Models of Interdependent Equations of Patents from Expenditures and Employees in Research and Development from European Union Countries with Different Levels of Innovation

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Abstract:

The aim of this study is to identify the regressive dependence of patents on research and development (R&D) expenditures or the number of R&D employees in models with interdependent equations in countries above and below the European Union (EU) innovation average belonging to the EU in 2016 and 2019. In addition, the marginal and average resource and labor intensity of patents in countries with different levels of innovation in the years under study are determined. The research results indicate that countries above the EU average for innovation have the lowest average patent resource and labor intensity. By contrast, countries below the EU average for innovation have the highest average patent resource and labor intensity.

Keywords: interdependent equations; marginal and average; patent resource; labor intensity.

JEL Classification: F02; L24; O32.

Introduction

The increase in the level of education and skills of those working in the economies increases the level of human capital and creates conditions for the growth of innovative capacity. These basic determinants of innovation in time and space increase the growth of the country's regions and economy. This results in differentiation in the state, growth and development of individual countries on the international scene. This means not only changes in the use of the economic situation by individual countries but also variation in the state of application of innovation in a given country.

The process of diffusion of innovation is the basis for the modernization of the country's economy. In the face of the increasingly rapid development of civilization, it causes deep transformations in the needs, aspirations, attitudes and behaviors of countries' societies. The source of innovation is the need for countries to achieve ever better economic results. Innovative attitudes are particularly popular where there are conditions conducive to the development of economically strong economies, where information about modern economies penetrates quickly and through many channels.

The source of improvement in the efficiency of countries' management is technical and technological progress, consisting in the introduction of various technical, technological, biological and organizational innovations. The following innovations are particularly important:

- improvement of technical and utilitarian properties of means of production (patents);
- improvement of manufacturing technology (linking R&D expenditures and employees in R&D);
- modernization of patent creation technologies;
- increase in the scale of R&D activity in a given economy;
- optimization of the division of tasks in R&D and means of action between particular sectors, regions and economies of countries.

Technical and economic knowledge is important here. In order to effectively assess the degree of innovation uptake in a country, it is necessary to classify countries so that their sets have the characteristics of intense innovation at an appropriate (above or below the EU innovation average) level (state) to assess innovation creation processes aggregated in patents.

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Quite often, economic effectiveness is measured with the help of a simple regression model, usually referring to full patents (number) and incomplete expenditures (or increments thereof). In order to increase the cognitive value, a simple regression model describing the situation was used to eliminate the impact of feedback between the R&D expenditure and R&D personnel in the years studied. The simple regression model with interdependent equations is a proposal that limits the occurrence of a negative parameter at the number of employees in R&D. The regression coefficients (parameters) must then be relativized by comparing the equations within each model. This methodology is a new research proposal.

The aim of this study is to identify the regressive dependence of patents on R&D expenditures or the number of R&D employees in models with interdependent equations in countries above and below the EU innovation average belonging to the EU in 2016 and 2019. In addition, the marginal and average resource and labor intensity of patents in countries with different levels of innovation in the years under study are determined.

The basis of the study is the hypothesis that countries above the EU average for innovation have the lowest average patent resource and labor intensity in 2016 and 2019. By contrast, countries below the EU average for innovation have the highest average patent resource and labor intensity.

The aim of the research requires the following tasks (sections): Section 1 presents literature review. Section 2 contains the research methodology. Section 3 econometric impact and discussion. Section 4 contains the final considerations.

1. Literature Review

Growth theory points to innovation as a source of economic growth of a country (Tebaldi, Elmslie 2013). There is no statistical relationship between R&D and economic growth. However, patents are significant determinants of GDP per capita growth (Kacprzyk, Doryń 2017). There is a link between entrepreneurship and patents, the legitimacy of credit and support in market implementation (Gaule 2018). However, patents are negatively linked to economic growth. A higher level of expenditure on R&D ensures an increase in the number of new innovative products and their profitability (Sudolska, Łopińska 2020; Artz *et al.* 2010). On the basis of patent maps created, technologies were identified as a state of some stagnation (phase) (Smojver *et al.* 2019). The patent is an indicator of technology innovation in countries.

In 2010, the number of patents worldwide was 1.98 million, up 7.2% on 2009. This was the largest growth in the last five years. About 83% of patents are international and concentrated in the US and Europe. Even if this is overestimated, 60% are certainly international. Only 17% of patents are not international. In contrast, 45% of patents were created from R&D activities, 34% from total R&D activities (Bergek, Bruzelius 2010). The countries that had the highest number of patents after 2010 were the USA and Japan (Bach *et al.* 2017). Access to resources, infrastructure, concentration of industries and universities concentrate 70% of R&D costs in technology development in Brazil (Viana *et al.* 2018). There is a correlation between international competition and international patents. In contrast, the elasticity of patents with regard to R&D decreases when there are productivity (qualitative) variables (Danguy *et al.* 2014). Trade with some patent confidentiality affects the balance of rivalry between R&D projects and social optimality within the range of the parameter value (Bulut, Moschini 2006). Studies show that patent secrecy is destroyed when inventions become more valuable (Graham, Hegde 2015). The reasons for countries' innovation are: 1) different access to and accumulation of knowledge and increase in R&D investments, 2) development of products and markets, 3) infrastructure development (Hong, Jung 2012).

Patents are a measure of innovation, and innovative production is the result of applying innovation. The acquisition of external knowledge is conditioned by an increase in internal knowledge. The taking into account of the existing knowledge is related to the existing relationship between knowledge substitution and R&D expenditure (Roper and Hewitt-Dundas 2015). Research shows that the approximation of information about an invention favors the growth of more recent information (theory) (Baruffaldi, Simeth 2020). Patents are also an indicator of innovative production. However, the innovation indicator should also include different types of sources and measures for measuring innovation (Fontana *et al.* 2013). It also points to a wider use of mechanisms for the growth of innovation and improvement in national economies (Hemel, Ouellette 2013). Research may involve the search for undisclosed inventions that occur in R&D activities not yet disclosed (Koh, Reeb 2015). There are differences in the creation of complex patents compared to those that businesses adapt to technology. Complementary types of categories used in the R&D activity are more crucial than the composition of teams in R&D (Teruel, Segarra-Blasco 2018). Scientific publications in most US states show stability with slight year-on-year increases. Fewer than half of the states show a level of performance measured by the number of patents and scientific publications from R&D that is close to that of the countries with the highest level of patenting. India has the highest R&D spending efficiency (Thomas *et al.*

2011). Research shows that an increase in R&D expenditure leads to an increase in employment in R&D and in total employment in industry (Buerger *et al*. 2012).

Research in 11 EU countries has shown that an increase in R&D and innovation expenditure up to 1%, on average, results in an increase in revenue by 0.19%, and when the increase in innovation reaches 1%, an increase in revenue of up to 4.05% follows. A two-way causality between R&D expenditure, innovation and revenue was observed (Gocer *et al.* 2016). Resources for R&D in the innovation process effectively increase the number of patents. However, the economic value of innovation depends on several factors, including complementary innovation. Therefore, it is beneficial for the technical side of the invention to stretch resources (Gambardella *et al.* 2011). Robinson's theorem points to a problem–in the capitalist system of resource allocation, with the management of funds for innovation, where a new idea triggers future new ideas (Robinson 1977). The theory of perspective indicates that differences between institutions are a source of risk, while cost rationalization leads to bonuses. Hence, the model should lead to the allocation of resources for the invention according to the market (Ullberg 2010). The value of patents constitutes an asset for a country's economy, and this helps to determine the value of intellectual property or proper ownership of the knowledge resource of the economies of EU countries (Gambardella *et al.* 2008).

Patents are a category of intellectual property (IP) and an important element in the strategic planning of R&D and innovation (Harhoff, Wagner 2009). Patent systems make a significant contribution to the protection of intellectual property; this conclusion can be drawn from the empirical and theoretical literature on patents (Cimoli *et al.* 2011). The new US patent system is conducive to the creation of patents and affects their largest patenting. This makes it common information for inventors (Feng, Jaravel 2020). No support was found between the value of patents in relation to the number of patents (Fischer, Leidinger 2014). Government loans in Sweden are focused on mainly small businesses. The government prefers worse projects that have been returned by private investors (Svensson 2013). Research indicates problems related to patents in small and large companies with the primary function of patents such as legal security (Galasso, Schankerman 2018). Studies have shown that countries are considering reducing taxes on invention fees. Germany is considering partial taxation of revenues from patent-based technologies. There is also the problem of transferring inventions for patenting in some countries, such as China (Karkinsky, Riedel 2012).

2. The Econometric Model and Dependencies

A survey in the regional R&D system in the provinces of China consists of statistical grouping and econometric analysis (Chen *et al.* 2017). In the statistical grouping of countries, the EU Innovation Index has been used as an indicator of innovation, which includes innovations from R&D and new innovative production together (Edquist, Zabala-Iturriagagoita 2015). Its content is based on the OECD's Manual, thus ensuring international comparability through rolling average innovation levels over time and space. The average EU Innovation Index was used to statistically group countries into two sets: above and below the EU innovation average. This also justifies the link that, as the number of patents increases, the intensity of relationships and technologies in countries decreases (Zobel *et al.* 2016).

The requirement of rational R&D activity is to achieve the highest possible effects in relation to outlays, *i.e.* the highest possible management efficiency. Economic effectiveness is a quantitative category; it characterizes the technical and economic side of the patenting process (its socio-economic equivalent is cost-effectiveness). It is therefore appropriate for its measurement to use natural units or such valuation units (assessments) which reflect as correctly as possible the specific technical and application characteristics of patents and factors, R&D expenditure and R&D personnel. Due to the technical nature, individual (studied separately) R&D expenditures and those working in R&D have been compared in four powerful models of straight curvilinear regression, each with two interdependent equations, with given models in the form:

$Y1 = \beta_0 \, X1^{\beta 1}$ and $Y1 = \beta_0 \, X2^{\beta 2}$ or $Y2 = \beta_0 \, X1^{\beta 3}$ and $Y2 = \beta_0 \, X3^{\beta 4}$ (1)

$Y1a = \beta_0 \, X1a^{\beta 5}$ and $Y1a = \beta_0 \, X2a^{\beta 6}$ or $Y2a = \beta_0 \, X1a^{\beta 7}$ and $Y2a = \beta_0 \, X3a^{\beta 8}$ (2)

The first two models were applied to the set of countries above the EU innovation average N = 11 and the next two to countries below the EU innovation average, N = 13.

By logarithmising them, we obtain:

$lnY1 = ln\beta_0 + \beta_1 lnX1;$ and $lnY1 = ln\beta_0 + \beta_2 lnX2;$ (3)

or

$lnY2 = ln\beta_0 + \beta_3 lnX1$; and $lnY2 = ln\beta_0 + \beta_4 lnX3$ (4)

$lnY1a = ln\beta_0 + \beta_5 lnX1a;$ and $lnY1a = ln\beta_0 + \beta_6 lnX2a;$ (5)

or

$lnY2a = ln\beta_0 + \beta_7 lnX1a$; and $lnY2a = ln\beta_0 + \beta_8 lnX3a$ (6)

Derivatives:

$$h(X1) = \beta_0\beta_1 \mathrm{X1}^{\beta_1 - 1}; \quad h(X2) = \beta_0\beta_2 \mathrm{X1}^{\beta_2 - 1} \quad (7)$$

$$h(X1) = \beta_0\beta_3 \mathrm{X1}^{\beta_3 - 1}; \quad h(X3) = \beta_0\beta_4 \mathrm{X1}^{\beta_4 - 1} \quad (8)$$

$$h(X1a) = \beta_0\beta_5 \mathrm{X1a}^{\beta_5 - 1}; \quad h(X2a) = \beta_0\beta_6 \mathrm{X2a}^{\beta_6 - 1} \quad (9)$$

$$h(X1a) = \beta_0\beta_7 \mathrm{X1a}^{\beta_7 - 1}; \quad h(X3a) = \beta_0\beta_8 \mathrm{X1a}^{\beta_8 - 1} \quad (10)$$

Derivatives in the marginal account are the product of average input or output and the corresponding parameter (flexibility).

Flexibility:

$$E(X1) = \beta_1; E(X2) = \beta_2;\ and\ E(X1) = \beta_3; E(X3) = \beta_4 \quad (11)$$

$$E(X1a) = \beta_5; E(X2a) = \beta_6;\ and\ E(X1a) = \beta_7; E(X3) = \beta_8 \quad (12)$$

3. Econometric Impact and Discussion

The characteristics of the variables in Table 1, countries above and below the EU innovation average, show significant variations, which means that the selection of these countries into statistical groups is justified. The average number of patents in countries above the EU innovation average in 2019 is more than 6% higher than in 2016 and 11% higher in countries below the EU innovation average.

By contrast, the internal variability of patents in countries below the EU innovation average is nearly 100 percentage points higher in the years under review. The significant directional increase in the average number of patents in 2019 compared to 2016 is associated with a relatively high increase in patent volatility in countries below the EU innovation average, although the average of patents in these countries is 10 times lower compared to countries above the EU innovation average. This is confirmed by the necessary separation of EU countries into statistical groups with different levels of innovation.

Table 1 Parameters of features of R&D expenditures and R&D employees in EU countries with different levels of innovation in 2016 and 2019

No.	Details	Year	Unit measures	Symbol	Arithmetic average	Range min.-max.	Coefficient variability, %
1.	Number of patents, above EU innovation average, countries: Germany, Estonia, Ireland, France, Cyprus, Luxembourg, Austria, Slovenia, Finland, Sweden, Belgium	2016 2019	Number Number	Y1 Y2	4,224 4,485	36 – 24,932 47–26,805	177.3 177.6
	▪ Number of patents below EU innovation average, countries: Bulgaria, Czech Republic, Greece, Croatia, Italy, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Romania, Slovakia	2016 2019	Number Number	Y1a Y2a	407 452	11–4,154 19–4,466	277.5 267.7
2.	▪ R&D expenditure above EU innovation average, countries: Germany, Estonia, Ireland, France, Cyprus, Luxembourg, Austria, Slovenia, Finland, Sweden, Belgium	2016	Euro	X1	20,593,128	143,180–139,492,794	200.0
	▪ R&D expenditure below the EU innovation average, countries: Bulgaria, Czech Republic, Greece,	2016	Euro	X1a	3,742,913	134,536–260,015,686	188.0

No.	Details	Year	Unit measures	Symbol	Arithmetic average	Range min.-max.	Coefficient variability, %
	Croatia, Italy, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Romania, Slovakia						
3.	▪ Number of employees above EU innovation average, countries: Germany, Estonia, Ireland, France, Cyprus, Luxembourg, Austria, Slovenia, Finland, Sweden, Belgium	2016	Number	X2	130,831	1,356–657,894	163.0
		2019	Number	X3	139,691	1,610–707,944	162.8
	▪ Number of employees below the EU innovation average, countries: Bulgaria, Czech Republic, Greece, Croatia, Italy, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Romania, Slovakia	2016	Number	X2a	53,824	1,505–290,040	143.0
		2019	Number	X3a	62,596	1,443–311,734	137.3

Source: Eurostat Statistics Database (Inn_cis10_exp). European Innovation Scoreboard 2017, 2019 and 2020. The author's own calculations.

Likewise, R&D expenditures in countries below the EU innovation average – they have an average value in Euro of these expenditures that is 5.6 times lower, and their internal diversification in these countries is similar (difference of 12%). Regardless of the level of R&D expenditure and the level of innovation of countries, they seem to be a variable whose higher intensity in the patenting process is necessary for its impact.

With the R&D expenditure in a feedback relationship there is employment in R&D, and the average of R&D employees in countries below the EU innovation average is more than two times lower, and their variability is similar in the innovation levels distinguished and between the years studied. This may indicate the need to have them in relation to R&D expenditure and to the extent of the number of patents created in time and space.

Models of curvilinear straight-line regression with paired interdependent equations are included in four models, in the table entry in Table 2. These models are of a macroeconomic nature, as they cover individual economies treated as countries (sectors) and are models of innovation growth.

Table 2 Models of curvilinear simple power regression with interdependent equations of the number of patents (Y1, Y2, Y1a and Y2a) from R&D expenditures (X1 and X2a) and the number of R&D employees (X2, X3, X2a and X3a) with the EU Innovation Index, countries above and below the EU Innovation Index in 2016 and 2019

Year	a*	Regression factor (parameter)			Standard error				Test t				R^2 Correction
		X1	X2	X3	a	X1	X2	X3	a	X1	X2	X3	
2016	0.000211	1.00			1.55	0.10			-5.44	9.98			0.91
2016	0.013601		1.06		1.36		0.13		-3.15		8.29		0.87
2019	0.000243	1.00			1.36	0.09			-6.19	11.27			0.93
2019	0.012868			1.07	1.29			0.12	-3.36			8.85	0.89
Countries below the EU innovation average													
		X1a	X2a	X3a	a	X1a	X2a	X3a	a	X1a	X2a	X3a	
2016	0.000130	0.94			2.57	0.18			-3.47	5.19			0.68
2016	0.011926		0.86		2.47		0.24		-1.80		3.59		0.50
2019	0.000187	0.93			2.28	0.16			-3.76	5.78			0.74
2019	0.015186			0.85	2.11			0.20	-1.97			4.17	0.59

Source: as in Table 1. The author's own calculations.

Note: *Fixed delogarithmised equations (free expression); Level of significance of parameters in all equations with the interval: 0.00–0.05

The data in Table 2 contain simple regression factors estimated in relation to one independent variable, excluding other relevant independent variables. These important independent variables are found in models with interdependent equations. With the help of these regression models, a high correlation between R&D expenditure and R&D personnel has been avoided, as well as possible co linearity and feedback relationships between these variables.

The strength of the relationship expressed by the simple correlation coefficient (R) (square root of R^2) (Table 2) between the number of patents and R&D expenditure or those employed in R&D in countries above the EU innovation average is 95% and 93% in 2016 and 96% and 94% in 2019. In countries below the EU average, innovation is 82% and 71% in 2016 and 86% and 77% in 2019. The strength of the relationship expressed by the simple correlation coefficient does not determine the cause and effect relationship (Griffith *et al.* 2006), but in the countries and years studied it is important because it is in the range: 70%–130% (0.7–1.3). All regression factors (parameters) have standard errors lower than 50% of their absolute values. Meanwhile, the absolute t-test values are several times higher than the regression factors. All regression coefficients have a significance level within the range: 0.00–0.05 Statistical evaluations of regression coefficients (parameters) indicate the possibility of their use in the econometric analysis of the variability of the number of patents in relation to R&D expenditures or those employed in R&D in the European Union countries with different levels of innovation in 2016 and 2019.

Estimated simple regression coefficients (parameters) (Table 2), are the average elasticity coefficients of the number of patents in relation to the value of R&D expenditures or the number of R&D employees. An increase in the value of R&D expenditure by 10% results in an increase in the number of patents in countries above the EU innovation average, on average by 10% (assuming a stable number of R&D employees). Similarly, an increase in the number of employees in R&D by 10% corresponds to an increase in the number of patents, on average by 10.6% (with a stable level of R&D expenditure) in 2016. The sum of the elasticities (2.06 = 100%) of the above interdependent equations shows that in the relative increase in the number of patents, the impact of R&D expenditures is 48.5% and the number of R&D employees is 51.5% in countries above the EU innovation average in 2016.

On the other hand, an increase in the value of R&D expenditures in countries above the EU innovation average by 10% (with a stable number of people employed in R&D) results in an increase in the number of patents, on average by 10%. In turn, an increase in the number of people employed in R&D by 10% results in an increase in the number of patents, on average by 10.7% (with a stable level of R&D expenditure). The sum of the elasticities (2.07 = 100%) shows that the relative increase in the number of patents is caused by the impact of the value of R&D expenditures in 48% and by the impact of the number of R&D employees in 52% in 2019.

A 10% increase in the value of R&D expenditure results in an increase in the number of patents in countries below the EU innovation average, on average by 9.4% (with a stable number of R&D employees). Respectively, an increase in the number of people employed in R&D by 10% results in an increase in the number of patents, on average by 8.6% (with a stable level of R&D expenditure). The sum of the elasticities (1.8 = 100%) shows that the relative increase in the number of patents is shaped by the value of R&D expenditures in 52% and R&D employees in 48%, in countries below the EU innovation average in 2016. An increase in the value of R&D expenditure by 10% results in an increase in the number of patents, on average by 9.3% (with stable employment in R&D); while an increase in the number of people employed in R&D by 10% results in an increase in the number of patents, on average by 8.5% (with stable R&D expenditure) in countries below the EU innovation average in 2019. The sum of the elasticities (1.78 = 100%) shows that the relative increase in the number of patents by the impact of the value of R&D expenditures is 52% and the number of R&D employees is 48% in countries below the EU innovation average in 2019.

An even comparison model, which assumes that if X_i and X_j are reactions to operations (elasticities) *i* and *j* respectively, then $P(X_i > X_j) = X_i / X_i + X_J$. The first two interdependent equations, countries above the EU innovation average (2016) = 0.48; the second two interdependent equations, countries above the EU innovation average (2019) = 0.48. The third two interdependent equations, countries below the EU innovation average (2016) = 0.52; the fourth two interdependent equations, countries below the EU innovation average (2019) = 0.52. In relation to 2016, there is no wave from Schumpeter's theory in 2019 in both countries above and below the EU innovation average.

The resource intensity of patenting is the ratio of R&D expenditure to the number of patents that they use to create patents in a given country and period. Patent resource intensity is a measure of the amount of R&D expenditure that a country needs to run in order to obtain a patent unit.

Mental work is qualified work; during it, the mental effort outweighs physical effort. Cumulative (full) labor intensity is expressed in terms of the number of employees in R&D in a given country per patent unit.

The marginal and average resource and labor intensity in countries above and below the EU average of innovation is shown in Tables 3, 4, 5, 6, 7, 8, 9, 10 and 11.

Table 3. Marginal and average patenting resource intensity in countries above the EU innovation average in 2016

Number of patents (Y1)	R&D expenditure (X1), Euro	Resource intensity:	
		average Euro/patents	marginal Euro/patents
2,703.19	12,811,326	4,739.34	4,739.34
5,376.17	25,479,472	4,739.34	4,739.34
8,049.15	38,147,618	4,739.34	4,739.34
10,722.13	50,815,764	4,739.34	4,739.34
13,395.11	63,483,910	4,739.34	4,739.34
16,068.08	76,152,056	4,739.34	4,739.34
18,741.06	88,820,202	4,739.34	4,739.34
21,414.04	101,488,348	4,739.34	4,739.34
24,087.02	114,156,494	4,739.34	4,739.34
26,760.00	126,824,640	4,739.34	4,739.34

Source: author's calculations using Tables 1 and 2.

The data in Table 3 shows that marginal R&D expenditure constitutes a marginal value of the marginal economic account and is one of the measures of the profitability of patent creation. According to the marginal account rules, the average outlay (average patent resource intensity) is the lowest when it equals the marginal resource intensity of patents. The equalisation of the marginal patenting effort constitutes one of the criteria for the cost-effectiveness of allocating R&D expenditures in patent creation processes in countries above the EU innovation average in 2016.

Table 4. Marginal and average patenting labor intensity in countries above the EU innovation average in 2016

Number of patents (Y1)	Number of employees in R&D (X2)	Labor intensity:	
		average, number of employees/number of patents	marginal, number of employees/number of patents
1,608.16	61,041	37.96	40.23
3,313.44	120,726	36.44	38.62
5,072.35	180,411	35.57	37.70
6,867.19	240,096	34.96	37.06
8,689.27	299,781	34.50	36.57
10,533.39	359,466	34.13	36.17
12,396.06	419,151	33.81	35.84
14,274.76	478,836	33.54	35.56
16,167.60	538,521	33.31	35.31
18,073.10	598,206	33.10	35.09

Source: author's calculations using Tables 1 and Table 2.

The data in Table 4 show that the average patent labor intensity is in constant relation to the marginal patent labor intensity and the constant difference of the two R&D workers. This nature of the relationship between average and marginal patent labor intensity with a constant small difference across countries makes a close alignment of these categories and means that average patent labor intensity is lowest in countries above the EU innovation average in 2016.

The data in Table 5 show the permanent nature of the marginal patent resource intensity, which is a constant average patent resource intensity in countries above the EU innovation average. The equation of marginal and average patenting resource intensity explains the optimal allocation of R&D expenditure between patenting activities in countries above the EU innovation average in 2019.

Table 5. Marginal and average patenting resource intensity in countries above the EU innovation average in 2019

Number of patents (Y2)	R&D expenditure (X1) Euro	Resource intensity:	
		average Euro/patents	marginal Euro/patents
3,113.15	12,811,326	4,115.23	4,115.23
6,191.51	25,479,472	4,115.23	4,115.23
9,269.87	38,147,618	4,115.23	4,115.23
12,348.23	50,815,764	4,115.23	4,115.23
15,426.59	63,483,910	4,115.23	4,115.23
18,504.95	76,152,056	4,115.23	4,115.23
21,583.31	88,820,202	4,115.23	4,115.23

Number of patents (Y2)	R&D expenditure (X1) Euro	Resource intensity:	
		average Euro/patents	marginal Euro/patents
46,531.67	191,488,348	4,115.23	4,115.23
27,740.03	114,156,494	4,115.23	4,115.23
30,818.39	126,824,640	4,115.23	4,115.23

Source: author's calculations using Tables 1 and Table 2.

Table 6 shows slightly declining decreases in marginal patent labor intensity that shape changes in average patent labor intensity. The differences between the marginal value and the average labor intensity of patents are insignificant in countries (0.2–0.3), which indicates their equalization. This explains the optimal allocation of R&D employees in countries above the EU innovation average in 2019.

Table 6. Marginal and average patenting labor intensity in countries above the EU innovation average in 2019

Number of patents (Y2)	Number of employees in R&D (X3)	Labor intensity:	
		average, number of employees/number of patents	marginal, number of employees/number of patents
18,414.85	65,822	3.57	3.82
38,155.04	130,034	3.41	3.65
58,620.27	194,246	3.31	3.55
79,573.48	258,458	3.25	3.48
100,898.04	322,670	3.20	3.42
122,523.69	386,882	3.16	3.38
144,403.19	451,094	3.12	3.34
166,502.52	515,306	3.09	3.31
188,795.95	579,518	3.07	3.28
211,263.30	643,730	3.05	3.26

Source: author's calculations using Tables 1 and Table 2

Table 7. Marginal and average patenting resource intensity in countries below the EU innovation average in 2016

Number of patents (Y1)	R&D expenditure (X1a) Euro	Resource intensity:	
		average Euro/patents	marginal Euro/patents
133.64	2,487,368	18,612.34	17,495.60
249.87	4,840,200	19,370.84	18,208.59
362.61	7,193,032	19,836.79	18,646.58
473.12	9,545,864	20,176.49	18,965.90
581.99	11,898,696	20,444.98	19,218.28
689.56	14,251,528	20,667.52	19,427.47
796.07	16,604,360	20,857.87	19,606.40
901.68	18,957,192	21,024.37	19,762.91
1,006.50	21,310,024	21,172.48	19,902.13
1,110.62	23,662,856	21,305.94	20,027.58

Source: author's calculations using Tables 1 and Table 2.

Table 8. Marginal and average patenting labor intensity in countries below the EU innovation average in 2016

Number of patents (Y1)	Number of employees in R&D (X2a)	Labor intensity:	
		average, number of employees/number of patents	marginal, number of employees/number of patents
789.77	27,735	35.12	30.20
1,399.95	53,965	38.55	33.15
1,968.16	80,195	40.75	35.04
2,510.45	106,425	42.39	36.46
3,034.15	132,655	43.72	37.60
3,543.45	158,885	44.84	38.56
4,041.05	185,115	45.81	39.40
4,528.85	211,345	46.67	40.13
5,008.22	237,575	47.44	40.80
5,480.22	263,805	48.14	41.40

Source: author's calculations using Tables 1 and Table 2.

Table 7 shows the growing marginal and average patenting resource intensity in countries below the EU innovation average in 2016. The average patent resource intensity is greater than the marginal patent resource intensity, from 1,210 to 1,280 Euros per patent unit. The development of the average patent resource intensity is a measure of the economic effectiveness of R&D investment and the profitability of patents. Average patent resource intensity continues to increase and is heading towards a point of inflection, from that level R&D input and increment per patent unit will decrease. The current state is in a zone of irrational management of patent creation processes in countries below the EU innovation average in 2016.

Table 8 shows that the marginal and average patenting labor intensity in countries below the EU innovation average is increasing. The average patent labor intensity is higher than the marginal patent labor intensity, by 5–7 R&D employees per patent unit (number). When this patent labor intensity grows, it heads towards the limit of inflection and declining growth of the R&D workforce. Increasing growth is taking place in the irrational management zone of R&D employment in countries below the EU innovation average in 2019.

The data in Table 9 show that the marginal and average patent resource intensity is increasing, the difference in the higher average patent effort is between 1,050–1,230 Euros per patent unit. This is taking place in a zone of irrational management of patenting processes in countries below the EU innovation average in 2019.

Table 9. Marginal and average patenting resource intensity in countries below the EU innovation average in 2019

Number of patents (Y2)	R&D expenditure (X1a) Euro	Resource intensity:	
		average Euro/patents	marginal Euro/patents
165.91	2,487,368	14,992.02	13,942.58
308.15	4,840,200	15,707.20	14,607.70
445.42	7,193,032	16,148.87	15,018.45
579.52	9,545,864	16,471.97	15,318.93
711.31	11,898,696	16,727.97	15,557.02
841.26	14,251,528	16,940.60	15,754.75
969.72	16,604,360	17,122.77	15,924.17
1,096.91	18,957,192	17,282.34	16,072.58
1,222.99	21,310,024	17,424.46	16,204.75
1,348.11	23,662,856	17,552.67	16,323.98

Source: author's calculations using Tables 1 and 2.

Table 10. Marginal and average patenting labor intensity in countries below the EU innovation average in 2019

Number of patents (Y2)	Number of employees in R&D (X3a)	Labor intensity:	
		average, number of employees/number of patents	marginal, number of employees/number of patents
96.09	29,651	308.58	262.29
169.61	57,858	341.12	289.95
237.71	86,067	362.06	307.75
302.48	114,275	377.79	321.12
364.87	142,483	390.50	331.93
425.42	170,691	401.23	341.04
484.49	198,899	410.54	348.96
542.30	227,107	418.79	355.97
599.04	255,315	426.20	362.27
654.85	283,523	432.96	368.01

Source: author's calculations using Tables 1 and Table 2.

The data in Table 10 show that marginal patent labor intensity is increasing, resulting in an increase in average patent labor intensity in countries below the EU innovation average in 2019. The differences from marginal patent labor intensity, in average patent labor intensity, vary from 52–64 R&D employees per patent unit. The average patent workload increases to a certain limit after which its growth begins to decrease. Increasing growth is taking place in the irrational management zone of R&D employment in countries below the EU innovation average in 2019.

In countries above the EU innovation average (Table 11), the average rate of growth of the number of patents is equal to the average rate of growth of R&D expenditures and the number of R&D employees in 2016 and 2019. On the other hand, the average rate of growth of marginal and average patent labor intensity is zero, and marginal and average patent labor intensity is negative. This is due to the equilibrium of marginal and average patent resource and labor intensity in countries above the EU innovation average in 2016 and 2019. The economic category of marginal patenting resource intensity explains the methodological rationality of the decisions made in the patent creation processes in these countries.

Table 11. Average growth rate of variables in countries above and below the EU innovation average in 2016 and 2019

Details	Table 3	Table 4	Table 5	Table 6	Table 7	Table 8	Table 9	Table 10
Countries above the EU innovation average								
Number of patents (Y1)	29.01	30.84						
Number of patents (Y2)			29.01	31.14				
R&D expenditure (X1)	29.01		29.01					
Number of employees in R&D (X2)		28.87						
Number of employees in R&D (X3)				28,84				
Patent resource intensity: - marginal - average	 0.0 0.0		 0.0 0.0					
Patent labor intensity: - marginal - average		 -1.57 -1.57		 -1.76 -1.76				
Countries below the EU innovation average								
Number of patents (Y1)					26.53	24.02		
Number of patents (Y2)							26.21	23.77
R&D expenditure (X1a)					28.44		28.44	
Number of employees in R&D (X2a)						28.44		
Number of employees in R&D (X3a)								28.51
Patent resource intensity: - marginal - average					 1.51 1.51		 1.77 1.77	
Patent labor intensity: - marginal - average						 3.57 3.57		 3.83 3.83

Source: author's own calculations based on Tables 3, 4, 5, 6, 7, 8, 9, 10 with the help of geometric mean.

In countries below the EU innovation average (Table 11), the average patent growth rate is slowed down by nearly 4% in 2016 and even 6% in 2019. The average rate of growth of R&D expenditures and R&D employment is similar to countries above the EU innovation average. The reason for the slowdown in the number of patents in countries below the EU innovation average is the slow increase in the average growth rate of marginal and average patent resource intensity (more than 1.5%) and marginal and average patent labor intensity of more than 2.5 times the average growth rate (3.8%). The latter economic categories indicate irrational methodological decisions taken in the patenting processes in these countries.

Conclusions

The study conducted confirms the hypothesis that countries above the EU average for innovation have the lowest average patent resource and labor intensity in 2016 and 2019. By contrast, countries below the EU average for innovation have the highest average patent resource and labor intensity in the years under consideration. Comparison of the average with marginal patenting resource intensity and the average with marginal patenting resource intensity in countries above the EU average of innovation indicates an optimal allocation of R&D expenditure and R&D personnel between activities in patenting processes in these countries. This also confirms the methodological rationality of the decisions made in the patent creation processes in these countries in 2016 and 2019.

The research shows that within the economic union of the EU countries, those of them which have a relative comparative advantage in the level of innovation meet the criteria of optimal allocation of expenditures on R&D and those employed in R&D. Moreover, they obtain the lowest average costs (outlays) in patent creation processes. This allows them to grow innovatively and efficiently.

The research indicates that an appropriate classification in terms of approximation of innovation levels in country sets contributes to the demonstration of the actual relationships between country sets in the development of innovation phenomena and processes. It also turned out that in the supply model of patent creation processes there is no wave from Schumpeter's theory regardless of the level of innovation in countries and years.

The author intends to apply further econometric models to study the phenomena and processes of innovation in supply and demand models of innovation.

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