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Measuring the efficiency of digital convergence

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ABSTRACT

The paper suggests the use of data envelopment analysis (DEA) and Malmquist productivity index for keeping up with the trends in digital economy development effectiveness in the European countries. We show that Central and Eastern Europe countries converge to the EU average concerning the level of digital economy development, while digital divide exists between the EU and the Western Balkan countries.

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1. Introduction

The difference in countries' economic performances and their global competitiveness greatly depends on the level of acceptance, availability, and use of ICT. Qiang and Rossotto (2009), Koutroumpis (2009), Czernich et al. (2011) and Kongaut and Bohlin (2014) have shown that an increased number of Internet users in developed countries leads to increase in GDP *per capita*. Gruber et al. (2014) demonstrate that, for the EU, the total economic benefits from investment in broadband infrastructure are higher than the cost. However, with ICT development, a digital divide also emerges – a gap between countries, regions, households, individuals, and companies with respect to ICT access and use (Van Dijk and Hacker, 2003).

By means of *Data envelopment analysis* (DEA), the paper analyses the dynamics and the achieved level of digital economy development in the European Unions (EU), Central and Eastern Europe (CEE) and Western Balkans (WB) countries. DEA numerically reports the achieved effectiveness of economic process which makes it a suitable tool for determining the analysed countries' effective or ineffective position. The degree of digital economy development is measured by a more advanced DEA approach – Malmquist productivity index (MI) – which analyses effectiveness in digital economy development in 40 countries in the period 2002–2017.

2. Methodology

MI evaluates productivity changes for the observed countries between two periods and exemplifies comparative statistical analysis (Fare et al., 1998). MI is defined as the product of the change in relative input use efficiency (*catch-up effect*) and the change (shift) in technological efficiency (*frontier shift effect*) (Fare et al., 1994).

In calculating MI, the value θ is obtained by DEA model and linear programming (Sánchez, 2018; Cook et al., 2014) with the following four equations, where s is the number of production possibility frontiers and takes the values of 1 and 2, while t is the number of periods observed and takes the values of 1 and 2 (that is, these are the marks of the two mutually compared periods), while values of $(x_0, y_0)^1$ and $(x_0, y_0)^2$ represent input and output vectors of the same DMUs (decision making units) observed in periods 1 and 2, respectively:

$$\delta^s(x_0, y_0)^t = \min_{\theta,\lambda} \theta$$

where

$$\delta^s x_0^t \geq X^s \lambda_i$$
$$y_0^t \leq Y^s \lambda_i$$
$$L \leq e\lambda_i \leq U$$
$$\lambda_i > 0$$

$$i = 0, 1, 2, \ldots, N \qquad (1)$$

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Table 1
Indicators used in DEA analysis.
Source: The DEA indicators' selection is based on the author's judgement. The statistical data source is ITU (www.itu.org).

Dimension	Indicator
Input	Internet users (%)
	International Internet flow per Internet user (bit/s)
	Number of fixed broadband Internet subscribers per 100 people
	Number of mobile cellular subscribers per 100 people
	Annual investments in telecommunication services (% of GDP)
Output	GDP per capita (PPP, $)

θ indicates the efficiency score of the observed DMU, while $\delta^s(x_0,y_0)^t$ denotes the efficiency of the DMU observed in period t measured by the frontier technology s. The stated DEA model is input oriented because it searches for the combination of the least possible quantities of input which can produce the given output. Vector $\lambda=(\lambda_1, \lambda_2,\ldots, \lambda_N)$ represents a series of N variables λ_i which construct the efficiency frontier (that is, production possibility frontier), while e represents the vector e=(1, 1, …, 1) with the size of 1×N. X is the input matrix, and Y is the matrix of output values for each observed country. For each pair of values *(s, t)*, the model is calculated N times (the number of observed DMUs). If $(L, U) = (1, 1)$, then it is a Banker, Charnes and Cooper model (Banker et al., 1984). In this model, the efficiencies are calculated with variable return scale (VRS) and it is suitable to compare DMUs (countries) of different sizes.

According to (Zhu, 2011), MI productivity is calculated as:

$$MI = \frac{\partial^2 (x_0, y_0)^2}{\partial^1 (x_0, y_0)^1} \times \sqrt{\left[\frac{\partial^1 (x_0, y_0)^1}{\partial^2 (x_0, y_0)^1} \times \frac{\partial^1 (x_0, y_0)^2}{\partial^2 (x_0, y_0)^2}\right]} \quad (2)$$

The first factor in the equation shows the change in relative efficiency (catch-up effect — EC) of the observed country in relation to other countries. The second factor shows the shift in the production possibility frontier, that is, technological changes (TC). In the above equation, $\partial^2(x_0, y_0)^2$ shows the observed country's efficiency in year 2 under technological limitation in that year, while $\partial^1(x_0, y_0)^1$ shows its efficiency in year 1 under technological limitation in that year. ∂^1 and ∂^2 relate to technological limitations in year 1 and year 2, respectively.

3. Data

To evaluate effectiveness in ICT application and digital economy development, the indicators shown in Table 1 were used to identify the presence of digital convergence.

To determine technological efficiency frontiers, that is, the production possibility frontiers, in this paper, DEA includes the data for the six above stated indicators in the period 2002–2017 for 40 selected EU, CEE and WB countries. Two main conditions were met for DEA application: that the number of observed countries should be at least twice the sum of inputs and outputs of variables used in analysis, and that the output should not decrease when input quantity is increased.

4. Results and discussion

Table 2 shows values of MI, EC and TC calculated by input-oriented DEA model with variable returns for all observed countries in three periods (2002–2008, 2008–2012, 2012–2017).

Most countries have reached MI values larger than 1 only after 2012. This is the period following the economic crisis when most countries recovered economically, in which new technologies were introduced and applied (in the period 2012–2017, all the countries except Slovakia have TC coefficient larger than 1).

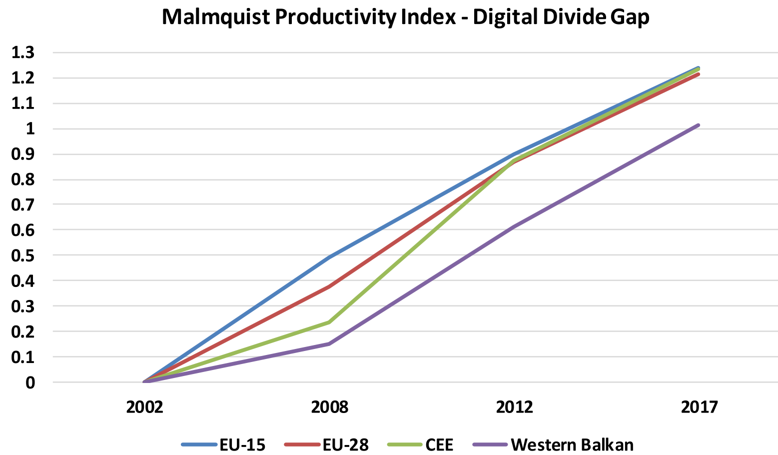

Fig. 1. Malmquist index and digital convergence (2002–2017).
Source: Author's calculation.

Although all the analysed countries have, more or less, been increasing investments towards digital economy development after 2012 (shown by TC coefficient values), the use of ICT technologies for the economic growth acceleration and improvement of competitiveness is still less efficient in a vast number of them (Portugal, Greece, Bosnia and Herzegovina, Croatia, Serbia, Montenegro, Albania and Slovakia). Fig. 1 shows the MI time dynamics per analysed groups of countries.

Based on the presented MI values, the CEE countries show convergence to the developed EU countries concerning digital economy development in the period 2002–2017. Conversely, WB countries diverged from the EU countries, especially comparing to the EU15. This shows that the digital gap (that is, the presence of digital divide) between WB and EU countries was rising until 2008, when it reached a peak, but it was not reduced thereafter. This digital gap was constantly present until 2017, which indicates that government institutions did not sufficiently recognize how important digital economy was for the increase of global competitiveness or did not put in sufficient efforts to adopt national strategies and action plans for development of information society.

5. Conclusion

Trends in effectiveness of ICT application and digital economy development in 40 European countries in the period 2002–2017 have been evaluated by means of DEA and Malmquist index. The applied methodology may indicate to the economic policies' creators in the European countries what are the strengths and weaknesses of their national strategies for digital economy development, as well as what factors cause digital gap widening with respect to the developed countries. The sources of the identified digital gap between the WB and EU countries are insufficient share of government and private R&D expenditures in GDP and a very low level of investments in human capital development, especially related to the skills for ICT use. Also, the WB countries are insufficiently dedicated to enforcement of the adopted national strategies and action plans concerning the development of information society and digital economy for many reasons (corruption, inadequately developed traditional physical infrastructure etc.). If the economic policies' creators in each country extend the DEA by choosing a larger number of indicators as inputs, it would enable them to identify the areas of digital economy that need an increase in efficacy in order to close the existing digital gap (e.g. investing in ICT, science and research

Table 2
Calculated MI values.
Source: Author's calculation.

DMU	2002–2008			2008–2012			2012–2017		
	MI	EC	TC	MI	EC	TC	MI	EC	TC
Albania	0.050	1.000	0.050	0.525	0.975	0.538	0.650	0.489	1.329
Austria	0.657	1.474	0.446	1.207	1.000	1.207	1.428	1.000	1.428
Belgium	0.696	1.152	0.604	0.955	0.944	1.012	1.077	0.816	1.320
Bosnia and Herzegovina	0.035	1.000	0.035	0.231	0.413	0.561	0.852	0.623	1.367
Bulgaria	0.071	0.527	0.135	0.779	0.912	0.854	1.083	0.759	1.427
Croatia	0.082	0.804	0.103	0.722	0.915	0.789	0.846	0.667	1.267
Cyprus	0.265	1.000	0.265	0.523	0.757	0.691	0.829	0.624	1.328
Czech Republic	0.123	1.167	0.105	0.845	0.826	1.023	1.436	0.982	1.462
Denmark	0.672	1.059	0.635	0.970	1.010	0.961	1.157	0.866	1.336
Estonia	0.485	1.434	0.339	0.978	1.173	0.834	0.653	0.504	1.294
Finland	0.645	1.355	0.476	0.865	0.841	1.029	1.150	0.784	1.466
France	0.463	0.975	0.475	0.802	0.877	0.915	1.422	1.100	1.293
Georgia	0.096	0.978	0.098	0.333	0.409	0.814	0.788	0.575	1.371
Germany	0.518	1.370	0.378	1.058	1.000	1.058	1.178	0.884	1.332
Greece	0.090	1.000	0.090	0.478	0.663	0.722	0.852	0.656	1.299
Hungary	0.266	0.798	0.333	1.003	1.012	0.991	1.298	0.881	1.474
Iceland	0.196	1.000	0.196	0.625	0.756	0.827	1.078	0.789	1.366
Ireland	0.144	1.000	0.144	0.889	1.000	0.889	1.585	1.000	1.585
Israel	0.370	1.000	0.370	0.425	0.734	0.580	1.162	0.883	1.315
Italy	0.381	1.410	0.270	0.754	0.936	0.806	1.365	1.069	1.277
Latvia	0.280	1.280	0.219	0.400	0.605	0.661	1.533	1.086	1.411
Lithuania	0.277	1.184	0.233	1.066	0.905	1.178	1.906	1.296	1.470
Luxembourg	0.327	1.000	0.327	0.908	1.000	0.908	1.421	1.000	1.421
Malta	0.417	0.921	0.453	0.771	0.878	0.878	1.209	0.972	1.245
Montenegro	0.503	2.489	0.202	0.455	0.655	0.695	0.836	0.657	1.272
Netherlands	0.573	0.928	0.617	0.948	0.952	0.996	1.247	0.869	1.434
North Macedonia	0.085	0.461	0.184	0.708	0.875	0.809	1.464	1.248	1.173
Norway	0.693	1.280	0.542	0.957	1.000	0.957	1.005	0.775	1.297
Poland	0.154	0.798	0.194	0.903	1.072	0.842	1.650	1.348	1.225
Portugal	0.388	1.017	0.382	0.872	1.103	0.790	0.863	0.667	1.295
Romania	0.096	0.734	0.131	0.953	0.978	0.974	1.519	1.073	1.416
Serbia	0.268	1.729	0.155	0.513	0.727	0.706	0.848	0.642	1.320
Slovakia	0.110	1.310	0.084	1.032	1.000	1.032	0.452	0.477	0.947
Slovenia	0.504	1.049	0.480	0.837	0.906	0.923	1.040	0.767	1.355
Spain	0.520	1.297	0.401	0.766	0.919	0.833	1.479	1.220	1.213
Sweden	0.762	1.145	0.665	1.055	1.064	0.991	1.286	0.955	1.346
Switzerland	0.637	1.111	0.573	1.009	1.039	0.971	1.095	0.822	1.333
Turkey	0.065	1.000	0.065	0.817	1.000	0.817	0.929	0.701	1.325
Ukraine	0.249	1.000	0.249	0.442	0.534	0.829	0.667	0.502	1.327
United Kingdom	0.559	1.572	0.355	0.909	0.767	1.185	1.097	0.682	1.609

sector, education system and human capital, or increasing the competitiveness in telecommunications markets). The closing of digital divide between countries is very important aim for government policies because of economic equality, social mobility, democracy, and economic growth in each country.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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