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## Article

# Modeled interdependencies between intellectual capital, circular economy and economic growth in the context of bioeconomy

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# MODELED INTERDEPENDENCIES BETWEEN INTELLECTUAL CAPITAL, CIRCULAR ECONOMY AND ECONOMIC GROWTH IN THE CONTEXT OF BIOECONOMY

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## Abstract

The bioeconomy-specific paradigm has changed the perception of economic growth in the sense that the growth limits do not matter, but new growth opportunities. These are focused on: knowledge, investment in research, innovation and technological performance, which give meaning to the concept of smart economic growth; green energy, low-carbon policies, reduced environmental collateral effects, which are attributes of sustainable economic growth. The paper dwells on the influence of bioeconomy on economic growth through an empirical study conducted between 2008 and 2015, using cross-sectional analysis applied to the interconnections between the data relative to the EU-28 member countries. Three econometric models, based on the Ordinary Least Square regression, have been developed to highlight the interdependencies between intellectual capital, circular economy and economic growth in the context of bioeconomy. The number of patents is the *proxy* variable designed to quantify innovative performance in the bioeconomic sectors, value added is the dependent variable that measures the achievements specific to the circular economy and gross domestic product quantifies the sensitivity of economic growth to the use of intangible resources (knowledge / intellectual capital) and of renewable resources used in cascade (specific to circular economy). The findings confirm the positive influence of research-development funding and of fiscal freedom on intellectual property rights materialized in patents. The added value created in circular economy responds well to recyclable raw material export, to population employment in circular economy and to municipal waste recycling rate. The productivity of bioeconomy employees positively influences economic growth in the EU-28. We also focused on negative aspects such as the poor results of innovation in relation to the allocated financing resources and the insufficient use of energy from renewable sources in the production process.

**Keywords:** bioeconomy, intellectual property, circular economy, economic growth, environmental performance.

**JEL Classification:** O3, O1, O4, Q57.

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## **Introduction**

Governments and international bodies worldwide have been looking for solutions and thinking about strategies for global human issues: food safety, climate change, excessive reliance on non-renewable resources, job creation, sustainable economic growth, etc. The search efforts led to the idea of intelligent use of biological resources and processes in the economy, through innovation, highly skilled workforce and the widespread use of knowledge. In the European political and scientific environments, these ideas have been included in different strategies and action plans, have fueled debates and have led to the creation of new concepts such as *knowledge economy*, *bio-based economy*, *knowledge-based bio-economy (KBBE)*, etc. Thus, *Europe 2020: A strategy for Smart, Sustainable and Inclusive Growth*, adopted by the European Council in 2010, refers to bioeconomy as an important sector in achieving its thematic priorities at EU level: smart, knowledge-based and innovation-driven economic growth; sustainable economic growth, based on efficient and greener resource management; inclusive economic growth, conducive to employment, social and territorial cohesion (European Commission, 2010).

As bioeconomy is considered a lever used by European institutions to pursue the objectives of its Europe 2020 strategy, research aims to quantify the interdependencies between smart, sustainable and inclusive growth. To this end, three hypotheses have been developed that test the association between: i) the results of the innovation process in bioeconomy, the financial and human effort, taking into account the degree of fiscal freedom of the EU-28 nations; ii) the added value and dimensions of circular economy; iii) the economic growth, efficiency of investments in research and development and productivity of employees in the bioeconomy sectors. In order to achieve the research objectives we included in the structure of our paper: the second section that reviews the literature; the third section presenting the research methodology, including the purpose, objectives and research hypotheses and detailing the variables analyzed, the data source and the proposed econometric models; the fourth section discussing the findings; the conclusions that summarize the contributions and the limitations of the research.

## **1. Literature review**

The global economic system has become a system of “technological ideas and innovations” (Toffler, 1995), in which life sciences are integrated in related fields (information technology, nanotechnology, chemistry, etc.) (Patermanna and Aguilarb, 2018), and value is created by moving the center of gravity from investments in fixed assets to investments in human capital, by exploiting less tangible resources, generically called *knowledge capital*, and renewable resources used in cascade and circularly.

In bioeconomy, knowledge is the most important intangible asset, and intellectual property is the currency. Creating knowledge value depends on the access to intellectual property rights (Krauss and Kutenkeuler, 2018).

Many bioeconomy companies worldwide have developed intellectual property portfolios and have increasingly become *knowledge capital* suppliers for traditional firms. Thus, they have earned substantial licensing revenues as an extension of their core business (Precob and Mironiuc, 2016), and sometimes even without actually using intellectual property

rights to protect their own products. Some companies have turned this into their only business strategy, thus acquiring the name of *non-practicing entities*.

This fact has led some authors to argue that financialisation, as a model of accumulation in which profits are made through financial channels rather than through the production and trade of goods, has deepened with the expansion of knowledge-based economy, both as a political-economic vision and as a science and innovation driving force (Birch and Mykhnenko, 2014; Birch, 2017).

When referring to bioeconomy, Mirowski (2012) describes the “biotech firm” as a “financial artifact”, arguing that most biotechnologies will never produce a finished product for sale because they are primarily configured as financial organizations and then as producers of science and technology. The long time span (5-15 year on the average) elapsing between a scientific breakthrough, its concrete application and launch of results on the market has a negative impact on investment recovery and accounts for the low number of private investors in the biotechnology sector (Sgard and Harayama, 2013).

Pisano (2006) claims that life sciences companies ensure knowledge monetization through intellectual property rights assignment. Intellectual property rights monetization is the best way to finance, in the long run, research and innovation in the field of bioeconomy, not necessarily by selling the developed products, but by revenues derived from the ownership of and control over the intangible assets that underpin the design of products, and from licenses, royalties, partnerships, etc. (Pisano, 2006; Yang, 2014; Birch, 2017). Consequently, intangible assets are monopolies of knowledge that accrue monopoly rent (Zeller, 2008). Andersson, et al. (2010) compare the financing of bioeconomy companies with chain competition, in which the surrender of intellectual property rights to the next investor provides the original investor with a return (royalties) from which the initial invested capital is recovered, without the need to rely exclusively on gains from the marketing of manufactured products (Hopkins, et al., 2013).

Birch (2017) notes the contradiction between the rising of the market value of companies in the bioeconomy sectors and the continuous downward trend in the value of products and services marketed in this sector. Paradoxically, this means that there are fewer incentives to develop products and services, because intangible assets themselves (intellectual property rights) can generate revenue and at the same time preserve their value as capitalized property. Birch (2017) believes that a dual process is identified in the bioeconomy sector that involves the transformation of knowledge into assets (*assetization of knowledge*) – intellectual property – and the transformation of these assets into currency through sale (*monetization of knowledge assets*) as a source of value.

Bioeconomy includes all the elements that determine the structure of intangible capital: intellectual property (*copyright, software, patents, know-how, etc.*), infrastructure (technologies and working procedures), human capital (employee skills and knowledge) and market assets (*brands, market segments, distribution channels / value chains*). The value of a company subsists in its ability to acquire, generate and distribute intangible resources, and to strategically and operationally apply knowledge (Toffler, 1995).

Research and innovation are essential components of circular economy, which create value through the “cascade use”, reuse and recycling of resources. Implementing the circular economy involves innovation that leads to reconfiguration of classical business models.

The concept of *circular economy* has emerged quite recently as a relevant political objective in the context of the rising prices of resources and of climate change (Gregson et al., 2015). Murray, Skene and Haynes (2017) argue that the term has both a linguistic and a descriptive meaning. Linguistically speaking, circular economy is opposed to linear economy, which converts natural resources into waste through production. The word circular also has a descriptive meaning, which is related to the concept of cycle.

As an economic system, circular economy aims at increasing the efficiency of resource use, with an emphasis on waste, in order to achieve a balance between economy, environment and society. Being in the early stages of its implementation in various parts of the world, circular economy is based on the production and consumption model and attempts to separate economic prosperity from resource consumption through recycling and reuse, as substitutes for the use of primary materials (Sauve, Bernard and Sloan, 2016). Its application involves the use of renewable technologies and materials and the implementation of stable and appropriate policies and tools for *cleaner production*. In this context, circular economy is intended to be a business model conducive to the sustainable and harmonious development of society, based on a *win-win* philosophy, according to which a healthy economy can coexist with a healthy environment.

According to Ghisellini, Cialani and Ulgiati (2016), the origin of the term circular economy may be linked to several schools of thought. Environmental economists Pearce and Turner claimed, in 1989, that they used the term circular economic system based on the 1969 environmentalist economist Boulding's studies, but also on Georgescu-Roegen's theory of thermodynamics of 1971. Connections may also be established with the general theory of systems that, through von Bertalanffy's works of 1950 and 1968, promote holism, complexity, systemic thinking, human resources development and organizational learning, all prerequisites of circular economy. Industrial ecology, promoting the transition from open cycles of materials and energy to closed ones, may be considered as another starting point of circular economy.

Geng et al. (2012) argue that circular economy may be approached on three levels. At micro level, it is based on eco-design and cleaner production promotion strategies. At the meso-level, the goal is the development of eco-industrial parks and networks, with positive effects both on regional economy and on the natural environment. At macro level, references are made to sustainable production and consumption oriented towards the creation of a recycling society. Many specialized studies use one of these approaches or combinations of them (Ghisellini, Cialani and Ulgiati, 2016).

In many cases, circular economy has been viewed only through one of its sub-sectors, being considered rather as an approach to *adequate waste management*, especially to those generated by consumers, also called *municipal waste*. This management involves their reconfiguration in resources for various industrial sectors. Ghisellini, Cialani and Ulgiati (2016) claim that this approach is limiting and may jeopardize the implementation of circular economy, since recycling is the least sustainable solution of the three Rs (Reduction, Reuse, Recycling), the pillars of circular economy in terms of resource efficiency and profitability. Other authors (Geissdoerfer et al., 2017; Moreau et al., 2017) criticize circular economy from another perspective: it only concerns economic and environmental aspects, but neglects the social side, which only indirectly benefits from the other two, and the institutional component, which may play a key role in establishing the rules for the transition to circular economy. Moreau et al. (2017) believe that the social

dimension has a major role because workforce should be the “heart” of economy due to its renewable nature. Lieder and Rashid (2016), in a review of literature on circular economy, group the papers depending on three topics: economic benefits, resource scarcity and environmental impact. Our paper attempts to combine these three topics.

The bioeconomy-specific paradigm has changed the perception of *economic growth*, (Meyer, 2017). The current trend suggests a reasonable economic growth model, able to generate social welfare and rising employment rates (inclusive economic growth) focused on: i) knowledge, investment in research, innovation and technological performance, according to the Neo-Schumpeterian vision (smart economic growth); ii) green energy, low carbon policies, diminishing collateral effects on ecological public goods – landscape, soil, water, climate, biodiversity, etc. – (sustainable economic growth).

## 2. Research methodology

This paper aims to analyze whether the performance of the research and innovation activities specific to the bio-economy sectors and the added value of the production and trade activities belonging to the circular economy are sufficiently representative to influence the economic growth in the EU28 countries.

Financial and human efforts to promote innovation in the bio-economy, when different levels of national fiscal burden exist, are determinants that can constrain or favor innovation performance. For this reason, a first objective of the research is to investigate these interdependencies by formulating and testing the hypothesis H<sub>1</sub>:

- *H<sub>1</sub>: Innovative performance in bioeconomy is significantly influenced by the resources allotted to research funding, by the researchers' efficiency, and by the degree of fiscal freedom of national economies.*

A second objective of the research is whether the extent of municipal waste recycling as an expression of integrated resource use, renewable energy production, export of recyclable raw materials, employment rate and greenhouse gas emissions create value in the EU28, according to the hypothesis H<sub>2</sub>:

- *H<sub>2</sub>: There is a strong connection between the added value derived from activities specific to circulation economy and the indicators that reflect the production and trade of recyclable materials, on the one hand, and the social and environmental dimension of the circular economy, on the other.*

The last objective of the research studies, for the EU28 countries, which are heterogeneous in terms of the innovation capacity in the bio-economy sectors, the correlation between the efficiency of the investment in research-development and the productivity of the employees, on the one hand and the economic growth, on the other hand, according to the hypothesis H<sub>3</sub>:

- *H<sub>3</sub>: The efficiency of investment in research and development and the use of workforce in bioeconomy have a significant impact on the economic growth of the EU-28 nations.*

## 2.1. Discussing variables and data sources

Table no. 1 provides a brief description of all dependent and independent variables used in our research.

**Table no. 1: Description of variables and data sources**

Variable	Description	Data source
<b>I. Dimensions of intellectual capital</b>		
Patents	Number of patent applications sent to the European Patent Office. It assesses the innovation performance of the various countries (number of patents per capita).	Eurostat database – Bioeconomy data catalogue
Total R & D expenditure (GERD)	Research and development expenditure in bioeconomy sectors (economic, governmental, academic, non-profit) (Euros per capita).	Eurostat database – Bioeconomy data catalogue
<b>II. Dimensions of circular economy</b>		
Trade in recyclable raw materials – imports (Imp)	Recyclable materials imported by EU countries. It characterizes trade within the EU and trade of the EU with the rest of the world (kg per capita).	Eurostat database – Circular economy indicators
Trade in recyclable raw materials – exports (Exp)	Recyclable materials exported by EU countries (kg per capita).	Eurostat database – Circular economy indicators
Employment in circular economy (Em)	Individuals employed in circular economy (% of the total number of employees). The indicator expresses the social component of circular economy.	Eurostat database – Circular economy indicators
Recycling rate of municipal waste (RoR)	The percentage of municipal waste (material recycling, composting and anaerobic digestion) of the total municipal waste produced (% of total waste).	Eurostat database – Circular economy indicators
<b>III. Dimensions of environmental performance</b>		
Greenhouse gas emissions (GhG)	Shows greenhouse gas emissions in all sectors according to the data reported by the European Environment Agency (kg per capita).	Eurostat database – Bioeconomy data catalogue
Share of energy from renewable sources (ShRE)	Assesses progress towards attaining the objectives of the EU's Sustainable Development Strategy (% of the final gross energy consumption).	Eurostat database – Bioeconomy data catalogue
<b>IV. Dimensions of economic development</b>		
Gross Domestic Product (GDP)	Economic growth per capita (current prices – Euros per capita).	Eurostat database
Value added (VA)	Gross income from operating activities adjusted for operating subsidies and indirect taxes (Euros per capita).	Eurostat database – Circular economy indicators
Productivity of research and development personnel (ProdRD)	Turnover per research and development employee (mil. Euros per no. of research and development employees).	Eurostat database – Bioeconomy data catalogue
Productivity of bioeconomy employees (Prod)	Turnover per bioeconomy employee (mil. Euros per number of bioeconomy employees)	Eurostat database – Bioeconomy data catalogue
Efficiency of the research and development investment (Eff)	Patents per GERD (number of patents/Euros per capita).	Eurostat database – Bioeconomy data catalogue
Fiscal Freedom (FF)	One of the 12 freedoms included in the Index of Economic Freedom that reflects the marginal taxation rates of individual and corporate income and the overall level of taxation as a percentage of GDP.	Heritage Foundation

Source: Authors' compilation

These variables are grouped into four categories that quantify the performance of intellectual capital, circular economy, as well as the environmental and economic performance of the EU-28 countries. The variables are analyzed on a sample including all EU-28 countries over two time intervals, depending on the availability of the data. Thus, patent-related indicators are reported up to 2013, while the reporting period for some circular economy indicators, such as added value, turnover and number of employees, starts in 2008 and ends in 2015. Therefore, the model using circular economy variables refers to an *eight-year* period (2008-2015) and takes into account *224 observations*, and those that include patents as a variable, to a *five-year* period (2008-2013) and considers *168 observations*. Except for the *Index of fiscal freedom*, taken from the Index of Economic Freedom found on the Heritage Foundation's website, the other indicators were retrieved / calculated from the Eurostat databases (in particular, circular economy and bioeconomy databases). The E-Views software package mediated data processing. Table no. 2 shows some descriptive statistics of each variable for the 28 countries included in the sample.

**Table no. 2: Descriptive statistics**

Variables	Mean	Standard Deviation
<b>Patents</b>	2.0000	5.0427
<b>GERD</b>	259.4305	3.2324
<b>Imp</b>	64.2126	5.9063
<b>Exp</b>	164.0547	2.1682
<b>Em</b>	0.0168	1.2230
<b>RoR</b>	0.2476	2.1053
<b>GhG</b>	7685.5710	1.7051
<b>ShRE</b>	0.1304	2.3177
<b>GDP</b>	20147.9675	5.0427
<b>VA</b>	259.1482	3.5616
<b>ProdRD</b>	0.5241	1.5062
<b>Prod</b>	0.0907	2.3832
<b>Eff</b>	0.0100	2.4273
<b>FF</b>	64.2390	1.2723

*Source:* Compiled by the authors based on research results provided by the E-Views software package

Technological knowledge held by companies, materialized in new and applicable technical solutions, is reflected in *patents*. From a legal point of view, a patent attests the inventor's exclusive right to commercially exploit their invention (practically a monopoly for the inventor) during their lifetime. As a physical document, the patent is the tangible materialization of the intangible asset (invention), which describes and defines the invention that is protected (Krauss and Kutteneuler, 2018). In a study conducted in 2016, the European Patent Convention and the Office for Intellectual Property in the EU point out the benefits of patents for the EU economy. To name only a few: patent exclusivity motivates technological progress, innovation and social welfare; patents contribute to the dissemination of new knowledge and the marketing of inventions; licensing patents makes it possible to attract venture capital as a result of invention exploitation in market areas where the holder him/herself is not commercially active (European Patent Office and European Union Intellectual Property Office, 2016; Krauss and Kutteneuler, 2018).



Exclusive invention rights through patents limit the risk of their reproduction and use by competing companies. The number of patents is a useful metric in assessing the success of the research-innovation activity. At EU-28 level, the analyzed period shows that the bioeconomy sector generates on average 2 patents per one million of inhabitants.

*Consumed financial resources (GERD)* support research and development expenditure, as research and development are considered a source of innovation. They are recorded when companies run projects to develop products, processes, etc. hoping to obtain income from the commercial exploitation of the results of such development. Research is conducted by research institutes and universities, which fund their research with grants awarded by their national governments and by various international bodies (e.g. the European Commission), or using the resources of non-governmental organizations or venture capital of private companies. As one may notice after analyzing the sample, the financing of research in the field of bioeconomy from the above mentioned sources, averages 259.43 Euro per capita.

The prospects for the dematerialization of economic systems are also reflected by the increasing use of recyclable and renewable materials and energy. Creating global networks through which these resources can move across the planet and reach as many world economies as possible allows for closing the loops and maximizing the use of recyclable and renewable materials. Therefore, our paper tackles indicators related to the *share of energy obtained from renewable resources in the total energy consumption (ShRE)*, *imports (Imp)* and *exports of recyclable raw materials (Exp)*. The first indicator shows a mean of 13.04% at EU-28 level, while the mean of imports, equal to 64.21 Kg per capita, is outpaced by the mean of exports of recyclable raw materials equal to 164.05 Kg per capita.

The environmental indicators refer to the *emission value (GhG)* of the main pollutants (CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, etc.), the decreasing levels of which reflect the better performance of circular economy. For the countries included in the sample, the average level of pollutant emissions is 7685.57 Kg per capita.

*The municipal waste recycling rate (RoR)* is an indicator of integrated resource use, the growth of which shows a reduction in the consumption of primary materials and a decrease in waste disposal to landfills (in favor of their recycling). Therefore, the EU aims to reach a municipal waste recycling rate of 50% by 2020. In the analyzed period, 2008-2015, a mean of 24.76% of the indicator was identified, which represents half of the target under the *Europe 2020* strategy.

Creating a more competitive economy with a higher *employment rate (Em)* by investing in research and innovation is one of the objectives of the Europe 2020 strategy adopted by the EU. *KBBE* offers investment opportunities generated by innovations, accelerates the change of technological paradigms (Pyka and Prettnner, 2018) and creates jobs. In reality, the analysis shows that the population employed in bioeconomy represents only 1.68% of the total number of employees at the EU-28 level, with significant variations between the states that recently joined the EU (Romania – 14.8%, Portugal – 7.4%, Croatia and Poland – 7.3%) and the founding members (Germany and France – 2.5%, the Netherlands – 2.4%, Belgium – 1.9%, Luxembourg – 1.7%).

Bioeconomy directly links innovation efficiency to *economic growth*. The mean of the GDP sample in the analyzed horizon is 20147.96 Euro per capita.

Circular economy involves the regrouping of production and processing activities with the purpose of reducing costs to the minimum and maximizing the *value added* (VA) resulting from reusable and recyclable material processing in a variety of products. The analysis conducted at EU-28 level revealed a mean value added of 259.14 Euros per capita.

When calculating the *labor productivity* (*ProdRd* and *Prod*) and *efficiency of investments in research and development* (*Eff*) variables, the bioeconomy *turnover* indicator is used, which expresses the market size in the EU bioeconomy strategy. For the analyzed horizon, the European *ProdRD* mean is 0.52 million Euros / number of employees in research and development, while the *Prod* mean is only 0.09 million Euros / number of employees in bioeconomy. As for *Eff*, one million Euros invested in research and development generates, on the average, 0.01 patents or a patent involves an average financial effort of one hundred million Euros.

The bioeconomic potential depends on the fiscal environment (tax incentives for investment). The *Index of Fiscal Freedom* (*FF*) reflects marginal tax rates on individual income and corporate profits, in connection with each country's overall tax levels (Mironiuc and Huian, 2017). Given that the sample includes heterogeneous countries in terms of fiscal burden, the *FF* mean is 64.23, which indicates a degree fiscal freedom above average.

## 2.2. Econometric specifications

In order to examine the association between the dependent variable and the independent variables, the *Ordinary Least Square* (*OLS*) regression is used. Model (1) is estimated in order to test the  $H_1$  hypothesis.

$$\text{Patents} = \alpha_0 + \alpha_1 \text{GERD} + \alpha_2 \text{FF} + \alpha_3 \text{ProdRD} + \varepsilon \quad (1)$$

where:

- Patents – number of patents per capita;
- GERD – research and development expenditure (Euros per capita);
- FF – index of fiscal freedom;
- ProdRD – productivity of research and development employees (mil. Euros per number of research and development employees);
- $\alpha$  – parameters of multifactor regression variables;
- $\varepsilon$  – residual variable.

All variables are naturally logarithmized to ensure normal data distribution (Jaba and Grama, 2004). This transformation does not change the relationship between variables. (Osborne, 2002).

Model (2) is used to test the second hypothesis  $H_2$ .

$$\text{VA} = \alpha_0 + \alpha_1 \text{Imp} + \alpha_2 \text{Exp} + \alpha_3 \text{Em} + \alpha_4 \text{RoR} + \alpha_5 \text{GhG} + \alpha_6 \text{ShRE} + \varepsilon \quad (2)$$

where:

- VA – value added (Euros per capita);
- Imp – trade in recyclable raw materials – imports (Kg per capita);
- Exp – trade in recyclable raw materials – exports (Kg per capita);
- Em – employees in circular economy (% of total employees);

RoR – municipal waste recycling rate (% of total waste);  
 GhG – greenhouse gas emissions (Kg per capita);  
 ShRE – share of energy from renewable sources (% of the final gross energy consumption);  
 $\alpha$  – parameters of multifactor regression variables;  
 $\varepsilon$  – residual variable.

The variables of the second model are naturally logarithmized.

Model (3) is estimated in order to test hypothesis  $H_3$ .

$$GDP = \alpha_0 + \alpha_1 \text{Eff} + \alpha_2 \text{Prod} + \varepsilon \quad (3)$$

where:

GDP – gross domestic product per capita;  
 Eff – efficiency of research and development investment (number of patents / GERD);  
 Prod – productivity of bioeconomy employees (mil. Euro per bioeconomy employee);  
 $\alpha$  – parameters of multifactor regression variables;  
 $\varepsilon$  – residual variable.

The variables of the third model are naturally logarithmized to ensure normal data distribution.

All models were tested for violation of the OLS regression assumptions. The tests were validated with the exception of the homoscedascity one. To solve this problem, we used a heteroscedasticity-consistent standard error estimator (HCSE), created by Hayes and Cay (2007), called the HC3 estimator, which does not suppose the existence of homoscedascity.

### 3. Findings and discussions

The findings shown in the tables hereunder derive from the application of the HC3 estimator which allows the existence of heteroscedasticity.

The findings of the first test based on model (1) are shown in table no. 3.

**Table no. 3: Regression results according to the HC3 estimator for model (1)**

Variables	Coefficient	Standard Deviation- (HC)	$p >  t $
Constant	-8.0294	2.0319	0.0001
GERD_ln	0.3332	0.1441	0.0220
FF_ln	0.9571	0.1812	0.0000
ProdRD_ln	-1.1267	0.3605	0.0021
$R^2$	0.7017		
F-statistic (p-value)	150.7979 (0.0000)		

Source: Compiled by the authors based on research results provided  
by the E-Views software package

Increasing the financing of multi-source research and development (GERD) activity in the field of bioeconomy positively influences the findings of research materialized in patents. Fiscal freedom proves to be a positive factor supporting innovation in bioeconomy, as proven by the positive (0.9571) and statistically significant ( $p$ -value 0.0000) connection between the analyzed variables. Contrary to expectations, increasing the productivity of

bioeconomy research and development employees does not determine the increase of the number of patents in the field. Negative dependence (-1.1267) is accounted for by the fact that much of the researchers' effort is materialized in other unpatentable elements of intellectual capital (copyright, know-how, software, working procedures, etc.). Hypothesis  $H_1$  is validated.

The findings of the second test based on model (2) are shown in table no. 4.

**Table no. 4: Regression results according to the HC3 estimator for model (2)**

Variables	Coefficient	Standard Deviation- (HC)	p> t
Constant	7.6749	1.7604	0.0000
Imp_ln	0.0639	0.0581	0.2731
Exp_ln	0.3757	0.0720	0.0000
Em_ln	0.8152	0.3249	0.0129
RoR_ln	0.3042	0.0839	0.0004
GhG_ln	-0.2902	0.1614	0.0736
ShRE_ln	-1.0021	0.1231	0.0000
R <sup>2</sup>	0.4324		
F-statistic (p-value)	21.0669 (0.0000)		

Source: Compiled by the authors based on research results provided by the E-Views software package

In terms of trade in recyclable raw materials, the only positive influence on value added is that of the export variable (*Exp*), imports (*Imp*) not representing a statistically significant factor (*p-value* 0.2731). The employment rate of the population in circular economy (*Em*) and the municipal waste recycling rate (*RoR*) have a positive effect on the newly created value in the field. There is an inverse relationship between the VA dependent and independent variables, the share of energy from renewable resources in the total gross energy consumption (*ShRE*), as *input* in the production of recyclable materials, suggesting its insufficient use in the production process, as evidenced by the mean of this indicator in our sample (13.04%). The indicator that measures greenhouse gas emissions (*GhG*) has a negative impact on value added but is statistically significant only at 10%, and is not an important determinant of it. The result obtained is explained by the fact that the value added in bioeconomy is based on renewable natural resources and not on fossil resources and petroleum-based materials to produce energy, goods and services. Due to the *Imp* and *GhG* variables, hypothesis  $H_2$  is partially confirmed.

The findings of the second test based on model (3) are shown in table no. 5.

**Table no. 5: Regression resultss according to the HC3 estimator for model (3)**

Variables	Coefficient	Standard Deviation- (HC)	p> t
Constanta	9.4689	0.6466	0.0000
Eff_ln	-0.1122	0.0373	0.0030
Prod_ln	0.6903	0.0392	0.0000
R <sup>2</sup>	0.7737		
F-statistic (p-value)	171.9188 (0.0000)		

Source: Compiled by the authors based on research results provided by the E-Views software package

The data in table no. 5 show that because the effect obtained (on average, a patent) based on a considerable financial effort (EUR 100 million) is insignificant (*Eff*), economic growth is not positively influenced. The EU-28 countries are heterogeneous in terms of innovation capacity in the bioeconomy sectors, quantified by the *research and development maturity index* (European Union, 2017). This is a composite index, determined by the existence of national research-innovation strategies in bioeconomy and of clusters of innovation, and by the intensity of the research-innovation activity. Countries like Denmark, Holland, Belgium, UK, Austria, Sweden, Finland are known to have a high degree of bioeconomy maturity. In spite of this, they also have modest *Eff* values (with a mean ranging between 0.60 and 2 patents per 100 million Euros invested). Countries with low-to-medium bioeconomic maturity levels, such as those in Central and Eastern Europe, have *Eff* values averaged between 0.17 and 0.40 patents per 100 million Euros invested. There is a positive and statistically significant link between economic growth in the EU-28 countries and the productivity of bioeconomy employees (*Prod*). Consequently, hypothesis H<sub>3</sub> is validated.

### **Conclusions**

The paper analyzed the link between intellectual capital in bioeconomy, for which the number of patents was used as *proxy*, the size of the resources allocated to research and development funding and the efficiency of research workers, in the context of the national fiscal framework of the EU-28 countries. The results confirm the positive influence of research and development funding and tax regimes characterized by low levels of tax rates on intellectual property rights embodied in patents. The negative relationship between the increase of the productivity of the bioeconomy research and development employees and the number of patents is accounted for by directing research efforts towards activities with unpatentable results, such as copyrights, know-how, software, working procedures, etc.

A responsible bioeconomy has to address the reduction of the dependence on non-renewable resources and the cascade use of renewable ones. These objectives are also the grounds of circular economy strategies. This assertion justifies the study of the dependence of value added created by circular economy on the production of and trade in recyclable materials, on the employment of population in circular economy and on the negative externalities reflected by greenhouse gas emissions. The value added is positively influenced by the export of recyclable raw materials, by the population employment rate in circular economy and by the municipal waste recycling rate. Insufficient use in the productive process of energy from renewable resources has a negative impact on value added.

Bioeconomy directly links innovation to economic growth, which is why we studied the association between economic growth, the efficiency of research and development investments and the productivity of bioeconomy employees. Although the EU-28 countries are heterogeneous in terms of bioeconomy innovation capacity, there are no notable differences between them as concerns the efficiency of research and development investment. In all the analyzed cases, we noted poor innovation results as compared to the level of funding allocated for this purpose, which is why economic growth does not react favorably. The productivity of bioeconomy employees positively influences economic growth in the EU-28 countries.

Our research contributes to the existing literature through an empirical study of the EU-28 countries on a timeframe of 5-8 years, using cross-section analysis of interconnections between data. Existent studies on bioeconomy refer to a lesser extent to quantitative empirical aspects and focus rather on: national strategy analysis *versus* European strategy in bioeconomy; investigating the contribution of bioeconomy to the economic and social development of a particular country; studying the relationship between innovation and bioeconomy; discussing specific concepts (biovalue, biocapital, etc.).

The limits of this research derive from the low volume and, in some cases, interrupted data presenting the achievements of the bioeconomy sectors of the circular economy, which greatly limits the choice of the variables that could be modeled and requires the reconsideration of the research ideas. The design and implementation of a harmonized and standardized system of reporting on achievements in the bioeconomy sectors at European level would make it easier to understand the contribution of bioeconomy to the smart, sustainable and inclusive development of the EU economy and implicitly to facilitate academic research. Such a reporting system would make local / regional authorities and companies more responsible and would determine them to make a real contribution to identifying sustainable bioeconomy growth and development means.

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