Application of Generalized Data Envelopment Analysis on Warsaw Stock Exchange

Sergiusz Herman[1]

Abstract

Fundamental analysis is one of the techniques used by stock investors. Its main aim is the estimation of financial situation of companies. Companies' financial statements are the source of information that allow for estimation of financial ratios for various operations of these companies. Elements of financial statements are also used to analyse analyse operating efficiency of companies with the use of parametric and non-parametric methods. Efficiency estimated with the use of these methods is rarely used for the assessment of joint-stock companies. There are three main goals of the research. Firstly, it aims to verify whether there is a statistical valid dependence between operating efficiency of joint-stock companies in Poland and their return rates on the Warsaw Stock Exchange. The second aim of the research is to point variables which should be used to estimate operating efficiency of companies in chosen industries. The other aim is to verify if an investor may benefit from information about operating efficiency of joint-stock companies when building an investment portfolio. Empirical studies were conducted on 72 joint-stock companies in Poland. These companies represent following industries: construction, clothes and cosmetics industry, food and drinks industry. The calculations were performed using the Generalized Data Envelopment Analysis.

Keywords: *operating efficiency, stock returns, Data Envelopment Analysis, stock exchange*
JEL Classification: C610, G300
DOI: 10.14659/SEMF.2018.01.16

1 Introduction

A good choice of securities for an investment portfolio is key for every investor on the Warsaw Stock Exchange. A fundamental analysis makes it possible to differentiate between companies in poor and good financial condition. One of company functional areas assessed by an investor is its performance (effectiveness). The inventory turnover, accounts receivable and payable ratios are the most popular ratios used for that purpose.

Numerous parametric (e.g. Stochastic Frontier Approach, Distribution-Free Approach) and non-parametric (e.g. Data Envelopment Analysis, Free Disposal Hull) methods for measuring efficiency are listed in the literature. Due to its computation complexity, results of these analysis are rarely used on the Warsaw Stock Exchange. G. Szafrański (2004) is a Polish author who conducted research on companies' operating efficiency. The study aimed to show whether DEA allows for the optimal choice of ratios which are widely used in

[1] Corresponding author: Poznań University of Economics and Business, Department of Econometrics, al. Niepodległości 10, 61-875 Poznań, Poland, e-mail: sergiusz.herman@ue.poznan.pl.

fundamental analysis. The study confirmed that there is a relation between a efficiency ratio and a change of stock price. It is worth mentioning that the author chose a priori a set of inputs and outputs of companies' operations. Moreover, the sample consisted of companies from various industries.

The Generalized DEA (GDEA) solved the problem of the a priori choice of variables for inputs and outputs. The method was used on a stock exchange by Edirisinghe and Zhang (2007) as well as Avkiran and Morita (2010). However, authors of both publications did not estimate companies' efficiency ratio. Financial indicators used in a standard fundamental analysis served as inputs and outputs and their results showed a financial condition of studied companies. The study presented in this article aimed to verify whether there is a valid statistical dependence between operating efficiency of joint-stock companies listed on the Warsaw Stock Exchange and their return rates. Next, the author investigated what variables should be used to estimate operating efficiency of companies from diverse industries of the Polish economy. The Generalized Data Envelopment Analysis (GDEA) was used for that purpose. The results revealed whether, when creating a securities portfolio, information on companies' operating efficiency may benefit an investor on the stock exchange.

2 Methodology

To conduct the research, a relevant sample of joint-stock companies listed on the Warsaw Stock Exchange had to be collected. Taking into account the methodology and analysis goal, the author chose companies representing three industry indexes: WIG-construction, WIG-food and WIG-clothes. Companies were chosen based on the following criteria: availability of their financial data and having been listed on the Warsaw Stock Exchange since 2011 or earlier. Information from the Notoria Serwis database was used to choose the sample. As a result, financial information of the following companies was collected:

- 37 joint-stock companies from the WIG-construction index (financial data for 2010-2016),
- 15 joint-stock companies from the WIG-clothes index (data for 2010-2016),
- 20 joint-stock companies from the WIG-food index (data for 2011-2016).

Data from financial statements was used as inputs and outputs of studied companies` operations. In total, 23 items from balance sheets and profit and loss accounts were used in the study (Table 1). The Data Envelopment Analysis (DEA) was used to measure operating efficiency of joint-stock companies. It is one of the most popular non-parametric methods of measuring companies' operating efficiency which allows for assessing efficiency of Decision

Making Units (DMU) defined by various inputs and/or outputs by solving a relevant optimization problem.

Table 1. Inputs and outputs underlying the research.

Potential inputs	**Potential outputs**
total assets	*net revenues from sales of products, goods and materials*
fixed assets	*gross profit (loss) on sales*
tangible fixed assets	profit (loss) on sales
intangible assets	*other operating revenues*
current assets	profit (loss) on operating activities
Inventory	*financial revenues*
short-term receivables	gross profit (loss)
cash and other pecuniary assets	*net profit (loss)*
equity	
share capital	
supplementary capital	
long-term liabilities	
short-term liabilities	
other operating expenses	
financial expenses	

The research used the BCC model named after its authors R.D. Banker, A. Charnes and W.W. Cooper (1984) who created it in 1984. The input-oriented BCC model (BCC-I), named after first letters of authors' names, may be expressed by:

$$min\theta_o \tag{1}$$

subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j \leq \theta_o x_{io} \quad i = 1, \dots, m, \tag{2}$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{ro} \quad r = 1, \dots, s, \tag{3}$$

$$\sum_{j=1}^{n} \lambda_j = 1, \;\; \lambda_j \geq 0 \quad j = 1, \dots, n. \tag{4}$$

where:

θ_0 – represents the efficiency score of unit *o*,

x_{ij} – is the amount of input *i* used by unit *j* (*i*=1, … , *m*),

y_{rj} – is the amount of output *r* used by unit *j* (*r*=1,2, …, *s)*.

λ_j – represent the variables that identify the benchmarks for inefficient units.

The reason for choosing the model was its result invariance which means that adding a constant to any result does not alter the optimum result of the problem.

Global analysis was carried out with the use of relevant financial data as inputs and outputs. The same joint-stock company was analyzed for various years.

3 Study of the relationship between operating efficiency and return ratios of joint-stock companies listed on the Warsaw Stock Exchange

First, the author verified whether the relationship between operating efficiency and return ration of joint-stock companies listed on the Warsaw Stock Exchange is statistically valid. In order to estimate efficiency ratios with the use of the BCC model, financial data serving as inputs and outputs of companies' operations needs to be defined. In diverse studies around the world, DEA was often used for companies' operating efficiency. Among authors who studied companies from the processing industry are: Ma et al. (2002), Fang et al. (2009), Hassan et al. (2010). Authors who studied companies from the construction industry are among others: Zheng et al. (2011), Horta et al. (2012), Wong et al. (2012) and Kapelko et al. (2014). Each author used a different set of financial variables in their research. However, there were some common features. Assets and a number of employees were often used as inputs. Whereas, items from profit and loss accounts were used as outputs. Taking into account literature and availability of financial data, the author decided to assess operating efficiency of joint-stock companies from relevant industries based on the following variables:

- version 1 – inputs: tangible assets, intangible assets, output: net profit/loss,
- version 2 – inputs: tangible assets, equity, output: net profit/loss.

Efficiency ratios were estimated for the years 2010-2016 (in the case of construction as well as clothing and cosmetic industries) and 2011-2016 (food industry). It was verified what is the relation between the results for consecutive years and companies' simple rate of return on the Warsaw Stock Exchange for the same period. Pearson correlation coefficient ($\gamma_{j,h}$ where j-th company is from the h industry) was used for that purpose. An average coefficient value was estimated for each studied industry:

$$\bar{\gamma}_h = \frac{1}{J}\sum_{j=1}^{J}\gamma_{j,h} \tag{5}$$

The following hypotheses were formulated to verify if there is a valid statistical dependence (where ρ_0 is an assumed positive correlation coefficient value).

$$H_0\colon\ \bar{\gamma}_h \leq \rho_0 \tag{6}$$

$$H_1\colon\ \bar{\gamma}_h > \rho_0 \tag{7}$$

The inference included the following test statistic (Edirisinghe and Zhang, 2007):

$$\bar{\Psi}_h = \frac{1}{J_h}\sum_{j=1}^{J_h}\frac{1}{2}log_e\frac{1+\gamma_{j,h}}{1-\gamma_{j,h}} \tag{8}$$

where: J_h – number of firms in each industry h.

Table 2 presents results for the studied industries.

Table 2. Dependence between performance and return rates.

	Version I			**Version II**		
	Construction	Food and drinks	Clothes and cosmetics	Construction	Food and drinks	Clothes and cosmetics
Correlation metric	0.218	0.248	0.323	0.220	0.297	0.338
Test statistic	0.261	0.326	0.367	0.263	0.389	0.387
Critical value	0.236	0.313	0.313	0.236	0.313	0.313

The results show that the strongest correlation can be observed for efficiency ratios and return rates of joint-stock companies from the clothing and cosmetic industry. Companies from the construction industry had the lowest value of correlation coefficient. The value was positive for all industries – the higher operating efficiency, the higher rates of return on the Warsaw Stock Exchange. According to test statistics, the null hypothesis stating that an average correlation coefficient is lower than 0.1 can be rejected for all cases (at significance level of 0.05).

4 Optimum variables for estimating operating efficiency of joint-stock companies from diverse industries

The second goal of the research is to point variables which should be used to estimate operating efficiency of joint-stock companies from diverse industries. The answer will

provide us with financial variables that should be taken into account when assessing operating efficiency of companies from various industries. The generalized DEA was used to solve that task. Its main purpose is to find a set of variables to be used as inputs and outputs based on a defined criteria - a relevant objective function. Owing to GDEA, variables are not attributed to inputs/outputs a priori. To measure efficiency ratios, the author introduced scale variables and variables which values determine how a variable (i-th variable describing j-th element) is attributed to inputs and outputs in the study. Due to the fact that the study concerns a defined number of variables *I*, variables create vectors scaling inputs and outputs. The GDEA approach makes it possible to find a pair which allows for maximizing (minimizing) the objective function of the optimization problem. According to Edirisinghe and Zhang (2007), the pair needs to belong to the following Binary Complementary Domain (BCD):

$$\Omega := \{(y,z): \sum_{i=1}^{I} y_i \geq 1, \quad y_i + z_i \leq 1, \quad y_i, z_i \epsilon \{0,1\}, \ i = 1, \dots, I\}. \tag{9}$$

Only then, none of the studied variables can simultaneously be an input and output while the study includes at least one input and output. Furthermore, in the study it was assumed that only 15 variables can be inputs and the remaining 8 can be outputs (Table 1). As a result, a pair $(\boldsymbol{y}, \boldsymbol{z})$ must belong to the Restricted BCD:

$$\Omega^* := \{(y,z) \in \Omega: \sum_{i=16}^{23} y_i = 0, \ \sum_{i=1}^{15} z_i = 0, \quad \}. \tag{10}$$

The above results confirmed that there is a valid statistical dependence between companies' operating efficiency and their rates of return on the Warsaw Stock Exchange. Therefore, a further research aims to find a set of inputs and outputs with the strongest dependence for each industry – the highest average value of a correlation coefficient for a given industry. Thus, a separate optimization problem needs to be solved for every industry:

$$\max_{y,z} \bar{\gamma}_h(y,z) \tag{11}$$

$$(y,z) \in \Omega^* \tag{12}$$

where:

$\bar{\gamma}_h$ – industry-correlation metric,

(y,z) – input/output scaling vector pair.

It is difficult to solve such formulated optimization problem as its objective function includes efficiency ratios for estimation of which it is required to solve optimization problems for each studied company. The simulated annealing algorithm was used to find an optimal solution. In order to define an initial solution of the algorithm, the author searched for all

possible solutions to a set of 10 potential inputs and 5 potential outputs (variables in italics in the Table 1). Additionally, it was assumed that variables strongly correlated with other variables are removed from the analysis (correlation coefficient higher than 0.90)[2]. Table 3 presents results achieved with the use of the simulated annealing algorithm for each studied industry.

Table 3. Dependence between operating efficiency and rates of return for GDEA.

	Construction	**Food and drinks**	**Clothes and Cosmetics**
Industry-correlation metric	0.319	0.411	0.429
Test statistic	0.396	0.490	0.505
Rejected null hypothesis	$\bar{\gamma}_h \leq 0.25$	$\bar{\gamma}_h \leq 0.25$	$\bar{\gamma}_h \leq 0.25$

The analysis of results indicated that again the strongest dependence between companies' efficiency ratios and their rates of return on the stock exchange was observed for clothes and cosmetic industry. The construction industry had the lowest correlation coefficient. After comparing the results with outcome of the prior study, it turned out that an average correlation coefficient for every industry increased due to the choice of variables with the use of GDEA. In the case of all analyzed industries, the null hypothesis can be rejected in favor of an alternative hypothesis stating that an average correlation coefficient is higher than 0.25. According to the results, it is advisable to use other methods than the expert method to choose input and output variables. It makes it possible to estimate efficiency ratios in such a way that better represents a market situation of companies on the Warsaw Stock Exchange.

The second aspect of the study is focused on an assessment of dependence between the estimated efficiency ratios and rates of return as well as an analysis of financial data that were considered owing to GDEA. They are presented in Table 4. A different set of variables serving as inputs and outputs was used for each studied industry. Similar variables were used for the food as well as clothes and cosmetic industries. In both cases, inputs included variables from liabilities which show sources of companies' equity. Similarities might stem from a comparable activity of studied companies. A completely different set of variables was used as inputs in the case of the construction industry. The study included only tangible and intangible assets. Results shows that variables used to estimate operating efficiency of joint-

[2] If two variables are strongly correlated, a variable with a higher average of absolute values of correlation coefficients is removed from the analysis.

stock companies differ from one industry to another. It should be taken into consideration in studies on their activity.

Table 4. Optimum inputs/outputs for relevant industries.

	Construction	Food and drinks	Clothes and cosmetics
tangible fixed assets	input		
inventory	input		
short-term receivables	input		
equity		input	
short-term liabilities		input	input
long-term liabilities		input	input
profit (loss) on sales			output
gross profit (loss) on sales	output	output	
other operating expenses			output
net profit (loss)	output		

5 Use of information on operating efficiency of joint-stock companies while creating investment portfolio

The results from previous stages of the study confirmed that there is a valid statistical dependence between operating efficiency of companies listed on the stock exchange and their rates of return. Companies performing effectively had higher rates of return on the Warsaw Stock Exchange. Finally, this dependence was used to create an investment portfolio. For this purpose, the author had to estimate efficiency ratios for studied companies in 2017. The author used values of efficiency ratios for periods 2010-2016 (construction as well as clothes and cosmetic industries) and 2011-2016 (food industry) with the use of the BCC model and variables from the previous stages of the study. Using the data, a comparative analysis of the following prediction methods was carried out (based on an ex-post forecast error): naive methods, methods based on simple average, methods based on weighted average and trend. On that basis, it was decided that performance of companies in 2017 will be predicted using a simple 4-element average.

A model developed by H. M. Markowitz was used to create an investment portfolio. Two portfolios were created for the period April 3 – October 2, 2017. The first portfolio was created with the use of share prices of all 72 studied companies (the “Markowitz” portfolio). The Markowitz model was also used to build a second portfolio. However, only 20 companies

considered as effective in 2017 were included (correlation coefficient higher than 0.7). Fig. 1 presents the rate of return of such portfolios in the studied time frame.

Results show that the compound return rate of the portfolio built based on effective companies is substantially higher (10.02%) than for the one based on all studied companies (-4.26%). Most importantly, the portfolio based on effective companies allows an investor to achieve higher return rates uninterruptedly for 70% of the time.

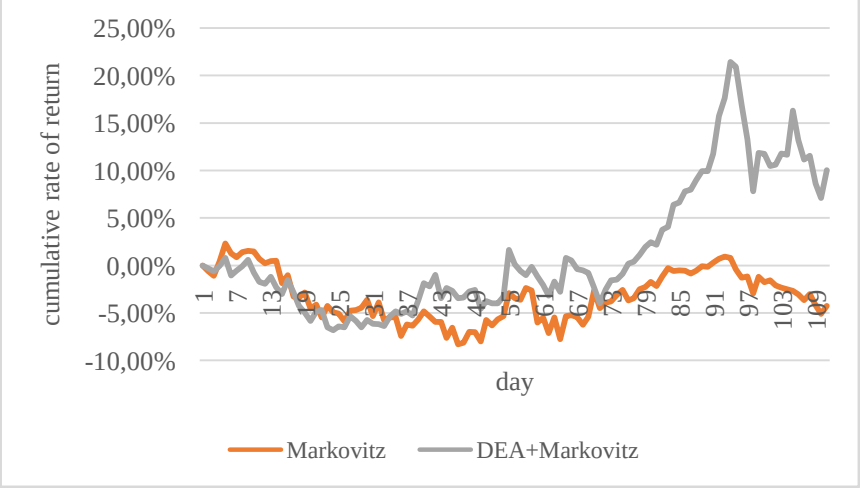

Fig. 1. Cumulative rate of return of two investment portfolios.

Conclusions

The results demonstrate that there is a valid statistical dependence between operating efficiency of Polish joint-stock companies and their return rates. It is a positive dependence which means that effective companies have higher return rates than those performing poorly. Variables used to estimate operating efficiency of joint-stock companies from various industries were discovered owing to the GDEA approach. Results demonstrated that a different set of variables serving as inputs and outputs should be used for operating efficiency estimation of joint-stock companies from various industries.

What's more, results showed that information on operating efficiency of joint-stock companies might be crucial for investors on the Warsaw Stock Exchange. If they take that into consideration when creating an investment portfolio, investments in companies performing well will give them higher return rates.

Further research should include the analysis of more industries in Poland. Moreover, the use of a different method (other DEA-like models) should give interesting results.

References

Avkiran, N. K. & Morita, H. (2010). Predicting Japanese bank stock performance with a composite relative efficiency metric: A new investment tool. *Pacific-Basin Finance Journal, 18*(3), 254-271.

Banker, R. D., Charnes, A. & Cooper, W. W. (1984). Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Science, 30(9),* 1078-1092.

Edirisinghe, N. & Zhang, X. (2007). Generalized DEA model of fundamental analysis and its application to portfolio optimization. *Journal of Banking & Finance, 31*(11), 3311-3335.

Fang, H., Wu, J. & Zeng, C. (2009). Comparative study on efficiency performance of listed coal mining companies in China and the US. *Energy Policy, 37*(12), 5140-5148.

Hassan, M. K., Isik, I. & Mamun, A. (2010). Trade liberalization and industry performance in Bangladesh. *Journal of Policy Modeling, 32*(3), 399-417.

Horta, I. M., Camanho, A. S., Johnes, J. & Johnes, G. (2012). Performance trends in the construction industry worldwide: an overview of the turn of the century. *Journal of Productivity Analysis, 39*(1), 89-99.

Kapelko, M., Lansink, A. O. & Stefanou, S. E. (2014). Assessing dynamic inefficiency of the Spanish construction sector pre- and post-financial crisis. *European Journal of Operational Research, 237*(1), 349-357.

Ma, J., Evans, D. G., Fuller, R. J. & Stewart, D. F. (2002). Technical efficiency and productivity change of Chinas iron and steel industry. *International Journal of Production Economics, 76*(3), 293-312.

Szafrański, G. (2004). Metoda DEA w analizie fundamentalnej polskiego rynku akcji. *Acta Universitatis Lodziensis. Folia Oeconomica, 177/2004*, 347-363.

Wong, W. P., Gholipour, H. F. & Bazrafshan, E. (2012). How efficient are real estate and construction companies in Irans close economy? *International Journal of Strategic Property Management, 16*(4), 392-413.

Zheng, X., Chau, K. & Hui, E. C. (2011). Efficiency assessment of listed real estate companies: an empirical study of China. *International Journal of Strategic Property Management, 15(2),* 91-104.