System Dynamics and Innovation in Food Networks 2014

Proceedings of the 8th International European Forum on System Dynamics and Innovation in Food Networks, organized by the International Center for Food Chain and Network Research, University of Bonn, Germany
February 17-21, 2014, Innsbruck-Igls, Austria
officially endorsed by

EAAE(European Association of Agricultural Economists)
IFAMA (International Food and Agribusiness Management Assoc.)
AIEA2 (Assoc. Intern. di Economia Alimentare e Agro-Industriale)
CIGR (Intern. Commission of Agric. and Biosystems Engineering)
INFITA (Intern. Network for IT in Agric., Food and the Environment)

edited by

U. Rickert and G. Schiefer

ISSN 2194-511X

Efficiency of Milk Processing Companies – Parametric and non-Parametric Approaches[1]

Sebastian Jarzębowski, Agnieszka Bezat-Jarzębowska
Department of Economics and Organisation of Enterprises
Warsaw University of Life Sciences
sebastian_jarzebowski@sggw.pl, agnieszka_bezat_jarzebowska@sggw.pl

Abstract

In the paper, the authors considered estimation of efficiency, which measures the ability of a company to obtain the maximum output from given inputs. The comparison of results obtained by using two approaches: parametric (on the example of the SFA method, Stochastic Frontier Analysis) and non-parametric (on the example of the DEA method, Data Envelopment Analysis) has been carried out. Data from the companies of a key food processing sector in Poland, namely the milk processing sector, was used in the paper. This sector was chosen due to the large size of the sample, as well as the strategic importance and significant contribution to the production of the entire agri-food sector. Furthermore, with respect to the milk processing sector there are no comparative analyzes carried out, which justifies the need for their conduction. The analysis covered the period 2006-2011, the sample included from 103 up to 160 enterprises (depending on the analyzed year).

Basing on the conducted analysis it was claimed that the integral use of the SFA and the DEA methods– combining advantages of both methods – allows preserving the analogy when comparing the results and formulating reliable conclusions.

Key words: *efficiency, the SFA method, the DEA method, food processing sector*

1 Introduction

The aim of the article was to assess the efficiency of milk processing enterprises that have a central position in the sector. The analysis was carried out using the SFA (Stochastic Frontier Approach) and the DEA (Data Envelopment Analysis) method. This sector was chosen due to the large size of the sample, as well as the strategic importance and significant contribution to the production of the entire agri-food sector. Furthermore, with respect to the milk processing sector there are no comparative analyzes carried out, which justifies the need for their conduction.

In order to indicate the place of milk processing enterprises in the supply chain the analysis of the chain's structure has been carried out.

Agricultural farms are the first stage in the milk supply chain. The need to compete with high productive Western European agriculture and increasing sanitary and veterinary requirements contributed to the concentration of milk production in Poland [Rudziński 2010, pp. 158]. However, despite the progress, Polish milk industry has been still in an initial period of concentration after nearly 20 years of transformation [Morkis 2010, pp. 52]. The largest part, almost 75% of domestic milk production, goes to the milk processing industry [9013 million PLN]. Self-supply represents more than 19% (2300 million PLN), while sales to other sectors of industry and other sales are of marginal importance [Seremak-Bulge et al. 2012, pp. 11].

Milk processing companies are the next stage of the supply chain. They are the biggest group of companies functioning in the Polish market. They are organized in the form of cooperatives or independent plants [Rudziński 2010, pp. 176]. Some companies produce for local markets, and some for domestic and international

[1] Research granted by National Science Centre from the funds for science in years 2011-2013 as a scientific project no 2011/01/B/HS4/02612 „Stopień integracji w łańcuchu dostaw a efektywność przedsiębiorstw przetwórstwa rolno-spożywczego" ("Degree of integration in supply chain and efficiency of food processing enterprises"). The project was financed by the National Science Centre - number of decision DEC-2011/01/B/HS4/02612.

markets, using direct and indirect distribution channels. Indirect distribution involves moving the goods first to high-bay warehouses, and then to shopping centers which are available for wholesalers and retail stores. In contrast, direct channel of distribution involves sales on the spot in brand stores. However, this distribution channel is of marginal importance as the brand stores have been almost completely closed in the milk industry. Wholesalers are the primary customers of dairies [Morkis et al. 2010, pp. 58].

The structure of the milk supply chain includes farmers (suppliers of milk), purchase and sales, the food processing industry producing milk products, wholesale traders (sale of processed milk to other companies), retail (retail networks, traditional trade) providing milk product for final customers (Figure 1).

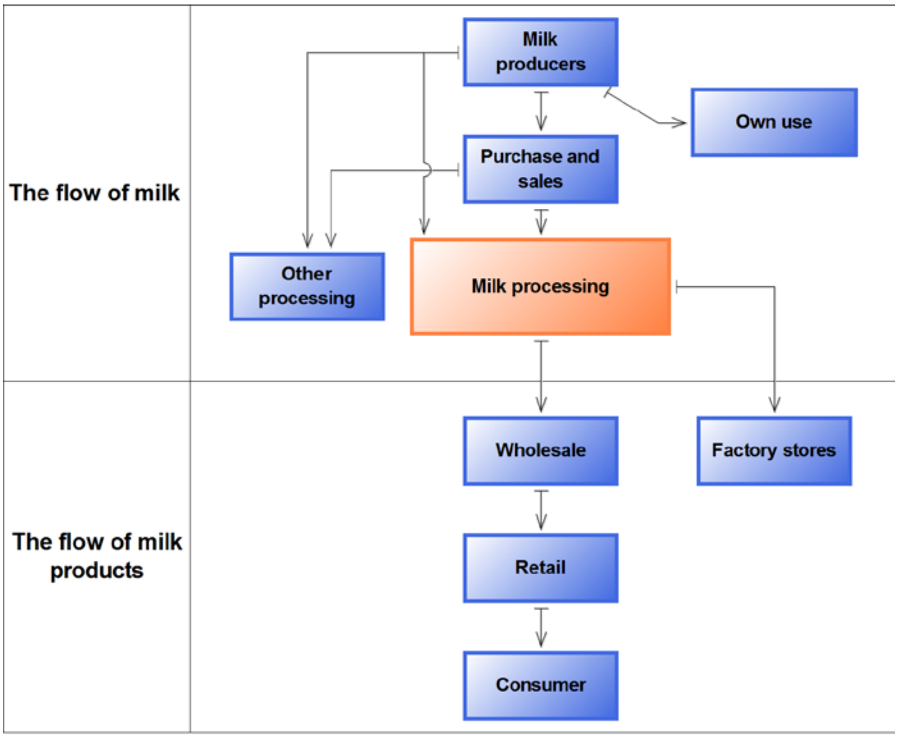

Figure 1. The structure of the supply chain of milk products
Source: own work.

In the next part of the paper, the efficiency analysis was conducted for the processing stage of the milk supply chain.

2 Efficiency of companies

A company operating on a competitive market seeks possibilities for maximization of expected profit by increasing production, especially by non-decreasing returns to scale[2]. Researchers confirm that the output growth in the agri-food sector is determined by a growth of demand for agri-food products occurring at a specific time[3]. The low growth rate of demand for agri-food products can limit the growth in the agri-food sector, and consequently, the production and processing growth inducing technical change. Therefore, the low growth rate of demand for agri-food products must determine the change of efficiency-based relations treated as a main growth factor in the sector. Thus, the authors believe that not the increase of input factors but the efficiency of its use is the main factor of companies' ability for a long-term and effective growth and performance [Bezat-Jarzębowska and Jarzębowski 2013].

The discussion on assessing efficiency of economic entities should start with the precise definition of efficiency. M. Bielski claims that there are several different concepts of efficiency, its measurement and expressions. He states that within the framework of the concept of efficiency, many terms of similar meaning may be applied:

[2] Authors assume that in competitive market equilibrium the price is fixed for processor in agri-food sector.
[3] For more details see: Figiel Sz., Rembisz W. (2009) Przesłanki wzrostu produkcji w sektorze rolno-spożywczym – ujęcie analityczne i empiryczne, Multi-annual Programme 2005-2009, No. 169, Wyd. IERiGŻ, Warsaw.

effectiveness, productivity, profitability [Bielski 2002, pp. 54]. However, these concepts are not identical, and the actual concept of efficiency is derived from the structure of the production function, therefore, is determined by changes in the productivity of production factors and their remuneration and refers to the allocation of production factors in the most technically efficient way[4]. W. Rembisz presented argument that the growth in efficiency is a function of changes in the productivity of capital and labour productivity and changes in the structure of expenditures (in production technology) [see Rembisz 2011]. Improvement in the efficiency level can lead to the increase in profitability. According to the author of the paper, these three concepts discussed, such as productivity, efficiency and profitability can be a reference point for assessing the degree of achievement of the objectives (effectiveness). A broader concept is effectiveness that focuses on the results and the degree of the objectives' achievement.

In the literature, there is a concept of economic efficiency that determines the ratio of outputs achieved and inputs used. Z. Adamowski assumes that economic efficiency may be understood as the ratio of output to input, or cost, or vice versa – input to output. The first case concerns input-oriented efficiency, second one – output-oriented efficiency (capital intensity of output) [Adamowski 1983, pp. 70]. The dual approach to efficiency is a result of the existence of two variants of the economic rationality principle. Adherence to this principle is understood as achieving given outputs by using minimal inputs or achieving maximal outputs by using a given level of inputs [Telep 2004, pp. 9]. The aspect of efficiency is perceived similarly by C. Skowronek, who claims that maximization of the output/input ratio (or the difference between output and input), as a measure of economic efficiency, can be achieved by maximizing outputs with given inputs, or by minimizing inputs with given outputs [Skowronek 1987, pp. 241].

The dual approach to efficiency is also presented by S.C. Krumbhakar and C.A.K. Lovell, according to whom an elementary objective of producers can be avoiding waste, by obtaining maximum outputs from given inputs or by minimizing inputs used in the production of given outputs [Krumbhakar and Lovell 2004, pp. 15], which is defined by the authors as technical efficiency. At a higher level, the objective of producers might entail the production of given outputs at minimum cost or the utilization of given inputs to maximize revenue, or the allocation of inputs and outputs to maximize profit. In these cases, productive efficiency corresponds to what the authors call economic (cost, revenue or profit) efficiency [Krumbhakar and Lovell 2004, pp. 16]. They indicate that technical efficiency can be graphically defined in terms of distance to a production frontier, and economic efficiency is defined in terms of distance to a cost, revenue or profit frontier [Krumbhakar and Lovell 2004, pp. 17]. Whereas technical efficiency is a purely physical notion that can be measured without recourse to price information, cost, revenue, and profit efficiency are economic concepts whose measurement requires price information.

T.J. Coelli, D.S.P. Rao, Ch.J. O`Donnell and G.E. Battese, that refer to the dual approach in their researches on the efficiency, argue that the efficiency ratio increases by maximizing outputs with given inputs (an output-oriented approach), or by minimizing inputs with given outputs (an input-oriented approach). A company uses materials, labour and capital (inputs) in order to manufacture the final product (output), on the basis of which the authors define efficiency of companies as their ability to transform inputs into outputs [Coelli et al. 2005].

3 Evaluation of efficiency of the milk processing companies

3.1 Dataset

The efficiency assessment was carried out on the basis of data from the Monitor Polski B. The sample covered from 103 up to 160 companies (depending on the analysed year) of milk processing sector from across Poland within the period 2006-2011. The selection of a specific sector was made because of different production technologies in different food processing sectors. The data was reported as revenue/expenditure denominated in PLN in constant prices. The efficiency was calculated for a single output and two inputs. The inputs and the output are identified in table 1. The variables were selected to reflect the cost sources and production possibilities on the input side and the revenue sources on the output side.

[4] The concepts of productivity and efficiency are often used interchangeably; however, they do not mean exactly the same [Coelli et al. 2005]. It can be stated that the highest value of productivity is achieved by an object lying at the point of tangency of the production frontier and a curve drawn from the origin of the coordinate system [Jarzębowski 2011].

Table 1.
Inputs and outputs used to assess the efficiency scores

Inputs	Outputs
X_1 – operational costs	Y – revenue on sales
X_2 – value of assets	

Source: own work based on Coelli et al. 2005, pp. 5.

3.2 The model specification and parameters estimation - the SFA method

Using the SFA method, a priori identification of a functional form determining the relationship between input(s) and output is required [Coelli et al. 2005]. In the literature on the efficiency determined basing on production function it may be observed that the Cobb-Douglas function is one of the most widely used functional form in empirical research. As it is shown by J. Piesse and C. Thirtle, the adequacy of the Cobb-Douglas model is tested with respect to a less restrictive form – the translog form [Piesse and Thirtle 2000, pp. 474]. To evaluate efficiency in the meat processing industry within the period 2006-2011, the SFA method was applied basing on well-established in theory and practice functions: Cobb-Douglas and Translog. The Cobb-Douglas function was presented in the equation (1), and the Translog function in the equation (2) [Coelli et al. 2005]:

$$\ln y_i = \beta_0 + \sum_{j=1}^{k} \beta_j \ln x_{ij} + v_i - u_i \tag{1}$$

and

$$\ln y_i = \beta_0 + \sum_{j=1}^{k} \beta_j \ln x_{ij} + \frac{1}{2} \sum_{j=1}^{k} \sum_{l=1}^{k} \beta_{jl} \ln x_{ij} \ln x_{il} + v_i - u_i \tag{2}$$

where:

i – index indicating the next object *i=1,…,I*, where I is the number of objects in the sample,

j – index indicating the next input *j=1,…,l*,

k – number of inputs,

y_i – effect of an object i,

x_{ij} – input j in an object i,

β – parameters to be estimated,

v_i – random variable representing the random component,

u_i – positive random component associated with inefficiency (*TE*).

The comparison of the functional form was made basing on the likelihood ratio test statistics (*LR*), which takes the following form

$$LR = -2[\ln L(\hat{\theta}_R) - \ln L(\hat{\theta}_N)] \tag{3}$$

where:

$\ln L(\hat{\theta}_R)$ – logarithm of the maximum likelihood value of the model with restrictions,

$\ln L(\hat{\theta}_N)$ – logarithm of the maximum likelihood value of the model without restrictions.

Table 2.
Hypothesis verification for the selection of model's functional form

	year	$\ln L(\hat{\theta}_R)$	$\ln L(\hat{\theta}_N)$	LR	result(1)	model
Milk processing	2006	-252,08	-247,15	9,86*	No reason for rejecting H_0	Cobb-Douglas
	2007	-242,55	-240,36	4,38**	No reason for rejecting H_0	Cobb-Douglas
	2008	-185,81	-185,22	1,19**	No reason for rejecting H_0	Cobb-Douglas
	2009	-267,97	-265,84	4,28**	No reason for rejecting H_0	Cobb-Douglas
	2010	-241,20	-235,88	10,64*	No reason for rejecting H_0	Cobb-Douglas
	2011	-203,49	-198,64	9,71*	No reason for rejecting H_0	Cobb-Douglas

(1) The value of χ2 distribution for 3[5] degrees of freedom and at the significance level of 0,05 (**) was equal to 7,82; at the significance level of 0,1 (*) was equal to 11,34. If LR*< χ2(3), there is no reason for rejecting H_0.

Source: own calculation, see also [Jarzębowski 2013].

Basing on the results of hypotheses' verification concerning the choice of the functional form, it was stated that the proper form describing relations between the adopted inputs and outputs is the Cobb-Douglas model in each of the sectors in all the analyzed periods (at the significance level of less than 0,1). The efficiency was assessed on the basis of the quotient of the observed output (*y*; equation 1) and the maximum output to be achieved characterized by *exp(v_i)*, denoted by *y** (this value assumes no inefficiency – $u_i=0$), thus the efficiency ratio may be written as [Coelli et al. 2005]:

$$TE_i = \frac{y_i}{y_i^*} = \frac{\exp(\beta_0 + \sum_{j=1}^{k} \beta_j \ln x_{ij} + v_i - u_i)}{\exp(\beta_0 + \sum_{j=1}^{k} \beta_j \ln x_{ij} + v_i)} = \exp(-u_i) \tag{4}$$

The efficiency frontier was determined on the basis of the estimation (using the maximum likelihood method6) of parameters of production function adopted in the SFA method, i.e. the Cobb-Douglas function.

Verification of parameter significance – and thus examining the correctness of variables' selection for the model – was conducted on the basis of t-Statistics (Table 3; in the analyzed models, the t-Statistics at the significance level of 0,1 varies from 1,72 up to 7,43. On the basis of hypotheses' verification *H0: βj=0; H1: βj≠0*), it was stated that all parameters are significant at the significance level of 0,1.

[5] The number of the degrees of freedom is equal to the difference in the number of parameters in the model without restrictions (here the Translog model) and in the model with restrictions (here the Cobb-Douglas model).

[6] The least squares method and its derivates are the other methods for estimation of the parameters of the production function while determining the efficiency frontier [Coelli et al. 2005].

Table 3.
The maximum likelihood estimates of the Cobb-Douglas function's parameters

year	variables	intercept	X_1	X_2	year	mean efficiency	scale effect	number of objects
	parameter	b_0	b_1	b_2		TE	$\Sigma\beta_j$	n
2006	par.'s value	***-4,38	*0,21	***0,93	2006	0,34	1,14	137
	T-value	-3,27	1,72	5,83				
2007	par.'s value	***-3,76	***0,27	0,86	2007	0,43	1,13	160
	T-value	-4,69	2,89	7,32				
2008	par.'s value	***-3,45	***0,30	***0,83	2008	0,30	1,14	103
	T-value	-3,05	2,88	5,29				
2009	par.'s value	***-3,79	***0,34	***0,80	2009	0,37	1,14	155
	T-value	-3,25	3,62	5,43				
2010	par.'s value	***-3,13	***0,28	***0,83	2010	0,32	1,11	141
	T-value	-3,06	3,54	7,43				
2011	par.'s value	-0,11	*0,20	***0,64	2011	0,33	0,81	122
	T-value	-0,10	1,86	4,92				

Signif. codes: 0.01 '***' 0.05 '**' 0.1 '*'

Source: own calculations.

The mean efficiency scores for each of six years of analysis are presented in table 3. In the analyzed period, the efficiency of milk processing companies was on the level of 0,4 which indicates a low level of technical efficiency. It is to note that the level of the technical efficiency was not very fluctuating over the time period 2006-2011, its level amounts from 0,30 up to 0,43.

On the basis of the parameters' sum[7] of the Cobb-Douglas function a type of returns to scale may be identified. In the case of models for 2006-2010 the sum is higher than one which indicates the existence of increasing returns to scale among the analysed companies. In 2011 the sum of parameters is lower than one, which confirms that there are decreasing returns to scale among the companies.

3.3 The model specification - the DEA method

The DEA method was applied in the paper as a complementary method. This method enables to conduct a complex efficiency assessment of companies. The DEA method is an alternative approach to the production function [Rembisz 2011, pp. 6]. Determination of the production possibility frontier is the equivalent of production function's estimation in the DEA method and bases on linear programming [Prędki 2003, pp. 87]. The DEA method was applied in the paper due to the fact that it provides detailed information on the individual

[7] The sum of the parameters is read as follows: if $\sum_{j=1}^{k}\beta_j > 1$, output increases faster than inputs (increasing returns to scale), if $\sum_{j=1}^{k}\beta_j < 1$, output increases slower than inputs (decreasing returns to scale), if $\sum_{j=1}^{k}\beta_j = 1$, output increases at the same rate as inputs. For $\sum_{j=1}^{k}\beta_j = 1$, parameters β_j may be treated as structural ratios determining the share of individual production factors. Hence, the function reflects the manufacturing technique [Rembisz 2011, pp. 43].

objects from the sample. The results obtained using this method are complementary to the results of the SFA method.

A researcher has a wide range of models while using the DEA method. They differ mainly within the framework of returns to scale that are attributed to objects of a given sample. The selection of a model influences the values of the efficiency ratios and – similarly to the case of variables' selection – also bases on expertise or practices used among other researchers. In the case of verification nature of the DEA method, it was considered to adopt the same assumptions on returns to scale, as in the stochastic analysis.

Efficiency assessment conducted in the previous Section with use of the SFA method based on the Cobb-Douglas model. On the basis of the sum of parameters ($\sum_{j=1}^{k}\beta_j$), it was found that the analyzed population was characterized by increasing returns to scale in 2006-2010, and by decreasing returns to scale in 2011. Similarly, in the case of the DEA method, for a sample characterised by increasing returns to scale a IRS model was applied, while for a sample described by decreasing returns to scale a NIRS model was applied.

Another aspect concerning the DEA models' specification is a choice between a given level of outputs and minimization of inputs or a given level of inputs and maximization of outputs (choosing the orientation of a model). Since the efficiency assessment based on the DEA method is complementary to the studies with use of the SFA method, it is appropriate to apply the output-oriented approach (in the SFA method, the production function is modified vertically which means that different values of outputs can be achieved by a given level of input). This approach aims at maximization of outputs by a given level of input(s).

In the context of the discussed assumptions, the IRS and NIRS[8] models were applied in the analysis. The IRS model is presented in equations (5)-(8) and (10), the NIRS model – equations (5)-(9).

$$\max_{\phi_k,\lambda_k} \phi_k \tag{5}$$

$$\phi y_k \le \sum_{i=1}^{I} \lambda_{ik} y_i \tag{6}$$

$$x_{nk} \ge \sum_{i=1}^{I} \lambda_{ik} x_{ni} \tag{7}$$

$$\lambda_{ik} \ge 0, \tag{8}$$

$$\sum_{i=1}^{I} \lambda_{ik} \le 1 \tag{9}$$

$$\sum_{i=1}^{I} \lambda_{ik} > 1 \tag{10}$$

where:

k – index of an analyzed object,

ϕ_k – multiplier of outputs level for an object *k*,[9]

i – index of a subsequent object *i=1,…,I*, where I is a number of objects in the sample,

y_i – an output determining sales revenues (*Y*) of an object *i*,

n – index of a subsequent input,

x_{ni} – an input n used by an object *i*,

λ_{ik} – coefficient of the linear combination between objects *i* and *k*.

[8] The NIRS-O model assumes non-increasing returns to scale and the output-oriented approach.
[9] It is the inverse of the efficiency ratio.

The description of output and inputs is consistent with table 2. In all the models the output orientation was assumed which was expressed in the objective function of the optimization problem (equation 5).

Within the framework of application of the DEA method the same group of objects as in case of the SFA method was included in the analysis for each year. There are the same variables in the models; the variables were used in estimation of the efficiency ratios in the stochastic approach (equation 1). This completely eliminates the problem of randomness or basing on expertise while selecting variables to the model.

4 The comparison of the results of the analysis using the parametric and nonparametric approach

In order to distinguish between the results obtained using the both methods, TE-SFA[10] and TE-DEA[11] terms will be used in the subsequent part of the paper.

The efficiency ratios obtained for the stochastic (using the SFA method) and deterministic model (using the DEA method) are compiled according to each year in a form of correlation charts (Figure 3). The results obtained by using the SFA and the DEA methods have been evaluated. On the basis of the correlation graphs it can be stated that the relation between the analyzed variables is best described by the exponential function. The matching of the functional form was based on the value of the coefficient of determination. The determination coefficients for the milk processing sector took values ranging from 0,77 to 0,94.

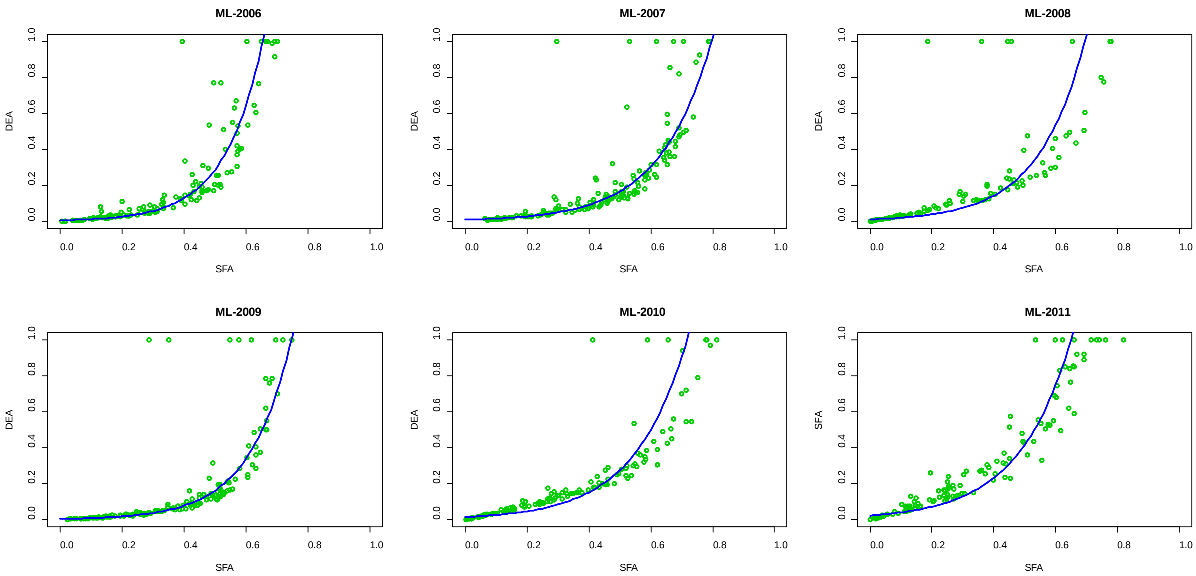

Figure 3. The relation between efficiency ratios determined using the SFA and DEA method for companies of the meat processing sector in years 2006-2011
Source: own calculations from the R software [R 2008].

On the basis of the conducted analysis it was stated that the results obtained using the DEA method (after the models' specification basing on the SFA method's results) and the results obtained using the SFA method indicate in case of analysed milk processing industry in period 2006-2011 the exponential dependence for the analyzed period.

[10] For the technical efficiency ratios obtained using the SFA method.
[11] For the technical efficiency ratios obtained using the DEA method.

5 Discussion

The SFA method (Stochastic Frontier Analysis) is a method of efficiency evaluation. Nevertheless, the deterministic tools are used in the literature as well. Their analytical background is not the production function but the optimization problem (e.g. the DEA method, Data Envelopment Analysis). The both methods require all decision making units to have comparable inputs and outputs and both can handle multiple input and multiple output models.

It should be noted that in the case of the deterministic methods, like DEA, one does not assume the presence of a random factor. Thus, the use of DEA method for objects operating in an environment characterized by randomness may lead to erroneous results deviating from the common-sense notions of analysed dependencies [Bezat and Stańko 2011, pp. 38]. Therefore, a concept of measuring the efficiency that bases on the integral use of SFA and DEA methods has been applied in this paper - in order to verify the correctness of the results obtained with usage DEA method, they were compared with the results of SFA method.

6 Conclusions

The SFA and the DEA methods were applied to evaluate the efficiency of companies of the milk processing sector. The similar results were obtained in case of both methods. On the basis of the conducted analysis it was stated that the results obtained using the DEA method (after the models' specification basing on the SFA method's results) and the results obtained using the SFA method indicate the exponential dependence for the analyzed period.

Basing on the conducted analysis it was claimed that the integral use of the SFA and the DEA methods – combining advantages of both methods – allows preserving the analogy when comparing the results and formulating reliable conclusions.

References

Adamowski Z. (1983). Podstawy ekonomiki i organizacji przedsiębiorstw rolnych, Wyd. IV popr., Państwowe Wydawnictwo Rolnicze i Leśne, Warsaw.

Bezat A., Stańko S. (2011). Efektywność przedsiębiorstw handlu zbożem a ich lokalizacja względem rynków zaopatrzenia. Roczniki Nauk Rolniczych. Seria G - Ekonomika Rolnictwa 2011, Vol. 98, no. 4, s. 36-48.

Bezat-Jarzębowska A., Jarzębowski S. (2013). Productivity changes over time - theoretical and methodological framework, Quantitative Methods in Economics 2013, Vol. 14, no. 1, p. 27-36.

Bielski M., 2002. Podstawy teorii organizacji i zarządzania. C.H. Beck, Warsaw.

Coelli, T.J., Rao, D.S.P., O`Donnell, Ch.J., Battese, G.E. (2005). An introduction to efficiency and productivity analysis. 2. Edition, . Springer, New York, p. 64-83.

Figiel Sz., Rembisz W. (2009). Przesłanki wzrostu produkcji w sektorze rolno-spożywczym – ujęcie analityczne i empiryczne, Multi-annual Programme 2005-2009, No. 169, Wyd. IERiGŻ, Warsaw.

Jarzębowski S. (2013). Integracja łańcucha dostaw jako element kształtowania efektywności sektora przetwórstwa rolno-spożywczego, Wydawnictwo SGGW, Warsaw.

Jarzębowski S. (2011). The efficiency of grain milling companies in Poland and in Germany- application of DEA method and Malmquist index, Universität Bonn-ILB Press, Bonn.

Krumbhakar S.C., Lovell C.A.K. (2004). Stochastic Frontier Analysis. Cambridge University Press, United Kingdom, Cambridge.

Morkis G., Nosecka B., Seremak-Bulge J. (2010). Monitorowanie oraz analiza zmian polskiego łańcucha żywnościowego, Wyd. IERIGŻ-PIB, Warsaw.

Piesse J., Thirtle C. (2000). A Stochastic Frontier Approach to Firm Level Efficiency, Technological Change and Productivity during the Early Transition in Hungary. Journal of Comparative Economics, Vol. 28, No. 3, p. 473-501.

Prędki A. (2003): Analiza efektywności za pomocą metody DEA: Podstawy formalne i ilustracja ekonomiczna. Przegląd statystyczny, Vol. 1.

R, R Development Core Team (2008). A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, available online at: http://www.R-project.org, (accessed December 2013).

Rembisz W. (2011). Analityczne właściwości funkcji produkcji rolniczej. [Analytical features of the agricultural production function]. Komunikaty, Raporty, Ekspertyzy, nr 544, IERiGŻ-PIB, Warsaw.

Rudziński R. (2010). Organizacja logistyki w zakładach przetwórstwa mleka, [in:] Zeszyty Naukowe Uniwesrytetu Przyrodniczo-Humanistycznego w Siedlcach, ZN nr 87, Seria: Administracja i Zarządzanie, Siedlce.

Seremak-Bulge J., Świetlik K., Mieczkowski M., Zdziarska T., Szajner P. (2012). Rynek mleka. Stan i perspektywy, Wyd. IERiGŻ-PIB, Warsaw.

Skowronek C. (1987). Efektywność gospodarki materiałowej: stan i metody oceny. Państwowe Wyd. Ekonomiczne, Warsaw.

Telep J. (2004). Podstawowe pojęcia z dziedziny organizacji i efektywności, [in:] Bombera Z., Telep J. (red.) (2004) Ocena efektywności funkcjonowania organizacji gospodarczych. DrukTur, Warsaw, p. 7-22.