J. BARAN, M. WYSOKINSKI, D. STAŠ, A. SAMOLEJOVÁ, R. LENORT

ISSN 0543-5846
METABK 55(2) 245-248 (2016)
UDC – UDK 669.011:338.45:658.911.6.001.1:438=111

EFFICIENCY OF POLISH METALLURGICAL INDUSTRY BASED ON DATA ENVELOPMENT ANALYSIS

Received – Prispjelo: 2015-05-02
Accepted – Prihvaćeno: 2015-09-25
Preliminary note – Prethodno priopćenje

The main purpose of this paper is to compare the technical efficiency of 12 sectors manufacturing basic metals and metal products in Poland. This article presents the use of Data Envelopment Analysis models, to determine overall technical efficiency, pure technical efficiency and scale efficiency of metallurgical branches in Poland. The average technical efficiency of metallurgical industry in Poland was quite high. The analysis gives a possibility to create a ranking of sectors. Three branches were found to be fully efficient: manufacture of basic iron and steel and of ferroalloys, manufacture of basic precious and other non - ferrous metals and manufacture of tubes, pipes, hollow profiles and related fittings, of steel. The results point out the reasons of the inefficiency and provide improving directions for the inefficient sectors.

Key words: metallurgy, industry, efficiency, programming, Data Envelopment Analysis, Poland

INTRODUCTION

The metallurgical industry in Poland is an important branch of the economy, which is proven by its 11 percent share in sold production of general industry in 2014. There are about 1 300 companies (with over 49 employees) in the field of metals and metal products production present on the Polish market [1]. The Polish metallurgical industry faces numerous challenges and problems such as competition of the rising economies and increase in import of comparable, cheap products, rigorous regulations regarding health and safety, emission and quality norms, tight binds with, and dependency on other trades such as construction, machining and automotive industry, high labour intensity of the sector placing it at a disadvantage comparing to competition from China or India, where labour cost is relatively low.

Therefore it is important whether the individual production factors (labour, capital) are being used efficiently to achieve a specific magnitude of production from the point of view of the entire national economy as well as of the individual entrepreneurs [2].

In economic literature methods for testing the efficiency of economic entities can be classified as: parametric, non-parametric and indicator - based.

Parametric methods are based on the function of production, which defines the relationship between inputs and effects. The parameters of this function are determined by means of standard econometric estimation tools. The parametric method group - apart from the production function - includes, inter alia: Thick Frontier Approach [3], Stochastic Frontier Approach [4], Distribution Free Approach [5].

Non - parametric methods do not take into account the impact of random factors on the efficiency of the tested elements and do not include potential measurement errors. Also, non - parametric methods do not require the adoption of any assumptions regarding the functional relationship between expenditure and effects. The efficiency curve is determined on the basis of empirical data using linear programming. Non - parametric methods include Data Envelopment Analysis [6] and Free Disposal Hull [3].

In turn, establishing efficiency in the case of indicator methods consists in the comparison of economic - financial indicators between businesses, e.g. indicators of profitability, productivity and labour efficiency [7].

The use of non - parametric methods for the assessment of the effectiveness of European industry is not a very popular direction of research [8]. The issue of efficiency in industry is usually considered in literature from a one -dimensional perspective, using conventional economic and financial indicators, such as: labour productivity, asset productivity or profitability, based on both sectorial data and an analysis of individual companies.

The main objective of this article is to determine the technical efficiency of individual metals and metal products production branches in Poland and identifying possible improvement directions for the ineffective branches.

METHODOLOGICAL BASIS

The basic source of data used in the study was the Central Statistical Office data regarding metallurgical

J. Baran, M. Wysokinski, Faculty of Economic Sciences, Warsaw University of Life Sciences, Poland, D. Staš, ŠKODA AUTO University, Czech Republic, A. Samolejová, R. Lenort, Faculty of Metallurgy and Materials Engineering, VŠB – Technical University of Ostrava, Czech Republic

industry branches of Poland in 2014. Based on the sample efficiency was evaluated using Data Envelopment Analysis (DEA). The DEA model may be presented mathematically in the following manner [10]:

$$\max \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \tag{1}$$

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, u_r, v_i \geq 0 \tag{2}$$

where s is quantity of outputs, m is quantity of inputs, u_r is weights denoting the significance of respective outputs, v_i is weights denoting the significance of respective outputs, y_{rj} is amount of output of r - th type (r = 1,…, R) in j - th object, x_{ij} is amount of input of i - th type (n = 1,…, N) in j - th object, (j = 1,…,J).

In the DEA model m of inputs and s of diverse outputs come down to single figures of "synthetic" input and "synthetic" output, which are subsequently used for calculating the object efficiency index. The quotient of synthetic output and synthetic input is an objective function, which is solved in linear programming. Optimized variables include u_r and v_i coefficients which represent weights of input and output amounts, and the output and input amounts are empirical data [9].

By solving the objective function using linear programming it is possible to determine the efficiency curve called also the production frontier, which covers all most efficient units of the focus group. Objects are believed to be technically efficient if they are located on the efficiency curve (their efficiency index equals 1, which means that in the model focused on input minimization there isn't any other more favourable combination of inputs allowing a company or sector to achieve the same outputs). However, if they are beyond the efficiency curve, they are technically inefficient (their efficiency index is below 1). The efficiency of the object is measured against other objects from the focus group and is assigned values from the range (0, 1). In the DEA method Decision Making Units (DMU) represent objects of analysis [6].

The DEA models may be categorized based on two criteria: model orientation and type of returns to scale. Depending on the model orientation a calculation is made of technical efficiency focused on the input minimization or on the output maximization. But taking into account the type of returns to scale the following models are distinguished: the CCR model providing for constant returns to scale, the BCC model providing for changing return to scale. The CCR model is used to calculate the overall technical efficiency (TE). The BCC model is used to calculate pure technical efficiency (PTE) [10].

With the overall technical efficiency and pure technical efficiency calculated, it is possible to determine the object scale efficiency (SE) according to the formula [10]:

$$SE = \frac{TE}{PTE} \tag{3}$$

RESULTS AND DISCUSSION

This article contains efficiency analysis of all metal and metal products production branches in Poland.

In the first stage of the study, traditional economic indicators such as labour productivity (in EUR thousand per person) and fixed assets productivity were used to compare efficiency of different metallurgical industry branches (see Table 1).

Those indicators are easy to use and interpret, but on the other hand they are one –dimensional. In addition, the indicators may provide divergent information on the given sector's efficiency. For example, upon comparison of metallurgical industry branches according to efficiency of labour and fixed assets productivity, we note that some branches (e.g. manufacture of basic iron and steel and of ferroalloys - M1) present lower fixed assets productivity, but they have a very high efficiency of the labour factor. Then, other branches such as manufacture of structural metal products (M6) have high fixed assets productivity and low labour efficiency (see Table 1).

Therefore, a problem arises - which of the compared branches is more efficient – does higher productivity of labour compensate for lower fixed assets productivity?

The financial and economic indicators do not provide an unequivocal answer to the question of operational efficiency, which can be measured in many ways. Having considered the above, in the second stage of the study, multidimensional efficiency measurement method of industry branches was used, namely Data Envelopment Analysis.

Based on applicable literature, a set of variables for the DEA models was determined. In this study, production magnitude measure (output) was defined as the value of production sold by the individual branches.

The variables explaining production magnitude, in accordance to the theory of economy are three production factors: land, labour and capital. In this study, labour factor (input 1) is expressed by number of employees, and capital (input 2) is expressed by fixed assets gross value.

As part of the study, DEA models oriented at minimization of input were utilized and both overall technical efficiency and pure technical efficiency of metallurgical industry in 2014 in Poland were calculated.

The average efficiency indicator in the CCR model was 0,70, while the BCC model provided a value of 0,85. Full technical efficiency (where the efficiency index was equal to 1) was achieved by three branches: manufacture of basic iron and steel and of ferroalloys, manufacture of basic precious and other non - ferrous metals and manufacture of tubes, pipes, hollow profiles and related fittings, of steel.

Table 1 **Labour productivity, fixed assets productivity, technical efficiency, scale efficiency and returns to scale for metallurgical branches in Poland**

Branches	Labour productivity	Fixed assets productivity	CCR –model (*TE*)	BCC –model (*PTE*)	Scale Efficiency (*SE*)	Return to Scale (RTS)
M1 - Manufacture of basic iron and steel and of ferroalloys	266	1,17	1,00	1,00	1,00	Constant
M2 - Manufacture of tubes, pipes, hollow profiles and related fittings, of steel	148	2,66	1,00	1,00	1,00	Constant
M3 - Manufacture of other products of first processing of steel	131	1,55	0,65	1,00	0,65	Increasing
M4 - Manufacture of basic precious and other non-ferrous metals	209	2,34	1,00	1,00	1,00	Constant
M5 - Casting of metals	76	1,50	0,56	0,61	0,93	Decreasing
M6 - Manufacture of structural metal products	75	2,36	0,89	1,00	0,89	Decreasing
M7 - Manufacture of tanks, reservoirs and containers	72	1,55	0,58	0,61	0,95	Decreasing
M8 - Manufacture of steam generators, except central heating hot water boilers	101	2,15	0,81	0,89	0,91	Increasing
M9 - Manufacture of weapons and ammunition	41	0,77	0,29	0,98	0,30	Increasing
M10 - Forging, pressing, stamping and roll-forming of metal, powder metallurgy	84	1,91	0,72	1,00	0,72	Increasing
M11 - Treatment and coating of metals, machining	71	1,80	0,68	0,75	0,90	Decreasing
M12 - Manufacture of cutlery, tools and general hardware	45	0,72	0,28	0,42	0,67	Increasing

Table 2 **Recommendations regarding reduction of inputs in individual branches in order to achieve efficiency**

Branches	Employment / %	Gross value of fixed assets / %
M3 - Manufacture of other products of first processing of steel	35	35
M5 - Casting of metals	49	44
M6 - Manufacture of structural metal products	49	11
M7 - Manufacture of tanks, reservoirs and containers of metal	52	42
M8 - Manufacture of steam generators, except central heating hot water boilers	32	19
M9 - Manufacture of weapons and ammunition	73	71
M10 - Forging, pressing, stamping and roll-forming of metal, powder metallurgy	43	28
M11 - Treatment and coating of metals; machining	52	32
M12 - Manufacture of cutlery, tools and general hardware	72	72

It is worth mentioning that in the BCC model, there were three additional branches on the efficiency curve: manufacture of other products of first processing of steel, manufacture of structural metal products and forging, pressing, stamping and roll-forming of metal, powder metallurgy. The weakest among the analysed branches turned out to be manufacture of cutlery, tools and general hardware (see Table 1).

In the course of the study, production scale efficiency was also calculated and returns to scale were also determined. Three branches (M1, M2, M4), which were deemed technically efficient according to both CCR and BCC models were characterized by scale efficiency and constant returns to scale. The remaining five branches noted increased returns to scale, which in turn means that the studied metallurgical industry sectors, the production growth rate is greater (in percent) than the inputs (production factors) growth rate. Therefore, those sectors should note increasing income due to the scale and decreasing long - term average costs.

In the subsequent stage of the study, in accordance to the benchmarking idea for inefficient branches, benchmarks were defined. Based on those benchmarks for inefficient branches, optimal technology allowing achievement of the same results (the value of production sold) at lower inputs levels was defined. Recommendations regarding inputs changes are presented in Table 2.

CONCLUSION

In the article, based on the Data Envelopment Analysis method, technical efficiency of carious metallurgical industry branches was evaluated and compared. Considering the DEA models, three branches were found to be fully efficient: manufacture of basic iron and steel and of ferroalloys, manufacture of basic precious and other non - ferrous metals and manufacture of tubes, pipes, hollow profiles and related fittings, of steel.

As for the ineffective industry branches, with the aid of object benchmarking, inputs level changes were suggested, which could improve the efficiency of individual industry branches as well as the entire metallurgical industry. The recommendations pertain to decreasing the inputs while maintaining present production levels.

On the other hand the conducted study brings the conclusion that the majority of metal and metal products manufacture industry branches are characterized by increasing returns to scale, which means that if they decide to increase production, it should grow faster than the engaged inputs.

The results of this study may be useful for managers controlling companies in the metallurgical sector as well as for the government for the purpose of forming policies and planning financial support for the industry sectors.

Considering the fact, that the efficiency of industry sectors is a very complex economic issue and the methods used in the process of its analysis have their respective advantages and limitations, it is the authors' opinion that integrated approach must be used – based on various methods that implement each other and therefore allow for formulation of even more credible conclusions.

From the methodological point of view, the proposed approach for ranking and benchmarking of Decision Making Units has a universal character and can be applied in different industries.

Acknowledgement

The work was supported by the specific university research of Ministry of Education, Youth and Sports of the Czech Republic No. SP2015/112.

REFERENCES

[1] Statistical Yearbook of Industry – Poland, Central Statistical Office, 2014.

[2] P. Wei, H. Tang, Y. Chen, X. Chen, Measuring technical efficiency of Chinese nonferrous metals enterprises on a background of industry consolidation, Transactions Nonferrous Metals Society of China 23 (2013), 2797-2806.

[3] A. N. Berger, D. B. Humphrey, Efficiency of financial institutions: International survey and directions for future research, European Journal of Operational Research 98 (1998) 2, 175-212.

[4] D. J. Aigner, C. A. K. Lovell, P. Schmidt, Formulation and Estimation of Stochastic Frontier Production Function Models, Journal of Econometrics 6 (1997) 1, 21-37.

[5] A. N. Berger, L. J. Mester, Beyond the Black Box: What Explains Differences in the Efficiencies of Financial Institutions, Journal of Banking and Finance 21 (1997) 7, 895-947.

[6] A. Charnes, W.W. Cooper, A. Rhodes, Measuring the Efficiency of Decision Making Units, European Journal of Operational Research 2 (1978) 6, 429-444.

[7] P. Pomykalski, S. Bakalarczyk, A. Samolejova, Benchmarking polish basic metal manufacturing companies, Metalurgija 53 (2014) 1, 139-141.

[8] R. Lenort, J. Baran, M. Wysokiński, Application of Data Envelopment Analysis to Measure the Efficiency of the Metal Production Sector in Europe, Proceeding, METAL 2014: 23th International Conference on Metallurgy and Materials, Ostrava: TANGER, 2014, pp. 1795-1802.

[9] W. W. Cooper, L. M. Seiford, K. Tone, Data Envelopment Analysis, A Comprehensive Text with Models, Applications, References and DEA-Solver Software, Kluwer Academic Publishers, New York, 2007, pp. 21-25.

[10] T. J. Coelli, D. S. Prasada Rao, C. J. O'Donnell, G. E. Battese, An Introduction to Efficiency and Productivity Analysis, Springer, New York, 2005, pp. 173-174.

Note: The responsible translator for English language is Krzysztof Bryzek, translator from ATET Translation Agency EURO-TŁUMACZE, Warsaw, Poland