Investigation of wheat efficiency and productivity development in Slovakia

Skúmanie vývoja efektívnosti a produktivity pšenice na Slovensku

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Abstract: This study has focused on two main tasks: verifying the suitability of using stochastic frontier analysis on a transforming sector, and providing empirical evidence to explain the technical efficiency structure among farms in the time period 2000–2004. Two stochastic frontier model specifications were employed, the Battese and Coelli 1992 specification with the systematically time-varying inefficiency effect, and the Battese and Coelli 1995 one stage specification explaining technical inefficiency based on farm-specific variables. Our analyses were carried out at the commodity level, wheat production, where the accessibility of a data panel allowed us to enrich the calculation of the level of technical efficiency by the analysis of productivity changes within the chosen period of time, supports this idea as well.

Key words: technical efficiency, total factor productivity index, stochastic frontier analysis

Abstrakt: Analýza je zameraná na dva hlavné ciele: verifikácia vhodnosti použitia analýzy stochastických hraníc v transformujúcom sa primárnom sektore a poskytnutie empirických dôkazov na vysvetlenie štruktúry technickej efektívnosti fariem v sledovanom časovom horizonte rokov 2000-2004. V analýze boli použité dve špecifikácie modelov, Battese a Coelli 1992 so systematicky meniacim sa vplyvom neefektívnosti v čase, a Battese a Coelli 1995 – jednoetapová špecifikácia, ktorá vysvetľuje technickú neefektívnosť založenú na špecifických premenných fariem. Analýza bola uskutočnená na komoditnej úrovni, produkcia pšenice, kde dostupnosť panelu dát umožnila obohatiť výpočet mier technickej efektívnosti o analýzu zmien produktivity v čase.

Kľúčové slová: technická efektívnosť, celková produktivita faktorov, analýza stochastických hraníc

The terms productivity and efficiency have been used frequently in the media over the last ten years by a variety of commentators. They are often used interchangeably, but this is unfortunate because they are not precisely the same things. The production frontier represents the maximum output attainable from each input level. Hence it reflects the current state of technology in the industry. Firms in that industry operate either on that frontier, if they are technologically efficient, or beneath the frontier if they are not technically efficient. Productivity of a firm is the ratio of the output(s) that it produces to the input(s) that it uses. When one considers productivity comparisons through time, an additional source of productivity change, called technological change, is possible. When we observe that firm has increased its productivity from one year to the next, the improvement need not have been from efficiency improvements alone, but may have occured due to technological change or the exploitation of scale economies or from some combination of these three factors.

METHODOLOGY AND MATERIAL

Based on the neo-classical production theory, the dependent variable of the production function should by expressed as the quantity of a given output produced in a given time period as a result of a production transformation of a given input quantity. This definition is followed by the first endogenous variable specification of the stochastic frontier production model, namely

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the output is the amount of a produced commodity in a farm (farm enterprises production), expressed in tons. By using this production definition, we assume that the production quantity is homogenous when comparing the analyzed farms.

Constructing production functions requires further information about inputs equipment in quantity references. Because only cost data is available for production factors, no breakdown between quantity and prices is possible. Since the agricultural production process is a complex activity, not only inputs quantity, but also input quality and functionality have a significant impact on input performance.

The data employed for the stochastic frontier analysis and productivity analysis are taken from a sample of farm data obtained from the Research Institute of Agricultural Economics and Nutrition in Bratislava (VÚEPP) from 2000–2004. The farms in the sample are classified as crop farms or as farms with combined crop and animal production.

To keep the indication of inputs equipment comparable over time and thus to capture technological changes, the cost data expressed in value terms have to be transformed to a constant price basis. Price indices for agricultural inputs, as given in Table 1, were used to deflate the cost data to the base year 2000 and thus to remove price change over time.

To avoid land heterogeneity, the farm enterprises were, due to the inadequate land quality data, selected from one production zone. For our analysis, there was selected the sugar beet production region. The above described production inputs comprise four input variables and one output of the stochastic frontier production models for the selected Slovak farm enterprises:

- own and purchased seed, in SK/ha
- own and purchased fertilizers, in SK/ha
- purchased chemicals, in SK/ha
- land, defined as the hectare area of an i-th farm enterprise, in ha
- wheat production, in tons.

The sample summary statistics for these variables are presented in Table 2. The statistics of the sample categorized with respect to the individual years.

The last variable integrated in the stochastic frontier production function is the time variable t.

Using a time variable (1, 2, 3, 4, 5 for the years 2000, 2001, 2002, 2003 and 2004, respectively) in these models allows for frontier shifts over time, which represents technological change.

Variables of the inefficiency model

The choice and definition of the variables for the inefficiency effect model are complicated by methodological requirements as well as by data availability. The important methodological requirement linked to variable specification is the elimination of potential specification problems such as multicollinearity, heteroscedasticity and the omitted variable problems. We concentrate on preventing the estimation inconsistencies which could be caused by multicollinearity between the inputs variables of the production frontier model and inefficiency determinants included in the second part, the inefficiency effect model, of the Battese and Coelli 1995 (Coelli et al. 1998) specification. Regarding this issue, variables such as size will have to be omitted from one-stage efficiency analysis since it always correlates with the input variables of the production frontier.

To avoid specification errors, when using the variable data, the set of explanatory variables of the inefficiency effect model of the Battese and Coelli 1995 stochastic frontier model specification is contracted to only two variable groups: the general market and economic conditions, and production diversification.

The variables are defined as follows:

- The *general economic and market conditions* are defined by the help of four dummy variables: Z_1 is a dummy variable taking value 1 in the year 2001, and 0 otherwise; Z_2 is a dummy variable taking value 1 in the year 2002, and 0 otherwise; Z_3 is a dummy variable taking value 1 in the year 2003, and 0 otherwise; Z_4 is a dummy variable taking value 1 in the year 2004, and 0 otherwise;

There are several effects which may be captured in these time dummy variables. These are, for instance,

Table 1. Price indices for Slovak agricultural inputs

	2000/1999	2001/2000	2002/2001	2003/2002	2004/2003
Seed	102.6	105.0	105.5	108.0	103.6
Fertilizers	103.5	111.6	103.0	102.6	103.0
Chemicals	107.2	102.5	100.6	100.0	97.6

Source: ŠÚ SR

the effect caused by the macro-economic environment, and the general tendencies of efficiency change over time. When interpreting these parameters, it must be kept in mind that these variables might capture the weather effects on annual yields.

– Production *diversification*, Z_5, is a variable which is, similar to the previous inefficiency variables, expressed by a dummy variable. This dummy variable takes the value 0 if the farm is only cultivating crops and does not have animal production. If the farm has both crop and animal production, the variable Z_5 takes the value 1. Because there is no explicit information about farm product diversification, the incorporation of animal production

Table 2. Summary statistics for variables of the stochastic frontier production model

Variable	mean	max	min	*sd*	*cv*	*N*
Year = 2000						
Production	2 551.17	7 560.00	323.00	1 791.22	0.70	24
Seed	1 771.45	3 427.67	756.44	696.27	0.39	24
Fertilizers	1 635.30	4 611.79	244.60	1 059.41	0.65	24
Chemicals	1 177.96	2419.14	361.93	598.02	0.51	24
Land	682.79	1 502.00	222.00	362.39	0.53	24
Year = 2001						
Production	3 846.54	11 406.00	753.00	2 644.22	0.69	24
Seed	2 099.62	3 006.42	1 098.84	485.47	0.23	24
Fertilizers	2 969.68	4 914.76	1 152.83	1 116.52	0.38	24
Chemicals	1 579.97	3 487.05	404.82	967.74	0.61	24
Land	806.67	3 280.00	215.00	640.22	0.79	24
Year = 2002						
Production	2 864.46	6 949.00	925.00	1 788.97	0.62	24
Seed	1 876.30	2 459.30	674.02	511.64	0.27	24
Fertilizers	2 774.66	5 288.26	1 034.71	1 194.39	0.43	24
Chemicals	1 608.62	3 632.83	427.57	868.63	0.54	24
Land	698.17	1 706.00	236.00	437.18	0.63	24
Year = 2003						
Production	2 241.08	6 397.00	615.00	1 805.70	0.81	24
Seed	1 873.07	3 532.68	224.70	723.92	0.39	24
Fertilizers	2 589.30	4 797.26	638.48	1 088.57	0.42	24
Chemicals	1 608.75	4 682.00	303.06	1 078.67	0.67	24
Land	655.79	1 679.00	152.00	443.50	0.68	24
Year = 2004						
Production	3 747.96	10 019.00	710.00	2 790.54	0.74	24
Seed	2 026.08	2 803.35	1 427.95	429.73	0.21	24
Fertilizers	2 492.58	4 988.03	590.19	1 034.50	0.42	24
Chemicals	1 725.34	3 184.69	538.68	708.82	0.41	24
Land	677.92	2 444.00	161.00	541.63	0.80	24

mean = arithmetic mean, max = maximum, min = minimum, *sd* = standard deviation, *cv* = coefficient of variation, *N* = number of observation

Source: own calculations

in the production spectrum is deducted from the non-zero value of own fertilizers.

Model specifications for empirical application

The Battese and Coelli's 1992 (Coelli et al. 1998) stochastic frontier production model for panel data, where technological inefficiencies of firms may vary systematically over time. This model defines inefficiency coefficients as an exponential function of time.

In the model specification of Battese and Coelli 1995, technical inefficiency effects are explicitly expressed as a function of a vector of firm-specific variables and random error and are integrated in the stochastic frontier model. This one-stage model is recognized as one which provides more efficient estimates than those which could be obtained using the two-stage estimation procedure. Another reason for estimating all parameters in one stage is that, in general, it is hard to distinguish between a variable that belongs to the production function and explanatory variables of the inefficiency model. In the one-stage model, explanatory variables directly influence the transformation of inputs and efficiency is estimated, controlling the influence of explanatory variables of technological inefficiency. This reduces the omitted variable problem in the two-stage estimation. However, it does not solve the problem of multicollinearity, which can cause bias in the estimates of β and TE_i in both approaches of TE explanation (Sotnikov 1998).

The selected Battese and Coelli 1992, and Battese and Coelli 1995 model specifications will be completed by setting a concrete functional form and supplementing it with informational substance. The choice of the functional form of the stochastic production frontier is a serious task of the econometric model specification. The translogarithmic function and the Cobb-Douglas functional form are the two most common functional forms which have been used not only in empirical studies on frontier productions, but in the studies on production behavior in general. In the efficiency analysis, it is of interest what effect the choice of functional form has on empirical measures of technological efficiency.

The Cobb-Douglas function is the simpler and less flexible form, carrying with it more theoretical curvature restrictions and imposing more restrictions on the elasticity of substitution between the factors than the translog function does. The advantage of this functional form is that it allows an examination of economic efficiency because it meets the requirements of self-duality. The Cobb-Douglas form has been used in many empirical studies, particularly those related to agriculture in developing countries, but it also in the studies on transitional agriculture (Sotnikov 1998). However, in the most recent studies, the translog functional form has been used more often for modeling the agricultural frontier production function. The preferential characteristic of this functional form is first of all its flexibility.

The drawback of the translog functional form is that it often does not yield coefficients of a plausible sign and magnitude, possibly due to the degrees of freedom. However, Curtiss (2002) argues that in the TE studies, the estimates of TE are of more importance that the statistical properties of the estimated coefficients. He also states that the most preferred property of the estimation of TE is consistency, while, in general, the most efficient estimator is chosen for the parameters of the production function β.

Based on the above argumentation, the more general translog functional form was chosen for the description of the production frontier behavior of the Slovak farm enterprises. The stochastic frontier production function employing the defined variables has the following form:

$$\ln Y_{it} = \beta_0 + \sum_{j=1}^{4} \beta_j \ln X_{jit} + \beta_t t + \sum_{j=1}^{4}\sum_{k=1}^{4} \beta_{jk} \ln X_{ji} \ln X_{ki} + \frac{1}{2}\beta_{tt} t^2 + \sum_{j=1}^{4} \beta_{tj} \ln X_{jit} + v_{it} - u_{it}$$

where:

Y_{it} = represents the outputs for the i-th farm enterprises (i = 1, 2. …, N, where N is the number of farm enterprises) in the t-th time period (t = 1, 2,…, T; T = 5 and corresponds to 2000, 2001, 2002, 2003 and 2004)

X_{jit} = the j-th input of the i-th farm enterprise in t-th year (j = 1, 2, 3, 4)

where:

X_1 = seed
X_2 = fertilizers
X_3 = chemicals
X_4 = land, and
t = time variable

β = parameters to be estimated

u_{it}, v_{it} = random variables which represent the technical inefficiency effects and statistical noise

If the coefficients of the second-order terms are zero, i.e., $\beta_{jk} = 0$, $j = k = 1, 2 \ldots 5$, the Cobb-Douglas function as a special case of the translog function will describe the production frontier. Further, this stochastic frontier model includes the cross-products of the year of observation and the logged inputs, which specify the non-neutral technical change. However, neutral change is present if the coefficients of the interaction between the years of observation and the inputs are zero, i.e., $\beta_{jt} = 0$, $j = k = 1, 2 \dots 4$. There would be no technological change among the farm enterprises if the coefficients of all variables involving year of observation were zero, i.e., $\beta_t = \beta_{tt} = \beta_{jt} = 0$, $j = k = 1, 2 \dots 4$.

This definition of the stochastic frontier production is identical for both the monotonically time-varying inefficiency model and the non-monotonically time-varying model specification. As defined by Battese and Coelli 1992, the non-negative inefficiency effect, u_{it} is an exponential function of time. Considering the condition of the analyzed time period, the systemically time-varying inefficiency model can be written into an equation,

$$u_{it} = u_i \, exp \, (-\eta \, (t - T))$$

The inefficiency effect model defined by the selected farm-specific variables of a form as proposed by Battese and Coelli (1995) is specified as follows:

$$u_{it} = \delta_0 + \sum_{n=1}^{5} \delta_n Z_{nit}$$

where:

μ = the firm-specific mean of a truncated normal distribution

δ = parameters to be estimated, and indices, *I* and *t*, are as defined earlier

Z_n = the *n*-th independent variable of the *i*-th farm expected to determine the level of technical inefficiency in *t*-th time period ($n = 1, 2, \dots, 5$),

where:

Z_1 = up to Z_4 are the time dummy variables associated with the years 2001 up to 2004,

Z_5 = a dummy variable representing diversification

RESULT AND DISCUSSION

Stochastic frontier production models

The ML estimates of the specification Battese and Coelli 1992 and 1995 models obtained using the software package Frontier 4.1c are presented in Table 3. In the first part of these tables, the parameters of the production frontier are introduced, and in the second part, four additional parameters associated with the distribution of the overall random effect. The estimated individual coefficients in the stochastic frontier productions given by the translog functional form are due to the joint effects of the inputs variables not directly interpretable as in the Cobb-Douglas function and their significance is not directly assessable given the standard errors. Furthermore, the statistical properties of the estimated coefficients of the production frontier are in the TE studies of less importance than the estimates of TE. For the evaluation of the stochastic frontier models, responses to its simplification will be presented by several tests. The tests applied will be the general likelihood-ratio test, λ, which is defined by

$$\lambda = -2[\ell(H_0) - \ell(H_1)]$$

where:

$\ell(H_0)$, $\ell(H_0)$ = the values of a restricted model under the null hypothesis H_0 and of the alternative model under the hypothesis H_1

The hypothesis imposing restriction on the parameters in the stochastic frontier models can be tested using a number of different test statistics. This test statistics is usually assumed to be asymptotically distributed as a chi-square random variable with degrees of freedom equal to the number of restrictions involved (Coelli et al. 1998). The most frequently applied test, or its slight variant, explicitly or implicitly conducted in empirical analyses involving the stochastic frontier model has been the Wald statistics.

Final model selection

No set of restrictions can be defined to permit a test of one specification versus the other since the model specifications applied are non-nested. The frequently used criterion of better statistical properties of an econometric model estimated through the ML method is the logarithmic value of the likelihood function. Another benchmark, derived from the Coelli's (1998) Monte Carlo analysis, is the magnitude of the percentage contribution of the farm inefficiency in the composed total error, denoted by γ. Models with very low γ-parameters should by viewed with caution or discarded if the alternative models with higher γ-parameter exist. Also, the plausibility of the results from the estimation is an important criterion for the choice of the stochastic frontier model specification for the final empirical analysis. If these three criteria do not give an unambiguous answer for the selection, the Akaike Information Criterion (AIC) could be utilized.

The higher logarithmic value of the likelihood function and the higher contribution of TE to the total variability illustrated in Table 4 suggest better statistical properties of the second model specification, Battese and Coelli 1995.

Table 5 shows that given the Battese and Coelli 1995 model specification, the null hypothesis of no non-neutral technical change, $H_0 : \beta_{jt} = 0$, where $j = 1, 2, 3, 4$ is rejected with both statistical tests. This implies that the isoquants do not significantly

Table 3. Maximum-likelihood estimates of parameters of the Slovak wheat stochastic frontier production function

Stochastic frontier model		Battese and Coelli 1992		Battese and Coelli 1995	
		parameters	st. error	parameters	st. error
I	β_0	12.8442	0.9907	8.9096	11.2286
X_1	β_1	–1.2627	0.8813	–0.4942	1.7003
X_2	β_2	–1.2187	0.8495	–0.9175	1.3034
X_3	β_3	–0.3909	0.9075	–0.1084	1.1687
X_4	β_4	0.0799	0.9138	–0.0598	0.9159
t	β_5	0.2912	0.9729	0.1651	0.3368
X_1^2	β_6	0.0746	0.1098	0.0339	0.0857
X_2^2	β_7	–0.0121	0.0649	0.0335	0.0511
X_3^2	β_8	0.1057	0.0750	0.0564	0.0466
X_4^2	β_9	0.0236	0.0517	–0.0139	0.0329
t^2	β_{10}	0.0599	0.0173	0.0149	0.0193
X_1X_2	β_{11}	0.1998	0.1160	0.0265	0.1296
X_1X_3	β_{12}	–0.1257	0.1145	–0.0509	0.0913
X_1X_4	β_{13}	–0.0348	0.1036	0.0544	0.0792
X_1t	β_{14}	–0.0506	0.0813	–0.0222	0.0353
X_2X_3	β_{15}	–0.0418	0.0785	–0.0408	0.0516
X_2X_4	β_{16}	0.0887	0.0824	0.1023	0.0457
X_2t	β_{17}	–0.0435	0.0478	0.0024	0.0257
X_3X_4	β_{18}	0.0335	0.0810	0.0130	0.0456
X_3t	β_{19}	0.0310	0.0368	0.0193	0.0218
X_4t	β_{20}	–0.0271	0.0269	–0.0312	0.0152
Inefficiency effect model					
I	δ_0			0.2298	0.1934
Z_1	δ_1			–0.9261	0.5849
Z_2	δ_2			–0.0893	0.2769
Z_3	δ_3			0.3163	0.2190
Z_4	δ_4			–0.7162	0.5060
Z_5	δ_5			–0.1225	0.1131
	$\delta_s^2 = \delta_v^2/\delta^2$	0.0507	0.0120	0.1018	0.0414
	$\gamma = \delta^2/\delta_s^2$	0.1343	0.1556	0.9587	0.0268
	μ	–0.1650	0.2016		
	η	0.5298	0.2510		
Log likelihood function		6.931	**LR test** 10.12	42.489	**LR test** 81.24

X_1 – seed, X_2 – fertilizers, X_3 – chemicals, X_4– land, t – time variable
Source: own estimation

Table 4. Selection between the B & C 1992 and B & C 1995 specification of the wheat stochastic frontier production models

Model specification		Log LF*	γ-parameter	AIC	Decision
Battese and Coelli 1992	Model I	6.931	0.1343	37.597	NO
Battese and Coelli 1995	**Model II**	**42.489**	**0.9587**	**–32.175**	**YES**

*Logarithmic value of the likelihood function, which relates to the economic preferred model
Source: own estimations

Table 5. Generalized likelihood-ratio and Wald tests of parameters in the Slovak wheat stochastic frontier productions in 2000–2004, defined by the Battese and Coelli 1995 model specifications

Production frontier	Null hypothesis	χ^2-statistics	p-value
Model II a	$\beta_{jt} = 0, j = 1, 2, 3, 4$	4.37[1]	0.3587
		4.32[2]	0.3649
Model II b	$\beta_t = \beta_{tt} = 0$	13.38***	0.0012
		12.60***	0.0018
Model II c	$\beta_t = \beta_{tt} = \beta_{jt} = \beta_{jk} = 0$ $j = k = 1, 2, 3, 4$	30.44**	0.0158
		26.50**	0.0474

[1]χ^2-statistics for Wald test, [2]χ^2-statistics for Generalized likelihood-ratio test
Source: own estimations

change their shape when/if they shift over the five years 2000–2004.

The second statistic provided for the test of the neutral technical change shows a significant parallel shift of the production frontier in 2000–2004 for wheat production at the 1% significance level. A significant technological change can be considered as technological progress due to a positive sign of the parameter, β_t, in Table 3.

The third null hypothesis, in Table 4, of constant input elasticities as given by the Cobb-Douglas technology, $H_0 : \beta_t = \beta_{tt} = \beta j_t = \beta_{jk} = 0, j = k = 1, 2, 3, 4$, is rejected with both statistical tests at the 5% significance level. Thus, in wheat production line, the production elasticities cannot be considered as constant under the given model specification.

Output elasticities

The main tool for the production technology description will be partial output elasticities. They imply to what extent the proportional individual input change, keeping the other inputs constant, is decisive for the proportional change in output quantity. The partial output elasticities for the translog function are farm-specific, which means they do not remain constant over the whole production function.

Partial elasticities of the mean output with respect to the k-th input variable ($k = 1, 2, 3, 4$) for firm i in year t are given as the partial derivation of the non-neutral stochastic frontier production function to the inputs as follows:

Table 6. Output and scale elasticities of the wheat stochastic frontier production function from 2000–2004

Inputs/period	2000	2001	2002	2003	2004
Seed	0.1401	0.1397	0.1392	0.1410	0.1430
Fertilizers	0.1716	0.1770	0.1800	0.1788	0.1775
Chemicals	0.1599	0.1599	0.1638	0.1657	0.1657
Land	0.7835	0.7706	0.7677	0.7704	0.7704
Scale elasticities	1.2552	1.2473	1.2508	1.2559	1.2565

Source: own estimations

$$\frac{\partial \ln[E(Y_{it})]}{\partial \ln X_k} = \left(\beta_k + 2\beta_{kk} \ln X_{kit} + \sum_{j \neq k}^{n} \beta_{kj} \ln X_{jit} + \sum_{j}^{n} \beta_{jt} t\right)$$

The sum of the elasticities of the mean frontier production with respect to all four inputs used in our study generates the scale elasticity. This is related to the concept of return to scale (RTS), which reflects the degree to which a proportional increase in all inputs increases output. This can be decreasing, constant or increasing.

The mean output elasticities estimated using the first proceeding described above, together with the estimates of scale elasticities, are presented in Table 6. The magnitudes of the output elasticities in Table 6 indicate that the utilized proportional change of land in most cases have the highest proportional contribution to the production generation when keeping other variables constant.

Technological efficiency development in 2000–2004

In this section, we focus on the evaluation of the estimated parameters of the stochastic frontier models, which contain information about the strength and direction in which efficiency changed over time. The parameters to be estimated are δ-parameters associated with time dummy variables, Z_1, Z_2, Z_3, Z_4, from the inefficiency effect model when the Battese and Coelli (1995) model specification was used. The significance of time inefficiency effect will be tested using the generalized likelihood-ratio test. The test

Table 7. Generalized likelihood-ratio tests of the time parameters in the Slovak wheat inefficiency effect model in 2000–2004

	χ^2-statistics	χ^2 0.01 (0.05)
$H_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$ No time effect	40.7943***	11.6678 ($\chi^2_{0.01}$) 7.7794 ($\chi^2_{0.05}$)

*** indicate the significance of the effect at the 1% significance level
Source: own estimations

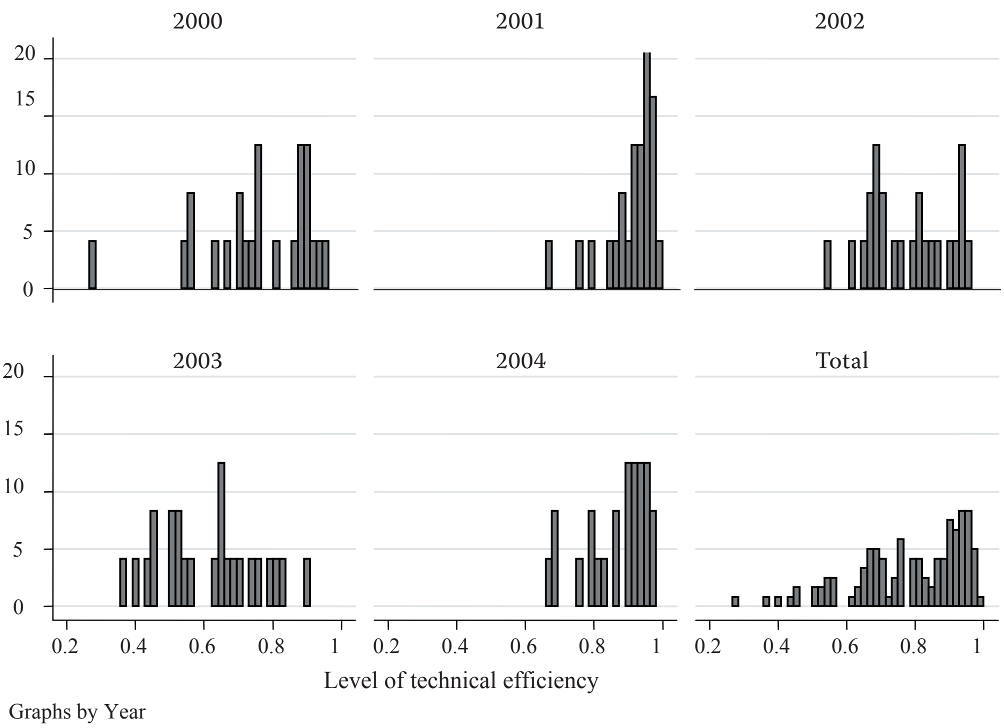

Figure 1. Distribution of technological efficiencies for Slovak wheat farm enterprises in 2000–2004
Source: own figure

Table 8. Technical efficiencies of wheat production in 2000–2004

	2000	2001	2002	2003	2004
TE	0.7587	0.9086	0.7764	0.6141	0.8655
Base index (%)	–	19.75	2.32	–19.06	14.07

Source: own estimations

results are presented in Table 7. The null hypothesis $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$, that macro-economic, market, legal, and also weather conditions captured in the time dummy variables do not change the level of technological efficiency, is rejected at the 1% significance level in wheat production.

Under these circumstances, it is important to determine which trend, improvement or worsening of the TE scores is captured in the δ's parameters values. Positive δ-parameters indicate an increasing effect of the environmental factors on the inefficiency levels, while negative parameters decrease inefficiencies, and thus improve technological efficiencies. These parameters are presented in inefficiency effect model in Table 2. The negative values of the δ_1, δ_2 and δ_4 parameters indicate significant positive development of wheat technological efficiency. In the years 2001, 2002 and 2004 we can expect a higher level of technological efficiency in comparison with the year 2000. Positive value of the δ_3-parameters indicate significant positive effect of the environmental factors on the inefficiency level. We can expect the lowest level of the technological efficiency of wheat production in the year 2003 in comparison with the year 2000.

The wheat seed technological efficiency estimates are significantly influenced by bad weather conditions in the hibernation period of 1999/2000 and by the poor wheat production in 2003. Even if these circumstances affected most of the farmers, there still remained farmers which achieved usually high yields. The Green Report (Zelená správa) explains the increase of the average wheat yields in 2004 in relation to the increased cultivated area, good wheather conditions and the improved agrotechnical use of the seed potential.

In the Table 8, we can view the concrete values of the technological efficiency in the individually analyzed years. The weather impact should be distinguished from the economic changes in efficiency measures. Based on the Green Reports (Zelená správa), bad weather condition affected wheat production in 2000 and 2003. In other analyzed years, there was experienced a relatively favorable weather impact on wheat yields. The efficiency distribution is graphically presented in the histogram in Figure 1. The distributions of wheat production technological efficiency are negatively skewed in the analyzed period 2000–2004.

The last variable included in the technological and revenue inefficiency effect model of the Battese and Coelli 1995 was the dummy variable representing the production diversification, Z_5. Farm production was defined as diversified when the farm's activity included crop production as well as animal production. Farms which concentrate their activity on crop production only are assigned as specialized farms. The significance of the effect of farm diversification on the TE level is tested by the help of the generalized likelihood-ratio test. The test of the null hypothesis, that diversification does not affect the technological efficiency scores, $\delta_5 = 0$, was accepted in the wheat production. In other words, the differences in wheat technological efficiency between farms with diversified production and farms which concentrate on crop production are insignificant.

Total factor productivity change

In the previous section, we described the wheat production over the analyzed time period based on the partial output elasticities and the estimated parameters relevant for the non-neutral shifts of the production frontier. All the analyzed factors were relevant for the efficiency explanation. We still have not evaluated the efficiency development over time. However, productivity development tendencies are not easy to obtain from the efficiency scores development over time without a simultaneous evaluation of technical changes. Measures of the overall or total factor productivity (TFP) changes will be the subject of this section.

To investigate the total factor productivity changes, we use the Malmquist TFP index to evaluate productivity development over the analyzed period considering the main farm categories. The Malmquist TFP index contains the efficiency change element and the technical change element. The efficiency change

Table 9. Technological, efficiency and productivity changes in Slovak wheat production in the period 2000–2004

Time period	Technical change (TC)	Efficiency change (EC)	Total factor productivity change (TFP)
2000–2001	1.0647	1.2668	1.3487
2001–2002	1.0089	0.8553	0.8629
2002–2003	1.1747	0.8017	0.9417
2003–2004	1.1480	1.4783	1.6970
Geometric mean	1.0919	1.0645	1.1680

Source: own estimations

element of the Malmquist TFP index, $EC_{i(t+1)/t}$, for time $t + 1$ and t, can be calculated as follows:

$$EC_{i(t+1)/t} = \frac{TE_{i(t+1)}}{TE_{it}}$$

which is the ratio of the individual TE levels in time t and $t + 1$. The technological change index, $TCH_{i(t+1)/t}$, which represents the second element of the Malmquist TFP index, can be conveniently calculated using the partial derivates of the production frontier with respect to time. Since technical change is non-neutral and the technological change index can vary for different input vectors, Coelli, Rao, Battese (1998) suggest using a geometric mean of the partial derivates for the two adjacent periods,

$$TCH_{i(t+1)/t} = \left\{\left[1 + \frac{\partial f\left(x_{i(t+1)},(t+1),\beta\right)}{\partial (t+1)}\right] \times \left[1 + \frac{\partial f\left(x_{it},t,\beta\right)}{\partial t}\right]\right\}^{0.5}$$

The technological change and efficiency change indices multiplied together then give the Malmquist TFP index, as follows:

$$TFP_{i(t+1)/t} = EC_{i(t+1)/t} \times TCH_{i(t+1)/t}$$

The calculated technological and efficiency change indices, together with the Malmquist TFP indices for the wheat production, for the adjacent periods and then for the whole analyzed period 2000–2004, are presented in Table 9.

The Malmquist TFP index for wheat production indicates an overall improvement in productivity in average by 16.8 percent over the analyzed period 2000–2004. Nonetheless, this should be viewed with caution since the significant decline or improvement in the TFP index was very likely caused by weather conditions. These weather conditions had a negative impact on wheat production in 2002, 2003 and positive impact in 2001 and 2004.

CONCLUSION

This study utilized the stochastic parametric approach for efficiency measurement because of its characteristics considering random effects related to both agricultural production generation and measurement problems, and the efficiency results' testability. Two SFM specification were employed, the Battese and Coelli 1992 specification with the systematically time-varying inefficiency effect, and the Battese and Coelli 1995 one stage specification explaining technical inefficiency based on farm-specific variables. Most of the empirical results of the SFA application show that the more complex Battese and Coelli 1995 SFM specification predicting TE by a detailed modeling of variables influencing the statistical distribution of the technical inefficiency allows for a better and more comprehensive production response analysis. The methodological part of the SFA has generated the conclusion of providing a better result for policy decision-making and remedying the low frequency of utilizing the prosperous SFA approaches of the efficiency analysis.

The quality of results obtained by the SFA is determined by the quality of input data. Problems connected with the validity of data will exist if farmers are not able to understand the fact that giving true data can lead to obtaining results of a higher quality. Consequently, these results can be used by the farmers to make their own decisions. Also the employees, who deal with primary data, should approach obtaining data and their primary processing with high responsibility.

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