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ARKADIUSZ KIJEK*, TOMASZ KIJEK**

The analysis of innovation input – output relationships in EU member states

Abstract

This article presents some findings of an analysis of innovation input – output relationship in EU member states. The first section of the paper considers the role of innovation in economic growth with particular attention to the new endogenous growth models. In the second part, the dichotomous approach to innovation and its measures is presented. The last section contains the methodology and outcome of research. The results of the study show that R&D expenditures, ICT and human capital are the key innovation inputs that affect such innovation outputs as innovation and patent propensity and new-to-market sales.

1. Introduction

Innovation is fundamental to economic growth and development. The ability to create economic value by introducing new products or services to the market, redesigning production processes or reconfiguring organizational practices is critical to competitive position of organizations and economies. There is a consensus that in order to strengthen innovation performance, the market agents must be efficient in transforming innovation inputs into innovation outputs. Consequently, the concept of innovation efficiency is a key

* Ph. D., Maria Curie-Skłodowska University in Lublin
** Ph. D., University of Life Sciences in Lublin

dimension of innovation policy. The relationship between innovation inputs and outputs is a crucial measure for national innovation system, since it allows institutional agents to encourage innovation activities in a right part of the economic system. Although there are a few models that combine a production function of R&D activity with innovation output, they still lacks a proper understanding of how different forms of innovation inputs transforms into innovation performance. For this reason, the presented article uses canonical correlation analysis to study innovation input–output relationship in the group of 22 EU countries.

2. Innovation and economic growth

The theoretical and empirical study of economic growth has resulted in a numerous literature. In neoclassical approach, the work of Solow (1957, pp. 312–320) is a starting point of any analysis on technical progress and growth. Algebraically in Solow's model, output Q can be assumed to be produced at constant returns in a production function with a purely time-dependent factors augmentation:

$$Q(t) = F(a(t)K(t), b(t)L(t)) \tag{1}$$

where K(t) capital, $L(t)$ labour, $a(t)$ and $b(t)$ are positive numbers and $a(t)K(t)$ and $b(t)L(t)$ are effective capital and labour inputs. In the simple but important purely labour augmenting case, $a(t)$ is set to equal one and $[db(t)/dt]/b(t)$ assumed to be constant at the exogenous rate m. In the long run only technological progress will allow real output to grow at a rate faster than that of the labour force. The faster the rate of technological progress, the faster output and real per capita rises.

Solow's major conclusion was that exogenous technical change, treated as a residual of the model, was responsible for 87,5% of economic growth in the American economy from 1909 to 1949. Later work of Denison (1962) confirmed the Solow's result in general but reduced the residual to around one third of economic growth. The methodology of neoclassical growth accounting, that uses aggregate production function, makes explicit and rigorous assumptions of 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. The main problem of this approach is that technical progress is a simple time trend and it is considered to be exogenous to the growth process. As a consequence, the models do not shed any light on technical progress features and determinants.

Dissatisfaction with the neoclassical growth theory led to the attempt to endogenize technical change as Kaldor (1957, pp. 591-624) and Arrow (1962, pp. 155–173) did by focusing on learning effects as a source of technology improvement. The approach presented by Kaldor and Arrow is classified as the "older" endogenous growth models in contrary to the "new" growth models that appeared three decades ago. The new growth models may be classified according to the sources of growth (Freeman, Soete 1999, pp. 325–326):

1. A first source of endogenous growth lies in investment in a certain factor. Romer (1986, pp. 1002–1037) consider a relative simple and traditional growth model not restrained by constant returns, but with economies of scale which are external to the firm.
2. A second source of growth is technological innovation, itself dependent on the amount of resources devoted to R&D and other knowledge generating activity. In model put forward by Romer (1990, pp. 71–102), capital is now not a homogonous good. New, intermediate inputs are discovered when R&D resources are devoted to a search process. A contrasting framework is presented by Aghion and Howitt (1992, pp. 323–351) where such innovation can also consist of a number of creative destructions rather than just new addition to the range of available inputs to production.
3. The accumulation of human capital is another source of endogenous growth. In the models developed by Lukas (1988, pp. 3–42) and Romer (1990, pp. 71–102), economic growth will be faster, the greater is the productivity of human capital employed in research.
4. Finally, growth may also be realized through public good and infrastructure such as communication networks, information services, etc. Such goods increase the productivity of private factors.

In spite of their dissimilarities in the theoretical foundations, the neoclassical and endogenous growth theories provide some rudimentary measures of innovation that will be broadened in the next paragraph of the paper.

3. Innovation output-input measures

What measure is a proper proxy for innovation, that goes beyond the residual measure used in neoclassical economic growth models, has attracted economists' attention over past decades. The problem of measuring innovation arises from the ambiguity of innovation concept. In scientific literature, there is a lack of a single definition of innovation, which undermines understanding of its nature (Adams et al. 2006, p. 22). To cover all aspects of innovation, Kimberly (1981, p. 108) proposes defining innovation from a different perspective which encompasses two stages of innovation, i.e.: innovation as a discrete item including, products, programs or services and innovation as a process. The former pertains to 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 organisation or external relations (OECD 2005, p. 46.). The latter means the process of the creation of new knowledge and ideas to facilitate new business outcomes, aimed at improving internal business processes and structures and to create market driven products and services (Plessis 2007, p. 21).

The key word in connection to innovation, regarded as the item, is the invention. Invention may be defined as the devising of new ways of attaining given ends that embraces both the creation of things previously non-existent and the creation of things which have existed all the time. Inventions themselves can be patented, i.e. the inventor possesses *erga omnes* property right In this approach, innovation is the commercial application of inventions for the first time (Kennedy, Thirlwall 1972, p. 56). In turn, the innovation regarded as a process, may be pictured as a logically sequential, though not necessarily continuous process, that can be divided into a series of functionally distinct but interacting and interdependent stages, i.e. learning and discovery (the research stage), implementation (the development stage) and commercialization. In other words the process of innovation represents the confluence of technological capabilities and market needs within the framework of the innovating firm (Rothwell 1992, p. 222).

Above definitions of innovation constitute a starting point to analyze the innovation metrics issues. Rose et al. (2009, p. 5) have portrayed innovation metrics as evolving through the following four generations:

1. First generation metrics reflect a linear conception of innovation focusing on inputs such as R&D investment.
2. Second generation complements input indicators by accounting for the intermediate outputs of science and technology (S&T) activities.
3. Third generation metrics focus on a richer set of innovation indicators and indexes based on surveys and the integration of publicly available data.
4. Fourth generation metrics, grounded in a knowledge-based networked economy, remain ad hoc and are the subject of measurement.

It is worth noting that some progress has been made in collecting microdata on innovation. The third and fourth generation metrics use a more elaborate measurement of innovation inputs (total innovation expenditure, including non-R&D expenditure), as well as attempt to measure newly developed indicators of the output side of the innovation process.

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 2008, p. 337). Thus:

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

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

If innovations arrive according to some Poisson style process, the socially optimal level of research and development expenditures would be where the first derivative of expected welfare is set to zero. Under these conditions, the level of research would lead to an average rate of growth in welfare adjusted per capita income.

Although R&D measures are intended to represent the current flow of resources devoted to the generation of innovation, they have a number of disadvantages (Kleinknecht et al. 2002, pp. 110-111). First, R&D is an input of the innovation process and inputs can be used more or less efficiently. In principle, R&D says nothing about the output side of the innovation process. Second, R&D is only one out of several inputs. Other inputs include product design, trial production, market analysis, training of employees, or investment in fixed assets related to innovations. Third, 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, Cruysen 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 2000, p. 257). Moreover, a significant fraction of technological innovations do not result in establishing the patent protection, so patent indicator misses many non-patented inventions and innovations. 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, Cruysen 2008, p. 26).

4. Methodology and results of research

The aim of the research was to measure the relationship between input and output factors of innovation in EU countries. The group of studied objects consisted of 22 UE countries after excluding 3 countries due to the lack of 30% of desired data. The analysis was carried out on the basis of the most recent complete data published by the EUROSTAT for the years 2005 and 2006.

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 the 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 – broadband penetration rate, number of broadband access lines per 100 inhabitants,
- 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, 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} – level of households Internet access, percentage of households who have Internet access at home.

The set of output variables contained:

- *y1 – patent applications to the European Patent Office (EPO), number of applications per million inhabitants,*
- *y2 – high-tech exports, exports of high technology products as a share of total exports,*
- *y3 – SMEs introducing product or process innovations, the percentage of SMEs who introduced a new product or a new process to one of their markets,*
- *y4 – new-to-market sales, the percentage of total turnover of new or significantly improved products.*

The associations between the input and output factors were identified and quantified by canonical correlation analysis (CCA). The technique was originally developed by Hotelling (1935, pp. 139-142) to study the relationship between a set of predictor (independent variables) and a set of criterion (dependent) variables. The exhausting introductions into this procedure give Thompson (1984), Marinell (1990), Hair et al. (1998), and Stevens (2002). CCA can be seen as the problem of finding linear combination of the variables in each set so that the correlation between these linear combinations is maximised.

For the original variables x_i ($i = 1, 2, ..., q$) and y_j ($j = 1, 2, ..., p$) k pairs of linear combinations with $k = \min(p, q)$ are made as follow:

$$u_m = \sum_{i=1}^{q} a_i x_i \quad (m = 1, 2, ..., k) \tag{3}$$

and

$$v_m = \sum_{j=1}^{p} b_j y_j \quad (m = 1, 2, ..., k) \tag{4}$$

where a_i $(i = 1, 2, ..., q)$ and b_j $(j = 1, 2, ..., p)$ are coefficients called canonical weights. New variables u_m and v_m are called m^{th} canonical variates, each pair of u_m and v_m is called the m^{th} canonical function.

Next, the loadings of the original variables on the canonical variates named canonical loadings are calculated. These loadings are correlations between the canonical variates and the variables in each set. Then, for each canonical variate the average proportion of variance explained by it in the set of variables is calculated. Finally, the redundancy coefficients are computed. They measure the amount of variance in one set of variables explained by a linear composite of the other set of variables.

By using the CCA, we study simultaneous relation between input and output factors of innovation in EU countries. Input factors set consists of ten variables and output factors set contains four variables, hence four canonical functions were calculated. Table 1 lists the canonical correlation coefficients and the canonical loadings.

Table 1. Canonical correlations and canonical loadings

	1st canonical function	**2nd canonical function**	**3rd canonical function**	**4th canonical function**
Canonical correlation	**0,9552*** **	**0,8219*** **	**0,6381** **	**0,5837***
Input variables	**Canonical loadings**			
x_1	0,4749	0,4599	0,1114	0,2103
x_2	0,9424	0,0949	-0,0632	-0,0071
x_3	0,8115	0,4105	-0,2381	0,1254
x_4	0,2007	0,3311	-0,3113	-0,5028
x_5	0,6752	0,4798	-0,0017	-0,1496
x_6	-0,6276	0,1322	0,1649	0,4039
x_7	-0,0356	-0,0614	0,3027	-0,3080
x_8	0,4938	0,1772	-0,7404	0,0786
x_9	0,1996	-0,4090	-0,2783	0,0943
x_{10}	0,6800	0,3760	-0,2204	0,2600
Output				
y_1	0,9919	0,1097	-0,0077	0,0566
y_2	0,4863	0,2769	-0,2933	-0,7854
y_3	0,6313	-0,2839	-0,7013	0,1966
y_4	0,2114	-0,9268	0,0184	-0,2627

* if $p < 0,1$; ** if $p < 0,01$; *** if $p < 0,001$

Source: Own calculations.

Three canonical correlations are highly significant ($p < 0,01$), which shows the high interrelationships between input and output factors. The analysis of the canonical loadings for first canonical function makes it clear that the strongest simultaneous relationship is between domestic expenditure on R&D and broadband penetration rate for input variables and patent applications for output variables. The second canonical variates are highly correlated with spending on Human Resources, information technology expenditure (input variables) and new-to-market sales (output variable). The third canonical correlation corresponds to youth education attainment level (input factor) and SMEs introducing product or process innovations (output factor). The input-output canonical relationships are presented in table 2. They show the structure of associations between output factors and input factors of innovation activity.

Table 2. Input-output canonical relationships

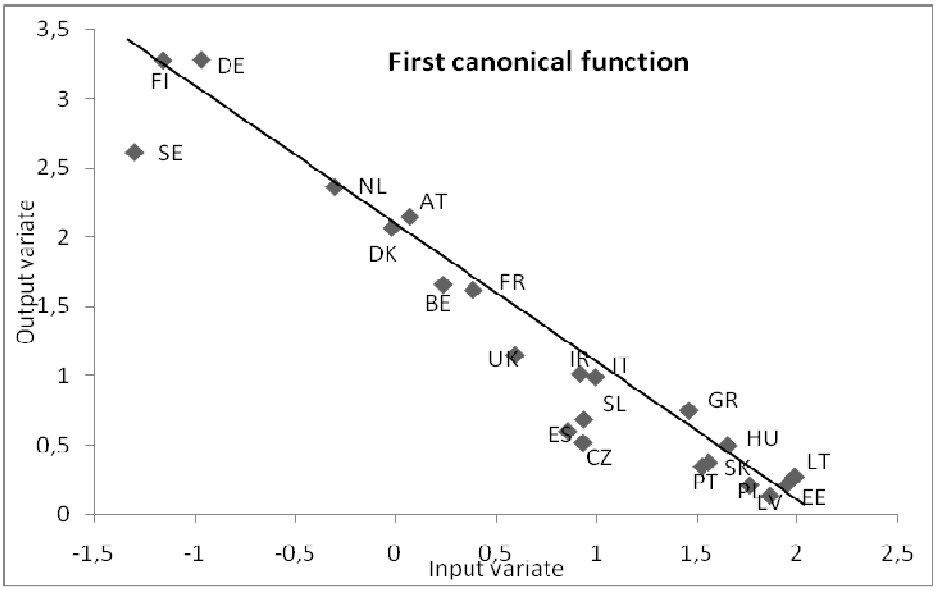
Canonical function	Input variables	Output variables
1st canonical function	gross domestic expenditure on R&D level of households Internet access broadband penetration rate information technology expenditure communications expenditure	applications to EPO SMEs introducing product or process innovations
2nd canonical function	information technology expenditure* spending on Human Resources*	new-to-market sales
3rd canonical function	e-government on-line availability	SMEs introducing product or process innovations
4th canonical function	science and technology graduates	high-tech exports

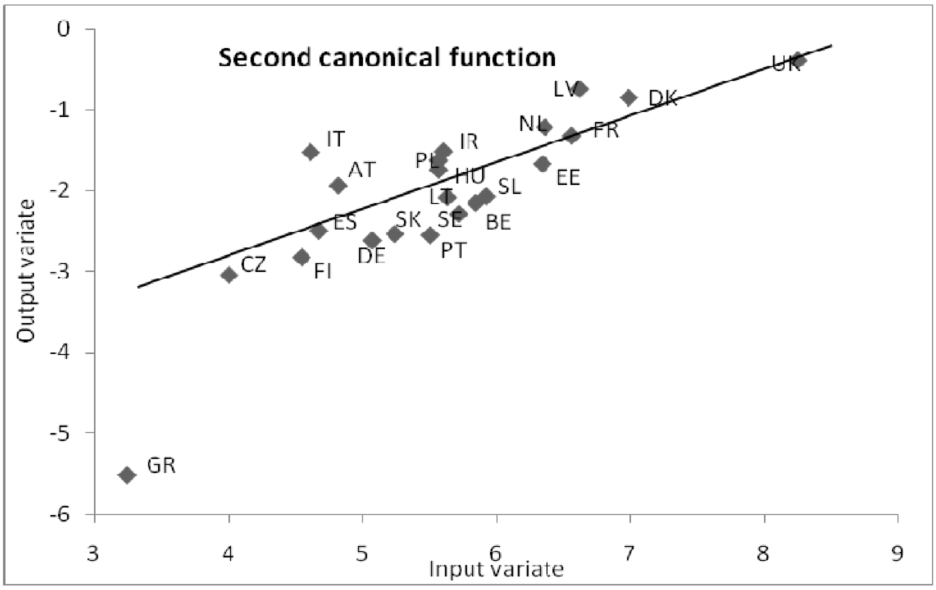
* canonical loading under 0,5

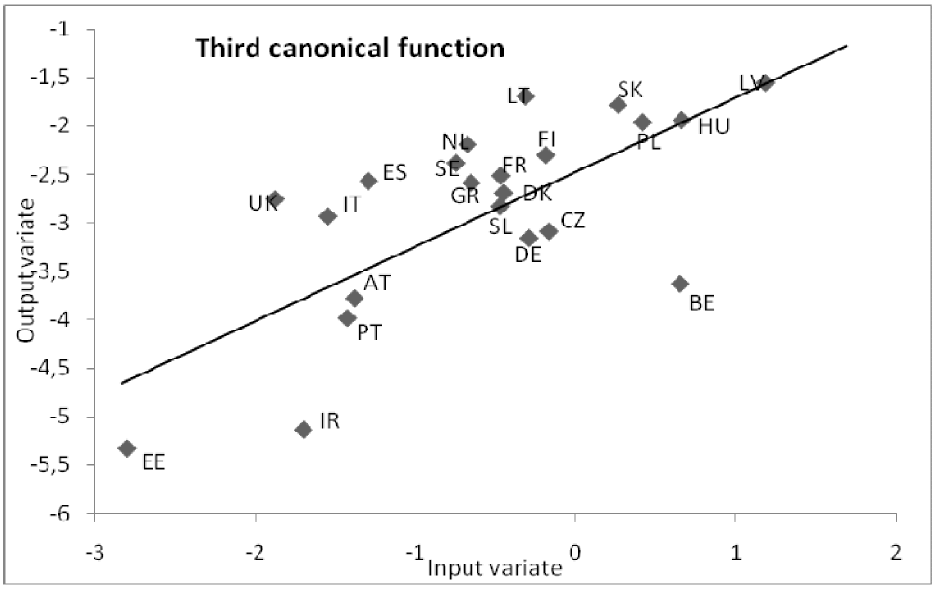
Source: Own calculations.

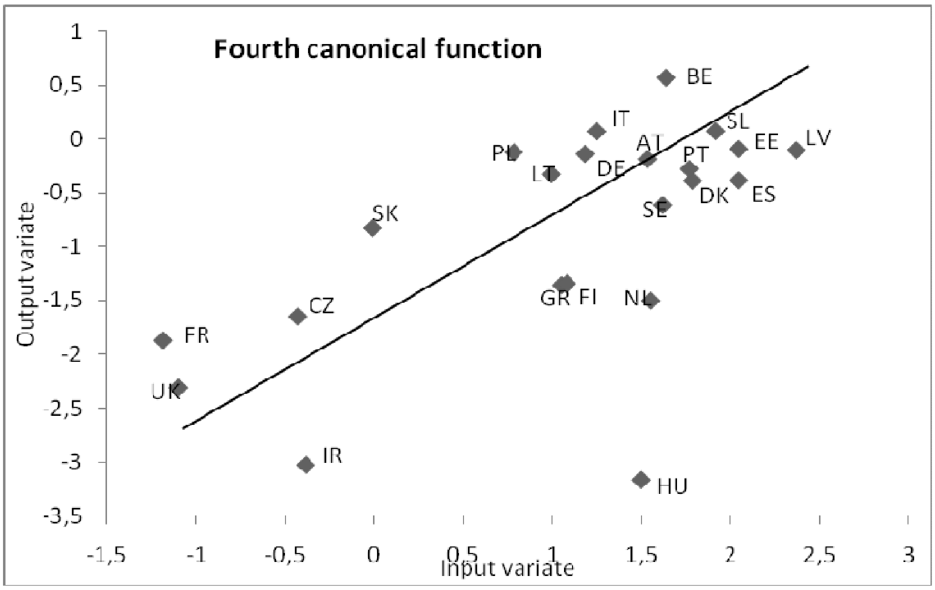
Next, the values of canonical variates for each canonical function are ploted in the diagrams (figure 1).

Figure 1. Position of 22 EU countries in relation to input and output variates of canonical functions for years 2005 and 2006









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

Source: Own calculations.

The lines on the diagrams indicate the direction of relationships between canonical variates of each canonical function. The points lying far from this lines show the countries which disturb relationships estimated by canonical functions. The first canonical function relationship is deviated mainly by Sweden and in less degree by Estonia, Czech Republik and Slovenia. Greece causes the greatest bias from the second canonical function relationship. The third and fourth function relationships are weaker, thus there are more points scattered from the lines.

Finally, the proportion of variance explained by each canonical variate and redundancy coefficients were estimated. The results are introduced in table 3.

Table 3. Variance extracted and redundancy coefficients

Canonical function	Input factors		Output factors	
	Variance extracted	Redundancy coefficient	Variance extracted	Redundancy coefficient
1st canonical function	0,3410	0,3111	0,4159	0,3794
2nd canonical function	0,1090	0,0736	0,2570	0,1736
3rd canonical function	0,0963	0,0392	0,1446	0,0589
4th canonical function	0,0676	0,0230	0,1819	0,0620

Source: Own calculations.

The first canonical variate for input factors extracts, on the average, 34 % of variance from its own set of variables. The next two canonical variates explain about 10 % of variance. The proportions of the total variance in output variables captured by the first two canonical variates are respectively 42 % and 26 %. Output factors are treated as dependent variables, thus only their redundancy coefficients are important for interpretation. 38 % and 17 % of variance in output variables are predicted from first two canonical variates. However, in the context of the survey this results seem to be satisfactory.

5. Conclusion

The canonical correlation analysis allows the authors to study innovation input-output relationship in EU countries. The results of research show that domestic expenditure on R&D and broadband penetration rate play a leading role in patent applications activity. The revealed relationships are consistent with the hypothesis of the positive impact of R&D expenditures on patent propensity. Moreover in the light of presented results, the access to internet should be interpreted as a mean of exchanging information on patent filling. Another interesting conclusion drawn from the second canonical function is that investing in human capital and information technology may be regarded as a sources of new-to-market sales growth. This finding is reinforced by the third canonical function that exposes the magnitude of skilled human capital in the level of innovation propensity of enterprises.

To sum, further research on the innovation input-output relationship should take into consideration more innovation input and output measures and focus on the link between innovation performance and economy productivity in the cross national context.

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Streszczenie

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Prezentowany artykuł przedstawia wyniki analizy powiązań nakładów i efektów działalności innowacyjnej w krajach UE. W pierwszej części opracowania przedstawiono rolę innowacji w kreowaniu wzrostu gospodarczego ze szczególnym uwzględnieniem nowych modeli wzrostu endogenicznego. W drugiej części pracy scharakteryzowano pojęcie i mierniki innowacji w ujęciu dwuwymiarowym. Ostatnia część artykułu prezentuje metodykę i wyniki badania. Zgodnie z nimi wydatki na BiR, technologie informacyjno komunikacyjne oraz kapitał ludzki, traktowane jako wkład w proces innowacyjny, mają istotny wpływ na wyniki działalności innowacyjnej, w szczególności na skłonność do innowacji i patentowania oraz przychody ze sprzedaży nowych produktów.