coeff.	0.3563	0.1209	-0.0203	-0.4598	0.026	-0.2004	-0.1856	-0.8402
		***	***	***	***	***	***	***	
Sweden	Coeff.	0.118	0.2388	-0.072	-0.2028	-0.0159	-0.0184	-0.8786	-1.1876
		***	***	***	***			***	
Slovenia	Coeff.	0.1153	0.505	-0.0158	-0.2384	-0.0582	-0.1084	-0.6908	-1.1116
		***	***		***	***	***	***	
Slovakia	Coeff.	0.2407	0.0912	-0.2036	-0.0454	-0.0464	-0.4551	-0.2791	-1.0295
		***	***	***	**	***	***	***	

Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

Source: own calculation

Table 1: First-order parameters of the multiple output distance functions.

EU member country		Alpha_m	Time	Labour	Land	Capital	Specific material	Other material	Alpha_mm
			t	x_1	x_2	x_3	x_4	x_5	
Austria	Coeff.	-0.2754	-0.0019	0.0119	0.0105	-0.0485	0.0006	0.0751	-0.0668
		***		*		***		***	***
Belgium	Coeff.	-0.192	-0.0083	0.1298	-0.0377	-0.0949	0.0117	0.0664	0.0768
		***	***	***	***	***		***	***
Bulgaria	Coeff.	-0.0959	-0.0052	-0.001	-0.1935	-0.057	0.2111	-0.0034	0.2898
		***			***	***	***		***
Czech Republic	Coeff.	-0.0309	-0.008	-0.0732	-0.2059	-0.0762	0.0675	0.2417	-0.1914
		***	***	***	***	***	***	***	***
Germany	Coeff.	-0.2377	-0.0028	-0.015	-0.0778	-0.0152	0.0413	0.0901	0.0397
		***	***	***	***	***	***	***	***
Denmark	Coeff.	-0.1044	0.0032	-0.0893	-0.1377	0.076	0.0313	0.1432	-0.3931
		***	*	***	***	***	***	***	***
Estonia	Coeff.	-0.1769	-0.0105	0.0388	-0.0525	0.0128	-0.0081	0.0226	0.0067
		***	**	**	**				
Spain	Coeff.	-0.3758	0.0159	-0.0645	-0.0818	0.0011	0.0718	-0.0108	-0.0953
		***	***	***	***		***	**	***
Finland	Coeff.	-0.0032	0.0068	-0.0686	0.0534	0.0258	0.0079	-0.223	-0.4836
			***	***	***	***		***	***
France	Coeff.	-0.2246	-0.0044	-0.0324	-0.015	-0.0032	0.008	0.0632	0.0494
		***	***	***	***		***	***	***
Great Britain	Coeff.	-0.2389	0.0091	-0.034	-0.0288	-0.0471	0.0632	0.0544	-0.0346
		***	***	***	***	***	***	***	***
Greece	Coeff.	-0.3394	0.0124	-0.1157	-0.1071	0.0418	0.1692	-0.1031	0.0734
		***	***	***	***	***	***	***	***
Hungary	Coeff.	-0.2094	-0.0122	-0.0185	-0.0485	0.0072	0.0563	-0.0091	-0.0499
		***	***	***	***		***		***
Ireland	Coeff.	-0.1844	0.0051	-0.0621	0.0138	0.0022	0.0358	0.055	0.0055
		***		***			**	***	
Italy	Coeff.	-0.2163	0.0065	-0.042	-0.1488	-0.0137	0.1425	0.0076	0.0084
		***	***	***	***	**	***	*	
Lithuania	Coeff.	-0.142	0.0109	-0.0213	-0.1637	-0.0524	0.1372	0.0549	0.0221
		***	***		***	***	***	***	**
Latvia	Coeff.	-0.0349	-0.0136	0.0883	0.2044	-0.0326	0.0122	-0.152	-0.2586
		***	***	***	***	***		***	***
Netherlands	Coeff.	-0.0722	0.0099	0.1844	-0.2183	-0.1071	-0.0037	-0.0666	0.3714
		***	***	***	***	***		***	***
Poland	Coeff.	-0.1336	-0.0068	0.0092	-0.0345	-0.0529	-0.0497	0.0407	0.2232
		***	***	***	***	***	***	***	***
Portugal	Coeff.	-0.0741	-0.0311	0.2429	0.0316	-0.077	0.0719	0.0457	0.224
		***	***	***	**	***	***	**	***
Romania	Coeff.	-0.2142	0.0234	-0.0353	-0.0281	0.0212	0.0075	0.0122	0.0362
		***	***	***	***	***		**	***
Sweden	Coeff.	-0.256	-0.0065	0.0934	-0.144	-0.0061	-0.0039	0.0844	-0.0871
		***	**	***	***			***	***
Slovenia	Coeff.	-0.182	0.0174	0.0155	-0.0678	-0.0257	0.077	0.0342	0.0186
		***	***		***		***	**	
Slovakia	Coeff.	-0.0959	-0.0212	-0.0111	-0.3302	0.0362	0.2205	0.0756	-0.1704
		***	***		***	***	***	***	***

Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

Source: own calculation

Table 2: Parameters on unobservable fixed management.

conclude that technology differs significantly among the countries.

As far as economies of scale are concerned, there is no indication of economies of scale (the sum of the elasticities is about one) for the average farm in the Czech Republic, Estonia, Lithuania, Latvia, Sweden, and Slovakia. Increasing returns to scale were found for the average farm in Austria, Germany, Denmark, France, Great Britain, Ireland, the Netherlands, Poland, and Slovakia. On the contrary, decreasing returns to scale were estimated for the average farm in Belgium, Bulgaria, Spain, Greece, Hungary, Italy, Portugal, and Romania. That is, these results already suggest that the impact of scale efficiency (SE) on productivity change will be quite large in most member countries (similarly to Wang et al. (2012), Wouterse (2010), Tozer and Villano (2013), and others).

Table 2 provides the parameter estimates on unobservable management. Since the coefficients on unobservable management are highly significant in the majority of cases, we can conclude that the chosen specification well approximates the estimated relationship and that heterogeneity among companies is an important characteristic of farmers with cereal specialisation in almost all member countries.

Unobservable management contributes positively to production in all member countries (positive Alpha_m). However, the positive impact of unobservable management accelerates for some countries (negative Alpha_mm) and decelerates for others (positive Alpha_mm). Unobservable management also has a different impact on production elasticities in individual countries. That is, if the coefficient is positive, increasing management leads to an increase in production elasticity, and vice versa. In terms of the relation between unobservable management and technical efficiency, a positive coefficient indicates the positive impact of a given input on technical efficiency, and vice versa. Since the impact of unobservable management on production elasticities differs among the countries and no common pattern can be identified, we concentrate only on the role of technological change. Technological change has a positive impact on technical efficiency in almost half of the analysed countries, namely in Denmark, Spain, Finland, Great Britain, Greece, Ireland, Italy, Lithuania, the Netherlands, Romania, and Slovenia. In the other countries, technological change makes a negative contribution to the development of technical efficiency. A similar conclusion was reached by Latruffe and Nauges (2014).

2. Metafrontier analysis

Table 3 provides parameter estimates of a stochastic metafrontier multiple output distance function for cereal production in 24 EU member states (Cyprus, Luxembourg and Malta are missing). As expected, the first-order parameters standardly discussed in a production function estimate as well as the parameters on unobservable fixed management are highly significant, even at a 1 % significance level. This also holds for the majority of second-order parameters.

As far as theoretical consistency of the estimate is concerned, we can conclude that monotonicity requirements as well as requirements on convexity in outputs and quasi convexity in inputs are met, evaluated on the sample mean.

Since the share of other plant production is 7 % and the share of animal production is 52 % for the analysed sample, cereal production dominates plant production in EU; however, more than half of the output is created by animal production. This holds true for the sample mean. As expected, the highest elasticities of production are for material inputs and land. On the other hand, the lowest elasticity was estimated for capital. These estimates correspond to the values estimated for individual countries.

Since the sum of production elasticities is -0.979, slightly decreasing returns to scale were estimated for the EU member countries. Since the sum is close to one, the impact of scale efficiency on a productivity change in the EU will not be large, on average. However, as concluded in the previous section, the impact might be large for individual countries since the returns to scale differ significantly among the countries.

The parameters on unobservable management are highly significant, which again suggests that the chosen specification well approximates the estimated relationship and that heterogeneity among firms is an important characteristic of farmers with cereal specialisation in EU member countries. Unobservable management contributes positively to production, and the impact accelerates over time. An increase in management has a positive impact on the production elasticities of material inputs and a negative impact on other inputs. The impact of technological change on technical efficiency is not pronounced (the coefficient is almost zero).

Technological change makes a significant positive contribution ($\beta_T < 0$) to production, and the impact of technical change is accelerating over time ($\beta_{TT} < 0$). Moreover, the biased technological change is pronounced. The technological change is labour- and land-saving and capital- and material-using. This direction of the technological change corresponds to our expectations. The adoption of innovations leads to a situation where labour become scarcer and capital more abundant.

The parameter λ is highly significant and equals about one. That is, the variation in u_{it} is almost equal to the variation in the random component v_{it}. The estimates indicate that efficiency differences among cereal producers are important reasons for variations in production. However, the estimate did not reveal significant differences among countries, and not even among regions. The results show that cereal producers in EU member countries greatly exploit their production possibilities (evaluated on the sample mean). The averages of technical efficiency calculated on the regional level (NUTSII) are in the interval 0.89 to 0.92.

Means for random parameters				Coefficient on unobservable fixed management			
Variable	**Coef.**	**SE**	**P [|z|>Z*]**	**Variable**	**Coef.**	**SE**	**P [|z|>Z*]**
Const.	-0.1763	0.0015	0.0000	**Alpha_m**	-0.3633	0.0006	0.0000
Time	-0.0036	0.0002	0.0000	**Time**	-0.0009	0.0003	0.0004
X1	-0.0751	0.0011	0.0000	**X1**	-0.0168	0.0010	0.0000
X2	-0.2274	0.0011	0.0000	**X2**	-0.0415	0.0009	0.0000
X3	-0.0352	0.0009	0.0000	**X3**	-0.0200	0.0007	0.0000
X4	-0.1259	0.0010	0.0000	**X4**	0.0404	0.0008	0.0000
X5	-0.5157	0.0010	0.0000	**X5**	0.0418	0.0008	0.0000
				Alpha_mm	-0.0493	0.0007	0.0000
Variable	Coef.	SE	P [|z|>Z*]	**Variable**	Coef.	SE	P [|z|>Z*]
TT	-0.0039	0.0002	0.0000	**X13**	0.0038	0.0013	0.0034
Y2	0.0743	0.0008	0.0000	**X14**	0.0037	0.0015	0.0156
Y3	0.5212	0.0005	0.0000	**X15**	0.0441	0.0014	0.0000
Y2T	0.0033	0.0003	0.0000	**X23**	-0.0133	0.0010	0.0000
Y3T	0.0035	0.0002	0.0000	**X24**	-0.0059	0.0011	0.0000
Y22	0.0274	0.0011	0.0000	**X25**	0.0264	0.0013	0.0000
Y33	0.1281	0.0003	0.0000	**X34**	0.0221	0.0009	0.0000
Y23	-0.0213	0.0005	0.0000	**X35**	0.0054	0.0011	0.0000
X1T	0.0036	0.0004	0.0000	**X45**	0.0011	0.0012	0.3752
X2T	0.0103	0.0004	0.0000	**Y2X1**	0.0114	0.0013	0.0000
X3T	-0.0071	0.0003	0.0000	**Y2X2**	-0.0288	0.0010	0.0000
X4T	-0.0015	0.0004	0.0000	**Y2X3**	-0.0007	0.0009	0.4109
X5T	-0.0078	0.0004	0.0000	**Y2X4**	0.0000	0.0010	0.9661
X11	-0.0045	0.0022	0.0398	**Y2X5**	0.0196	0.0011	0.0000
X22	0.0500	0.0017	0.0000	**Y3X1**	-0.0266	0.0007	0.0000
X33	-0.0239	0.0007	0.0000	**Y3X2**	0.0414	0.0006	0.0000
X44	-0.0355	0.0010	0.0000	**Y3X3**	0.0145	0.0006	0.0000
X55	-0.0917	0.0018	0.0000	**Y3X4**	0.0155	0.0005	0.0000
X12	-0.0469	0.0017	0.0000	**Y3X5**	-0.0300	0.0008	0.0000
Sigma	0.1641	0.0007	0.0000				
Lambda	0.9925	0.0173	0.0000				

Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

Source: own calculation

Table 3: Parameter estimates – metafrontier.

3. Development of technical efficiency

Table 4 provides the development of technical efficiency. The development of technical efficiency is rather stochastic in many EU member countries. The average percentage change is positive for Austria, Belgium, Estonia, France, Hungary, Italy, Lithuania, Latvia, Portugal, Slovenia, and Slovakia. However, positive but very weak trends were estimated only for Belgium, Bulgaria, Portugal, and Romania. Despite the rather stochastic development of technical efficiency, one common pattern for most countries can be observed. Technical efficiency experienced a drop in most EU member countries in the years 2008 and 2009 and an increase in the years after that. However, the decrease was stronger than the increase. That is, the majority of countries experienced a drop in technical efficiency between 2008 and 2011.

Factors determining the development of technical efficiency were also rather specific for each member country. The positive impact of technical change on the development of technical efficiency was pronounced in Spain, Great Britain, Greece, Italy, Lithuania, the Netherlands, Romania, and Slovenia. In other countries, technical change either contributed negatively to the development of technical efficiency or the impact was rather small. The management and scale effects varied significantly among the countries and contributed mainly to the rather stochastic development of technical efficiency. However, the management effect was much more pronounced than the scale effect.

The question of stability can be analysed using the Spearman's rank correlations of technical efficiency in the analysed EU member countries. Since the order of farmers in all countries changes dramatically, leapfrogging appears to be a common phenomenon for all member countries. That is, catching-up and falling-behind processes are important characteristics of cereal producers in all countries. This also holds true even if we take into consideration the character of the data. Since we have an unbalanced panel, the values are affected to some extent by the entry and exit of producers to and from the sample.

EU member country	2004	2005	2006	2007	2008	2009	2010	2011	Average change	Trend function	R2
Austria	NA	0.461	-1.867	2.717	1.019	-0.723	-2.286	1.622	0.135	y = 0.248 - 0.028t	0.000
Belgium	-0.042	-0.279	0.257	-0.391	-0.237	0.354	-0.046	2.014	0.204	y = -0.653 + 0.191t	0.360
Bulgaria	NA	NA	NA	-0.614	-0.006	-1.004	1.48	-0.105	-0.05	y = -0.801 +0.250t	0.180
Czech Republic	0.108	0.247	-0.196	0.574	-0.968	0.002	0.103	-0.104	-0.029	y = 0.140 - 0.038t	0.040
Germany	3.446	1.668	3.839	-0.55	-2.437	-1.675	-0.603	-6.094	-0.301	y = 4.872 - 1.150t	0.740
Denmark	-1.78	0.504	1.257	3.721	-4.052	-7.06	3.009	0.916	-0.436	y = -0.365 - 0.016t	0.000
Estonia	-0.338	3.911	-6.119	5.208	-4.262	3.622	-1.467	1.106	0.208	y = 0.048 + 0.035t	0.000
Spain	3.28	-14.073	2.29	5.556	1.117	-4.376	0.6	3.879	-0.216	y = -3.062 + 0.632t	0.060
Finland	2.325	0.128	-6.188	6.593	-3.786	-8.878	2.746	3.211	-0.481	y = -0.526 + 0.010t	0.000
France	-0.856	1.029	1.457	1.22	-1.551	-3.224	2.362	-0.152	0.036	y = 0.095 - 0.088t	0.010
Great Britain	0.145	-0.415	1.068	1.481	-1.941	-5.551	2.449	0.373	-0.299	y = 0.315 - 0.062t	0.010
Greece	-0.672	0.343	-0.45	1.441	1.421	-1.267	-1.718	0.696	-0.026	y = 0.146 - 0.038t	0.010
Hungary	2.437	2.025	-0.393	-2.819	5.684	-2.197	-3.031	-0.519	0.148	y = 2.446 - 0.511t	0.170
Ireland	-0.458	-2.021	3.32	4.927	-4.632	-7.589	2.176	2.498	-0.222	y = -0.190 - 0.007t	0.000
Italy	-0.012	0.195	0.334	5.556	-3.737	-5.658	1.798	2.087	0.07	y = 0.315 - 0.054t	0.000
Lithuania	7.018	3.657	-17.848	6.55	5.27	-0.545	0.992	-0.316	0.597	y = 1.349 - 0.167t	0.000
Latvia	5.836	-0.853	-0.785	2.058	-3.328	1.879	-4.538	1.87	0.267	y = 2.602 - 0.519t	0.150
Netherlands	-2.033	3.726	-0.146	-2.782	-0.862	0.586	4.218	-2.762	-0.007	y = -0.086 + 0.018t	0.000
Poland	0.156	0.009	-0.105	-0.055	-0.895	-0.014	1.762	-1.119	-0.033	y = 0.007 - 0.009t	0.000
Portugal	3.113	-10.765	1.622	0.092	5.628	-2.325	2.763	4.392	0.565	y = -3.200 + 0.837t	0.160
Romania	NA	NA	NA	-0.778	-0.039	-0.796	0.857	-0.285	-0.208	y = -0.773 + 0.188t	0.190
Sweden	1.425	-0.804	-7.594	7.116	3.73	-5.972	-4.231	2.818	-0.439	y = -0.123 - 0.070t	0.000
Slovenia	-4.641	2.215	-2.367	8.155	0.474	-4.09	-5.561	7.842	0.253	y = -1.657 + 0.424t	0.040
Slovakia	0.83	-1.048	2.636	4.246	-0.435	0.771	-3.303	-1.009	0.336	y = 2.180 - 0.410t	0.180

Source: own calculation

Table 4: Development of technical efficiency (% change) .

Conclusion

In the conclusion we focus on the research questions raised in the introduction. That is, we deal with the differences in cereal production technology among the EU countries and with the differences in technical efficiency and its development. The results showed that agricultural companies in the majority of EU countries are highly specialized in cereal production. However, there exist countries where animal production is more pronounced (Austria, Belgium, Germany, France, the Netherlands and Slovenia) or where other plant production also plays a significant role (Belgium, Bulgaria, the Czech Republic, Germany, the Netherlands and Romania). A comparison of the production elasticities of the individual countries showed that there are some common patterns – the highest elasticity for material inputs and the lowest for capital. However, the differences among the countries are highly pronounced in the value of all elasticities. Thus, we can conclude that technology differs significantly among the countries.

As far as technical efficiency is concerned, no significant differences among EU countries and, even more so, among regions, were revealed by the estimate. On average, cereal producers in EU member countries greatly exploit their production possibilities. However, the Spearman's rank correlations of technical efficiency show that catching-up and falling-behind processes are important characteristics of cereal producers in all EU countries.

The development of technical efficiency is rather stochastic in many EU member countries and, in addition, factors which determined the development of technical efficiency (namely technical change, management and scale effect) were rather specific for each member country. However, we can make a cluster of countries where technical change had a positive impact on the development of technical efficiency – Spain, Great Britain, Greece, Italy, Lithuania, the Netherlands, Romania, and Slovenia. In other countries, technical change either contributed negatively to the development of technical efficiency or the impact was rather small.

This has important implications for the efficiency of Common Agricultural Policy and its goal of improving the competitiveness of European agriculture. As far as the technical efficiency is concerned the results suggest that cereal producers made improvements to move near to the production frontier only in six old and two new member states. Despite the fact that cereal producers highly exploit their production possibilities on average there is a space for improvements, especially by the adoption of innovations.

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