A C T A U N I V E R S I T A T I S L O D Z I E N S I S
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THE COMPARATIVE ANALYSIS OF INNOVATION PERFORMANCE IN THE EU COUNTRIES

Abstract. This article presents some findings of a comparative analysis of innovation performance in the EU member states. The first part of the paper considers the role of innovation in economic growth models and the measures of innovation performance. In the second part, the methodology of innovation index construction is presented. The summary innovation index allows the authors to conduct an analysis of the innovation performance at the EU level. The results show that the EU member states reveal high level of heterogeneity in the field of innovation performance.
Keywords: innovation, economic growth, innovation measures, synthetic measure.

1. INTRODUCTION

Countries that generate innovation and create new technologies grow faster than those that neglect investing in knowledge capital. In the theoretical and empirical front, innovation is pointed out as the main factor that provides long-term productivity and economic growth. According to the Lisbon Agenda, innovation is a key pillar of UE policy and panacea for meeting its objective to become the most competitive knowledge based economy in the world by 2010. Given the importance of innovation to economic growth, it is useful to compare innovation performance in EU member states and trace the reasons for the dissimilarities among countries. Moreover, such analysis may enable the institutional agents to verify the effectiveness and efficiency of innovation promotion policies. In order to conduct comparative analysis, this paper deals with a fundamental problem in the study of innovation that is the lack of satisfactory measure of innovation that permits readily interpretable cross-country comparisons.

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2. INNOVATION AND ECONOMIC GROWTH

Traditional neoclassical approach portrays economic growth through a standard aggregate production function model, where input-output relationship often takes the form of:

$$Y = f(K, L, T) \tag{1}$$

where Y is the output, L the labour input, K the capital input and T is the level of technology.

In particular, Solow (Solow R. [1957], pp. 312-320) and Swan (Swan T. [1956], pp. 334-361) models assume the existence of perfect competition, maximizing behaviour, no externalities, constant returns to scale, diminishing returns to each input, and some positive and smooth elasticity of substitution between the inputs. Under these rigorous assumptions, the models predict productivity growth as a result of the increases in the amount of capital per each worker and progress in technological change to offset diminishing marginal returns. Solow showed that with augmenting productivity of labour at an exogenous and constant rate, the marginal product of capital need not decline as capital per worker increased. Even with a constant population, the capital stock would grow to keep pace with the effective labour force. In neoclassical stream of studies, technology was considered to be exogenous to the growth process (Denison E. [1962]). As a consequence, differences in growth rates among countries stem mainly from differences in capital accumulation.

An alternative approach to neoclassical growth models is endogenous growth theory that has been built on insights of Schumpeter's Theory of Economic Development. In Schumpeterian view, innovations are changes in production function and come from within, not exogenously for economic process (Schumpeter J. [1942], p.84). Inspired originally by Schumpeter, Romer presented a model in which growth is driven by technological change that arises from intentional investment decisions made by profit-maximizing agents (Romer P. [1986], pp. 1002–1037; Romer P. [1990], pp. 71–102). The most convincing implication of the model is that an economy with a larger total stock of human capital will experience faster growth.

In the same vain as Romer, Grossman and Helpman argued that purposive, profit-seeking investments in knowledge play a critical role in the long-run growth process (Grossman G., Helpman E. [1991], Chapters 1–5). Moreover, they stated that econometric estimates of aggregate production functions confirmed their suspicion that returns to physical capital, human capital, and other accumulable factors were far from constant. More recently, Grossmann formulated a model in which he exposed an important role of entrepreneurs for productivity growth (Grossmann V. [2009]). In Grossmann model, equilibrium with price-taking firms can be supported despite constant returns to scale production technology, once entrepreneurial human capital is accounted for.

In spite of their dissimilarities in the theoretical foundation, the neoclassical and endogenous growth theories provide several interrelated measures of innovation performance that will be deeply discussed in next part of the article.

3. MEASURES OF INNOVATION

What measure is a proper proxy for innovation has attracted economists' attention over past decades. The problem of measuring innovation arises from the ambiguity of innovation concept. According to Organization for Economic Co-operation and Development, that has partly adapted Schumpeter's approach, innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations (OECD [2005], p. 46). This broad definition of innovation raises further questions about how, where and what to exactly measure. Next issue of measuring innovation performance is the scope of analysis that ranges from organizational to national level. Assuming that innovation performance of an economy is a result of enterprises' innovation activity, there is the necessity to collect and aggregate data in a manner that allows users to correctly interpret data and judge its quality. Despite these difficulties, measures of innovation may be broadly classified as measures of either innovative inputs or outputs.

Most commonly, innovative effort is measured by expenditures, both public and private, on R&D or by personnel engaged in R&D. From a public perspective, R&D spending is crucial for making the transition to a knowledge based economy as well as for stimulating growth. In turn from business perspective, R&D expenditure relates to the process of the formal knowledge creation within enterprises. In an ideal setting, the optimal level of research and development is that which generates a maximum level of innovation (LeBel P. [2008], p. 337). Thus:

$$U = \int_0^\infty e^{-r\tau} y(\tau) dt = \int_0^\infty e^{-r\tau} \left(\sum_{t=0}^\infty \Pi(t,\tau) A_t x^\alpha \right) d\tau \qquad (2)$$

where U is the level of social welfare, τ the number of innovations, t the time, and A is the level of technology.

The socially optimal level of research and development expenditures would be where the first derivative of expected welfare is set to zero.

Although R&D measures are intended to represent the current flow of resources devoted to the generation of innovation, they are flawed (Cohen W., Levin R. [1989], pp. 1062-1066). R&D data suffer from several problems when used as a proxy for the level of innovation. Firstly, the relationship between R&D and innovation outputs is likely to be time varying, possibly nonlinear, and is also likely to occur with uncertain lags. Secondly, R&D data suffer from the problem that certain R&D expenditures are likely to reflect important, productive, inventions, while others are unlikely to increase productivity and GDP (Crosby M. [2000], p. 256). Thirdly, dynamic R&D strategy is important in the science-based sector, contrary to services and low-tech manufacturing sectors.

Another widely applied proxies for innovation input relate to the supply of highly skilled human resources. The term of human resources ranges from the youth having completed at least upper secondary education to science and technology graduates. The upper secondary education is generally considered to be the minimum level required for successful participation in a knowledge-based society (Hollanders H., Cruysen A. [2008], p. 15). In turn, S&T graduates are an indicator of an economy's potential for developing and diffusing advance knowledge and supplying the labour market with qualified workers. Moreover, exploring human resources' potential depends on creating the conditions for internet and broadband access to it, as well as e-government flourish. Access to the internet may be regarded as a measure for the openness of the society to new communication technology and as a mean of exchanging information. On the other hand, e-government enables the individuals to have widely access to public services using Information and Communication Technologies (ICTs).

Direct measures of innovative output are the most scarce. Patent counts have been used most frequently to approximate the innovative output of firms or industries. There are significant problems with patent counts that affect both within-industry and between-industry comparisons. Most notably, patents data suffer from the problem that certain patents are likely to reflect important, productive, inventions, while other patents are unlikely to increase productivity and GDP (Crosby M. [2000], p. 257). Moreover, a significant fraction of technological innovations do not result in establishing the patent protection. An additional pitfall with the patents data is that some companies may patent in countries other than the country where research was conducted.

Among others measures of innovative output, the propensity to innovation, measured by the number of SMEs who introduced a new product or a new process to one of their markets, play a leading role in the evaluation of innovation activity. Thus, higher number of technological innovators should reflect a higher level of innovation. In looking at the number of technological innovators, the commercialization aspect of innovation must be considered. The most useful measure of innovation commercial success is the percentage of total turnover generated by new or significantly improved products. At the national level, the ability to commercialise the results of research and development (R&D) and innovation can be measured by exports of high technology products as a share of total exports (Hollanders H., Cruysen A. [2008], p. 26).

4. METHODOLOGY AND RESULTS OF RESEARCH

The aim of the research was to measure the level of innovation performance in EU countries. The group of studied objects consisted of 22 UE countries and 3 countries were excluded because of more than 30% of missing values. The analysis was carried out on the basis of the most recent complete data published by the EUROSTAT for the years 2004 and 2005. As a measure of innovation performance, authors proposed the innovation index, which was constructed based on diagnostic variables referring to many aspects of innovation activity. The multivariate comparative analysis methods enables formation such index.

First, the variables referring to innovation performance were chosen. They were grouped in two blocks: the first one capturing the main drivers of innovation, which were called input factors, and the second one consisting of indicators reflecting effects of innovation activity, named output factors. The set of input variables included:

- x_1 – spending on Human Resources, total public expenditure on education as a percentage of GDP,
- x_2 – gross domestic expenditure on R&D (GERD), as a percentage of GDP,
- x_3 – level of households Internet access, percentage of households who have Internet access at home,
- x_4 – science and technology graduates, tertiary graduates in science and technology per 1000 of population aged 20-29 years,
- x_5 – information technology expenditure, as a percentage of GDP,
- x_6 – communications expenditure, as a percentage of GDP,
- x_7 – youth education attainment level by gender, percentage of the population aged 20 to 24 having completed at least upper secondary education,
- x_8 – e-government on-line availability, percentage of online availability of 20 basic public services,
- x_9 – e-government usage by enterprises, percentage of enterprises which use the Internet for interaction with public authorities,
- x_{10} – broadband penetration rate, number of broadband access lines per 100 inhabitants.

The set of output variables contained:

- x_{11} – patent applications to the European Patent Office (EPO), number of applications per million inhabitants,
- x_{12} – high-tech exports, exports of high technology products as a share of total exports,
- x_{13} – SMEs introducing product or process innovations, the percentage of SMEs who introduced a new product or a new process to one of their markets,
- x_{14} – new-to-market sales, the percentage of total turnover of new or significantly improved products.

Then a preliminary data statistic analysis was performed in order to evaluate discriminating properties of the variables. For all variables, the coefficient of variation were higher than 20 % and none of them were excluded. After that the influence of the indicators on the studied phenomenon was analyzed. All variables were stimulants, which means that they have the positive impact on innovation performance.

The next step was to normalize the variables in order to ensure their comparability. The zero unitarisation method was used, according to the following mathematical formula (Kukuła K. [2000], p. 167):

$$z_{ik} = \frac{x_{ik} - \min_i \{x_{ik}\}}{\max_i \{x_{ik}\} - \min_i \{x_{ik}\}} \tag{3}$$

where:

z_{ik} – normalized value of the k^{th} diagnostic variable for the i^{th} object ($i = 1, 2, ..., n$, $k = 1, 2, \dots, m$),

x_{ik} – original value of the k^{th} diagnostic variable for the i^{th} object.

After normalization, the diagnostic variables were aggregated. The method without pattern was arranged by using the following formula (Grabiński T. [1992], p. 141):

$$z_i = \sum_{k=1}^{K} \alpha_k z_{ik} , \tag{4}$$

where:

z_i – synthetic measure value for the i^{th} object,

z_{ik} – normalized value of the k^{th} diagnostic variable for the i^{th} object,

α_k – wage of the k^{th} diagnostic variable (Grabiński T. [1992], p. 34):

$$\alpha_k = \frac{V_k}{\sum_{k=1}^{K} V_k}, \tag{5}$$

where:

V_k – coefficient of variation for k^{th} diagnostic variable.

The synthetic measure ranges from 0 to 1. Its values near 1 characterize objects with high level of studied phenomenon, and values near 0 indicate objects with low level. Thus, the synthetic measure reflects the level of innovation performance. Table 1 contains the results of synthetic measure for 22 EU countries.

Table 1 Values of synthetic measure for 22 EU countries for years 2004 and 2005

Countries	2004		2005	
	Value of synthetic measure	Ranking position	Value of synthetic measure	Ranking position
Austria	0.56	4	0.59	4
Belgium	0.50	8	0.51	9
Czech Republic	0.32	12	0.35	13
Denmark	0.67	3	0.69	3
Estonia	0.41	11	0.46	11
Finland	0.72	2	0.76	1
France	0.52	7	0.57	7
Germany	0.55	6	0.58	6
Greece	0.25	18	0.26	19
Hungary	0.28	15	0.34	15
Ireland	0.43	10	0.46	10
Italy	0.31	14	0.34	14
Latvia	0.17	22	0.22	21
Lithuania	0.24	19	0.27	18
Netherlands	0.56	5	0.58	5
Poland	0.21	20	0.24	20
Portugal	0.27	16	0.32	16
Slovakia	0.18	21	0.21	22
Slovenia	0.32	13	0.38	12
Spain	0.26	17	0.28	17
Sweden	0.75	1	0.73	2
United Kingdom	0.47	9	0.53	8

Source: Own calculations.

The leading countries in the ranking, for both years, are Scandinavian countries: Sweden, Finland and Denmark. In turn, Western European countries: Austria, Netherlands, Germany and France hold the next positions. It is worth mentioning that Estonia, Czech Republic and Hungary have the relatively high position. The other Eastern European countries (Latvia, Lithuania, Poland and Slovakia) take the lowest places in ranking. The group of low innovation performance countries also consists of Iberian Countries (Portugal, Spain) and Greece.

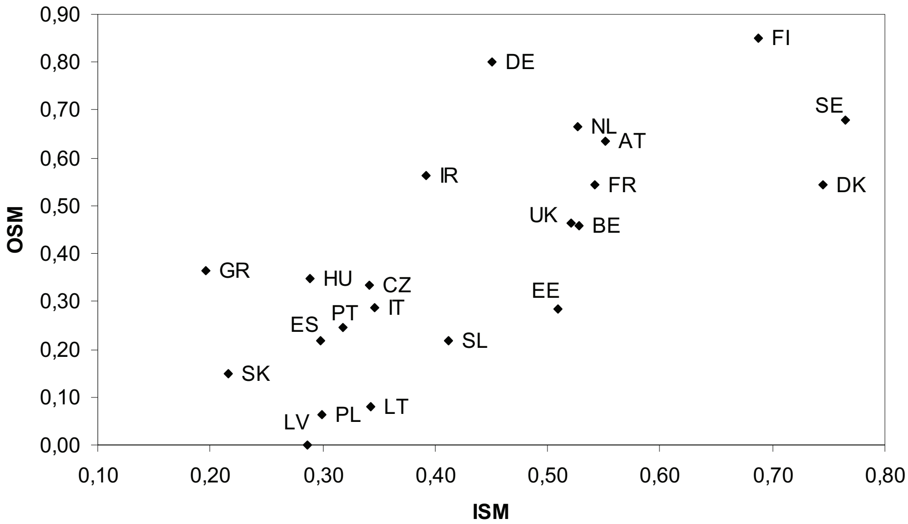
The countries vary in the level of input and output factors and it is worth raising the issue of exploring the differences in these two group of factors among the countries. For this purpose, authors constructed two synthetic measures for input (ISM) and output factors (OSM) using the formula (4). The values of ISM and OSM are presented in table 2. After calculating the average of ISM and OSM for years 2004 and 2005, the results were presented at the diagram (figure 1).

Table 2 Values of ISM and OSM for 22 EU countries for years 2004 and 2005

Countries	2004				2005			
	ISM	IR	OSM	OR	ISM	IR	OSM	OR
Austria	0.53	4	0.58	5	0.64	5	0.63	5
Belgium	0.51	5	0.55	9	0.47	9	0.45	10
Czech Republic	0.31	15	0.37	14	0.35	13	0.32	13
Denmark	0.73	2	0.76	2	0.54	8	0.55	7
Estonia	0.47	9	0.55	8	0.28	15	0.28	15
Finland	0.67	3	0.71	3	0.82	1	0.87	1
France	0.50	6	0.58	4	0.56	7	0.53	8
Germany	0.43	10	0.47	10	0.81	2	0.80	2
Greece	0.19	22	0.21	22	0.37	11	0.36	11
Hungary	0.23	20	0.35	17	0.37	12	0.33	12
Ireland	0.37	11	0.41	12	0.56	6	0.56	6
Italy	0.32	14	0.37	13	0.29	14	0.28	14
Latvia	0.25	19	0.32	19	0.00	22	0.00	22
Lithuania	0.32	13	0.37	15	0.08	20	0.08	20
Netherlands	0.50	7	0.56	7	0.69	4	0.64	4
Poland	0.28	18	0.32	18	0.06	21	0.06	21
Portugal	0.28	16	0.35	16	0.25	16	0.24	16
Slovakia	0.20	21	0.23	21	0.13	19	0.16	19
Slovenia	0.36	12	0.46	11	0.24	17	0.19	18
Spain	0.28	17	0.31	20	0.22	18	0.22	17
Sweden	0.76	1	0.77	1	0.72	3	0.64	3
United Kingdom	0.48	8	0.56	6	0.46	10	0.47	9

IR – ranking position for ISM, OR – ranking position for OSM
Source: Own calculations.

The points on the diagram lie along diagonal line from lower-left corner to upper-right corner. It proves that the countries with low values of ISM are characterized by low values of OSM, and countries with high level of ISM obtain high values of OSM. This situation is obvious because higher expenditures on innovation should result in higher effects. The countries located above diagonal line are more effective in deploying resources to innovation activity than the countries pointed under diagonal line. The first group contains Greece, Germany, Finland, Ireland and Netherlands, and the second one consists of Latvia, Poland, Lithuania, Estonia, and Slovenia.



AT – Austria, BE – Belgium, CZ – Czech Republic, DK – Denmark, EE – Estonia, FI – Finland, FR – France, DE – Germany, GR – Greece, HU – Hungary, IR – Ireland, IT – Italy, LV – Latvia, LT – Lithuania, NL – Netherlands, PL – Poland, PT – Portugal, SK – Slovakia, SL – Slovenia, ES – Spain, SE – Sweden, UK – United Kingdom

Figure 1. Position of 22 EU countries in relation to ISM and OSM for years 2004 and 2005
Source: Own calculations.

Finally, the index combining previous measures, i.e. level of innovation performance and effectiveness of innovation activity, was constructed. This index was calculated using following formula:

$$I_i = \frac{OSM_i}{ISM_i} z_i , \qquad (6)$$

where:

I_i – innovation index for the i^{th} object,

OSM_i – output factors synthetic measures (OSM) for the i^{th} object,

ISM_i – input factors synthetic measures (ISM) for the i^{th} object,

z_i – synthetic measure value for the i^{th} object.

The high values of innovation index refer to countries with both high performance level and high effectiveness of innovation activity. In turn, the low values of index refer to 'weak' countries in both categories. The levels of innovation index for 22 countries are shown in table 3.

Table 3 Values of Innovation index for 22 EU countries for years 2004 and 2005

Countries	2004		2005		2004-2005	
	Innovation index	Ranking position	Innovation index	Ranking position	Average of innovation indices	Ranking position
Austria	0.69	5	0.65	4	0.67	4
Belgium	0.46	11	0.42	11	0.44	11
Czech Republic	0.37	13	0.30	13	0.33	13
Denmark	0.50	8	0.50	8	0.50	8
Estonia	0.25	15	0.24	15	0.24	15
Finland	0.89	2	0.94	2	0.91	2
France	0.58	7	0.51	7	0.55	7
Germany	1.03	1	0.98	1	1.00	1
Greece	0.49	9	0.44	9	0.47	9
Hungary	0.44	12	0.32	12	0.38	12
Ireland	0.66	6	0.63	5	0.64	6
Italy	0.28	14	0.26	14	0.27	14
Latvia	0.00	22	0.00	22	0.00	22
Lithuania	0.06	20	0.06	20	0.06	20
Netherlands	0.78	3	0.67	3	0.73	3
Poland	0.05	21	0.05	21	0.05	21
Portugal	0.24	16	0.22	16	0.23	16
Slovakia	0.12	19	0.15	19	0.13	19
Slovenia	0.21	17	0.16	18	0.19	18
Spain	0.20	18	0.20	17	0.20	17
Sweden	0.71	4	0.61	6	0.66	5
United Kingdom	0.46	10	0.44	10	0.45	10

Source: Own calculations.

Innovation indices range from 0 (for Latvia) to 1.03 (for Germany). The group of leading countries consists of Germany, Finland, Netherlands, Austria and Sweden. Germany's high position was the result of high innovation effectiveness, the Scandinavian countries' and Austria's position – of high innovation performance and Netherlands position was combination of both. The high effectiveness of innovation activity led Ireland and Greece to sixth and ninth places. The worst situation with regard to innovation activity was observed in Eastern European countries (Latvia, Poland, Lithuania, Slovakia, Slovenia) and Iberian countries (Portugal, Spain). Unfortunately, the weak position of Poland was the result of low innovation performance and low effectiveness.

5. CONCLUSIONS

The used methodology allows the authors to study innovation performance at EU level. The results of research show that the EU countries are heterogeneous in their innovation activity. Scandinavian countries and Western European countries are performing better with innovation activity than all other countries. The high position of Scandinavian countries can be explained from their high level of innovation performance, whereas the strength of Western European lies in their high innovation effectiveness. The group of worst countries consists of Eastern European countries and Iberian countries. Poland and other Eastern European have a relatively weak performance in financing innovations activity as well as low effectiveness of them. Thus, Poland should take firm actions to improve both innovation performance and innovation effectiveness.

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ANALIZA PORÓWNAWCZA WYNIKÓW DZIAŁALNOŚCI INNOWACYJNEJ W KRAJACH UE

W artykule zaprezentowano wyniki badań porównawczych dotyczących poziomu innowacyjności poszczególnych krajów członkowskich Unii Europejskiej. W pierwszej części opracowania omówiono rolę innowacji w ekonomicznych modelach wzrostu gospodarczego, jak również scharakteryzowano mierniki poziomu innowacyjności. Następnie zaprezentowano metodologię konstruowania sumarycznego indeksu innowacyjności. W oparciu o opracowany miernik syntetyczny przeprowadzono analizę porównawczą, której rezultaty wskazują na wysoki poziom heterogeniczności poziomu innowacyjności w badanej grupie krajów.

Słowa kluczowe: innowacja, wzrost gospodarczy, mierniki innowacyjności, miara syntetyczna.