# DIGITIZATION FRONTIER AND IT'S INTERTEMPORAL CHANGE

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**Abstract**

The aim of this paper is to manifest an alternative measure to the present digitization indexes. Proposed method allows us to find benchmarks with relatively similar structure of digitalization results. Digitization indexes use predetermined weights to evaluate number of sub-indexes. Then the score is used to the ranking of countries. We propose to use output-oriented data envelopment analysis (DEA) model with constant returns to scale which behaves in certain condition as if returns were variable. This type of DEA provides opportunity to find benchmarks which score structure is radialy nearest to achieve. Lately, we use decomposition of Malmquist index on catch-up and frontier-shift effect to investigate which countries and regions achieved the biggest progress in the very fast-moving digitization environment.

**Keywords**

Data Envelopment Analysis, Digitization, Benchmark, Malmquist Index

## I. Introduction

As the European Commission (2018) sums up, the development of the mobile internet and the increased role of internet-based social networks connected with commercial platforms, have greatly shaped economy and have profoundly affected businesses, public organizations and personal life. In this paper we propose data envelopment analysis as an alternative to score evaluating indexes with predetermined weights. Number of digital economy indexes, that provide vast of data series, has occurred in last years. In this paper we focus particularly on the one of them. The Networked Readiness Index (NRI) published yearly by The World Economic Forum consists of data from 2012 to 2016. This index as many others struggles with common hurdles. Firstly, NRI consist of complex indicators with inconsistent measuring units. Then, predetermined weights could influence final results. Proposed data envelopment analysis provides weights for sub-indexes, not as apriori set up, but as a result of optimization problem. This provide us an opportunity to derive different weights for each decision-making unit (DMU) and find efficient countries as optimal benchmarks.

Paper is split into three sections. In the first part we introduce output-oriented DEA model, which is later used to recognize the frontier of efficient countries. We pinpoint the special case of constant input. In methodology section is introduced also Malmquist index with its decomposition on catch up and frontier shift effect. The second section is determined to the database description and we explain the choice of output set. In the last part, we present results from static efficiencies for year 2012 and 2016 together with intertemporal change in the digitization, then we search for feasible optimal benchmarks and conclude.

## II. Methodology proposed

Our paper is based on the use of nonparametric DEA method as an alternative to the common benchmarking. Benchmarking is a process of defining valid measures of performance comparison among peer DMUs. It is used to determine the relative positions of the peer DMUs and, ultimately, establishing a standard of excellence. In this sense, DEA can be regarded as a benchmarking tool, because the frontier identified can be regarded as an empirical standard of excellence (Zhu, 2003). There are numerous advantages in using DEA approach. Firstly, it is the fact that the main objective of DEA is to recognize efficient DMUs, which are benchmarks for the rest of inefficient DMUs. We

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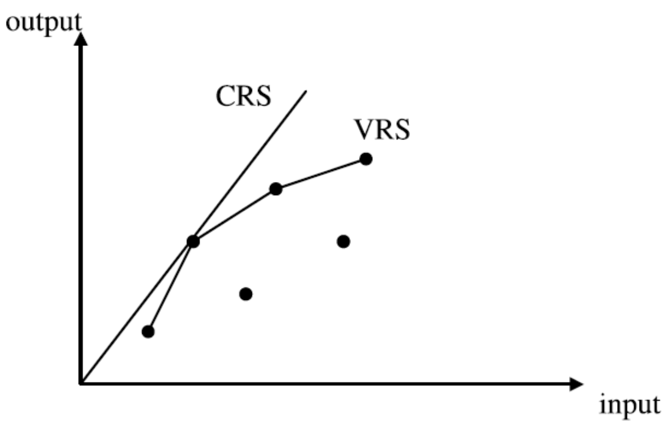
are proponents of this approach also for the possibility to find closest efficient DMUs and mark them as the best benchmarks. Usual indexes come just with the final order of countries score but ignore the unique features of specific DMU groups. Finally, the important plus of this approach is that it does not require the same measuring units. This paper finds the benchmarks by using output-oriented DEA model with constant returns to scale in two time periods and focuses on the improvement of 10 regions among time.

For our analysis within the time-period we use mathematical programming–based technique for measuring the efficiency of a particular organizational unit relative to other units and thus estimating a "best practice", proposed by Charnes, Cooper, and Rhodes (1978). As far as we have numerous outputs, we decided to use CCR DEA model as an output oriented (CCR-O) and as inputs we use unity vector. This special case is described in the Seiford and Zhu (1998), later by Dyson et. al. (2001) and, also by Cook, Tone and Zhu (2014). All these papers explain, that if the index value is the same across all DMUs, or more generally, if one input (in an output- oriented CRS model) or one output (in an input-oriented CRS model) has an equal value across all DMUs, the CRS becomes variable returns to scale (VRS) model. This is because the related input or output constraint becomes the convexity constraint in the CRS model (Cook, Tone, Zhu, 2014).

**Figure 1 Constant versus variable returns to scale**




*Source: Dyson et. al. (2001)*

Later, the convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$ de facto makes, in our case, BCC-O model from the CCR-O model. Seiford and Zhu (1998) prove, that the expression $\sum_{j=1}^{n} \lambda_j x_j + s^- = x_0$ from (1)

$$
\begin{gathered}
max\varphi_k \\
s.t. \\
\sum_{j=1}^{n} \lambda_j y_j - s^+ = \varphi_0 y_0 \\
\sum_{j=1}^{n} \lambda_j x_j + s^- = x_0 \\
s^-, s^+, \lambda_j \geq 0; (j = 1, 2, \ldots n);\ \varphi_k\ free
\end{gathered}
\tag{1}
$$

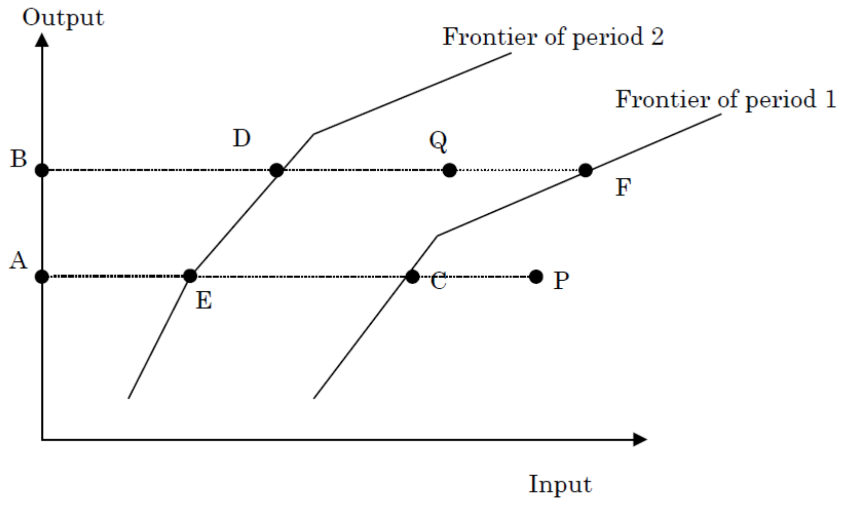
is, in the case of all inputs are equal unity, equal to the expression $\sum_{j=1}^{n} \lambda_j = 1$ from the (2).

$$\begin{gathered} max \varphi_k \\ s.t. \\ \sum_{j=1}^{n} \lambda_j y_j - s^+ = \varphi_0 y_0 \\ \sum_{j=1}^{n} \lambda_j = 1 \\ s^-, s^+, \lambda_j \geq 0; (j = 1, 2, \dots n);\ \varphi_k\ free \end{gathered} \quad (2)$$

So far, we inducted the efficiency or benchmarking within a one time period. In the results section we provide efficient benchmarks for each of the two time periods. Later we analyse which countries do consist of the efficient frontier. Then we identify benchmarks for the individual inefficient DMUs and investigate groups of underperforming countries with similar benchmarks.

Second part of the methodology section is dedicated to the short description of intertemporal changes in efficiency measured by Malmquist index. Following Cooper, Seiford and Tone (2007) we introduce a concept of Malmquist productivity change of DMU between two time periods. Here is also explained it's decomposition on catch-up and frontier shift parts. Catch-up effect term relates to the degree to which a DMU improves or worsens its efficiency, while the frontier-shift (or innovation) term reflects the change in the efficient frontiers between the two time periods (see on the Figure 2).

**Figure 2 Catch-up and frontier shift effect**




$$(Catch-up) = C = \frac{BD/BQ}{AC/AP} \qquad (Frontier\ shift) = F = \left[\frac{AC/AP}{AE/AP} \times \frac{BF/BQ}{BD/BQ}\right]^{1/2}$$

*Source: Cooper et. al. (2007)*

For the numerical measure we employ the following notation. Efficiency score of DMU from the time period $t_1$, $DMU(x_0, y_0)^{t_1}$ is measured by the frontier technology $t_2$.

$$\delta^{t_2}((x_0, y_0)^{t_1})$$

Using this notation, the catch-up effect can be expressed as (3),

$$C = \frac{\delta^{t_2}((x_0, y_0)^{t_2})}{\delta^{t_1}((x_0, y_0)^{t_1})} \tag{3}$$

then the frontier shift effect is shown on (4)

$$F = \left[\frac{\delta^{t_1}((x_0, y_0)^{t_1})}{\delta^{t_2}((x_0, y_0)^{t_1})} \times \frac{\delta^{t_1}((x_0, y_0)^{t_2})}{\delta^{t_2}((x_0, y_0)^{t_2})}\right]^{1/2} \tag{4}$$

and the final Malmquist index as a $MI = F \times C$ is expressed on (5)

$$MI = F \times C = \left[\frac{\delta^{t_1}((x_0, y_0)^{t_2})}{\delta^{t_1}((x_0, y_0)^{t_1})} \times \frac{\delta^{t_2}((x_0, y_0)^{t_2})}{\delta^{t_2}((x_0, y_0)^{t_1})}\right]^{1/2} \tag{5}$$

In this section we introduced basic methodological models. In the next part is dedicated to dataset of digitization indicators.

## III. Indicators Selection for our Dataset

Following section explains digitization indicators selection for our analysis. We choose the database of World Economic Forum (WEF) as the main source of data. WEF prepares The Networked Readiness Index (NRI). This index consists of 53 individual indicators for 139 economies, covering the time-period of 5 years, from 2012 to 2016. WEF (2016) in The Global Information Technology Report divides NRI indicators on 10 pillars and 4 sub-indexes. Treating data for the DEA analysis requires to define inputs and outputs. Because we decided to use inputs in the form of unity, we searched just for output series in the WEF dataset. In the other words, we do not focus on the very often used digital infrastructure, affordability or ICT skills of the population, but instead we chose end or use indicators as in the Table (1). We vote for indicators with high variability, availability in both of years 2012 and 2016 and we use variables which could be significant proxies of individual, business and government usage of digital technologies.

**Table 1 Indicator selection for our dataset**

| Indicator | Code | Pillar | Sub-index |
|---|---|---|---|
| Software piracy rate | 1.07 | Political and regulatory environment | Environment |
| Use of virtual social networks | 6.07 | Individual usage | Usage |
| Business-to-consumer Internet use | 7.05 | Business usage | Usage |
| Internet access in schools | 10.02 | Social impacts | Impact |
| ICT use and gov't efficiency | 10.03 | Social impacts | Impact |

*Source: World Economic Forum (2016)*

Further, the availability of data in both time-periods is not perfect, that is why we use dataset just for 95 economies (DMUs) from total 135. In the last section of the analysis we do not present results for each single country, but rather look on the weighted averages of 10 regions as in Table 2.

**Table 2 Regions used in the analysis**

| Region | Code | Countries |
|---|---|---|
| Africa | AF | 11 |
| Central Asia | CA | 3 |
| East Asia | EA | 4 |
| East Europe | EE | 19 |
| Latin America | LA | 16 |
| Meddle East | ME | 10 |
| North America | NA | 3 |
| Oceania | OC | 2 |
| South Asia | SA | 8 |
| West Europe | WE | 19 |

*Source: World Economic Forum (2016)*

To sum up for results section, indicators from the Table 1 are treated as outputs for output-oriented DEA model with constant returns to scale (CCR-O DEA) with the input of unity and with outputs as selected digitization variables. In the next section we show results of our models and interpret them for 10 regions within the 2 time periods and compare them also intertemporally.

## IV. Results of the DEA Analysis of the Digitization Efficiency

In the results part we apply introduced methodology. In the first step we derive static efficiencies. Later we focus on the intertemporal change using decomposition of Malmquist index. Firstly, following our methodological section, we used the CCR-O DEA model to calculate the results for each country separately. Because we used numerous outputs and constant input for each DMU, the model behaves as with the variable instead of constant returns to scale. We chose not to present results for 95 economies, but instead we show the regional weighted average scores as in the Table 4.

If we would use arithmetic averaging of the country results, scores could be easily misinterpreted. The main cause of the error would be the size of the population in different countries. For all let’s mention the case of Ukraine and Estonia in the East Europe region. Scores of these countries is in 2012 0.996 for Estonia and 0.727 for Ukraine, while the population is 1.3 million and more than 45 million respectively. If we would treat this pair of countries as a single region, regional scores would be significantly different using arithmetic and weighted average. For this reason, we vote for presentation of regional population weighted averages of digitization score. This population weighted regional score could be then interpreted as “regional per capita digitization scores” because it describes average digitization score per capita of the particular region.

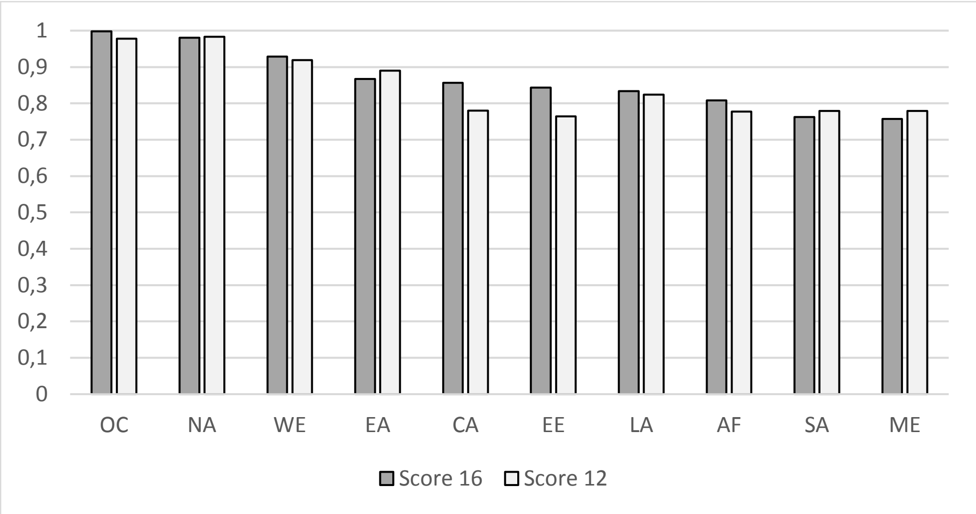
**Table 4 weighted regional results**

| Region weighted average | AF | CA | EA | EE | LA | ME | NA | OC | SA | WE |
|---|---|---|---|---|---|---|---|---|---|---|
| Catch-up | 1.49 | 1.40 | 1.25 | 1.29 | 1.31 | 0.97 | 1.12 | 1.03 | 1.95 | 1.08 |
| Frontier | 0.83 | 1.06 | 1.05 | 1.05 | 1.00 | 0.99 | 1.04 | 1.07 | 0.92 | 1.13 |
| Malmquist | 1.20 | 1.48 | 1.31 | 1.36 | 1.31 | 0.99 | 1.17 | 1.10 | 1.81 | 1.21 |
| Score 12 | 0.78 | 0.78 | 0.89 | 0.76 | 0.82 | 0.78 | 0.98 | 0.98 | 0.78 | 0.92 |
| Score 16 | 0.81 | 0.86 | 0.87 | 0.84 | 0.83 | 0.76 | 0.98 | 1.00 | 0.76 | 0.93 |

*Source: World Economic Forum (2016) and author’s calculations*

Results from the Table 4 describes the relative scores in both years 2012 and 2016, intertemporal improvement in the form of the Malmquist index and it’s decomposed parts catch-up effect and frontier shift. Within time-period scores of years 2012 and 2016 are depicted on the Figure 3 ordered according to score in 2016. We see, that the highest scores for both years is in North America (NA) and Oceania (OC) following by West Europe (WE) region. The high score for NA is derived from the two countries this region consists of. Both, USA and Canada are digital leaders. The sample selection and data availability for OC countries caused that this region is represented just by Australia and New Zealand, which are on the digitization frontier as well. Weaker digitization results occur in East Asia (EA), Central Asia (CE), East Europe (EE) and Latin Amerika (LA). Worst results in both years whose regional weighted score did not exceed 0.8 Middle East (ME) and South Asia (SA) which follow Africa, which reached just the 0.80 score in 2016. For the subsequent intertemporal improvement analysis is important to divide regions according to results from the first period. Let's introduce 3 score Groups (G1, G2 and G3) for 2012 score evaluation. In the year 2012 the best performing Group 1 consist of high scored OC and NA regions with efficiency of 0.98. Then the Group 2 contains WE (0.92), EA (0.98) and LA (0.82), there are countries above score 0.80. Group 3 consist of countries performing below the score of 0.80 ant it is with score 0.78 AF, CA, ME with SA and EE with score 0.76. We expect that regions with lower score have more potential to improve its digitization score.

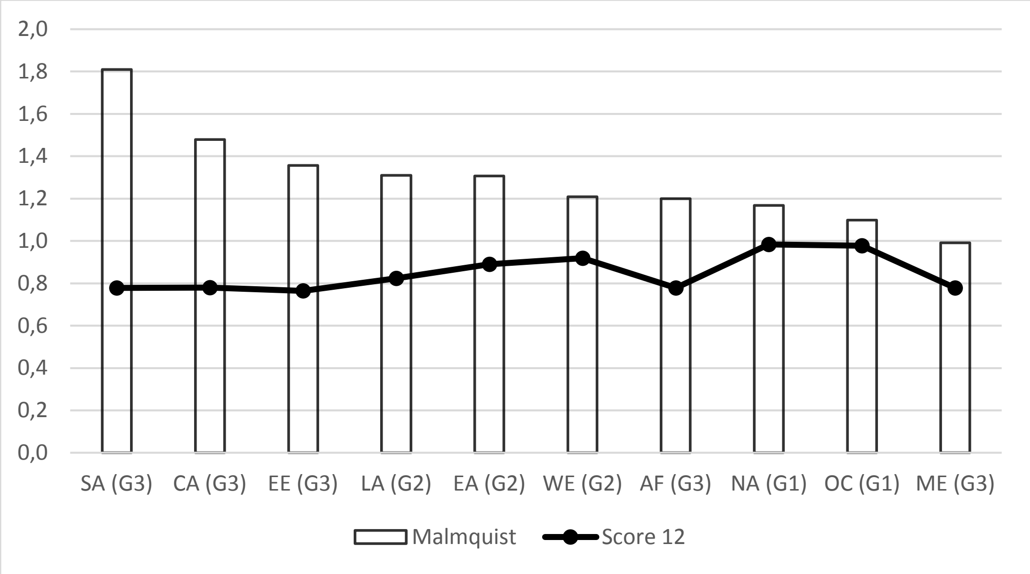
**Figure 3 Weighted regional scores in 2012 and 2016**




*Source: World Economic Forum (2016) and author's calculations*

Static comparison of the two periods is not sufficient for intertemporal changes in efficiency. As DMU improves, in other words, it catches-up the optimal frontier, in the same time, it challenges the shift of the efficient frontier. The real measure of the intertemporal improvement is Malmquist productivity index (MI) expressed on the Figure 4 ordered according to MI score. The Malmquist digitization index literary says us, how much the economy, or in our case, how the weighted average of region digitization has change between 2012 and 2016. On the Figure 4 is Malmquist index depicted together with 2012 score to check if lower scored regions improved more. As we would expect the digitization process has increased the most, relatively to other regions, in South Asia (SA), followed by Central Asia countries (CA) and East Europe (EE), all from in 2012 worst performing Group 3. Next Latin America (LA) and East Asia (EA) with West Europe (WE) from Group 2 improved according to our expectation following by 4 other regions. Least 4 countries consist of Africa (AF), North America (NA), Oceania (OC) and with the least improvement the region of Middle East (ME). For OC and NA is the low Malmquist index reasonable and in line with expectation, but AF and mainly ME did not utilize the digital potential.

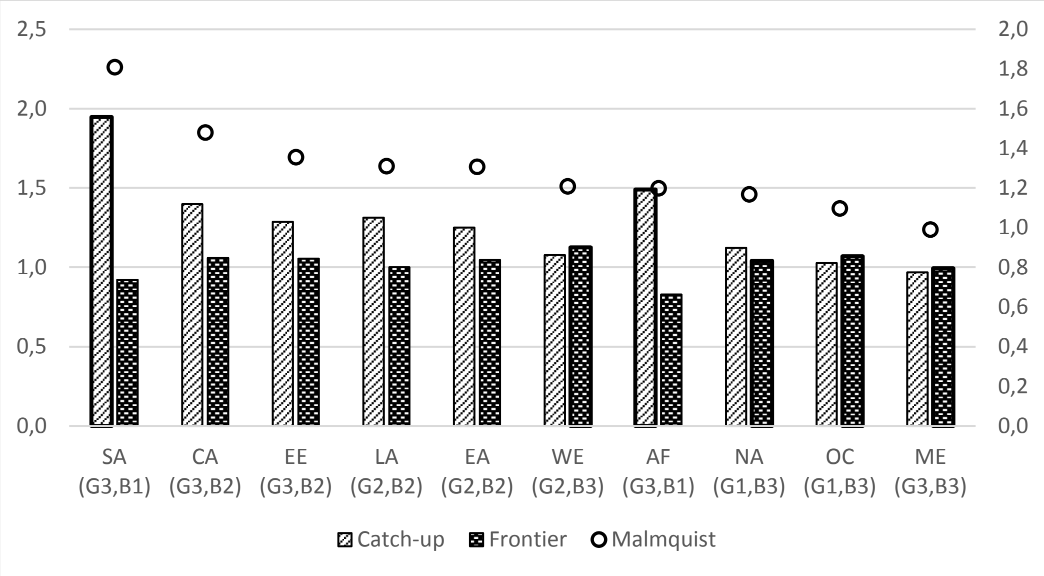
**Figure 4 Malmquist index between 2012 and 2016 and score in 2012**




*Source: World Economic Forum (2016) and author's calculations*

The Malmquist productivity index could be further decomposed on the catch-up and the frontier shift terms. Catch-up effect term relates to the degree to which a DMU improves or worsens its efficiency. The frontier-shift term reflects the change in the efficient frontiers between the two time periods. Results of these two effects between years 2012 and 2016 are shown on Figure 5. Regions are ordered according the score in Malmquist index (right-hand axis) and the values for catch up and frontier shift effect are on the left-hand axis. As we see on the, the highest share of the catch-up effect on the efficiency improvement reached South Asia (SA) and Africa (AF) region. Following the theory economies in these regions got closer to their benchmarks, than the benchmarks frontier shifted further in time. Further we can divide 10 regions on 3 let's say baskets (B1, B2 and B3) with common features of these two effects. Basket 1 contains mentioned South Asia and Africa with dominant catch-up effect. Second group is created by regions Central Asia (CA), East Europe (EE), Latin America (LA) and East Asia (EA) with less dominant catch-up than B1. Basket 3 consists of regions of which the contribution of catch-up and frontier shift effect is on the similar level. B3 include West Europe (WE), North America (NA), Oceania (OC) and unexpectedly Middle East (ME). The main characteristic of B1 comes from the very low results in 2012. Africa and South Asia have similar scores of digitization in the year 2012, but in the Malmquist index South Asia dominates among all regions. Africa is one of the regions with lowest improvement expressed by Malmquist index, but dominant portion of this improvement comes from catch-up effect relative to its frontier shift. 4 regions in B2 have very common value of Malmquist index and similar score within the period 2012. While two countries are from G2 and two from G3 it's score in 2012 is between 0.78 and 0.89. Finally, we see one paradox in the B3 group. Among the digitally most developed regions like North America (NA), West Europe (WE) and Oceania (OC) surprisingly occurs Middle East (ME). Middle East improves at least pace and does not catch-up the best practice as we would expect, but its benchmarks improves more, than the region catches-up. From this part of analysis is obvious, that worst digitally performing region is Middle East. It has low score of digitization efficiency and does not improves it at all.

**Figure 5 Catch up and frontier shift effects**




*Source: World Economic Forum (2016) and author’s calculations*

In the last part of the analysis section we focus on active benchmarks for 10 regions. DEA analysis solver provides us information about effective DMUs which form effective frontier, in our case treated as benchmarks. Their level is radially reachable by other ineffective DMUs. If ineffective DMU improves efficiency in the given proportion, it gets on the effective frontier as a convex combination of its benchmarks. DEA analysis is done for all the countries for the year 2016. We get benchmarks for each country separately. Further we sort individual benchmarks according to regions and calculated for how many percent is the given region benchmarked by one of the 10 efficient countries. For example, Table 5 shows that African region is benchmarked by Iceland in 65% of cases. Secondly, easy interpreted regions are Oceania and North America. These two regions consist of two countries from which one is always efficient. That is why we see, that for Canada, the US is benchmark from 40% and for New Zealand is Australia efficient benchmark on 50%. On this example we see, that the results in these countries are similar and that is why they are benchmarks one for each other. Later more robust benchmarks are United Arab Emirates for Central Asia and Middle East region or Estonia for East Europe. In the most of cases, Iceland is the universal benchmark in the biggest proportion. It is true for Africa countries, Latin America or South Asia. On the other hand , the best benchmark for region is the most often one of the efficient countries from the selected region. This fact is quite reasonable while regions has very alike results structure.

**Table 5 Benchmarks for Regions in 2016**

| Region | AF | CA | EA | EE | LA | ME | NA | OC | SA | WE |
|---|---|---|---|---|---|---|---|---|---|---|
| Countries in region | 11 | 3 | 4 | 19 | 16 | 10 | 3 | 2 | 8 | 19 |
| **United Arab Emirates (ME)** | 18 | 43 | 13 | 3 | 8 | 35 | | | 7 | 7 |
| **Australia (OC)** | | | | | | | 20 | 50 | | 2 |
| **Estonia (EE)** | | | 25 | 3 | | | | | 14 | 2 |
| **United Kingdom (WE)** | 6 | 14 | 25 | 15 | 8 | 5 | | | 21 | 11 |
| **Iceland (WE)** | 65 | 43 | | 47 | 64 | 45 | 20 | | 43 | 18 |
| **Luxembourg (WE)** | | | 13 | | | | | | | 11 |
| **Norway (WE)** | | | | 3 | 4 | 5 | | | | 14 |
| **Singapore (EA)** | | | 13 | | | 5 | | | | |
| **Sweden (WE)** | | | | | | | 20 | 25 | | 11 |
| **United States (NA)** | 12 | | 13 | 29 | 16 | 5 | 40 | 25 | 14 | 23 |

*Source: World Economic Forum (2016) and author's calculations*

## IV. Conclusion

Our paper functionalized data envelopment analysis as an alternative to the usual indexing with predetermined weights usage. We analyzed chosen indicators as outputs in the CCR-O DEA model with unity input. Further, we showed that model in this environment behaves as with the variable returns to scale. Results from DEA analysis show which regions are in average on the digitization frontier. In the next part we used Malmquist index and its decomposition to find out that relatively developed regions grow slower and vice versa. On the Figure 4 we show, that this is not true in the case of Middle East and partly is not applied on Africa. These regions have higher potential to grow, than we seen in the last 5 years. Than we decompose Malmquist index on the catch-up and frontier shift effect. On the Figure 5 we depicted mentioned effects and find out, that South Asia with highest progress in the digitization reached the improvement mainly from catching the frontier. South Asia digitization frontier raised but the region developed in faster pace. Middle East behaves differently than the others. This region performs low development of digitization, what creates an opportunity for catch-up effect. But Middle East keeps its bad results. What is more, it does not utilize digitization potential and improves digitization slower than its benchmarks shift the frontier. Finally, we introduced average benchmarks for each region in the year 2016. From this part we sum up that Iceland is the universal benchmark for the most of regions and that commonly the best benchmark for the regions is one of its efficient countries.

As we mentioned in the introduction, digitization significantly shapes economy and have profound affect on businesses, public organizations and personal life. The leading countries in digitization indexes have better economic results, are more competitive and have higher potential for future growth. For this reason, it is important to know about present situation, to investigate drivers of digitization and name benchmarks, which could be easily followed to reach goals of economic policy.

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