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Comparison of Multi-Output Frontier Models: Application to Slovak Agriculture

Bohuš Kollár, Zlata Sojková

Abstract: *In this paper the multiple output distance function is used to investigate the technical efficiency of the Slovak agricultural subjects. The main aim of this paper is to compare the results of two chosen stochastic frontier models, namely ratio model and ray model. Furthermore, the effect of Common Agricultural Policy subsidies on the efficiency of farms is estimated. The technical efficiency is studied on the balanced panel data consisting of 308 agricultural subjects for the 7 periods of years 2007-2013. The data is drawn from the Information Sheets of the Ministry of Agriculture and Rural Development of Slovak Republic. The applied distance functions eliminate the main disadvantage of the stochastic frontier analysis. Hence, allowing for the multiple outputs in the analysis. In this paper, there are two outputs considered, namely animal breeding revenues and crop production revenues. The main findings of this paper are similar to the results of previous research. There is a high degree of correlation between the models` estimated efficiencies. The correlation coefficients range from 0.71 to 0.82 for the studied period. Furthermore, the pairwise comparison of the efficiency scores proves no significant difference between the models` estimations. Considering the effect of the subsidies on the efficiency of farms, both models prove the statistically significant impact of the non-investment subsidies. The considered ratio model and ray model not only give similar efficiency estimates, but also similar interpretation of the chosen variables.*

Key words: Agriculture · Efficiency · Multiple Output · Ratio Model · Ray Model · Stochastic Frontier Analysis · Subsidies

JEL Classification: C33 · C52 · H21 · Q14

1 Introduction

There are several ways in which the production technology can be represented. Describing such a technology is mostly performed applying the production, cost, profit or revenue functions. Additionally, input and output distance functions can be used in the research of a production technology (Coelli and Perelman, 1998). Motivation for empirical estimation is to calculate the efficiency of studied decision making units (DMUs).

The main advantage of distance function application is that it allows for the multiple-input, multiple-output technology. However, most of the analyses apply only one of the methods to estimate the efficiency. Studies by Coelli and Perelman (1998), Zhang and Garvey (2008) or Rashidgalam et al. (2016) compare results of various distance functions.

Traditionally, there are two main groups of methods to measure efficiency, namely:

- linear programming model – data envelopment analysis (DEA),
- econometric model – stochastic frontier analysis (SFA).

Methods mentioned above have their advantages and disadvantages. DEA can be quite easily used for the multiple-input, multiple-output technology estimation and does not require the specification of the functional form of the production frontier. On the other hand, as a deterministic method, DEA does not account for the statistical noise and all the deviations from the frontier are assigned to the inefficiency of the DMU. SFA handles the statistical noise, but requires the underlying functional form of the production frontier. In addition, the SFA cannot be directly used for the multiple-input, multiple-output frontier estimation. Certain adjustments have to be made in order for SFA to be suitable for multi-product analysis. Such adjustments result in two types of models compared in this paper:

- stochastic distance function model or ratio model (Fare et al., 1993, Lovell et al., 1994),
- stochastic ray frontier (Lothgren, 1997).

Ing. Bohuš Kollár, Slovak University of Agriculture in Nitra, Faculty of Economics and Management, Department of Statistics and Operational Research, Tr. Andreja Hlinku 2, 94901 Nitra, e-mail: xkollarb@is.uniag.sk

prof. Ing. Zlata Sojková, Slovak University of Agriculture in Nitra, Faculty of Economics and Management, Department of Statistics and Operational Research, Tr. Andreja Hlinku 2, 94901 Nitra, e-mail: zlata.sojkova@is.uniag.sk

Furthermore, there are alternative approaches to estimating the technical efficiency in the stochastic frontier models. Acquah and Onumah (2014) compared Jondrow et al. (1982) and Battese and Coelli (1988) approaches. Most of the papers apply only one of these approaches. Exception is Hoyo et al. (2014). Results of the co-existing approaches of estimation based on the simulated data show that although the actual values differ, there is strong positive correlation between results. The difference exists in the variance of the efficiency scores where Battese and Coelli (1988) approach gives results with smaller variance (Acquah and Onumah, 2014).

Efficiency in agriculture

Analysis in this paper focuses on the Slovak agricultural subjects. Agriculture is typical for the multiplicity of outputs. Most of the agricultural subjects produce crop and animal outputs. Agriculture and Common Agriculture Policy (CAP) subsidies are subject of the number of studies focusing on the efficiency of farms and the impact of the subsidies.

As mentioned earlier, the estimation of the efficiency is usually conducted with the application of the DEA or the SFA. Applying the SFA, the efficiency of Slovak and Czech milk producers was compared. Metafrontier multiple output distance function revealed regional differences, where only West Slovak regions could keep up with competitors from Czech Republic (Čechura et al., 2014). Using the same approach (i.e. SFA) the impact of subsidies from the Rural Development Programme 2007-2013 was studied for the Czech Republic by Pechrová (2015). Results for the panel data on 454 farms show statistically significant differences of efficiency between supported and unsupported farms. Furthermore, applying the contrafactual analysis, the impact of the investment support measures was researched by Medonos et al. (2012). The analysis shows, that the bigger farms were favoured as these have easier access to loans and hence, easier access to investment subsidies. In addition, the investment support had positive effect on the added value and productivity.

The SFA was further applied in the research of the technical efficiency of organic and biodynamic farms in Czech Republic. Applying the Cobb-Douglas specification with one output on the panel data of years 2005-2012 suggests that the subsidies had positive effect on the production possibilities. (Pechrová and Vlašicová, 2013). On the other hand, multiple-output distance function was used in comparison of EU countries` crop production. The estimation results proved no significant differences between efficiencies of the countries. Given the CAP goal of improving the competitiveness of the farms, this occurred in 6 old and 2 new member states, i.e. moved nearer to production frontier (Čechura et al., 2015).

For the further research on the efficiency in agriculture see Brummer et al. (2016), Pechrová (2014), Revoredo–Giha (2009), Madau (2011).

The paper is organized as follows, section 2 describes the methods of efficiency estimation and data used in this paper, section 3 describes the obtained results, section 4 concludes.

2 Methods

As mentioned before, the aim of this paper is two-fold. The focus is put on the comparison of the two SFA approaches of efficiency estimation, namely:

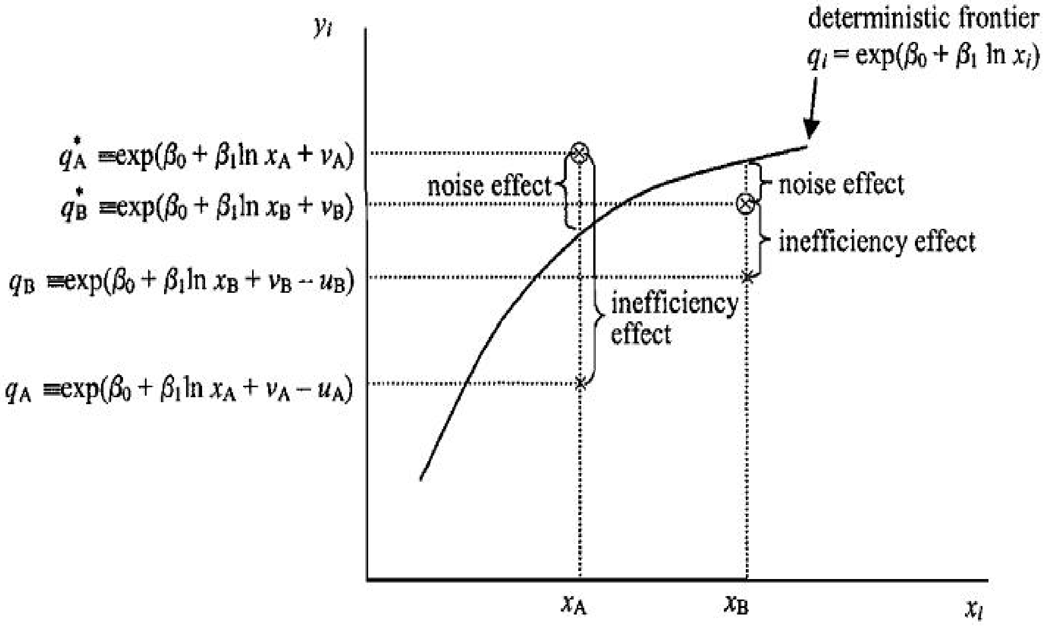
- stochastic distance function model or ratio model (Fare et al., 1993, Lovell et al., 1994),
- stochastic ray frontier (Lothgren, 1997).

Initially proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) the SFA allows for the estimation of the production function model given by the Equation 1:

$$ln(y) = \alpha + \beta * ln(x_i) + v_i - u_i \tag{1}$$

The SFA accounts for the fact that the quantity of i's firm output is influenced not only by the efficiency of a subject but also by the noise effect (v_i). Deviation from the frontier is known as the compound error term, where the noise effect (v_i) represents impact of random external factors and can be positive or negative (Greene, 2008). Therefore, SFA model (Eq. 1) consists of three parts, namely deterministic frontier, noise effect and inefficiency (Figure 1)

Figure 1 Three parts of the stochastic frontier



Source: Coelli et al., 2005

Measure of *i*'s farm technical efficiency (TE) is computed as:

$$TE_i = \exp(-u_i) \tag{2}$$

This measure (Eq. 2) takes values 0 - 1 and represents quantity of *i*'s farm output relative to the output achievable if the inputs had been used efficiently. The SFA assumptions are:

- v_i is symmetrically distributed,
- v_i and u_i are independent and identically distributed variables,
- v_i is distributed independently of u_i and both error terms are uncorrelated with the explanatory variables,
- v_i and u_i are homoskedastic (Coelli et al., 2005).

2.1 Stochastic distance function for multiple output technical efficiency

The major disadvantage of the SFA is that only one output can be included in the analysis. Fare et al. (1993) introduced the distance function in estimating the multiple product technology. The technology is specified as a translog function. However, the value of the distance function cannot be directly estimated. An approach to overcome this problem was suggested by Lovell et al. (1994, Eq. 3)

$$lnD_i(X,Y) = lnY_L + lnD_i(X,Y/Y_L) \tag{3}$$

In the Eq. 3, the Y is a vector of outputs of dimension L and Y_L is arbitrarily chosen output. However, Eq. 3 has to be further adjusted to the final form, which can be then estimated (Eq. 4, Zhang and Garvey, 2008)

$$-lnY_L = \alpha_0 + \sum_{k=1}^{K} \alpha_k lnX_k + \sum_{l=1}^{L} \beta_l \, ln\left(\frac{Y_l}{Y_L}\right) + \frac{1}{2}\sum_{k=1}^{K}\sum_{k`=1}^{K} \alpha_{kk`} lnX_k lnX_{k`} + \sum_{k=1}^{K}\sum_{l=1}^{L-1} \gamma_{kl} lnX_k ln\left(\frac{Y_l}{Y_L}\right) + U_i$$
$$+\frac{1}{2}\sum_{l=1}^{L}\sum_{l`=1}^{L} \beta_{ll`} ln\left(\frac{Y_l}{Y_L}\right) ln\left(\frac{Y_{l`}}{Y_L}\right) \tag{4}$$

From the Eq. 4, the technical efficiency can be calculated as:

$$TE_i = \exp(-U_i) = D_i(X,Y) \tag{5}$$

2.2 Stochastic ray frontier

Lothgren (1997) generalized the multi-output ray function using a polar-coordinate angle output vector. This function can be rewritten as:

$$Y = \|Y\| \cdot m(\theta) \tag{6}$$

$$\|Y\| = (\sum_{i=1}^{P} Y_i^2)^{1/2} \tag{7}$$

In Eq. 7, the *P* represents the number of outputs.

Applying the number of adjustments, the natural log-linear stochastic ray function suitable for the empirical analysis can be written as:

$$\|Y\| = \alpha_0 + \sum_{k=1}^{K} \alpha_k lnX_k + \sum_{l=1}^{L} \beta_l ln\theta_l + \frac{1}{2}\sum_{k=1}^{K}\sum_{k`=1}^{K} \alpha_{kk`} lnX_k lnX_{k`} + \frac{1}{2}\sum_{l=1}^{L}\sum_{l`=1}^{L} \beta_{ll`} ln\theta_l ln\theta_{l`} + \sum_{k=1}^{K}\sum_{l=1}^{L} \gamma_{kl} lnX_k ln\theta_l - U \tag{8}$$

In Eq. 8, the θ stands for the polar-coordinate angle, K denotes the number of inputs and L equals *P-1*. Note that *P* represents the number of outputs.

For more details see Zhang and Garvey (2008).

2.3 Data and variables

In this paper, the efficiency of Slovak agricultural subjects is studied with the main aims of comparing the two SFA methods and assessing the impact of CAP subsidies on the efficiency of farms. Both methods described earlier are applied on the same balanced panel data consisting of 308 farms for the years 2007-2013. The data is drawn from the Information Sheets of the Ministry of Agriculture and Rural Development of Slovak Republic. Given the data`s financial nature, the appropriate indices drawn from the Eurostat are used to adjust for inflation and to express the financial entries in the 2014 prices.

The analysis is conducted using the crop revenues and animal breeding revenues as the outputs. For the stochastic distance function the animal revenue output is chosen as the Y_L (see previous chapter). The inputs are capital, average wage, farmed land (area), long-term assets acquirement (LTAA) and total amount of subsidies. Investment subsidies, non-investment subsidies, national additional payment, LTAA and subsidies from the Rural Development Programme 2007-2013 are used for the explanation of the variance of the inefficiency.

3 Research results

The results are obtained with the use of two statistical programmes. The stochastic ray frontier is modelled in the R-software. The rest of the analysis, i.e. the stochastic distance function and comparison of results is conducted in the STATA 13.

3.1 Frontier models estimation

The stochastic distance function model is presented in Table 1, stochastic ray function in Table 2. Following the previous chapter, estimation of both models is conducted using the same dataset of 308 farms for the years 2007-2013, which is also the programming period for the Rural Development Programme (RDP).

Comparing the two models (Table 1 and Table 2), the highest coefficient in both frontier models is estimated for the variable Wage, i.e. this variable has the highest elasticity. Furthermore, both models` results signify negative impact of the long-term assets acquirement and the amount of subsidies on the production level. However, the significance of these variables differs. Given the fact that the panel data is used, one of the variables of the interest is the time variable. It can be concluded that neither of the considered models proved the time variable to be statistically significant.

Table 6 Stochastic distance function model

Variable	Coef.	Std. Err.	z	P>|z|	95% Conf. Interval	
Capital	1.481	0.865	1.710	0.087	-0.215	3.177
Wage	18.064	4.053	4.460	0.000	10.120	26.008
Farmed land	8.388	2.544	3.300	0.001	3.401	13.375
LTAA	-0.266	0.600	-0.440	0.657	-1.442	0.910
Subsidies	-8.568	2.015	-4.250	0.000	-12.518	-4.618
Time	0.863	0.665	1.300	0.194	-0.440	2.167
Crop / Animal	0.266	0.032	8.190	0.000	0.202	0.330
Capital*Capital	4.264	0.590	7.230	0.000	3.108	5.420
Capital*Wage	-0.998	0.164	-6.100	0.000	-1.318	-0.677
Capital*Farmed land	-1.180	0.148	-8.000	0.000	-1.470	-0.891
Capital*LTAA	-0.079	0.031	-2.540	0.011	-0.140	-0.018
Capital*Subsidies	0.633	0.124	5.120	0.000	0.391	0.876
Capital*Time	0.024	0.102	0.230	0.817	-0.176	0.224
Wage*Wage	-1.968	0.477	-4.120	0.000	-2.903	-1.033
Wage*Farmed land	-0.763	0.515	-1.480	0.139	-1.773	0.247
Wage*LTAA	0.122	0.130	0.940	0.348	-0.133	0.377
Wage*Subsidies	1.472	0.424	3.470	0.001	0.641	2.303
Wage*Time	0.326	0.140	2.320	0.020	0.051	0.601
Farmed land*Farmed land	1.371	0.262	5.240	0.000	0.858	1.884
Farmed land*LTAA	0.113	0.099	1.140	0.253	-0.081	0.308
Farmed land*Subsidies	-1.030	0.278	-3.700	0.000	-1.576	-0.484
Farmed land*Time	0.335	0.188	1.780	0.075	-0.033	0.704
LTAA*LTAA	0.022	0.005	4.130	0.000	0.012	0.033
LTAA*Subsidies	-0.053	0.066	-0.810	0.420	-0.182	0.076
LTAA*Time	0.079	0.053	1.470	0.141	-0.026	0.184
Subsidies*Subsidies	0.128	0.021	5.990	0.000	0.086	0.170
Subsidies*Time	-0.453	0.158	-2.870	0.004	-0.762	-0.143
Time*Time	-0.607	0.087	-7.000	0.000	-0.777	-0.437
(Crop/Animal)*Capital	-0.039	0.018	-2.150	0.031	-0.074	-0.004
(Crop/Animal)*Wage	-0.313	0.065	-4.780	0.000	-0.441	-0.184
(Crop/Animal)*Farmed land	-0.302	0.044	-6.890	0.000	-0.387	-0.216
(Crop/Animal)*LTAA	0.002	0.013	0.190	0.849	-0.023	0.028
(Crop/Animal)*Subsidies	0.419	0.042	9.860	0.000	0.336	0.502
(Crop/Animal)*Time	-0.072	0.026	-2.750	0.006	-0.124	-0.021
Constant	-59.002	20.154	-2.930	0.003	-98.504	-19.500
lnsig2v	-2.361	0.096	-24.610	0.000	-2.549	-2.173
Inefficiency model						
Subsidies	-0.403	0.039	-10.400	0.000	-0.478	-0.327
Non-invest. Subs.	0.027	0.074	0.370	0.715	-0.118	0.173
Invest. Subs	-0.006	0.015	-0.400	0.686	-0.035	0.023
Top-up payment	-0.029	0.015	-1.850	0.064	-0.059	0.002
Non-invest RDP	0.163	0.012	14.060	0.000	0.140	0.186
Invest. RDP	0.010	0.016	0.600	0.545	-0.022	0.042
LTAA	-0.191	0.040	-4.780	0.000	-0.270	-0.113
Constat	6.693	0.853	7.850	0.000	5.021	8.365

Source: Own processing

Table 7 Stochastic ray model

Variable	**Coef.**	**Std. Err.**	**z**	**P>|z|**
Capital	2.180	1.207	1.805	0.071
Wage	16.925	2.569	6.589	0.000
Famed land	0.366	0.478	0.767	0.443
LTAA	-1.375	0.467	-2.942	0.003
Subsidies	-0.720	0.441	-1.634	0.102
Time	0.072	1.080	0.067	0.947
Capital*Capital	0.649	0.065	9.947	0.000
Capital*Wage	-0.273	0.127	-2.160	0.031
Capital*Famed land	-0.087	0.030	-2.882	0.004
Capital*LTAA	-0.133	0.027	-4.895	0.000
Wage*Wage	-1.848	0.252	-7.344	0.000
Capital*Subsidies	-0.035	0.022	-1.635	0.102
Wage*Famed land	-0.010	0.048	-0.215	0.830
Capital*Time	-0.887	0.061	-14.527	0.000
Wage*LTAA	0.160	0.050	3.215	0.001
Wage*Subsidies	0.070	0.051	1.355	0.175
Wage*Time	-0.812	0.117	-6.946	0.000
Famed land*Famed land	-0.033	0.016	-1.989	0.047
Farmed land*LTAA	0.001	0.009	0.072	0.942
Farmed land*Subsidies	0.015	0.012	1.282	0.200
Farmed land*Time	1.144	0.039	29.362	0.000
LTAA*LTAA	0.099	0.009	10.636	0.000
LTAA*Subsidies	-0.003	0.008	-0.417	0.677
LTAA*Time	-0.230	0.028	-8.192	0.000
Subsidies*Subsidies	0.029	0.007	3.973	0.000
Subsidies*Time	-0.059	0.027	-2.162	0.031
Time*Time	-0.237	0.153	-1.544	0.123
Constant	-66.051	13.857	-4.767	0.000
Inefficiency model				
Subsidies	-0.016	0.097	-0.167	0.868
Non-invest. Subs.	0.239	0.139	1.716	0.086
Invest. Subs	-0.065	0.042	-1.541	0.123
Top-up payment	-0.031	0.024	-1.272	0.203
Non-invest RDP	0.429	0.076	5.623	0.000
Invest. RDP	0.017	0.043	0.388	0.698
LTAA	-0.858	0.113	-7.577	0.000
sigmaSq	3.130	0.603	5.187	0.000
gamma	0.958	0.009	105.409	0.000

Source: own processing

For both models, there are variables chosen for the explanation of the inefficiency term, as described in the previous chapter. Once again, the models (Table 1 and Table 2) give similar results. The variables non-investment subsidies from the RDP 2007-2013 and long-term assets acquirement proved to be statistically significant with the same direction of the relation to the inefficiency. While the non-investment RDP subsidies appear to increase the variance of the inefficiency term, the long-term assets acquirement significantly decreases such variance. Other variables chosen for the explanation of the inefficiency term did not prove to be statistically significant.

3.2 Comparison of the efficiency scores

Estimation of the efficiency scores follows the estimation of the models. The comparison is conducted with the use of correlation coefficient and the test of equality of medians. The higher the correlation coefficient, the tighter the results of stochastic distance function and stochastic ray function. The null hypothesis for the chosen test states that the medians of models` efficiency scores are equal. If the null hypothesis stands, we consider the results of the models to be the same, i.e. neither of the models gives out significantly higher (lower) efficiency scores. (Table 3).

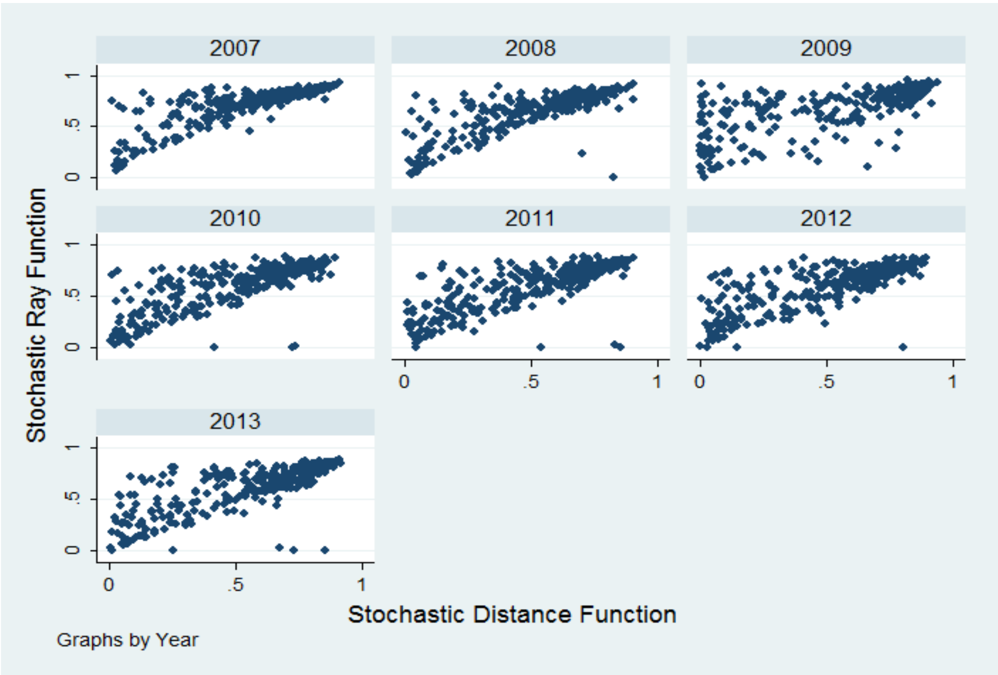
Table 8 Comparison of distance and ray function efficiencies

Year	Correlation Coefficient	Equality of medians
2007	0.8155	1.0000
2008	0.7944	1.0000
2009	0.7098	1.0000
2010	0.7707	1.0000
2011	0.7797	1.0000
2012	0.7645	1.0000
2013	0.7765	0.9974

Source: own processing

Table 3 documents the results of the comparison of the stochastic distance function and stochastic ray function. Estimated efficiency scores of the models prove to have high correlation for each year. The correlation is the highest in the year 2007 with the value 0.8155 and ranges from 0.7098 to 0.8155. Although the actual efficiency scores differ, such correlations signify the fact that the models give out similar results.

Figure 2 Efficiency scores scatterplot



Source: own processing

Furthermore, the pairwise comparison of the efficiency scores proves no significant difference between the models` estimations. The test`s null hypothesis is not rejected in any of the studied years. Therefore, it can be concluded that the models` efficiency scores are not only highly correlated, but there is no significant difference between them.

The relationship between the model`s efficiency scores can be further seen in the Figure 2. Scatterplots document the previously obtained results of the high positive correlation, where only small number of farms is estimated with highly different efficiency scores. Once again, the matched pairs test proved that there is not significant difference in scores. The scatterplots for the studied period depict strong linear relationship between the models` efficiencies.

4 Conclusions

The main aim of this paper was to compare the results of two stochastic frontier methods applicable to the multiple output, multiple input technology. Namely, these approaches are the stochastic distance function and stochastic ray function. The comparison of these methods is conducted on the sample of 308 Slovak farms for the period of years 2007-2013. In addition, the impact of the CAP subsidies is assessed using both mentioned approaches.

Firstly, both models give similar frontier coefficients and efficiency scores estimation. Both models estimate the statistically significant impact of the non-investment RDP 2007-2013 subsidies and long-term assets acquirement on the variance of the inefficiency term. Furthermore, both models indicate the same direction of the impact of these variables.

Secondly, given the estimated efficiency scores, there is a high degree of correlation between models` results. The correlation coefficients for the studied years do not fall under 0.70 and go as high as 0.82. In addition to this, comparison of medians of efficiency scores proves no significant difference in model`s estimates and scatterplots depict linear relationship between estimates.

To sum up the results, both of methods used in this paper support the conclusion of previously conducted research, i.e. that both multiple output stochastic frontier approaches offer similar efficiency estimates.

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