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Assessment of EU12 Countries' Efficiency Using Malmquist Productivity Index

Abstract

The paper deals with an application of Data Envelopment Analysis (DEA) method in an efficiency analysis of the "new" European Union (EU) Member States (EU12) during reference period 2000 – 2011, resp. in years of growth period 2000-2007 and in years of crisis and post-crisis period 2008-2011. DEA method becomes a suitable tool for setting an effective/ineffective position of each country, because measures numerical grades of efficiency of economical processes within evaluated countries. When applying DEA method, indicators of the Country Competitiveness Index (CCI) are used. Indicators included in CCI are interrelated; therefore correlation is used for assessment of internal relations between indicators and for reduction of their high number to a smaller number of variables, but at a minimum loss of information contained in the original variables. The main aim of the paper is to measure efficiency changes over the references periods and to analyse a level of productivity in individual countries based on the Malmquist Productivity Index, and then to classify EU12 countries according to efficiency results. The theoretical part of the paper is devoted to the fundamental basis of efficiency theory and DEA method – especially the Malmquist Productivity Index. The empirical part is aimed at measuring the degree of productivity and level of efficiency changes of evaluated countries by the Malmquist Productivity Index, measuring the change of technical efficiency and the movement of the production possibility frontier in reference period. The final part of the paper offers a comprehensive comparison of results obtained by calculating the Malmquist Productivity Index.

Introduction

In the European Union (EU), the process of achieving an increasing trend of performance and a higher level of competitiveness is significantly difficult by the heterogeneity of countries and regions in many areas. Although the EU is one of the most developed parts of the world with high living standards, there exist significant and huge economic, social and territorial disparities having a negative impact on the balanced development across EU Member States and their regions, and thus weaken EU's performance and competitiveness in a global context and in a globalized economy. The European integration process is thus guided by striving for two different objectives: *to foster economic competitiveness* and *to reduce differences* [4]. The support of cohesion and balanced development together with

increasing level of competitiveness belong to the temporary EU's *key development objectives*. In relation to competitiveness, performance and efficiency are *complementary objectives*, which determine the long-term development of countries in a globalized economy.

Globalization, rapid technological changes, an ageing population and new knowledge economies are external factors which are becoming a growing threat. The EU needs to transform its economy and society. Europe's economic challenge is to secure its position in global markets facing intense challenges from its competitors. The EU makes an effort to restore the foundations of its competitiveness through increasing its growth potential and its productivity. Due to global competitive conditions and economic crisis, significant changes in economic processing play an increasingly important role in maintaining a competitive position across individual countries. Based on the theory of Data Envelopment Analysis (DEA), DEA approach represents a convenient way to analyse the efficiency of countries, and the order of them taking into account their level of efficiency.

1. Theoretical Background of Efficiency Analysis

In recent years, the topics about assessment of efficiency have enjoyed economic interest. Although there is no *uniform definition* and understanding of this term*, no mainstream approach* for measuring of efficiency, this multidimensional concept remains one of the basic standards of performance evaluation (besides the concepts of competitiveness and productivity) and it is also seen as a reflection of success of area in a wider comparison. Increasing efficiency is generally considered to be the only one sustainable way of improving living standards in the long-term period; see e.g. [6].

1.1 Definition of Efficiency and Effectiveness

Performance management is one of the major sources of sustainable national efficiency and effectiveness (Fig. 1). A systematic understanding of the factors that affect productivity, and subsequently also competitiveness, is very important. Performance is also highly important for many economic subjects as a whole and for the individuals involving in it. Performance comprises both a behavioural and an outcome aspect. It is a multidimensional concept as well as competitiveness.

**Fig. 1 The triangle of the performance**
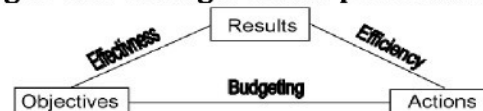
Source: [5, p. 8]

Efficiency and effectiveness analysis is based on the *relationship between the inputs* (entries), *the outputs* (results) and *the outcomes* (effects). The *efficiency* can be achieved under the conditions of maximizing the results of an action in relation to the resources used, and it is calculated by comparing the effects obtained in their efforts. As it can be seen in Fig. 2, the *efficiency is given by the ratio of inputs to outputs*, but there is

difference between *the technical efficiency* and *the allocative efficiency* [5]. The technical efficiency implies a relation between inputs and outputs on the frontier production curve, but not any form of technical efficiency makes sense in economic terms, and this deficiency is captured through the allocative efficiency that requires a cost/benefit ratio. The *effectiveness implies a relationship between outputs and outcomes.*

Fig. 2 The relationship between the efficiency and the effectiveness
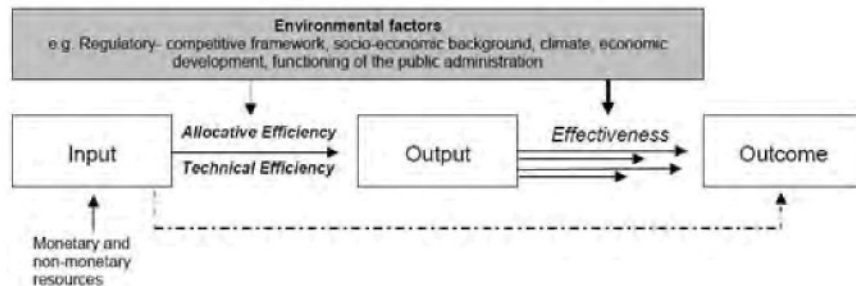
1.2   Approaches to Efficiency Evaluation

Techniques to measure efficiency are improved and investigations of efficiency become more frequent. Measurement of efficiency of countries and regions, resp. their factors, *remains a conceptual challenge*, because there are *difficulties in efficiency measuring.* Measurement of efficiency is highly sensitive to the data sets being used. Good quality data are needed because the techniques available to measure efficiency are sensitive to outliers and may be influenced by exogenous factors. *Data used for international comparisons* require a minimum level of homogeneity. In the early research studies focused on separate measures for productivity, there was a failure to combine the measurements of multiple inputs into any satisfactory measure of efficiency. These inadequate approaches included forming an average productivity for a single input (ignoring all other inputs), and constructing an efficiency index in which a weighted average of inputs is compared with output. Responding to these inadequacies of separate indices of labor productivity, capital productivity, etc., Farrell [2] proposed an activity analysis approach that could more adequately deal with the problem. Farrell confined his numerical examples and discussion to single output situations, although he was able to formulate a multiple output case. Twenty years after Farrell's model, and building on those ideas, *A. Charnes, W. W. Cooper* and *E. Rhodes* in 1978 [2], responding to the need for satisfactory procedures to assess the relative efficiencies of multi-input/multi-output production units, introduced a powerful methodology – *Data Envelopment Analysis* (DEA) in the form of CCR model with constant returns to scale (CRS).

Measurement and evaluation of efficiency 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 efficiency of each must be evaluated in a fair and consistent manner. The other is that as time progresses, better efficiency is expected. Hence, the units with declining efficiency must be identified in order to make the necessary improvements [7]. The

efficiency of countries can be evaluated in either a cross-sectional or a time-series manner, and the *DEA is useful method for both types of efficiency evaluation* [6].

2. Empirical Analysis of Efficiency of EU12 Countries

2.1 Methodological Background of the Empirical Analysis

If we want to evaluate the degree of efficiency or search for sources of efficiency, it is appropriate to use the formulation of DEA model. DEA is a relatively new "data oriented" approach for providing a relative efficiency assessment and evaluating the efficiency of a set of peer entities called *Decision Making Units* (DMUs) which convert multiple inputs into multiple outputs. DEA is thus a multi-criteria decision making method for evaluating effectiveness, efficiency and productivity of a homogenous group (DMUs). The aim of DEA method is to examine DMU if they are effective or not effective by the size and quantity of consumed resources by the produced outputs. DEA can successfully separate DMUs into categories which called efficient DMUs, high and slight efficient and inefficient DMUs [2]. Efficient DMUs have equivalent efficiency score. However, they don't have necessarily the same performance. DMU is efficient if the observed data correspond to testing whether the DMU is on the imaginary *'production possibility frontier'*. All other DMU are simply inefficient, and DEA identifies a set of corresponding efficient units that can be utilized as benchmarks for improvement of inefficient units. Efficiency score of DMUs is defined as follows (1):

$$Efficiency\ of\ DMU = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}} . \tag{1}$$

2.2 Data Base Characteristics for Efficiency Analysis

The efficiency analysis, based on application of DEA approach, is used for evaluating national development quality and potential (with respect to the national factors endowment). Based on the above facts, it is possible to determine the initial hypothesis of the analysis, which is based on the assumption that more advanced Central European countries achieving best results in efficiency (especially Visegrad countries and Slovenia) are countries best at converting inputs into outputs and therefore having greater performance and productive potential than Balkan countries and Baltic countries. Database of indicators is part of a common approach of WEF and EU in the form of Country Competitiveness Index (CCI). Eleven pillars of CCI are grouped according to the different dimensions (input versus output aspects) of national competitiveness they describe. The terms 'inputs' and 'outputs' are meant to classify pillars into those which describe driving forces of competitiveness, also in terms of long-term potentiality, and those which are direct or indirect outcomes of a competitive society and economy. Methodology of CCI is suitable for measuring national competitiveness by DEA method [3]. Set of CCI data file consists of 66 CCI indicators – 38 of them are inputs and 28 outputs. Indicators selected for the CCI framework are all of

quantitative type (hard data) and the preferred source has been *the European Statistical Office*. Whenever information has been unavailable or inappropriate at the required territorial level, other data sources have been explored such as the *World Bank, Euro barometer, Organization for Economic Co-operation and Development* and *European Cluster Observatory*. In this paper, all CCI indicators are not used because all indicators were not available for the whole period for each country, but for some indicators were found comparable indicators. The pillars and 62 used indicators are listed in Appendix 1. Empirical analysis is based on a frontier non-parametric approach and aims to study productivity growth and performance effectiveness. This is based on Malmquist index (MI) for measuring the change of technical efficiency and the movement of the frontier in terms of individual countries, in during reference period 2000 – 2011, in years of growth period 2000 – 2007, and in years of crisis and post-crisis period 2008 – 2011.

Suppose we have a production function in time period *t* as well as period *t+1*. MI calculation requires two single period and two mixed period measures. The two single period measures can be obtained by using the *CCR model with Constant Returns to Scale* (CRS). For simplicity of the Malmquist index calculation, it is presented basic DEA models based on assumption of a single input and output. Suppose each *DMU$_j$ (j=1, 2... n)* produces a vector of output $y_j^t = \left(y_{1j}^t, ..., y_{sj}^t \right)$ by using a vector of inputs $x_j^t = \left(x_{1j}^t, ..., x_{mj}^t \right)$ at each time period *t, t=1... T*. From time *t* to time *t+1*, *DMU$_0$*'s efficiency may change or (and) the frontier may shift. MI is calculated via (2) comparing x_0^t to the frontier at time *t*, i.e., calculating $\theta_0^t \left(x_0^t, y_0^t \right)$ in the following input-oriented CCR CRS model (2):

$$\theta_0^t \left(x_0^t, y_0^t \right) = \min \theta_0, \tag{2}$$

subject to

$$\sum_{j=1}^{n} \lambda_j x_j^t \leq \theta_0 x_0^t, \quad \sum_{j=1}^{n} \lambda_j y_j^t \geq y_0^t, \quad \lambda_j \geq 0, \, j = 1, ..., n,$$

where $x_0^t = \left(x_{10}^t, ..., x_{m0}^t \right)$ and $y_0^t = \left(y_{10}^t, ..., y_{s0}^t \right)$ are input and output vectors of *DMU$_0$* among others; λ represent vector of weights assigned to individual units, resp. *DMUs*.

MI is further calculated via (3) comparing x_0^{t+1} to the frontier at time *t+1*, i.e., calculating $\theta_0^{t+1} \left(x_0^{t+1}, y_0^{t+1} \right)$ in the following input-oriented CCR CRS model (3) for $\lambda_j \geq 0, \, j = 1, ..., n$:

$$\theta_0^{t+1} \left(x_0^{t+1}, y_0^{t+1} \right) = \min \theta_0, \tag{3}$$

subject to

$$\sum_{j=1}^{n} \lambda_j x_j^{t+1} \leq \theta_0 x_0^{t+1}, \quad \sum_{j=1}^{n} \lambda_j y_j^{t+1} \geq y_0^{t+1}.$$

MI is further calculated via (4) comparing x_0^t to the frontier at time *t+1*, i.e., calculating $\theta_0^{t+1} \left(x_0^t, y_0^t \right)$ via the following linear program (4) for $\lambda_j \geq 0, \, j = 1, ..., n$:

$$\theta_0^{t+1}\left(x_0^t, y_0^t\right) = \min \theta_0,$$

(4)

subject to

$$\sum_{j=1}^{n} \lambda_j x_j^{t+1} \leq \theta_0 x_0^t, \quad \sum_{j=1}^{n} \lambda_j x_j^{t+1} \geq y_0^{t+1}.$$

MI is further calculated via (5) comparing x_0^{t+1} to the frontier at time t, i.e., calculating $\theta_0^t\left(x_0^{t+1}, y_0^{t+1}\right)$ via the following linear program (5) for $\lambda_j \geq 0$, $j = 1, \ldots, n$:

$$\theta_0^t\left(x_0^{t+1}, y_0^{t+1}\right) = \min \theta_0,$$

(5)

subject to

$$\sum_{j=1}^{n} \lambda_j x_j^t \leq \theta_0 x_0^{t+1}, \quad \sum_{j=1}^{n} \lambda_j x_j^t \geq y_0^{t+1}.$$

MI measuring the efficiency change of production units between successive periods t and $t+1$, is formulated via (6):

$$M_0\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = E_0 \cdot P_0,$$

(6)

where E_0 is change in the relative efficiency of DMU_0 in relation to other units (i.e. due to the production possibility frontier) between time periods t and $t+1$; P_0 describes the change in the production possibility frontier as a result of the technology development between time periods t and $t+1$. The following modification of M_0 (7) makes it possible to measure the change of technical efficiency and the movement of the frontier in terms of a specific DMU_0,

$$M_0 = \frac{\theta_0^t\left(x_0^t, y_0^t\right)}{\theta_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)} \left[\frac{\theta_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)}{\theta_0^t\left(x_0^{t+1}, y_0^{t+1}\right)} \cdot \frac{\theta_0^{t+1}\left(x_0^t, y_0^t\right)}{\theta_0^t\left(x_0^t, y_0^t\right)}\right]^{\frac{1}{2}}.$$

(7)

The first component E_0 measures the magnitude of *technical efficiency change* (TEC) between time periods t and $t+1$. Obviously, $E_0 < = > 1$ indicating that technical efficiency improves remains or declines. The second terms P_0 measures the shift in the possibility frontier, i.e. *technology frontier shift* (FS), between time periods t and $t + 1$. Productivity declines if $P_0 > 1$, remains unchanged if $P_0 = 1$ and improves if $P_0 < 1$. In Tab. 1, characteristics and trends of MI are shown.

Tab. 1 Characteristics and trends of Malmquist index

Malmquist Index	Productivity	Efficiency Change	Technical Efficiency
MI > 1	Declining ↓	Change < 1 Improving	Change < 1 Improving
MI = 1	Unchanging —	Change = 1 Unchanging	Change = 1 Unchanging
MI < 1	Improving ↑	Change > 1 Declining	Change > 1 Declining

Source: Own elaboration

For solution of DEA method software tools based on solving linear programming problems are used in the paper, e.g. Solver in MS Excel 2010, such as *the DEA Frontier.*

3. The Results of Efficiency Analysis and Discussion

The *initial hypothesis* was *partly confirmed* through analysis by *Malmquist index*, as it is illustrated in following evaluation. Most of evaluated countries have recorded both increasing and decreasing trend in efficiency development during reference years of period 2000 – 2011, but in years 2007 – 2008, most of countries have recognized considerable deterioration in efficiency (due to economic crisis). It is recognized gradually improving in economic development, but it is still very slow. Apparently the best results are traditionally achieved by economically powerful countries (in the group of countries which are new EU Member States) which were '*highly efficient*' during the reference period. In Tab. 2, results of '*efficient*' *countries* are recorded and also development´ trend in efficiency of individual countries in the context of their effective/ineffective position based on efficiency results is recorded. Best results (of all evaluated countries and in all reference years) have recognized *Slovenia*, which is coloured by grey colour in Tab. 2. This country has recorded clear increasing trend and best levels of MI.
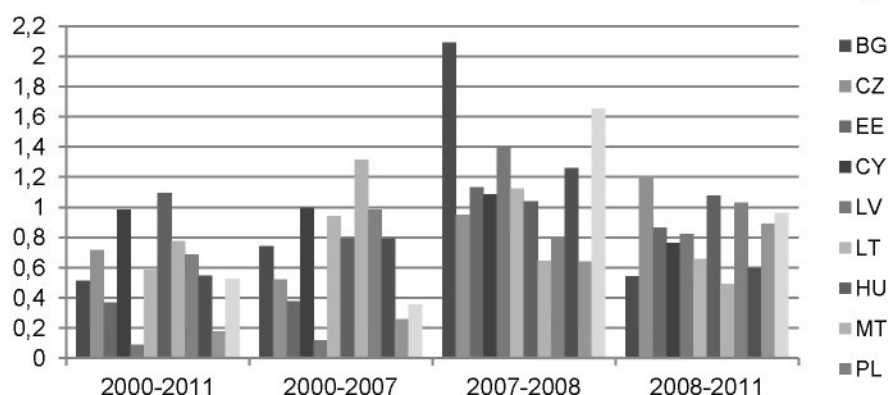
Tab. 2 Application of MI for EU 12 countries

Code		Country/Time	IO CCR CRS MI*							
			2000 – 2011		2000 – 2007		2007 – 2008		2008 – 2011	
1	BG	Bulgaria	0.5132	↑	0.7399	↑	2.0892	↓	0.5445	↑
2	**CZ**	**Czech Republic**	**0.7153**	↑	**0.5209**	↑	**0.9491**	↑	**1.2040**	↓
3	EE	*Estonia*	0.3686	↑	0.3766	↑	1.1319	↓	0.8657	↑
4	CY	*Cyprus*	0.9824	↑	0.9951	↑	1.0867	↓	0.7649	↑
5	LV	Latvia	0.0900	↑	0.1173	↑	1.4020	↓	0.8230	↑
6	LT	*Lithuania*	0.5852	↑	0.9411	↑	1.1225	↓	0.6575	↑
7	*HU*	*Hungary*	*1.0923*	↓	*0.7939*	↑	*1.0404*	↓	*1.0759*	↓
8	**MT**	**Malta**	**0.7770**	↑	**1.3164**	↓	**0.6434**	↑	**0.4926**	↑
9	**PL**	**Poland**	**0.6860**	↑	**0.9818**	↑	**0.8015**	↑	**1.0318**	↓
10	RO	Romania	0.5486	↑	0.7947	↑	1.2572	↓	0.5991	↑
11	**SI**	**Slovenia**	**0.1787**	↑	**0.2569**	↑	**0.6388**	↑	**0.8884**	↑
12	**SK**	**Slovakia**	**0.5276**	↑	**0.3545**	↑	**1.6554**	↓	**0.9637**	↑

Source: Own calculation and elaboration

Except Slovenia, other countries have recognized very prosperous results in efficiency scores. These countries are mostly countries of Visegrad Four Group, thus *Czech Republic, Slovakia* and *Poland*, then also *Malta*; in the reference period 2000 – 2011 (these countries are highlighted by bold format in Tab. 2). These countries belong to countries which have recorded best results in efficiency during all references years 2000 – 2007, 2007 – 2008, 2008 – 2011 and 2000 – 2011. These countries have recognized best results across reference periods according to the results of technical and technological efficiency changes; they have recorded previously increasing trend and only in one reference period have recorded decreasing trend. In the frame of paper hypothesis, these could be *countries with the best competitive potential and perspective to*

further development, as it is also illustrated in Figure 1 in MI development trends for evaluated countries in individual reference periods.

Fig. 1 Trends of MI in individual countries in selected reference periods

Group of efficient countries is followed by a group of countries which are also *'highly efficient'*. These countries do not achieved best results in efficiency' scores and trends, but their efficiency indices reached consistently fairly values during the reference years. These countries are *Estonia, Cyprus*, and *Lithuania*. Their efficiency results, and especially efficiency trend across reference years in selected periods, were poorer and were less satisfactory (as it is shown in Figure 1). All these countries also belong to less powerful new EU Member States and have recorded decreasing trend in their efficiency, and also deteriorating in technical and technological efficiency changes. These countries are highlighted by italics in Tab. 2.

Countries with the worst levels of efficiency' scores and trends are classified as *'slightly efficient' countries*, i.e. these countries are considered as countries with lower competitive potential. From the group of new EU Member States (EU12) belongs to the group of slightly efficient countries with lower competitive position and potential, *Bulgaria, Romania* and *Hungary*. In Tab. 2, the most 'inefficient' country is highlighted by light grey colour and italics; this country is *Hungary* with the lowest development potential; its trends show decreasing level of convergence to other EU12 countries.

Conclusion

Based on DEA approach has been found out that in evaluated countries is a *distinct gap between economic and social standards*, so differences still remain. Measuring the Malmquist index on the basis of DEA is an important method which has many applications. This index has been used in this paper to analyse and evaluate performance of EU12 countries across selected years of reference period 2000 – 2011. Regarding the findings and the analysis of each country can decide whether it had a efficiency increase during the time period, or not. By having this information and dividing productivity into its elements, the basic trend in performance whether it be increase or decrease is observed. According to MI results, in EU12 countries noticeable

productivity decreases were mostly achieved; more or less balanced performance and efficiency trend were recognized during reference years. Most countries experienced decline in their performance as a result of economic crisis. The economic crisis has threatened the achievement of sustainable development in the field of competitiveness. The crisis has underscored importance of competitiveness-supporting economic environment to enable economies better absorb shocks and ensure solid economic performance going in future.

Acknowledgements

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Appendix

Tab. 1 Indicators of inputs and outputs in years 2000 – 2007 – 2008 – 2011 relevant to DEA

Dimension	Pillar	Indicator of input or output*
Inputs	Institution	Political Stability, Voice and Accountability, Government Effectiveness, Regulatory Quality, Rule of Law, Control of Corruption
	Macroeconomic Stability	Harmonized Index of Consumer Prices, Gross Fixed Capital Formation; Income, Saving and Net Lending/Net Borrowing, Total Intramural Research & Development Expenditure, Labour Productivity per Person Employed; ~~General Government Gross Debt~~
	Infrastructure	Railway transport – Length of Tracks, Air Transport of Passengers, Volume of Passenger Transport, Volume of Freight Transport; Motorway Transport – Length of Motorways, Air Transport of Freight
	Health	Healthy Life Expectancy, Infant Mortality Rate, Cancer Disease Death Rate, Heart Disease Death Rate, Suicide Death Rate; Hospital Beds, Road Fatalities
	Primary, Secondary and Tertiary Education; Training and Lifelong Learning	Mathematics-Science-Technology Enrolments and Graduates, Pupils to Teachers Ratio, Financial Aid to Students, Total Public Expenditure at Primary Level of Education, Total Public Expenditure at Secondary Level of Education, Total Public Expenditure at Tertiary Level of Education, Participants in Early Education, Participation in Higher Education, Early Leavers from Education and Training, Accessibility to Universities; Lifelong Learning
	Indicators for Technological Readiness	Level of Internet Access; E-government Availability
Outputs	Labour Market Efficiency	Labour productivity, Male employment, Female employment, Male unemployment, Female unemployment, Public expenditure on Labour Market Policies; Employment rate, Long-term unemployment, Unemployment rate
	Market Size	Gross Domestic Product; Compensation of employees, Disposable income
	Business Sophistication	Gross Value Added in sophisticated sectors, Employment in sophisticated sectors, ~~Venture capital (investments early stage), Venture capital (expansion-replacement)~~
	Innovation	Human resources in Science and Technology, Total patent applications, Employment in technology and knowledge-intensive sectors, Employment in technology and knowledge-intensive sectors-by gender, Employment in technology and knowledge-intensive sectors-by type of occupation, Human resources in Science and Technology – Core, Patent applications to the EPO, Total intramural R&D expenditure, High-tech patent applications to the EPO, ICT patent applications to the EPO, Biotechnology patent applications to the EPO; ~~Employment in technology and knowledge-intensive sectors-by level of education~~

Note: * Number of indicators for inputs was decreased from 38 to 37; Number of indicators for outputs was decreased from 28 to 25

Source: [1]; own elaboration