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Business – education collaboration in R&D investment: Analysis of development gaps and critical points using MAR-splines

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Abstract. The purpose of the article is to determine development gaps and critical points in the system of business – education collaboration in R&D investment using MAR-splines. The study attempts to confirm hypotheses about the impact of business – education collaboration in R&D investment on the sustainable development, and, in turn, the influence of chosen factors on the level of cooperation of business and education in R&D investment taking into account development gaps and critical points. These factors include the values of gross domestic expenditure on R&D spent by the business enterprise sector and by the higher education sector, and the level of the informal economy. The study is

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based on the sample of the 10 countries leading the ranking of Sustainable Development Index for 2011-2018 (time limits are set due to the availability of all studied indicators in the statistical databases of the World Bank, UNDESA, OECD and WIPO). Critical points and knots are determined using MAR-splines and two-way median-spline plots in STATA software. It has been proven that the business – education collaboration in R&D investment contributes to increasing the level of sustainable development if the value of this indicator is in the range of critical points from 62.04 to 68.96 (1% growth increases the estimate of sustainable development by 0.7%). In turn, development gaps and critical points have also been found for factors influencing the level of business-education R&D collaboration.

Keywords: business, coopetition, development gaps, education, R&D investment, sustainable development, splines.

JEL Classification: I23, M21, O32.

1. INTRODUCTION

Today, business – education collaboration in R&D investment is positioned as a necessity for achieving personal goals in business and higher education sectors on the one hand, and innovation, economic and social development, and sustainability in general, on the other hand.

The effectiveness of the strategy of sustainable development implies a relationship with public administration, in particular, in the field of education and business (Vorontsova et al., 2020). The cooperation of business and education is an important element of the concept of a research and entrepreneurial university, and accordingly, a prerequisite for improving the transfer of knowledge, technologies and innovations and their commercialization (Novikova et al., 2020). Knowledge bases, technological and human capital formed because of collaboration between business and education are the main resource for maintaining and increasing competitive advantages in today's dynamic environment (Vidic, 2022; Rigelsky et al., 2022). Quality of R&D activity and application of the lifelong learning approach by both education and business sectors are drivers of socio-economic development (Didenko et al., 2022; Şavga, 2022; Şavga & Livițchi, 2022). In the conditions of Industry 4.0, this issue takes on a new significance, taking into account the potential of the additive economy and innovative business to accelerate economic growth and reduce social risks (Melnyk et al., 2022).

At the same time there are many different external and internal factors – catalysts and inhibitors – that influence the business-education R&D collaboration. Macro stability, the level of shadow economy, state regulations in legal, financial, economic, social, educational, and international spheres and so on have a great influence on the capacities of effective business – education collaboration in R&D investment. A number of internal characteristics of business companies, indicators of competitiveness, obstacles to the modernization of technologies, especially in developing countries, play an important role too (Mallinguh et al., 2022).

The low quality of higher education is a significant inhibitor on the way to increase the effectiveness of collaboration between business and education (Liuta et al., 2021; Hryhorash et al., 2022). In return, the digitalization, building informational system, active applying ICT, artificial intelligence, etc. are significant stimulators (Chen et al., 2022; Volk et al., 2022; Skrynnyk et al., 2022; Antoniuk et al., 2022; Sadigov et al., 2022; Gladden et al., 2022; Sobczak, 2022; Košovská, 2022). ICT makes collaboration more easy, timely,

optimal, cheaper, and effective. Besides it, innovative modeling, digital business simulators and other breakthrough technologies can help to test projects in in conditions as close as possible to reality.

Human capital, effective personnel management, attraction, and stimulation of employees in the field of business to invest in their scientific potential and R&D investment is of no less importance (Bila et al., 2020; Ievdokymov et al, 2020; Oliinyk, 2020; Gad & Yousif, 2021; Melnyk, 2021; Girdauskiene, 2022; Khushk, 2022, Ngcobo & Mhlanga, 2022; Profiroiu et al., 2022; Rózsa et al., 2022; Skakane-Masango, 2023). Behavioural aspects of business – education collaboration in R&D investment impacts on its level too (Domokos & Baracskai, 2021; Isik, 2022; Saher et al., 2022; Oloveze et al., 2022; Paramasivan & Ravichandiran, 2022; Muchak & Magaiza, 2022). At that time some factors reduce the effectiveness of R&D activity during the war, other cataclysms, and challenges (Suchikova et al., 2023).

Considering the importance of the outlined issue, this study pays attention at the same time to the impact of business – education collaboration in R&D investment on the sustainable development, and, in turn, the influence of the following factors on the collaboration's level: the values of gross domestic expenditure on R&D performed by the business enterprise sector and by the higher education sector, and the level of the informal economy. In addition, the aspect of determining development gaps and critical points regarding these indicators in their relationship has not been investigated enough.

That is why the article's purpose is to determine development gaps and critical points in the system of business – education collaboration in R&D investment using MAR-splines.

2. LITERATURE REVIEW

2.1. Business – education collaboration

Nahla (2023) described university – company R&D collaboration based on Algeria evidence. The study empirically confirmed that the level of research partnerships between university and industrial institutions is low, despite the relevance of the issue and its wide discussion in scientific and governmental fields. Czako et al. (2021) highlighted the problem of finding and maintaining partnerships between universities and local business firms, identified common and distinctive features in the communication of partnership-oriented universities.

Høgevold et al. (2020) tested a model of collaboration, continuity, and coordination as mediators between economic and non-economic satisfaction, particularly in business-to-business relationships. Kosch & Szarucki (2020) analysed models and dynamics of scientific collaboration. Artyukhov et al. (2023) proposed a combined SPACE-RL model for evaluating the prospects of innovation transfer "science - production - business" according to external and internal influencing factors.

Kobylińska & Lavios (2020) analysed the concept of the university entrepreneurship ecosystem in the context of the results of research commercialization support, identified challenges in this area and proposed ways to solve them. Lekovic et al. (2020) analysed the impact of education and competencies of entrepreneurs to cooperate with other organizations as a chance for them to involve new technologies that contribute to the rapid and early commercialization of innovations.

Okuneviciute Neverauskiene & Pranskeviciute (2021) emphasized the influence of enterprises based on the model of social partnership and the creation of partner ecosystems on regional development, economic stability, and innovation. Malys (2023) and Alzate et al. (2022) studied cooperation for company's economic performance and sustainable development.

Bilan et al. (2020) examined the role of organizational learning on firm capabilities, corporate governance, leadership, and resilience. They used innovation culture as a moderating variable between organizational learning and firm stability. Świadek & Gorączkowska (2020) conducted a survey, which

showed that institutional support influences the establishment of innovation collaboration, and concluded that in economically weak territories, the focus should be on stimulating innovation activity, and in developed ones – to move to innovation cooperation.

Roszko-Wójtowicz et al. (2022) confirmed that business R&D expenditures have a positive effect on inventions expressed by patents and trademarks, especially in the long term. In addition, the main determinants of innovativeness are not only R&D investment and the expenditures of business entities on R&D, but competencies expressed by the level of education or participation in higher education, as well as the number of specialists with ICT and the percentage of people employed in science and technology.

2.2. R&D investment

Kuzior et al. (2022) investigated R&D investment in determinants of financial inclusion for sustainable development. Hamdan A., & Hamdan, R. (2020) explained the interconnection of economic growth and investment in higher education based on evidence from Saudi Arabia. Triyonowati et al. (2023) studied the influence of innovation investment and its efficiency, which is considered as the optimal combination of innovative contribution and innovative result. Wang et al. (2022) paid attention on technological and innovation efficiency in China.

Yu (2023) presented results of research on public R&D investment in Chinese higher education including factor analysis. Yu et al (2023) explore the relationship between human capital, R&D investment, and investment in education on the example of China. Shin & Lee (2022a) analysed the impact of competition on R&D investment and changes of this impact depending on corporate management. Shin & Lee (2022b) established a positive relationship between related party transactions and R&D investment using the evidence of Korean business.

Hasan (2022) determined the impact of R&D investment and spending on education on unemployment rates. Possibilities, challenges, and advantages of R&D investment based on creation of investment lab was deeply described by Kaya et al. (2023). Suroso et al. (2020) estimated entrepreneur incubation program and research at higher education.

Kurmanov et al. (2022) studied the influence of various factors on the organization and development of R&D and innovation activities at medium and high-tech enterprises (on the example of the manufacturing industry of Kazakhstan), including the investment environment, innovation development, scientific potential, etc. Dou et al. (2022) analysed the impact of monetary policy on industrial R&D investment based on a selection of business companies divided into labour-intensive, capital-intensive and technology-intensive, etc.

2.3. Development gaps and critical points using MAR-splines

Dalampira et al. (2022) studied methodological gaps in technology transfer, in particular, gaps between science and practice in the context of innovation transfer in agriculture, lack of methodological tools capable of spreading innovations among farmers and other stakeholders, using hybrid Farmers Field School strategy.

Fang et al. (2022) investigated the impact of the pay gaps on corporate R&D and innovation and found that the pay gap can significantly contribute to both the input and output of innovation.

Pokrivčák & Tóth (2022) analysed the issue of financial gaps based on survey results and focus group meetings, arguing that small businesses have the largest financial gap (77.4% of total financial deficit). This requires further investment in R&D and new technologies.

Saâdaoui & Khalfi (2022) used the multivariate adaptive regression splines (MARS) method to evaluate the performance of Islamic banks in developed and developing countries because this method is effective for such flexible modelling of multivariate data. Gackowski et al. (2022) used the approach of identifying

development gaps and critical points using multivariate adaptive regression splines (MARSplines) in the medical field for quantitative studies of relationships, etc.

As a result of literature review it should be noted that development gaps and critical points regarding business – education collaboration in R&D investment, its impact on the sustainable development, and, in turn, the influence of chosen for research factors on the collaboration's level (the values of gross domestic expenditure on R&D performed by the business enterprise sector and by the higher education sector, and the level of the informal economy) have not been investigated enough, especially using splines construction method.

3. METHODOLOGY

The information base of the study is the statistical data of the World Bank, the statistics department of the Department of Economic and Social Affairs of the United Nations Organization (UNDESA), the Organization for Economic Cooperation and Development (OECD) and the World Intellectual Property Organization (WIPO), formed for the sample of countries of this study, which made up by the 10 leading countries in the ranking of sustainable development for 2021 (UNDESA, 2021), namely: Finland, Denmark, Sweden, Norway, Austria, Germany, France, Switzerland, Ireland and Estonia) for 2011-2018 (time limits are due to the availability of all studied indicators in the used statistical databases).

The studied indicators include the following:

– the level of business – education collaboration in Research & Development (R&D) investment. It is evaluated according to the University-industry R&D collaboration Indicator, which is determined within the Global Innovation Index (WIPO, n.d.; World bank, n.d.b);

– the level of sustainable development. It is evaluated according to the overall score of the Sustainable Development Index (UNDESA, 2021, n.d.);

– the level of the informal (shadow) economy. It is estimated on the basis of dynamic general equilibrium model of informal output, % of official GDP (Elgin et al., 2021: World bank, n.d.a);

– gross domestic expenditure on R&D (GERD) performed by the business enterprise sector (OECD, n.d.a);

– gross domestic expenditure on R&D performed by the higher education sector (OECD, n.d.b).

The research puts forward the following hypotheses:

Hypothesis 1: the increase of business-education collaboration in R&D investments has a positive effect on the level of sustainable development.

Hypothesis 2: the growth of GERD performed by business sector leads to strengthening business-education collaboration in R&D investments.

Hypothesis 2: the growth of GERD performed by higher education contributes to increasing business-education collaboration in R&D investments.

Hypothesis 2: the expanse of informal economy has a negative effect on business-education collaboration in R&D investments.

But in addition to actual confirmation or refutation of the above hypotheses, development gaps, and critical points under which this influence is potentially possible are defined.

Critical points and breaking points (knots) are determined using the spline construction method – MAR-splines in STATA software, in particular, linear and cubic spline construction tool (STATA, n.d.a). Accordingly, the following commands were used to construct linear MAR-splines: Menu Data – Create or change data – Other variable-creation commands – Linear and cubic spline construction.

Linear splines make it possible to estimate the relationship between the resulting variable (y) and the factor variable (x) as a "piecewise linear function" consisting of linear segments - straight lines. One line

segment represents the function for values of x below x0, another line segment handles values between x0 and x1, and so on, and they are arranged to connect at the points x0, x1, . . . , which are called knots. That is, the MAR-splines method allows you to create variables containing a linear spline: newvar1, . . . , newvark, which in turn includes the linear spline oldvar with nodes at the specified #1, . . . , #k−1. The location and distance between nodes (critical points / discontinuities) is determined by the specification of the nknots() and knots() parameters (STATA, n.d.a; Gould, 1993; de Boor, 2001; Newson, 2012).

For the visualization of MAR-splines and graphical presentation of development gaps, the toolkit for constructing two-way median-spline plots was used. In the corresponding software, the Graphics – Twoway graph (scatter, line, etc.) command menu is responsible for implementing this tool (STATA, n.d.b).

4. EMPIRICAL RESULTS AND DISCUSSION

Figure 1 depicts a two-way median-spline plot to assess existing development gaps and critical points in the level of business – education collaboration in R&D investment (UI-R&D – factor variable) to ensure a sufficient level of sustainable development (SDG – result variable).

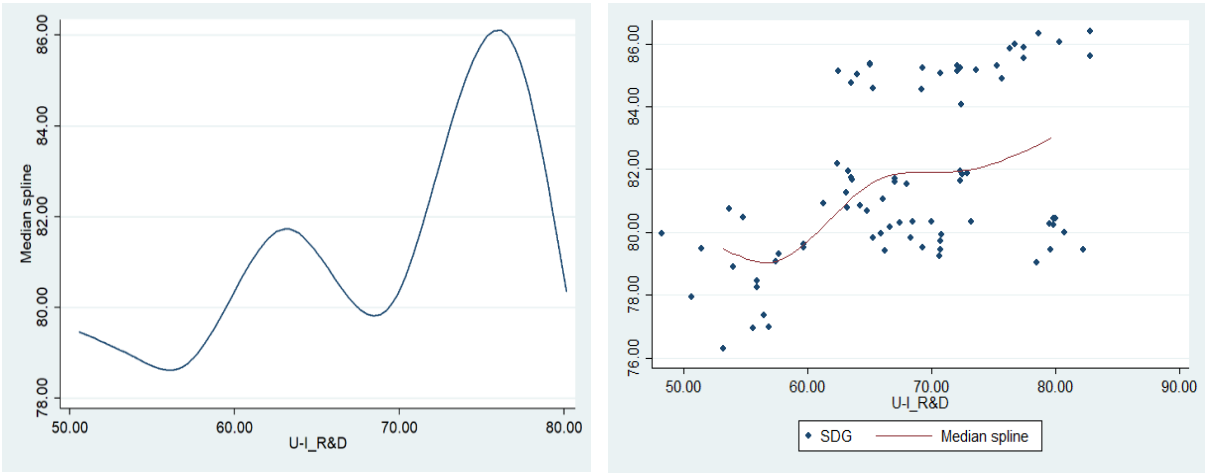

Figure 1. Two-way median-spline plot to assess existing development gaps in the level of business – education R&D collaboration for sustainable development (left – line, right – scatter)

Source: built by the authors

So, there is a significant development gap in many countries of the sample, and the evaluations of the studied indicators cover 5 knots / critical points, which will be further quantified.

Figure 2 shows a two-way median-spline plot to assess the existing development gaps and critical points in the level of total R&D expenditure represented by the business sector (GERD_Bus – the factor variable) for business – education collaboration in R&D investment (UI_R&D – the outcome function).

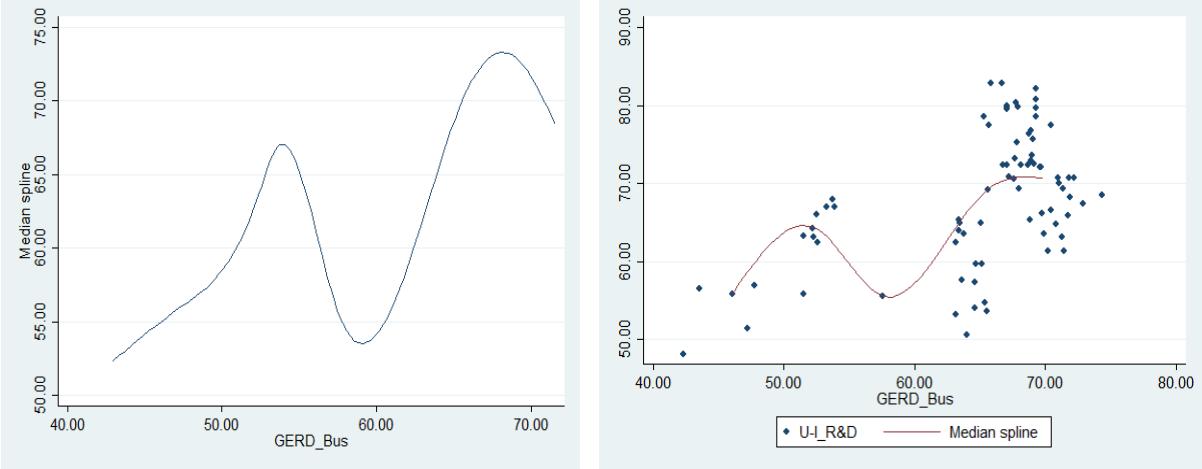

Figure 2. Two-way median-spline plot to assess existing development gaps in the level of total R&D expenditure represented by the business sector for business – education R&D collaboration (left – line, right – scatter)

Source: built by the authors

Similarly, during the construction, 5 knots / critical points were foreseen, which will be further quantified.

The existing developments gaps and critical points in the level of total R&D investment represented by the education sector (GERD_Edu – the factor variable) for business – education collaboration in R&D investment (UI_R&D – the result function) are showed by a two-way median-spline plot in Figure 3.

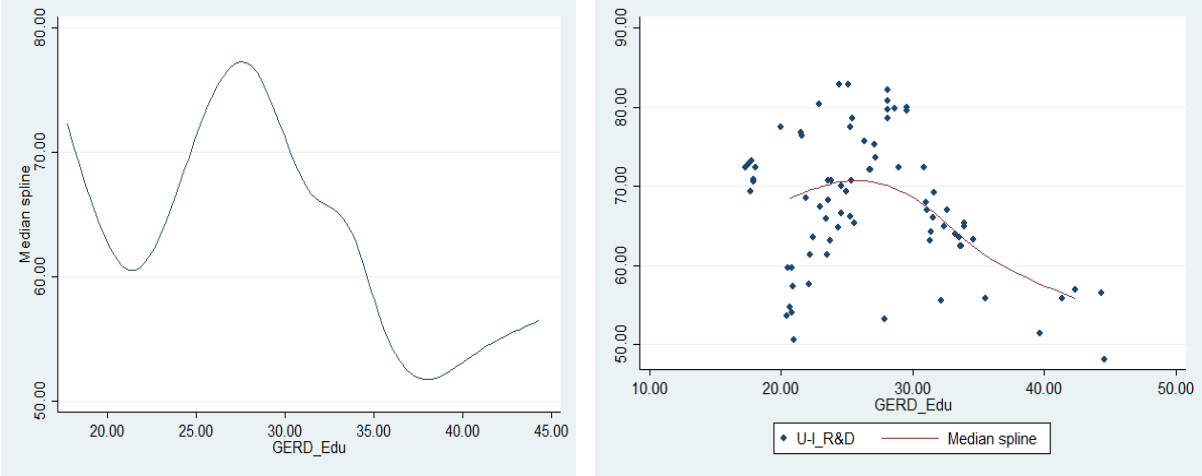

Figure 3. Two-way median-spline plot to assess existing development gaps in the level of total R&D expenditure represented by the higher education for business – education R&D collaboration (left – line, right – scatter)

Source: built by the authors

And in turn, Figure 4 describes a two-way median-spline graph for assessing the development gaps and critical points in the level of shadowing economy (DGE – dynamic general equilibrium model-based estimates, factor variable) to ensure coopetition of business and education in R&D investment (UI-R&D – resulting function).

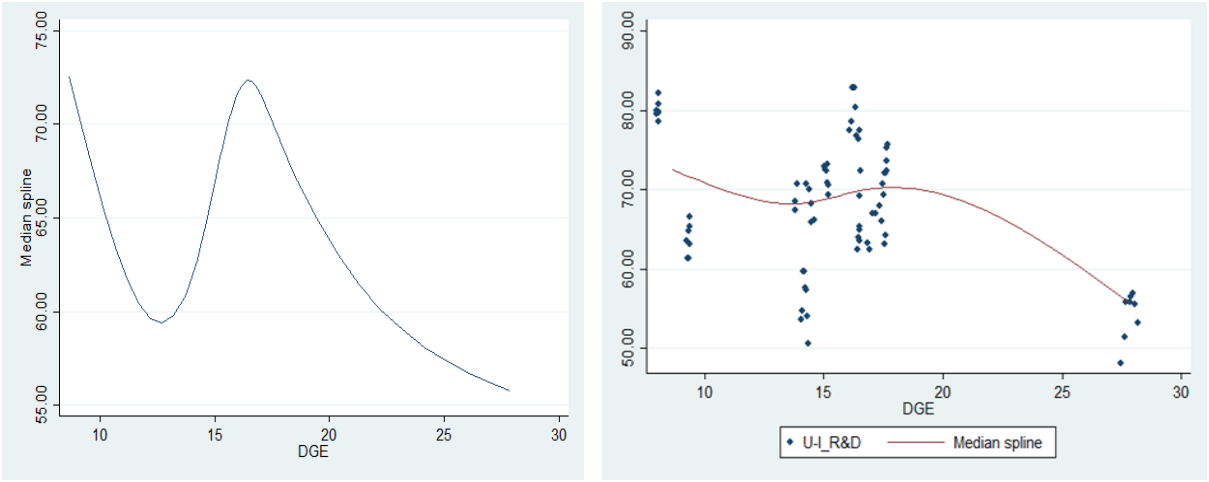

Figure 4. Two-way median-spline plot to assess development gaps in the level of shadowing economy to ensure business – education R&D collaboration (left – line, right – scatter)

Source: built by the authors

Critical points and breaking points (knots) are determined using the spline construction method – MAR-splines in STATA software, in particular, linear and cubic spline construction tool (STATA, n.d.a). Table 1 shows the generalized results of determining the knots / values of critical points of splines for each studied indicator, for which, in turn, five new variables were created (k=5), the number of knots is four (k–1), as mentioned above according to the spline modelling methodology.

Table 1

Results of determination of breaking points based on MAR-splines

Indicator	Knot1	Knot2	Knot3	Knot4
SDG	78.32445	80.34556	82.36666	84.38777
UI_RD	55.12	62.04	68.96	75.88
GERD_Bus	48.74138	55.13509	61.5288	67.92252
GERD_Edu	22.73466	28.18627	33.63787	39.08947
DGE	12.01023	16.05361	20.09699	24.14037

Note: SDG – indicator of sustainable development; UI_RD – indicator of business – education collaboration in R&D investment; GERD_Bus – gross domestic expenditure on R&D performed by the Business Enterprise sector; GERD_Edu – gross domestic expenditure on R&D performed by the Higher Education sector; DGE – indicator of informal (shadow) economy.

Source: authors' calculations

Next, a linear regression model was built for each pair of the resulting – factor variable, taking into account the influence of five newly created variables corresponding to the critical points of development gaps / knots of splines. All models are statistically significant and adequate, which is confirmed by the obtained significance indicators Prob > F (in all cases 0.0000) and the value of the coefficients of determination (R-squared) (0.3803, 0.5471, 0.4381, 0.5978, respectively). After that, the obtained coefficients of the models were checked for statistical significance according to the estimates of the p-significance of the t-statistics (P>|t|) and those that did not exceed 0.05 were selected (acceptance of the hypothesis is 95% reliable). On the basis of this, critical points were determined regarding the values of the investigated indicators.

Table 2 presents the generalized results of modelling and assessment of development gaps and determination of critical points.

Table 2

Matrix of generalized results of regression modelling and assessment of existing developed gaps and determination of critical points using MAR-splines

Indicator: result / factor	Break point 1 / regression coefficient value	Break point 2 / regression coefficient value	Break point 3 / regression coefficient value	Break point 4 / regression coefficient value
SDG	55.12	62.04	68.96	75.88
UI_RD1				
UI_RD2		.6996585		
UI_RD3				
UI_RD4				.518114*
UI_RD5				
UI_RD	48.74138	55.13509	61.5288	67.92252
GERD_Bus1				
GERD_Bus2				
GERD_Bus3				
GERD_Bus4				3.889587
GERD_Bus5				
UI_RD	22.73466	28.18627	33.63787	39.08947
GERD_Edu1				
GERD_Edu2		2.474906		
GERD_Edu3				
GERD_Edu4				
GERD_Edu5				
UI_RD	12.01023	16.05361	20.09699	24.14037
DGE1	-7.831378			
DGE2				
DGE3			-4.510145*	
DGE4				
DGE5				

Note: SDG – indicator of sustainable development; UI_RD – indicator of business – education collaboration in R&D investment; GERD_Bus – gross domestic expenditure on R&D performed by the Business Enterprise sector; GERD_Edu – gross domestic expenditure on R&D performed by the Higher Education sector; DGE – indicator of informal (shadow) economy.
Source: authors' calculations

Thus, the business – education collaboration in R&D investment (in particular, level of the University-industry R&D collaboration Indicator within the Global Innovation Index) contributes to increasing the level of sustainable development (especially, the overall score of the Sustainable Development Index) in case of the value of the indicator of business – education collaboration in R&D investment is in the range of critical points from 62.04 to 68.96 (with its growth by 1%, the estimate of the Sustainable Development Index will increase by 0.7% on average). At the same time, in the range from 62.04 to 75.88 there is also a positive effect, however, when passing through the point of the fourth development gap / knot, the value of this potentially possible growth decreases from 0.7% to 0.5%, which requires additional research on the simultaneous influence of other factors and other resulting effects. That is, in general, a value of at least 62.04 can be considered a critical point.

In turn, development gaps and critical points were also found for factors influencing the direct level of cooperation of business and education in R&D investment.

Thus, a 1% increase in the level of general expenditures on scientific research and development represented by the business sector has a positive effect on the level of cooperation of business and education in R&D investment, leading to its increase by an average of 3.89%, if the value of the indicator of total expenditures on scientific research and development represented by the business sector is no less than the critical mark of 67.92.

A 1% increase in the level of gross domestic expenditures on R&D represented by the higher education sector also has a positive effect on the level of coopetition between business and education in R&D investment, leading to an average increase of 2.47%, if the value of the indicator of gross domestic expenditures on R&D presented by the higher education sector belongs to the range of critical points from 28.19 to 33.64.

The level of shadowing economy (according to the level of the informal (shadow) economy estimated on the basis of dynamic general equilibrium model of informal output, % of official GDP) has an inverse effect on the level of business – education collaboration in R&D investment. And accordingly, the "detinization" of the economy has a positive effect on stimulating the cooperation of business and education. In particular, a decrease in the level of shadowing economy by 1% will lead to an increase in the level of business – education collaboration in R&D investment by an average of 7.83% in case of the score of the level of shadowing economy is less than the indicator of the critical point 12.01. In the range from 12.01 to 20.09, there is also a reverse reaction between these processes, however, when moving to the third development gap, the magnitude of the detected impact will decrease from 7.83% to 4.5%.

5. CONCLUSION

This research was aimed to determine development gaps and critical points in business – education collaboration in R&D investment using MAR-splines. The hypotheses about the impact of business – education collaboration in R&D investment on the sustainable development, and, in turn, the influence of investigated factors on the level of coopetition of business and education in R&D were confirmed paying attention on knots and critical points. A linear regression model was built for each pair of the resulting – factor variable, and statistical significance and adequacy was proved for all models. Matrix of generalized results of regression modelling and assessment of existing developed gaps and determination of critical points using MAR-splines was presented. Obtained results showed that business – education collaboration in R&D investment contributes to increasing the level of sustainable development in case of its value is in the range of critical points from 62.04 to 68.96 (with its growth by 1%, the estimate of sustainable development will increase by 0.7%). In turn, a 1% increase of GERD performed by business has a positive effect on business – education collaboration in R&D investment, leading to its increase by an average of 3.89% if its value is no less than the critical mark of 67.92. A 1% increase of GERD represented by the higher education also has a positive effect, leading to an average increase of 2.47%, if its value belongs to the range of critical points from 28.19 to 33.64. A decrease the shadowing economy by 1% will lead to an increase in business – education R&D collaboration by 7.83% in case of its score is less than critical point 12.01. However, the results of the study contain certain limitations related to the sample of countries, which should be expanded in further studies.

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