R&D Efficiency for Pharmaceutical Companies in the EU

Heri Bezić, Tomislav Galović, and Petar Mišević

***Abstract*—** This study constructs research and development (R&D) as a factor of productivity of European pharmaceutical industry. We introduce an empirical model derived from the Data Envelopment Analysis model to calculate R&D and efficiencies for selected European pharmaceutical companies. This research brings a mathematical view with Data Envelopment Analysis which is a mathematical modeling method of calculating relative efficiencies of Decision Making Units (DMUs), based on predetermined inputs and outputs. Performance evaluation of R&D activity is important for continuous improvement of performance of pharmaceutical companies. The model was used to obtain the overall level of exports with input factors of R&D activity. The subject of analysis are efficiency values and rank. After identifying relative efficiencies of the observed countries, the results are discussed.

***Keywords*—**DEA efficiency, R&D performance, EU pharmaceutical companies

I. Introduction

IMPACT of the global economic crisis and competition growth had certain implications on export activity of the high-tech industry as an important segment of the processing industry.

Therefore, high-tech industrial companies should invest more efforts in overcoming economic challenges. One of the possible solutions is measuring company efficiency and making economic decisions based on the data envelopment analysis. The main research hypothesis implies that it is possible to assess the efficiency of the pharmaceutical industry of the selected countries.

The main objective of the paper is reflected in the calculation of efficiency of the pharmaceutical industry (as a representative of the high-tech industry) by implementation of the DEA (Data Envelopment Analysis), objective assessment of their efficiency, and, pursuant to the results, proposing measures and activities for improvement of export competitiveness of the pharmaceutical industry of the selected European countries.

Ph. D..Heri Bezić is a full-time professor at the University of Rijeka, Faculty of Economics, 51000 Rijeka, Croatia (phone: 0038551355148; e-mail: bezic@efri.hr).

B.Sc. Tomislav Galović, is an assistant at the University of Rijeka, Faculty of Economics, 51000 Rijeka, Croatia (phone: 0038551355155; e-mail: tgalovic@efri.hr).

Ph. D. Petar Mišević is a PhD student at the University of Rijeka, Faculty of Economics, 51000 Rijeka, Croatia.

II. Measuring Company Efficiency in the High Tech-Industry

Firstly, it is important to point out that the pharmaceutical industry is a constituent part of the processing industry. The pharmaceutical industry assumes characteristics of the high-tech industry. Certain scientific research [1]-[2] use data envelopment analysis to measure the efficiency of the processing industry as a whole. A few scientific research are characterised by narrow specialisation in the measuring of efficiency of a certain branch and sub-branch of the processing industry.

In terms of results of DEA analyses of high-tech i.e. pharmaceutical industry, some authors reached interesting conclusions. According to [3], inefficiency of high-tech companies is reflected in insufficient use of R&D capacities, including investments in R&D, number of employees and R&D researchers. High-tech companies stimulate their own R&D activity when they properly allocate R&D resources or define adequate R&D strategies. With the objective to increase efficiency, inefficient high-tech companies should improve their R&D activity and allocation of R&D resources (R&D investments). The authors [3] point out that new high-tech companies can fulfill the basic criteria in the context of implementation of knowledge and technology of the existing high-tech companies.

The authors [4] point out the determinants of efficiency of pharmaceutical companies like patents, exports, foreign direct investments and their profitability. Their research results are verified by the authors [5] who add that a high level of R&D activity indeed contributes to company efficiency. However, for companies which are not R&D-intensive, import of capital goods increases their technical efficiency. Therefore, inclusion of economy into global trade flows has an impact on company efficiency. Exports of products depend on rigid standards of the importing countries which indirectly condition efficient use of the available resources. The pharmaceutical companies have the possibility to increase efficiency through an increase in export orientation. The companies lacking R&D resources usually import foreign capital goods to stay competitive. In other words, import of capital goods is an adequate substitute for internal R&D activity of the company. The authors [5] also point out the importance of policy-makers in supporting R&D activities of pharmaceutical companies.

The objective of the above-mentioned results of data envelopment analysis is to measure and assess the efficiency of the observed inputs and outputs. However, it should be

pointed out that there are limitations. The importance of limitations is reflected in a measurable impact on the results of specific research. In order to clearly analyse company efficiency in the high-tech sector, this chapter provides analysis of the main limitations in the data envelopment analysis.

One of the mentioned limitations is direct impact of R&D research on the output of high-tech companies. In accordance with the views of the author [3], costs of the analysed companies are characterised by a different structure. Therefore, stimulation of investments in R&D does not necessarily result in direct increase in outputs (for example, innovation). In other words, high-tech industrial company need not always be marked inefficient because of a low degree of R&D activity. The authors add that universality of characteristics of R&D inputs has an impact on aggravated specification of indicators of direct inputs. Excluded effects and circumstances which can imply efficiency of the observed companies are also singled out.

If the subject of analysis are R&D investments during a period of several years, the authors propose using panel data analysis which reduces the differences between R&D investments and resources of the analysed high-tech companies.

The authors [4] point out unavailability of data as one of the limitations of data envelopment analysis. In the research, the authors point out that the research would be more interesting if results were used from the period of the emergence and expansion of the global economic crisis. It is suggested that a special model of data envelopment analysis be used, in which predictor coefficients of Tobit regression are used for estimation of the value of inputs.

The authors [5] refer to the adequate selection of inputs and outputs in the measuring of relative efficiency. Namely, efficiency and company performance are relative for each industrial company. In other words, relative efficiency is conditioned by possibilities of the company of abilities of the management through improved use of the available resources in relation to the competition. This enables growth of outputs through new market conditions which can boost company growth. The presented case is that of an Indian pharmaceutical company which is facing unpredictable market activities. The conclusion is derived that most parametres which stimulate company growth are, in fact, external factors which are more difficult to assess.

The focus of attention is on research conducted on the efficiency of the high-tech industry, [5]-[8] which also include the pharmaceutical industry.

The performance analysis provided by DEA method can be used for evaluating national development efficiency with respect to the national factor endowment [9].

Although high-tech industry is the research subject through the DEA analysis, it still remains an insufficiently explored field in the framework of other research.

Data envelopment analysis represents a non-parametric method based on linear programming. DEA has been widely used by researchers to measure efficiency and productivity [10]. It was first introduced by Charnes and associates in 1978 [11]. This mathematical, non-parametric technique describes the mathematical programming approach to the construction of production frontier and measurement of efficiency of developed model. It is used for assessment of relative efficiency of comparable entities based on empirical data on their inputs and outputs. Data envelopment analysis is recommendable in cases when other approaches do not provide the expected results.

Data envelopment analysis also defines the empirical efficient frontier (i.e. a frontier of production possibilities) by using the bottom-up input envelopment and the top-down output envelopment. This is why it is defined by the (most efficient) existing decision making units; an efficient frontier is an achievable objective which must be realised by inefficient decision making units. Such efficiency is achieved by projection to the efficient frontier. Most standard statistical approaches are based on average values. However, data envelopment analysis is based on extreme observations, where each decision making unit is compared only with the most efficient one.

Measurement and evaluation of performance and productivity is an important issue for at least two reasons. One is that in a group of units where only limited number of candidates can be selected, the performance of each must be evaluated in a fair and consistent manner. The other is that as time progresses, better performance is expected. Hence, the units with declining performance must be identified in order to make the necessary improvements. The performance of a Decision Making Unit (DMU) can be evaluated in either a cross-sectional or a time-series manner, and the DEA is a useful method for both types of evaluation [12].

Decision making units imply using certain inputs with the objective to produce outputs. Generally, several inputs represent a foundation for the production of a single or several outputs in the decision making units. Selection of inputs and outputs follows after the selection of the decision making units.

Adequate selection of the number of inputs and outputs is very significant in terms of the results of the data envelopment analysis. If, by any chance, the inputs and outputs of the model are not properly selected when the analysis is initiated, the results of the conducted analysis are questionable. What is more, the number of inputs and outputs depends on the type of the analysed field (industry). It is recommendable to include at least two to three inputs (outputs) in the scope of the data envelopment analysis.

The absolute efficiency measure may be determined under the condition that there is an explicitly defined correlation between inputs and outputs, i.e. when a connection which connects a group of possible outputs to any combination of inputs is known. If there is a correlation, it is possible to establish their absolute efficiency from the relations of really achieved and theoretically achievable outputs.

In more simple terms, models of data envelopment analysis make a distinction between efficient and non-efficient decision making units. From this point of view, a decision making unit

is efficient when it comes close to the effficient frontier with the corresponding combination of inputs and outputs under the assumption of constant returns (Figure 1).

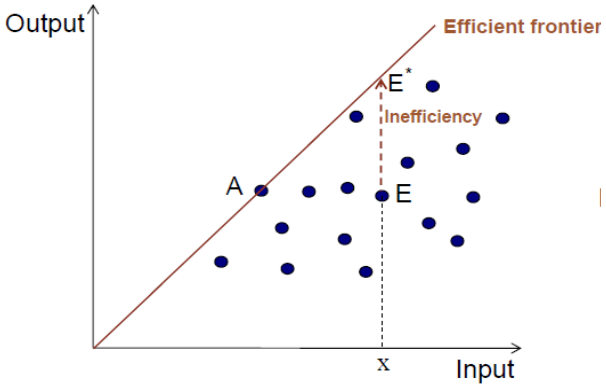

Figure 1: The efficient frontier and non-efficiency of the data envelopment analysis method

Based on the data on the used inputs and outputs, it is evident that the data envelopment analysis method measures relative efficiency of the decision making units by constructing the empirical efficient frontier, i.e. limits of production capacity. The most successful decision making unit (or the Best Practice Unit) is the one which determines the efficient frontier and is rated 1 in the process. Thus, the level of technical innefficiency of other decision making units is calculated on the basis of the distance of their input-output ratio from the efficient frontier.

DEA represents a powerful aggregate comparative method for assessing the productivity of organizations with multiple incomparable inputs and outputs [13].

It is useful to point out that each efficiency analysis is preceded by a detailed research of characteristics and results of actual models. If this is not the case, the results of conducted analyses may significantly differ and result in unreliable guidelines and conclusions. Special emphasis is placed on the Charnes-Cooper-Rhodes (CCR) model which is used in the framework of the DEA analysis.

The CCR model, named after the authors Charnes, Cooper, and Rhodes, [11] represents one of the generally accepted and frequently used models of data envelopment analysis. The original CCR model is based on the assumption of constant returns. The model is used for measuring total efficiency for decision making units.

The CCR model is used with the objective to measure „technical“ efficiency of the analysed decision making units with the assumption of constant returns. However, in many analysed cases, inefficiency does not only originate from the allocation inefficiency, but it also appears as a result of techical inefficiency and inefficiency of returns. The basic premise of the BCC model classifies the total „technical“ efficiency of the CCR model according to which technical efficiency and efficiency of returns would be dependent on variable returns. The Charnes-Cooper-Rhodes model is presented graphically in Figure 2.

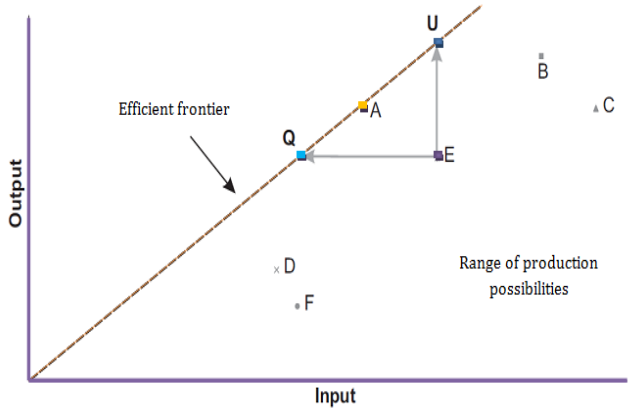

Figure 2: The CCR-DEA Model

Figure 2 presents an input and an output with the efficient frontier. Inefficient DMU achieves efficiency through projection to the efficient frontier. For E, point Q includes projection to an input-oriented model. On the other hand, point U represents projection to an output-oriented model. Empirical research indicate that it is sometimes difficult to achieve this great reduction of inputs or increase in outputs. Therefore,it is proposed that the two directions reach a compromise, wherein compromise represents reaching any point on the part of the frontier between points Q and U.

The CCR-DEA model formulation is demonstrated as follows:

$$Min \quad h_k = \theta - \varepsilon \sum_{i=1}^{m} s_i^- - \varepsilon \sum_{r=1}^{s} s_r^+$$

$$s.t \qquad \sum_{j=1}^{n} \lambda_j x_{ij} - \theta x_{ik} + s_i^- = 0, \quad i = 1,\dots,m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ - y_{rk} = 0, \quad r = 1,\dots,s$$

$$_j, s_i^-, s_r^+ \geq 0, \quad j = 1,\dots,n \quad i = 1,\dots,m \quad r = 1,\dots,s$$

$$\theta \ free$$

(1)

where:

i=inputs, i= 1,…,4 ; r=outputs, r =1,…,4; j=DMUs, j=1,…,195

s_i^- and s_i^+ denote input and output slack variables, respectively,

θ indicates the ration of minimum input and actual input,

x_{ij} denotes the value of the rth input of the jth DMU, (i=1,…,4)

y_{rj} represents the value of the rth output of the jth DMU, (r=1,…,4)

ε is the non-Archiedean quantity

This model can be used to estimate the input-oriented technical efficiency. Values of $\theta = 1$ and $s_i^- = s_i^+ = 0$ indicate that a DMU attains a 100% productivity efficiency and has an efficiency score of 1. Meanwhile, $\theta < 1$ demonstrated that a DMU does not attain 100% productivity efficiency. That is, the input is decreased by $x'_{ik} = \theta x_{ik} - s_i^-$ and the output is increased by $y'_{rk} = y_{rk} + s_r^+$ to achive a DMU of 1.

III. RESULTS

Assessment of the efficiency of companies in the pharmaceutical industry was systematically conducted through several interconnected levels. The efficiency analysis starts with the selection of inputs and outputs of the model. Testing of the correlation between the inputs and the outputs included in the model follows. Research is then expanded by implementing window analysis in the period from 2006 to 2009. What follows is calculation of the results of the relative efficiency variation, CCR window efficiency analysis, and the average through the windows.

The final R&D result originates from different R&D activity processes. The immediate impact of R&D on income and profit of a high-tech company is questionable. Therefore, in the framework of the conducted analysis, time shifting (lagging) of the investment variables in the R&D is used. Taking into consideration significant impact of R&D activities on intensive activities in terms of knowledge and technology, investments in the R&D represent one of the selected inputs. Therefore, investments in the R&D are represented as an input or an indicator of R&D, i.e. innovative investments, [14]-[16]. Investments in R&D in the framework of the following analysis are expressed in millions of PPP (Purchasing Power Parity).

The number of R&D researchers represents the key segment of R&D, i.e. innovative activities [17]-[18]. Productivity of R&D researchers significantly contributes to strengthening of the above-mentioned activities. Therefore, the variable of the number of researchers for R&D is considered an adequate input of the model and subjected to time lagging..

In most of the conducted research, export, patents, sales income and ROI take the place of direct outputs of R&D activities. Furthermore, export growth is frequently stimulated by a higher level of R&D activities as inputs [6], [12]. This fact is verified by the research results in [20] which point out the significance of R&D intensity. Namely, the impact is under the influence of increase in the number of innovative products and in growth of the sales of the export company.

In this regard, in the framework of the DEA analysis in the paper, export value is selected as the only output of the model. Export activity is expressed in millions of euros. Taking all of the above-mentioned into consideration, it is justified to select the above-mentioned inputs and outputs of the model which at the same time have both theoretical and empirical base in the implementation of data envelopment analysis. Furthermore, the inputs and outputs may be simply analysed through the following mathematical function model from the aspect of an individual company:

$$IZV_{i,t} = f\,(IR\ IZDV_{i(t-1)}, IR\ IST_{i(t-1)}, O) \quad (2)$$

where the dependent variable $IZV_{i,t}$ represents export of the company *i* in the period *t*, the variable $IR\ IZDV_{i(t-1)}$ includes investments in the R&D of the company in the period *t-1*, while the $IR\ IST_{i(t-1)}$ variable is the number of R&D researchers in the period *t-1*. *O* represents other impact factors on export. Taking into account that it takes a certain period of adjustment and transformation of inputs, input variables are lagged for one year before. It is important to point out that other variables, i.e. factors (gross investments in fixed capital, export prices, labour costs, demand) affect export activity. However, in this paper, efficiency is analysed exclusively through R&D activity.

Conclusions of the relevant sources represent foundations for the selection of inputs and outputs in the analysis presented in the paper. Taking into consideration the assumption that R&D activity is relevant for production and export of the high-tech industry, the production branch of pharmaceutical, medical and herbal products is considered a representative of the high-tech industry.

Therefore, two inputs are used – investments in R&D (in millions of PPP), and the number of the R&D employees marks exclusively R&D researchers of the production of pharmaceutical, medical and herbal products. It should be pointed out that a small number of inputs and outputs may be viewed as a potentially limiting factor of the analysis. However, the condition of DEA analysis regarding the number of analysed units and inputs/outputs is fulfilled.

Ten decision making units i.e. pharmaceutical industries were selected in countries which include the Czech Republic, Spain, Cyprus, Hungary, Malta, Poland, Romania, Slovenia, and Croatia. One of the key reasons for selection lies in their comparability and relatively similar economic power in most of the selected countries. Naturally, a limiting factor of the DEA analysis should be pointed out, which is unavailability of data from other EU countries. In order to provide an objective assessment, industries which are more dominant than most of the analysed countries in terms of input costs, but also development, are eliminated from the implemented DEA method.

In the framework of the research on production efficiency of pharmaceutical, medical and herbal products, data from the Eurostat statistical database are used [21]. The objective of the analysis is to compare efficiency of pharmaceutical companies as representatives of the high-tech industry in 2009, i.e. in the four-year period (2006-2009) for ten selected European countries. The analysis is conducted by implementation of the

DEA SolverPro 6.0 software. Based on the selected inputs and outputs, analysis of production efficiency of pharmaceutical, medical and herbal products (representative of the high-tech sector) is conducted by implementation of the Charnes-Cooper-Rhodes model focused on inputs. Measuring of the correlation between the selected inputs and outputs represents the initial stage of the DEA. Correlation is tested on the basis of results of the Pearson's correlation test. By analysing the range of values of the correlation coefficient (0-1), conclusions are derived on smaller (the coefficient is closer to zero) or larger (the coefficient is closer to one) linear correlation. Table 1 below illustrates the correlation matrix of inputs and outputs of the production of pharmaceutical, medical, and herbal products.

	IR IZDV	***IR IST***	***IZV***
IR IZDV	1		
IR IST	0,967484	1	
IZV	0,960717	0,890062	1

Table 1: The correlation matrix of inputs and outputs (2009)

Table 1. shows linear correlation between the analysed variables, i.e. there is a correlation between the available inputs and outputs. Therefore, the obtained positive values from the correlation matrix fulfill the basic precondition of the DEA.

It is necessary to learn the fact that negative values of the coefficient indicate a limiting factor in the efficiency measuring, which is not the case in this research.

Taking into consideration the crucial role of R&D i.e. innovative activity of the high-tech industry and the selection of variables, the results of the conducted DEA are presented below.

The DEA analysis is a statistical method. In other words, it does not include a longer period of time to which the combination of the selected inputs and outputs relates. This problem can be solved by implementation of the window analysis. Window analysis conditions the selection of input and output data on decision making units for the selected consecutive periods (windows). The objective of window analysis is to estimate the efficiency of each decision making unit and, at the same time, it represents a temporally dependent method of the DEA. The basic characteristics of windows analysis are based on analysing each individual decision making unit like they are different decision making units in each of the analysed years. The selected decision making unit is compared with itself during the analysed period. Table 2 below presents efficiency of the pharmaceutical industry in the selected countries by implementation of the Charnes - Cooper - Rhodes window analysis in the period between 2006 and 2009.

The significance of Table 2 is reflected in the possibility to analyse efficiency trends of the presented pharmaceutical industries in the European countries. Value 1 denotes the maximum value, i.e. realised efficiency for the analysed decision making unit. For each pharmaceutical indsutry, the first window includes a period, i.e. 2006, 2007, and 2008. The analysis continues in the manner that, by introducing every new analysed year, the first year of the analysed period is eliminated from the analysis. In other words, the next window presents the efficiency in 2009 and eliminates 2006. the second window comprises 2007, 2008, and 2009.

The analysis of aggregated average of the selected EU pharmaceutical companies indicates that average efficiency shows certain dynamics. In general terms, the analysed four-year period is marked by a predominantly downward trend.

COUNTRY/YEAR	2006	2007	2008	2009	AVERAGE	C-AVERAGE
PORTUGAL	0,230171	0,170154	0,249792		0,216706	
		0,361789	0,336139	0,434676	0,377534	0,2971202
MALTA	1	0,165845	0,195553		0,453799	
		0,227972	0,269391	0,265099	0,254154	0,3539765
THE CZECH REPUBLIC	0,527904	0,850221	1		0,792708	
		0,859301	1	0,705921	0,855074	0,8238913
CYPRUS	0,257993	0,03674	0,059261		0,117998	
		0,050929	0,081137	0,09436	0,075475	0,0967366
POLAND	0,020076	0,015484	0,01917		0,018243	
		0,020596	0,026594	0,021812	0,023001	0,0206221
HUNGARY	0,093876	0,123565	0,119209		0,112216	
		0,134996	0,125862	0,136292	0,132383	0,1222999
SPAIN	0,072509	0,073967	0,070004		0,07216	
		0,101602	0,100483	0,114336	0,105474	0,088817
ROMANIA	0,049492	0,069926	0,051399		0,056939	
		0,090436	0,058985	0,654275	0,267899	0,1624189
SLOVENIA	0,30419	0,3103	0,312922		0,309138	
		0,475754	0,47095	0,389932	0,445545	0,3773415
CROATIA	1	0,752909	0,672465		0,808458	
		1	0,943916	0,160345	0,70142	0,754939
AVERAGE	**0,355621**	**0,294624**	**0,308162**	**0,297705**		

Table 2: Charnes - Cooper - Rhodes window analysis of the pharmaceutical industry efficiency in the selected countries

Data from Table 2 may be interpreted in a more simple manner and analysed through the following Figure. Figure 2 below presents relative efficiency variations and illustrates relative efficiency trends of the selected EU pharmaceutical industries.

Based on the results from Table 2 and Figure 2, it is evident that relative value variations place the pharmaceutical industries of the Czech Republic, Croatia, and Slovenia high on the chart. These countried proved to be the leading

countries according to the achieved average efficiency results.

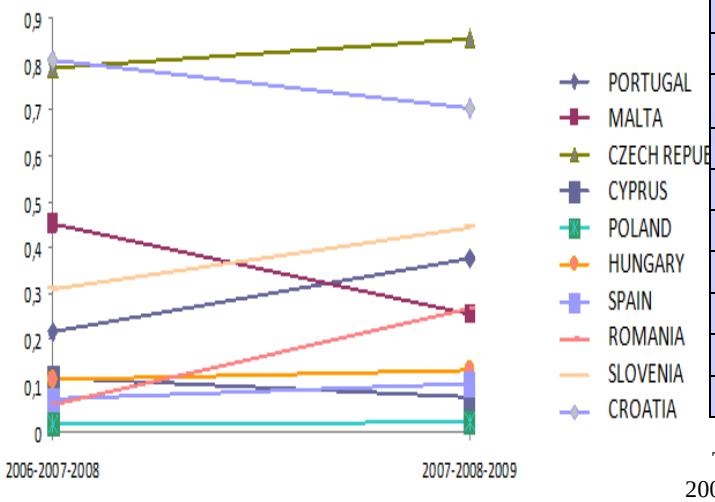

Figure 2: Relative efficiency variations of the selected pharmaceutical industries

The comparison of the selected countries indicates that only Croatian pharmaceutical industry recorded a slight downward trend. It is to point out that the Czech Republic achieved the best result; its C-average amounts 0,8238913. The Croatian pharmaceutical industry achieved an impressive average efficiency result of 0,754939, while Slovenia is characterised by average efficiency of 0,309138. Poland's pharmaceutical industry takes the last place on the average efficiency chart with the achieved result of 0,0206221.

The relative efficiency analysis in the analysed period of four years indicates that 2006 and 2008 may be singled out as years with the highest average relative efficiency. This conclusion is logical because 2006 and 2008 precede the development period of the global economic crisis as one of the possible factors. The negative change of the analysed average trend may also be explained by the achieved rentability of R&D investments in some pharmaceutical industries.

Table 3 below presents the relative efficiency average of pharmaceutical industries of the selected countries through two windows separately divided into three analysed years in a period.

Overview of the results in the Table 3 provides the conclusion that the period between 2007 and 2009 is marked by the best results of average relative efficiency for all the analysed countries except Malta and Cyprus. However, in the examples of Malta and Cyprus, the period from 2006 to 2008 indicates higher efficiency. What is more, there are significant changes evident in the average relative efficiency in most pharmaceutical industries of the analysed countries, and they are especially visible in the case of countries like Romania, the Czech Republic, Portugal, Malta, Croatia, and Slovenia.

COUNTRY/YEAR	2006-2007-2008	2007-2008-2009
PORTUGAL	0,216705966	**0,377534381**
MALTA	**0,453799289**	0,254153794
THE CZECH REPUBLIC	0,792708422	**0,855074116**
CYPRUS	**0,117998021**	0,075475263
POLAND	0,018243439	**0,023000832**
HUNGARY	0,112216465	**0,132383352**
SPAIN	0,07216012	**0,105473817**
ROMANIA	0,056939001	**0,267898757**
SLOVENIA	0,309137597	**0,445545305**
CROATIA	**0,80845777**	0,701420313

Table 3: The average through the windows in the period between 2006 and 2009

In the scope of the dynamic window analysis, results of the period from 2006 to 2009 are monitored, while statistical relative efficiency analysis conditions using a minimum of one year. Taking into consideration that analysis of several years indicates greater objectivity in relation to only one year, the implemented dynamic analysis is taken as a reference in the process of reaching the research conclusions.

IV. Conclusion

The efficiency assessment is based on the implementation of the DEA analysis in ten pharmaceutical industries of the selected European countries. The analysis was conducted by implementation of the Charnes-Cooper-Rhodes (CCR) model focused on inputs. Considering the relevance of R&D activities in high-tech industry sectors, such as the pharmaceutical industry, the selection of inputs was based on R&D activities. On the other hand, export represented an output in the scope of the analysis. One of the DEA limitations points out the line between the selection of inputs, outputs and the selected group of analyses, which was definitely taken into consideration during the research.

The following conclusions are made in order to improve efficiency of the pharmaceutical industry in the analysed countries: Firstly, taking into consideration that a higher level of rentable investments in R&D stimulates efficiency, the pharmaceutical industry should focus on making investments into the R&D. In order to achieve higher efficiency, companies in the pharmaceutical industry of the selected countries should review their own strategies and plans in order to readily face upcoming challenges on the foreign market. Companies in the pharmaceutical industry should also create an attractive environment for increasing investments in material assets, R&D, but also transfer of technology by foreign partners. The companies should allocate resources for researchers more productively by investing in the generation of their knowledge as well as creation of a stimulating environment.

By reaching these results, the research contributed to the

scientific approach in the efficiency analysis of the pharmaceutical industry through the presentation of new results and their interpretation, and the implemented methodological approach (by using the DEA analysis). Future research may be complemented by including the decision making units, inputs and outputs significant for efficiency of the high-tech-, but also medium-high-tech or low-tech industry.

REFERENCES

[1] Leachman, C., Pegels, C. C., Shin, S. K., Manufacturing performance: evaluation and determinants, *International Journal of Operations & Production Management*, 25 (9), 2005, pp. 851-874.

[2] Amornkitvikai, Y., Harvie, C., Identifying and measuring technical inefficiency Factors, Faculty of Commerce – Economics, *Working Papers Faculty of Commerce*, 2010.

[3] Yung-Hsiang L., Chung-Chi S., Chung-Te T. and Chun-Hsien W., Research and development in productivity measurement: An empirical investigation of the high technology industry, *African Journal of Business Management Vol. 4(13)*, pp. 2871-2884, 4 October, 2010

[4] Tripathy I.G, Yadav S.S. and Sharma S., Measuring the Efficiency of Pharmaceutical Firms in India: An Application of Data Envelopment Analysis and Tobit Estimation, 2010 availible at: http://gcoe.ier.hit-u.ac.jp/CAED/papers/id062_Tripathy_Yadav_Sharma.pdf (July 6th, 2013)

[5] Saranga, H., Phani, B. V., Determinants of operational efficiencies in the Indian pharmaceutical industry, *International Transactions in Operational Research*, 16 (1), pp.109–130.

[6] Chen, C., Chien, C., Lin, M., Wang, J., Using DEA to evaluate R&D performance of the computers and peripherals firms in Taiwan, *International Journal of Business* 9 (4), 2004, pp. 347-360

[7] Chiu, Y., Huang, C., Chen, Y., The R&D value-chain efficiency measurement for high-tech industries in China, Asia Pacific Journal of Management Vol 27,2010.

[8] Hashimoto, A., Haneda, S., Measuring the change in R&D efficiency of the Japanese pharmaceutical industry, *Research Policy*, 37 (10), 2008, pp. 1829-36.

[9] Staníčková, M., Skokan, K., Evaluation of Visegrad Countries Efficiency in Comparison with Austria and Germany by Selected Data Envelopment Analysis Models, *Recent Researches in Business and Economics* available on WSEAS Library, http://www.wseas.us/e-library/conferences/2012/Porto/AEBD/AEBD-26.pdf, (July 6th, 2013)

[10] Deraman, N. A., Said, J. M., Saman, F. I., Data Envelopment Analysis (DEA) Evaluation Framework of Hotel Services, *Recent Researches in Business and Economics* available on WSEAS Library, http://www.wseas.us/e library/conferences/2011/Montreux/ICICIC/ICICIC-24.pdf (July 6th, 2013)

[11] Charnes, A., Cooper, W. W., Rhodes, E., Measuring the efficiency of decision making units, *European. J. Operational. Res.*, 2, 1978, pp. 429-444.

[12] Hančlová, J., Staníčková, M., Assessment of the Visegrad Countries Performance by Application of the DEA Based Malmquist Productivity Index, *Advances in Economics, Risk Management, Political and Law Science*, available on WSEAS Library, http://www.wseas.us/elibrary/conferences/2012/Zlin/EPRI/EPRI-06.pdf , (July 6th, 2013)

[13] Ekinci, Y., Evaluation of Economic Indicators of EU Countries by DEA, *12th WSEAS Int. Conf. on APPLIED MATHEMATICS*, 29-31, 2007 Science available on WSEAS Library,http://www.wseas.us/elibrary/conferences/2007egypt/papers/568-460.pdf , (July 6th, 2013)

[14] Graves, S. B., Langowitz, N. S., R&D Productivity: A Global Multiindustry Comparison, Technology Forecasting. *Soc. Change*, 53(2), 1996, pp. 125-137.

[15] Bagchi-Sen S., Product innovation and competitive advantage in an area of industrial decline: the Niagara region of Canada, *Technovation*, 21(1), 9., 2001, pp. 45–54.

[16] Wang, E. C., Huang, W., Relative efficiency of R&D activities_A cross-country study according for environmental factors in the DEA approach, *Res. Policy*. 36(2), 2010, pp. 260-273

[17] Koschatzky, K., Bross, U., Stanovnik, P., Development and innovation potential in the Slovene manufacturing industry: analysis of an industrial innovation survey, *Technovation*, 2(5), 2001, pp. 311-324.

[18] Serrano-Cinca, C., Fuertes-Callen, Y., Mar-Molinero, C., Measuring DEA Efficiency in Internet Companies, *Decision. Support. Syst.* 38(4), 2005, pp. 557-573.

[19] Wakelin, K., Innovation and export behaviour at the firm level, *Research Policy* 26, 1998, Issues 7-8.

[20] Roper, S., Love, J. H., Innovation and Export Performance: Evidence from the UK and German Manufacturing Plants, *Research Policy* 31, 2002, pp. 1087-1102.

[21] Eurostat Database, http://www.eurostat.eu, 2013.