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Measuring productivity of construction industry in Europe with Data Envelopment Analysis

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Abstract

The purpose of the article is to present the use of DEA and Tobit regression for analysing productivity of the construction industry in Europe. Differences and similarities between construction sectors in various European countries are discussed. Labour productivity was calculated with DEA method. Changes in the efficiency score over the period of 2006-2012 were estimated using Malmquist index. Tobit regression was applied to explore the impact of the economic performance of a country on the labour productivity in its construction industry. The results reveal huge differences in the productivity of the construction industry across Europe. Trends in productivity change are also explored. On the basis of regression analysis it was proven that the interpretation of the efficiency scores without taking into account the general economic conditions of a country may lead to false conclusions.

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Keywords: Data Envelopment Analysis (DEA); Malmquist index; Tobit regression; efficiency; productivity; construction; evaluation.

1. Introduction

Construction is an industry that contributed 5,9% of the European Union (EU) member states total gross value added in 2012. This sector is the also one of the largest industrial employer. It was particularly heavily affected by the financial and economic crisis and its aftermath. Construction experienced the deepest and longest contraction, with its value added falling by 18.9% between 2007 and 2013, with output falling every year during this period [8].

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European construction sector is predicted to return to moderate growth in 2014 [7]. GVA as a metric of money value for the products and services that have been produced or provided minus the cost of all inputs attributable to the production is intended to reflect the financial situation in construction sector. According to the authors, it is justified to evaluate the performance in terms of labour productivity in the industry before the crisis and for now.

In this paper the labour productivity of the construction industry in European countries was analysed using DEA method and Malmquist index. DEA method – through the simultaneous analysis of several indicators of economic activity – provides more objective assessment and gives the possibility to take into account strengths of each country. The combination of DEA method and Malmquist index allows not only to evaluate the changes in relative productivity but also to determine the factors affecting the change (technical efficiency change or technological change). Then the Tobit regression approach was employed to gain insights the role of GDP per capita in the efficiency.

2. Main statistical findings

Productivity of the construction sector in 25 European countries is analysed in the article. Firstly, based on public data from Eurostat, the key differences and similarities between countries are presented.

European countries differ in the number of construction enterprises and in the number of people employed in relation to the population size (Table 1). There are differences in construction enterprises' contribution to Gross value added (GVA). However, some similarities can be found. In the set of the 25 analysed states, construction contributes on average to more than 6% of the total GVA and employs more than 3% of the citizens of each country.

Table 1. Performance of construction in European countries in 2012

No	Country	Gross value added (at basic prices) [million euro]			Number of construction enterprises	Number of people employed in construction	Population	Number of people employed in construction in population [%]
		Total	Construction	Contribution [%]				
1	Belgium	335324,0	19748,0	5,9%	95549	317544	11094850	2,9%
2	Bulgaria	34296,4	2105,6	6,1%	19068	150381	7327224	2,1%
3	Czech Republic	137251,5	8619,7	6,3%	175799	395214	10505445	3,8%
4	Denmark	211267,9	10036,1	4,8%	31300	166230	5580516	3,0%
5	Germany	2386790,0	111320,0	4,7%	274002	1962860	80327900	2,4%
6	Estonia	15205,1	1153,4	7,6%	8376	43437	1325217	3,3%
7	Spain	944219,0	80827,0	8,6%	320872	1112233	46818219	2,4%
8	France	1820900,4	114133,7	6,3%	512864	1772057	65287861	2,7%
9	Italy	1402117,6	82721,6	5,9%	572412	1553237	59394207	2,6%
10	Cyprus	16116,5	942,1	5,8%	6224	28575	862011	3,3%
11	Latvia	19901,4	1224,0	6,2%	8000	59775	2044813	2,9%
12	Lithuania	29737,6	1775,8	6,0%	20242	93448	3003641	3,1%
13	Luxembourg	38465,5	2379,7	6,2%	3365	41066	524853	7,8%
14	Hungary	81215,6	3090,6	3,8%	60284	198317	9931925	2,0%
15	Netherlands	538037,0	26551,0	4,9%	134589	474618	16730348	2,8%
16	Austria	277586,2	18882,9	6,8%	32174	285320	8408121	3,4%
17	Poland	337912,4	25352,6	7,5%	233731	890864	38538447	2,3%
18	Portugal	144509,6	7314,7	5,1%	88797	344185	10542398	3,3%
19	Romania	114841,4	11278,1	9,8%	44607	410340	20095996	2,0%
20	Slovenia	30707,8	1822,2	5,9%	18392	62357	2055496	3,0%

Table 1. Continued

21	Slovakia	65002,1	5341,0	8,2%	86412	153110	5404322	2,8%
22	Finland	165372,0	11500,0	7,0%	42781	182778	5401267	3,4%
23	Sweden	358004,8	18841,4	5,3%	93598	353468	9482855	3,7%
24	United Kingdom	1700620,3	102624,3	6,0%	257192	1293991	63495303	2,0%
25	Norway	347834,3	20364,4	5,9%	52763	210095	4985870	4,2%

Note: Source Eurostat. Available from Internet: http://ec.europa.eu/eurostat/statistics-explained/index.

In order to find groups of similar countries k-mean cluster analysis was employed. Taking into account the contribution of construction to the total GVA and the number of people employed in construction in relation to the population size 3 clusters were identified. The appropriate number of clusters was determined using the cross-validation method. Table 2 comprises the results. The analyses were carried out in Statistica Data Miner.

Table 2. Cluster analysis

Cluster	Country	Construction in total gross value added [%]	Number of people employed in construction in population [%]
1	Luxembourg	6,2%	7,8%
2	Belgium, Bulgaria, Czech Republic, Denmark, Germany, France, Italy, Cyprus, Latvia, Lithuania, Hungary, Netherlands, Portugal, Slovenia, Sweden, United Kingdom, Norway	5,6%	2,9%
3	Estonia, Spain, Austria, Poland, Romania, Slovakia, Finland	7,9%	2,8%

The first cluster consists of Luxembourg where constructions has a slightly above-average contribution to GVA but has the highest percentage of employment in Europe. Second cluster represents the European average. The last cluster has the similar share of people employed but can be distinguished by the high contribution of the sector to GVA.

There are also significant differences in terms of productivity, expressed in the relation of turnover, value added and gross operating surplus to personnel costs or number of persons employed (Table 3). For the purpose of this work Eurostat glossary definitions have been adopted: gross operating surplus (profits) is defined as value added minus personnel costs, turnover comprises the totals invoiced by the observation unit during the reference period, and this corresponds to the total value of market sales of goods and services to third parties, personnel costs are made up of wages, salaries and employers' social security costs (Eurostat).

Table 3. Labour productivity characteristic of European countries in 2012 in million euro

No	Code	Country	Gross value added (at basic prices)	Turnover or gross premiums written	Gross operating surplus	Personnel costs	Number of persons employed
1	BE	Belgium	19748,0	61178,2	5802,1	9885,2	317544
2	BG	Bulgaria	2105,6	7169,3	594,4	648,5	150381
3	CZ	Czech Republic	8619,7	27923,1	2478,2	3547	395214
4	DK	Denmark	10036,1	26933	1840,9	7022,9	166230
5	DE	Germany	111320,0	211333,3	20639,2	58447,6	1962860
6	EE	Estonia	1153,4	3898,5	322,9	593,2	43437
7	ES	Spain	80827,0	118555,3	12876,4	27702,9	1112233
8	FR	France	114133,7	282147,1	15120,1	71340,2	1772057
9	IT	Italy	82721,6	194737,4	21038,5	32370,2	1553237
10	CY	Cyprus	942,1	2272,9	360,8	653,8	28575

11	LV	Latvia	1224,0	3868,2	334,3	422,6	59775

Table 3. Continued

12	LT	Lithuania	1775,8	3608,3	277,9	674,0	93448
13	LU	Luxembourg	2379,7	5977,8	435,4	1672,3	41066
14	HU	Hungary	3090,6	10442,1	799,3	1395,5	198317
15	NL	Netherlands	26551,0	82483,2	7007,3	18209,9	474618
16	AT	Austria	18882,9	42577,1	4229,3	10762,4	285320
17	PL	Poland	25352,6	58112,8	6378	6947,3	890864
18	PT	Portugal	7314,7	22370,2	1232,8	4578,2	344185
19	RO	Romania	11278,1	17428,7	2211,9	1944,2	410340
20	SI	Slovenia	1822,2	4827,4	359,5	881,5	62357
21	SK	Slovakia	5341,0	7731,1	1600,5	922,6	153110
22	FI	Finland	11500,0	28884,6	2710,8	6726,4	182778
23	SE	Sweden	18841,4	61293,4	4017,4	15617,4	353468
24	GB	United Kingdom	102624,3	233296,2	45301,3	42191,2	1293991
25	NO	Norway	20364,4	54813,7	5047,9	12677,3	210095

There are linear, positive relationships between GVA, turnover, gross operating surplus and personnel cost or the number of persons employed. Pearson correlation coefficients are presented in Table 4.

Table 4. Correlation

	Gross value added (at basic prices)	Turnover or gross premiums written	Gross operating surplus	Personnel costs
Turnover or gross premiums written	0,977			
Gross operating surplus	0,856	0,856		
Personnel costs	0,961	0,972	0,755	
Number of persons employed	0,963	0,942	0,779	0,924

It was assumed that gross operating surplus and turnover represent a somewhat different aspects of business operations and including them both as the outputs in the productivity assessment is justified. However, there is a high and statistically significant correlation between them.

3. Previous research

DEA gained a wide popularity as a method for determining the effectiveness and has been widely investigated and successfully applied in many different areas. Because of the capability of including not only financial data and incorporating uncontrolled inputs (such as environmental circumstances) is well suited especially for the evaluation non-profit organizations [4,16]. However, DEA method also performs well in estimating a synthetic indicator to measure the effectiveness of construction enterprises in many countries.

In paper [6] DEA was utilized to benchmark safety performance of 45 construction contractors randomly selected from member lists of the Jordanian Contractors Association. DEA has been recognized as a robust tool that is useful for evaluating the performance of construction entrepreneurs.

Paper [20] employs a DEA-based Malmquist productivity index to measure the productivity changes on the example of Chinese construction industry from 1997 to 2003. Malmquist index was used also in [10] to assess, from the financial perspective, the stability of efficiency of 118 construction companies operating in 18 countries from three continents. The relationship between the efficiency levels and company location and activity, using a panel data truncated regression with categorical factors was studied.

Different types of efficiency (cost, allocative and technical) in the Korean construction industry were analyses in work [21]. The Authors assumed that construction firms try to maximize output (sales) consuming three type of input (labour, capital and materials) and highlighted that the low level of cost efficiency in construction companies in Korean of is mainly due to allocative inefficiency (inappropriate mix of input factors) rather than to technical inefficiency. Efficiency scores are regressed using Tobit regression model on a vector of variables representing the characteristics of the firms (leverage ratio, export, institutional ownership, asset and receivables overdue turnover).

Two-stage evaluation: DEA with regression approach was also applied to analyses of profitability efficiency and efficiency in the market value-generating process of nineteen construction firms listed on the Athens Exchange [19].

In this article Authors propose DEA to evaluate and Tobit approach to assess the labour efficiency of the construction industry in European countries.

4. The DEA, Malmquist and Tobit approach

In this study a BCC DEA model built on the assumption of variable return to scale was employed. A DMU that has a minimum input value for any input item, or a maximum output value for any output item, is BCC effective [5]. The basic output-oriented radial BCC DEA model for measuring performance of (DMU_{jo}) can be written as [22]:

$$max\, \phi_{j_o} = \frac{1}{\theta_{j_o}} \tag{1}$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{ij_o}, \qquad i = 1, \dots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq \phi_{j_o} y_{rj_o}, \qquad r = 1, \dots, s$$

$$\lambda_j \geq 0, \quad j = 1, 2, \dots, n.$$

Where:

$X_j = (x_{1j}, x_{2j}, x_{3j}, \dots, x_{mj},)$ – input vector,

$Y_j = (y_{1j}, y_{2j}, y_{3j}, \dots, y_{sj},)$ – output vector,

λ_j – intensity levels at which the production activities are conducted by the j-th DMUs,

r = 1, 2, …, s – number of outputs,

i = 1, 2, …, m – number of inputs,

j = 1, 2, …, n – number of DMUs,

ϕ_{j_o} – efficiency ratio.

Malmquist index not only assesses the performance between two points in time but also distinguishes between improved possibilities of performance (technological change – TC) and the degree to which DMU has taken advantage of these possibilities in both periods (technical efficiency change – TEC). In other words, TC reflects the change in the efficient frontiers between two periods (frontier-shift) while TEC relates to the degree to which a DMU improves or worsens its efficiency measures between period t and t+1 (catch-up efficiency). The most widely used Malmquist productivity index model can be written as follows [9]:

$$M(x^t, x^{t+1}, y^t, y^{t+1}) = (TEC) \times (TC) \tag{2}$$

$$TC = \left[\frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \times \frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})}\right]^{1/2},$$

$$TEC = \left[\frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)}\right].$$

Where: D is the distance function based on DEA model, respectively: $D^{t+1}(x^t, y^t)$ measures productivity in period t using period $t+1$ technology as a benchmark, $D^t(x^{t+1}, y^{t+1})$ measures productivity in period $t+1$ using period t technology as a benchmark.

Malmquist index is greater than, equal to, or less than 1 when the efficiency is improving, unchanged, or deteriorating, respectively. TC is greater than, equal to, or less than 1 when the frontier technological best practice is improving, unchanged, or worsening, respectively. Analogously, TEC is greater than 1 indicates progress in relative efficiency, equal or less than 1 indicate no change or regress in efficiency [5].

Regression analyses are the typical approach to determine the impact of independent variables on either quality or productivity. One of the models that is gaining popularity is Tobit model. Tobit model was first proposed by [18] and assumes that the dependent variable has a number of its value clustered at a limiting value, usually 0. The Tobit model assumes that the observed dependent variables Y_j for observations j = 1, .., n satisfy:

$$Y_j = max(Y_j^*, 0) \tag{3}$$

where the Y_j^* are latent variables generated by the classical linear regression model:

$$Y_j^* = \beta' X_j + U_j \tag{4}$$

with X_ja vector of regressors, possibly including 1 for the intercept, and β the corresponding vector of parameters. The model errors U_j are assumed to be independent $N(0, \sigma^2)$ distributed, conditional on the X_j [1]. The maximum likelihood method is used to obtain the value of β.

5. Efficiency evaluation

The data used in the study covers the period from 2006 to 2012 and comes from the Eurostat databases. In order to measure productivity of construction industry in Europe DEA BCC-O model was used. Number of persons employed was chosen as the input. Turnover and gross operating surplus are outputs. Table 5 contains the DEA score and Malmquist index.

Table 5. DEA Scores and Malmquist index

Country	GDP per Capita	DEA efficiency 2012	DEA efficiency 2006	Malmquist index	TEC	TC
Belgium	35100	0,844	0,838	1,274	1,006	1,266
Bulgaria	5600	0,191	0,146	1,532	1,311	1,168
Czech Republic	15300	0,327	0,396	1,009	0,826	1,221
Denmark	44900	0,639	0,635	1,272	1,007	1,264
Germany	33600	0,798	0,663	1,143	1,205	0,949
Estonia	13300	0,587	0,449	1,337	1,306	1,024
Spain	22600	0,583	1,000	0,477	0,583	0,818
France	31900	1,000	0,791	1,214	1,265	0,960
Italy	27000	0,750	0,781	0,898	0,960	0,935
Cyprus	22500	1,000	1,000	0,808	1,000	0,808
Latvia	10900	0,340	0,375	0,961	0,907	1,060
Lithuania	11200	0,171	0,198	0,976	0,863	1,131
Luxembourg	82400	1,000	1,000	0,962	1,000	0,962
Hungary	9900	0,203	0,326	0,810	0,622	1,302

Netherlands	38200	0,838	0,973	1,029	0,862	1,194
Austria	37600	0,634	0,674	1,179	0,940	1,254
Poland	10000	0,348	0,298	1,328	1,169	1,136

Table 5. Continued

Portugal	16100	0,291	0,402	0,880	0,724	1,215
Romania	6700	0,199	0,172	1,396	1,152	1,212
Slovenia	17500	0,398	0,428	1,045	0,929	1,125
Slovakia	13400	0,335	0,366	0,976	0,915	1,066
Finland	36900	0,620	0,783	0,947	0,792	1,195
Sweden	44500	0,782	0,747	1,313	1,046	1,255
United Kingdom	32000	1,000	1,000	0,909	1,000	0,909
Norway	79000	1,000	1,000	1,243	1,000	1,243
Belgium	35100	0,844	0,838	1,274	1,006	1,266
Bulgaria	5600	0,191	0,146	1,532	1,311	1,168
Czech Republic	15300	0,327	0,396	1,009	0,826	1,221
Denmark	44900	0,639	0,635	1,272	1,007	1,264

In 2006, in comparison to 2012, average labour productivity slightly decreased from 0,618 to 0,595. Five of out of 25 European states were fully effective, among them four (United Kingdom Luxembourg, Norway, Spain, Cyprus) were fully efficient in the two evaluated periods. The change concerns France which increased the DEA score and in 2012 is 100% effective and Spain which decreased its score nearly two-fold. 14 countries observed productivity growth form period 1 to 2, other (11 states) observed deterioration in total productivity. In case of 18 states there was a progress in the frontier technology and only 9 states indicated progress in technical efficiency change.

DEA assumes that efficiency is the result of management policy, hence it does not take into account the impact of exogenous factors. Therefore, a further step in the analysis is the Tobit regression to determine their effects on the DEA efficiency scores. GDP per capita was chosen in the article as a criterion of labour productivity of the country in construction . Thus it was assumed:

Efficiency = function (GDP per Capita) (5)

Because the observed dependent variable Y (Efficiency) is confined to an interval (a, b], where if a = 0 and b = 1 logarithmic transformation was done on the dependent variable and the new variable $ln(Y)\,\epsilon(-\infty,0]$. Linear combination of variables and use the coefficient -1 create the variable Z=$-ln(Y)\,\epsilon[0,\infty)$. In this case a negative coefficient of an X variable implies a positive effect on the original dependent variable Y, because $\frac{\partial Z}{\partial Y}=-\frac{1}{Y}<0$. The visualization of the relationship is presented in Figure 1.

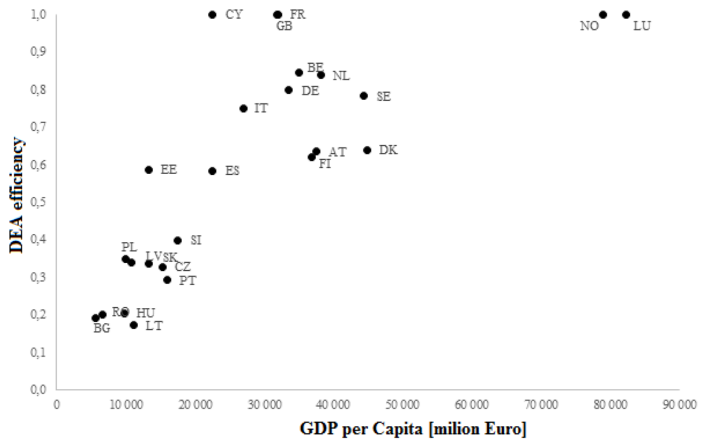

Fig. 1. Relationship between DEA score and GDP per Capita

Coefficients, the t-statistic, associated p-values, pseudo-R2 are presented in table 6. Since the absolute value of t-value is large enough, it can be assumed that the GDP per capita, is useful in estimating the expected value of efficiency score. The inverse of the two-tailed Student's T distribution for probability 0,05 and degrees of freedom 23 is -1,71. In general, the lower GDP per capita the state has, the lower labour productivity index it reaches. The Pearson correlation coefficient between variables is 0,75.

Table 6. Tobit regression results

	Estimated coefficient	t-value	p-value
Intercept	1,5873107	9,8975	0,00000
GDP per capita	-0,0000380	-6,1445	0,00000
Pseudo R^2	0,72137		
Log likelihood	-12,6418940		

6. Conclusions

Multi-stage combination of non-parametric DEA, Malmquist index and parametric regression model have allowed to adjust DEA score and have opened new possibilities for research. The DEA results revealed huge differences in productivity of construction industry and their trends. Malmquist index identified possible technological change during analysed periods. It was proven, on the basis of regression analysis, that the interpretation of efficiency scores without taking account general economic conditions of the country can lead to inappropriate conclusions. However, one should be aware that far-reaching conclusions and radical proposals are limited by small degrees of freedom in Tobit regression model. Therefore, although there is a relationship between DEA score and GDP, the parameters' estimation results may be unreliable.

The analysis of productivity change in construction industry can give valuable insights and be the basis for the design, monitoring and evaluation of EU policies in the sector. Reliable monitoring of the change of countries performance allows to identify best practices and make appropriate management decisions.

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