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Impact of university-industry R&D collaboration on innovation transfer and startup performance

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Abstract. Effective partnership of education and business is a catalyst for innovation transfer, startup ecosystem development and sustainable economic growth. The research aims to identify the impact of university-industry R&D collaboration on startups performance, taking into account existing knots and gap intervals. The study sample was formed for 100 world countries, represented in the Global Startup Ecosystem Index rating. The formed base includes data of the University-industry R&D collaboration indicator within the Global Innovation Index 2023 by WIPO and data of the Global Startup Ecosystem Index 2023 by StartupBlink. In the first stage, the procedures for checking the significance of investigated indicators were applied, including descriptive statistics, checking the distribution

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law and regression analysis. The second stage covers the construction of median-spline plots, scatter plots and spline modelling using the STATA 18 program complex. The range of values of the University-industry R&D collaboration index was determined on the condition of reaching which the maximum statistically significant value of the indicator of startup productivity is predicted. The obtained results confirm the importance of an entrepreneurial university concept for innovation transfer and their commercialization and provide a view of the targeted value of the University-industry R&D collaboration on average at the world level.

Keywords: business, education, entrepreneurial university, entrepreneurship, partnership, R&D cooperation, R&D investment.

JEL Classification: I23, O32

1. INTRODUCTION

In today's conditions of an unstable macro-environment and, at the same time, rapid digital development, the issue of the development of startup ecosystems, as well as innovation development in general, is gaining more and more importance. Global and local challenges (pandemics, wars, natural disasters, crises, etc.) condition the search for the latest solutions both in the public sector, the business environment, and the higher education sector, and civil society in response to the emerging demands of consumers of goods and services and changes in consumer behaviour. Stimulating innovations for the sake of economic growth and sustainable development is a trend that does not lose its relevance and significance, even in the face of complex challenges. Therefore, it is important to understand which factors are really the catalysts of innovation development and what impact they could provide.

The dissemination and effective implementation of the criteria of sustainable economic development into everyday life requires not only a large-scale transformation of classical structures but also a rethinking of the old economic paradigm for the promotion of innovative business models and sustainable entrepreneurship (Andrei et al., 2023; Melnyk et al., 2023). Partnership is one of the crucial Sustainable Development Goals despite the last serial number in their list. The number of stakeholders is quite wide, and there is a need for a deeper understanding of the factors underlying trust-based open innovation collaboration, flexible coopetition, and the perception of open innovation as a win-win game (Runiewicz-Wardyn & Winogradska, 2023; Avlogiaris et al., 2023; Tomášková & Kaňovská, 2022).

Partnership between education and business is not an exception. Precisely effective university-industry R&D collaboration could be a great catalyst for innovation transfer, sustainable economic growth, and competitive advantages at the global level. It is designed to increase the success of the entrepreneurial university, the commercialization of innovations, the introduction of startups and the improvement of the productivity of startup ecosystems in general.

At the same time, the issue of empirical, statistical, and mathematical substantiated confirmation of the importance of an entrepreneurial university concept for innovation transfer and their commercialization is still relevant. So, identifying the impact of business and education coopetition on startups performance based on spline modelling is an actual research problem.

The purpose of the article is to identify the impact of university-industry R&D collaboration on startups performance, taking into account existing knots and gap intervals.

2. LITERATURE REVIEW

The development of innovation entrepreneurship both in the small and medium business sector and in the educational environment is a topical subject of scientific publications. The field of entrepreneurship contributes to innovation and economic development, job creation, accumulation of financial resources, development of various management and organizational solutions for society (Hossain et al., 2023).

The issue of innovation potential of national economy including analysis of different factors, consequences, parameters, strategic vectors and road maps; integral assessment and modelling national cases, platforms development, etc. was investigated by Vasylieva & Kasyanenko (2013), Stoliarchuk et al. (2022), Pozovna et al. (2023), Roszko-Wójtowicz et al. (2022), Slávik et al. (2022), Shkarupa et al. (2022), and Springs, D. (2024). In today's global and competitive world, universities as companies are forced to invest in innovation technologies for economically successful development (Polishchuk et al., 2019; Novotna &Volek, 2023). But some authors put attention to the inadequacy of financial support in the field of education, in connection with which the productive co-operation of business and education, the development of an entrepreneurial university, the commercialization of innovations and the introduction of startups, can become one of the ways to improve this situation (Yu et al., 2024a, 2024b).

However, start-up development is closely interconnected with volume of investments, alternative financing sources, venture funds too (Kaya et al., 2023, Tanaya & Suyanto, 2024; Tarek & Albaqami, 2024; Benlefki et al., 2024; Bigos, 2024; Hedegaard et al., 2024). Nevertheless, Kartanaitė et al. (2021), Kuzior et al. (2022a) and Dobrovolska et al. (2023b) empirically confirmed that financial and investment indicators have a positive quantitative impact on the level of innovation development. And the transition to an innovative economy changes attention to the creation of favourable conditions for the commercialization of scientists' developments and the possibility of realizing the accumulated scientific potential (Sitenko et al., 2024; Slavik & Zagorsek, 2023).

Another direction of improving cooperation between business and science, as well as the development of startup ecosystems, is human resources (Baidybekova et al., 2023; Kuzior et al., 2022b; Potjanajaruwit, 2023). So, individual entrepreneurial interest and skills should be developed started with student's study (Kaouache et al., 2024; Ledi et al., 2022). Startups also face technological, regulatory and market risks (Dobrovolska et al., 2024). During commercialization, companies face problems of political, economic, social instability, the lack of an established practice of marketing research to understand the needs of the market, etc. (Khomenko & Saher, 2022). Lulaj (2023) analysed management issues of innovation relationship with customers, service technology and model of multidimensional scaling based on a questionnaire (online) of 200 enterprises and consumers and meetings with enterprise managers with further processing of the results using tests and econometric analysis.

Andrei et al. (2021a; 2021b), Vasanicova et al. (2022) and Jonek-Kowalska (2023) prove the role of European Union countries experience in this research context, ground a close connection between the implementation of modern European socio-economic models and the effectiveness of entrepreneurship, taking into account innovation development and demographic characteristics of business. At the same time Popescu et al. (2023) is sure that in the short term, EU regions tend to behave as competitors for investment in innovation, but in the long term, innovation can cause spillover effects for neighbouring regions.

Melnyk et al. (2022) describes sustainable development strategies in conditions of Industry 4.0. Lewandowska et al. (2023) also analysed innovation development of SMEs during Industry 4.0 and Industry 5.0. Song (2023) put special attention on business intelligence and big data possibilities as trends of Industry 5.0 to increase business performance.

Ogunleye et al. (2023) and Katernyak et al. (2023) studied the impact of virtual technologies, especially virtual learning for business education. No less attention is attracted by the possibilities of virtual reality and artificial intelligence (Prieto-Gutierrez et al., 2023, Folgado-Fernández et al., 2023; Kuzior et al., 2023; Orlandić et al., 2024). So, modern business needs to received innovation skills in different spheres are possible to be realized through the coopetition with higher education for achievement of readiness for digital and other transformations in business (Al-Omoush et al., 2023; Ponomarenko et al., 2024). Vorontsova et al. (2021) determined education expenditures as a factor in bridging the digital gap.

Artyukhov et al. (2023) proposed SPACE-RL innovation transfer model "Science – Business" aimed to development of 'business-education' coopetition, innovation transfer and innovation commercialisation, covering different factors. Today universities are real innovation clusters due to European Experience (Borodiyenko et al., 2023). Knowledge at different stages of creation, diffusion, etc. and technology transfer within higher education are presented as important factor by Dobrovolska et al. (2023a) and Janasz et al. (2024).

The development of an effective entrepreneurial ecosystem also aimed at creating favourable circumstances for the successful implementation of startups, including those that play an intermediary role between the business, education and science (Yassin et al., 2024; Duong, 2023). Liu & Cai (2023) identified an effect of business R&D innovation from the view of uncertain environment. Arsawan et al. (2023) singles out cooperation, opportunities and innovation in the SME sector as a special trigger too.

During and after the COVID-19 pandemic administrative and scientific cooperation was statistically connected with the involvement of women in small and medium-sized entrepreneurship (Hossain et al., 2023). New challenges in business and education collaboration are connected not only with post-pandemic and post-crisis period, but also with war. Polishchuk et al. (2024) emphasizes the importance and necessity to run a business during wartime using a case of Ukrainian relocated business.

Besides it, science initiatives are determined as a great factor during the wartime (Polishchuk et al., 2023). In such conditions educational resilience and education quality are investigated by Artyukhov et al. (2024) and Didenko et al. (2022), who studied how education adapt, sustain, and recover in challenging environments.

The role of formal education in promoting entrepreneurship on the example of Ghana was considered by Osman et al. (2023), conducting a structured questionnaire survey among 140 entrepreneurs and a correlational analysis to study the relationship between formal education and entrepreneurial activity.

Despite the significant number of existing scientific publications on the outlined issue, the application of spline modelling in the context of detecting the influence of university-industry R&D collaboration on startups performance is not sufficiently investigated, it needs further scientific development, which justifies the relevance of this research.

3. METHODOLOGICAL APPROACH

The study sample was formed for 100 world countries, represented in Global Startup Ecosystem Index rating (StartupBlink, 2023). The formed base includes the data of the University-Industry R&D Collaboration Indicator within Global Innovation Index 2023 by WIPO (Dutta et al., 2023), and the data of Global Startup Ecosystem Index 2023 by StartupBlink (StartupBlink, 2023).

At the same time, certain countries were excluded before starting the research because of the following reasons: Russia – due to the authors' convictions; Belarus – unavailable data for the University-Industry R&D Collaboration Indicator; Andorra, Cape Verde, Liechtenstein, and Somalia are not represented in the Global Innovation Index in general, and Taiwan is not evaluated separately from China (as a province of China) in the Global Innovation Index.

Therefore, in fact, the results of the study are based on the above data for 93 countries of the world.

At the first stage, to identify the impact of university-industry R&D collaboration on startups performance, the procedures for checking the significance of investigated indicators were applied, including descriptive statistics (Scott & Rogers, 2015; STATA, n.d.b), checking the distribution law (Shapiro & Wilk, 1965), and the confirmation of dependence existence between these indices (regression analysis).

The second stage covers spline modelling using STATA 18 program complex, especially 'mkspline' – the instrument for linear and restricted cubic spline construction (STATA, n.d.a), including also construction of median-spline plots: line and scatter plots (twoway median-spline plots – 'graph twoway mspline') (STATA, n.d.c).

Thanks to the 'mkspline' tool, new variables could be created as the following ones: 1) new variables 'newvar $_1$', … , newvar $_k$' containing the linear spline 'oldvar' with knots at the specified interval '1, …, k-1'; 2) variables 'stubname$_1$', … , 'stubname#' containing a linear 'oldvar' spline on which the knots are equally spaced in the 'oldvar' range or 'oldvar' percentiles; 3) variables containing the bounded cubic spline 'oldvar', the so-called natural spline, on which the location and distance between the knots are determined by the specification of the 'nknots()' and 'knots()' parameters. Option 'displayknots' allow to show the values of the knots. The 'pctile' tool identifies the knots to divide the data into five equal sample size groups (but not into five bands of equal width), placing the knots at the 20th, 40th, 60th, and 80th percentiles of the data (STATA, n.d.a).

A constrained cubic spline may be a better choice than a linear spline when dealing with a highly curved function. Using a restricted cubic spline yields a continuous smooth function that is linear before the first knot, a piecewise cubic polynomial between adjacent knots, and linear again after the last knot (Gould, 1993; Harrell, 2001).

The 'twoway mspline' tool is based on the calculation of transverse medians, which are further used as knots of the corresponding cubic spline. The resulting spline is displayed as a line. To visualize the obtained results, the graph of the median spline can be superimposed on the scatter diagram of the observed data using the 'twoway scatter mspline' tool. Such splines provide a convenient way to show the relationship between the factor and outcome variables under study (STATA, n.d.c).

So, spline modelling is applied to identify the range of values of the University-industry R&D collaboration index for prediction of achieving the maximum statistically significant value of the startup productivity index.

4. CONDUCTING RESEARCH AND RESULTS

4.1. Cross-country analysis of the current state

StartupBlink's Global Startup Ecosystem Index (GSEI) ranks startup ecosystems in 1,000 cities and 100 countries. GSEI is built using hundreds of thousands of data points, processed by an algorithm that takes into account several dozen sets of parameters: quantities (number of startups, investors, co-working spaces, accelerators, etc.); quality (investment in private sector startups, employees of the startup sector, number and size of unicorns and exits over 1 billion USD, traction of startups in each ecosystem, presence of strategic branches and research centres of international technologies of the corporation, research centres of multinational companies, number and size of global startup events and conferences, presence and influence of Pantheon members, presence and influence of Global Startup Influencers, etc.), and business environment (diversity index, Internet speed, Internet cost, Investment in R&D, availability of various technology services , ease of labour laws for startups, corruption perception index, best universities by location, etc.) (StartupBlink, 2023). The overall score is used not only for ranking ecosystems and showing the gaps between countries, but also allow to find out insights into why there is such a difference.

Figure 1 presents the results of comparative analysis of top 20 countries in GSEI 2023 (overall score).

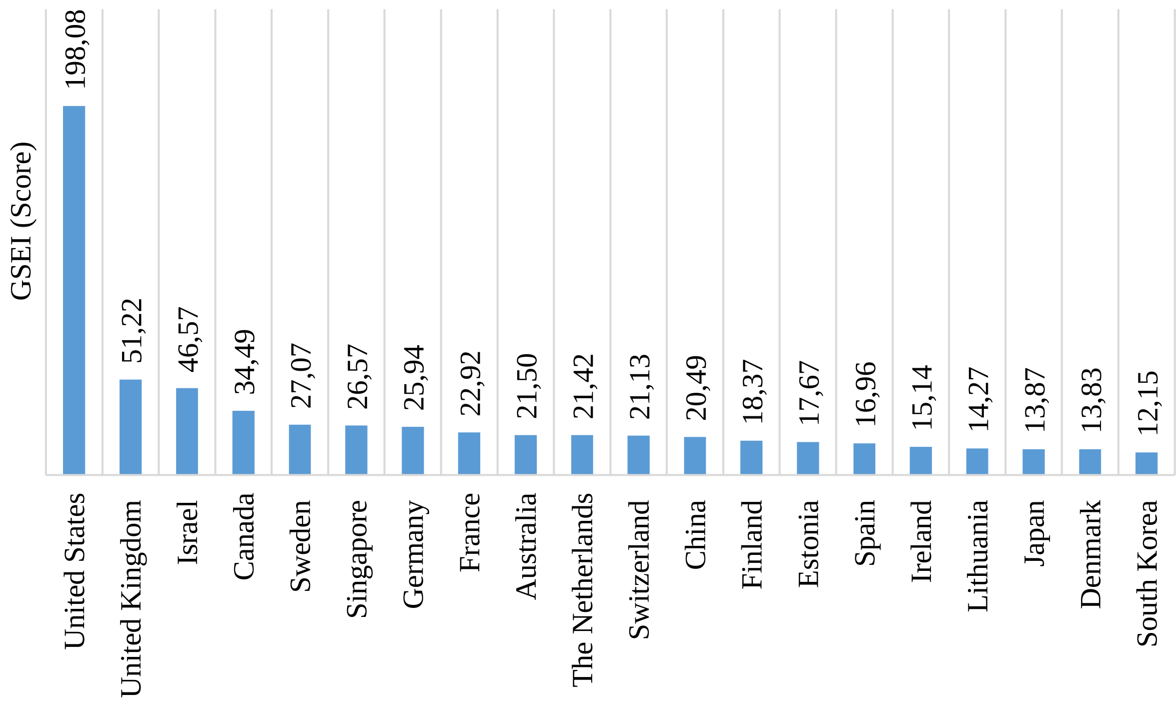

Figure 1. Results of comparative analysis of top 20 countries in GSEI 2023
Source: *own compilation*

The USA remains the leader for many years (198.08), while the indicator of Bosnia and Herzegovina, which occupies the last position in the rating, is only 0.29, which is 683 times less than the leader's score. At the same time, the gap even from the second place is quite significant. The United Kingdom has a score of 51.22, which is also almost 4 times less than the USA's achievement. The USA is recognized as the most business-friendly country in the world, the number of US cities in the world top 100 is more than 30%.

University-Industry R&D Collaboration Indicator shows the degree of cooperation and partnership between companies and universities, business and the higher education sector in the field of research and development, estimated by WIPO. The base of assessment is a survey of heads / managers of institutions / companies held by the World Economic Forum. The question is 'To what extent do businesses and universities cooperate in R&D in your country?' The average score of all the answers is taken (general criteria: 1 = do not cooperate at all; 7 = cooperate to a great extent) (Dutta et al., 2023).

Figure 2 shows the results of comparative analysis of top 20 countries in the University-Industry R&D Collaboration as an indicator of Global Innovation Index (GII) 2023 (score).

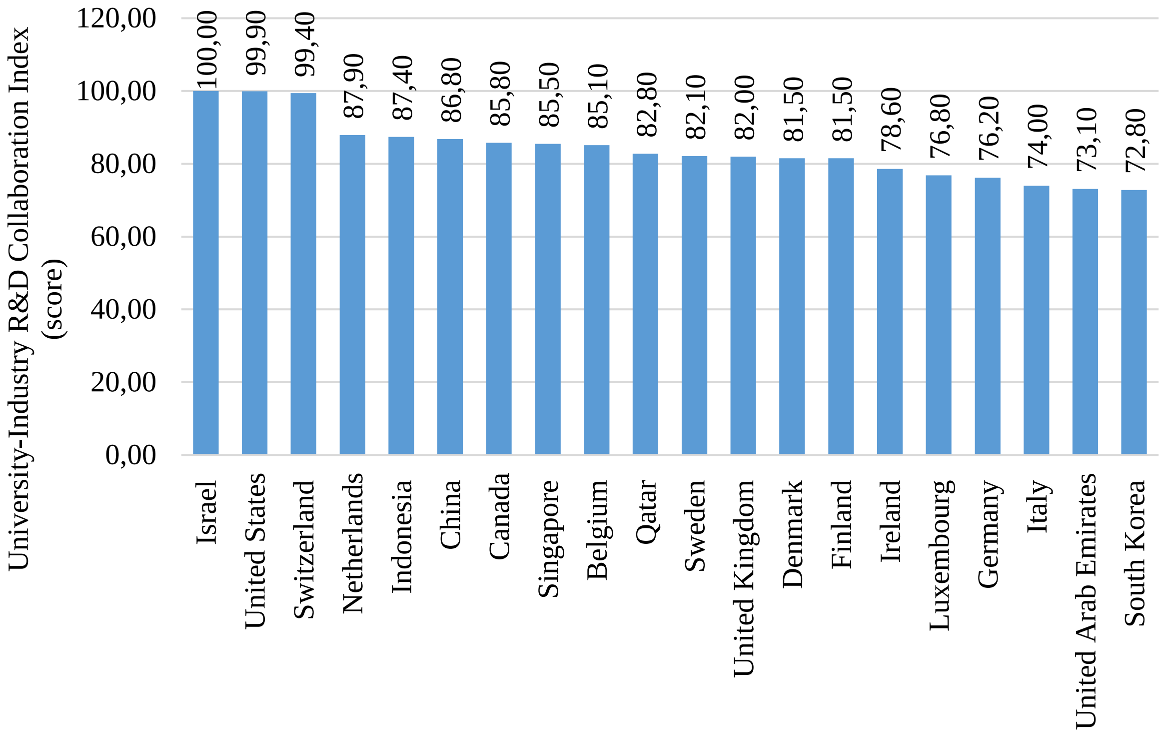

Figure 2. Results of comparative analysis of top 20 countries in the University-Industry R&D Collaboration as an indicator of Global Innovation Index 2023

Source: *own compilation*

Unlike the previous ranking, the scores do not differ so much from country to country, at least in the top twenty countries, because the lowest positions correspond to scores from 0 to 10, etc. The USA also leads in this ranking in the second position, lagging Israel by only 0,01. It is worth noting that other countries also occupy high positions in both ratings (Switzerland, the Netherlands, Canada, United Kingdome, China, Singapore, etc.), which actualizes the question of research on how cooperation between business and education affects the productivity of startups in the world, taking into account such significant gaps in development.

4.2. Descriptive statistics and significance grounding

Based on the accumulated data for chosen 93 countries and toolkit of STATA 18 program complex the results of descriptive statistics were obtained (Table 1).

Table 1

Results of descriptive statistics for research sample

Variable	Obs	Mean	Std. dev.	Min	Max
GSEI	93	9.637968	22.00354	.288	198.08
UI_RD_C	93	51.26452	22.9135	0	100.00

Note: GSEI – Global Startup Ecosystem Index (score); UI_RD_C – University-Industry R&D Collaboration Index (score).

Source: *own compilation*

Table 1 shows minimum, maximum and mean values of studied indicators for 93 obstacles. As there are significant gaps it is necessary to check dependent indicator's data for normal distribution (Table 2).

Table 2

Shapiro–Wilk test for normal data for dependent variable

Variable	Obs	W	V	z	Prob>z
UI_RD_C	93	0.98205	1.395	0.736	0.23098

Note: GSEI – Global Startup Ecosystem Index (score); UI_RD_C – University-Industry R&D Collaboration Index (score)

Source: *own compilation*

Test result (Prob>z) is more than 0,05, so the data is normally distributed. Besides it, histogram of normal distribution was built (Figure 3).

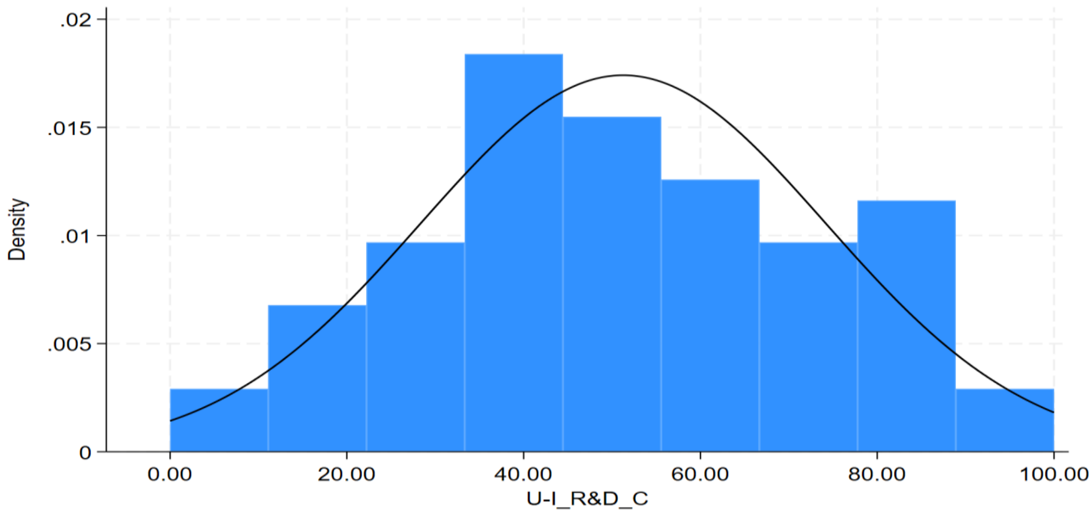

Figure 3. Histogram of normal distribution for dependent variable

Source: *own compilation*

Above histogram also grounds a normal distribution.

The studied data for both the dependent and the outcome variable have the same unit of measurement, so the data normalization procedure is not applied.

To ground the significance of chosen dependence for investigation – between the value of Global Startup Ecosystem Index (outcome variable) and the value of University-Industry R&D Collaboration Index (dependent variable) the regression analysis was applied (Table 3).

Table 3

The results of regression analysis

Source	***SS***	***df***	***MS***	F (1,91)	27.24
Model	10260.9235	1	10260.9235	Prob > F	0.0000
Residual	34281.3958	91	376.718635	R-squared	0.2304
Total	44542.3193	92	484.155645	Root MSE	19.409
GSEI	*Coefficient*	*Std. err.*	*t*	*p>|t|*	*[95% conf. interval]*
UI_RD_C	0.4609012	0.0883127	5.22	0.000	.2854789 .6363235
Const.	-13.98991	4.954518	-2.82	0.006	-23.83145 -4.148366

Note: GSEI – Global Startup Ecosystem Index (score); UI_RD_C – University-Industry R&D Collaboration Index (score)

Source: *own compilation*

Table 3 presents the results of a regression analysis that assesses the relationship between the University-Industry R&D Collaboration Index (UI_RD_C) and the Global Startup Ecosystem Index (GSEI). The analysis aims to determine how university-industry R&D collaboration impacts the performance and productivity of startup ecosystems.

The coefficient for the UI_RD_C is 0,4609, indicating a positive relationship between university-industry collaboration and startup performance. Specifically, a 1% increase in UI_RD_C is associated with a 0,46 point increase in the GSEI score, on average. The standard error for the coefficient is 0,0883, which is relatively small compared to the coefficient value, suggesting that the estimate is precise. The t-statistic of 5,22 and a p-value of 0,000 indicate that the relationship between UI_RD_C and GSEI is highly statistically significant. The p-value being well below 0,05 implies strong evidence against the null hypothesis, confirming that university-industry collaboration significantly contributes to the performance of startup ecosystems. The intercept (constant) is -13,9899, with a standard error of 4,9545, which is statistically significant (p-value = 0,006). This suggests that when UI_RD_C is zero, the GSEI would theoretically have a negative value; however, this should be interpreted cautiously as it is beyond the range of realistic UI_RD_C values. The R-squared value is 0.2304, indicating that approximately 23,04% of the variance in the GSEI is explained by the UI_RD_C. Although the R-squared is moderate, it suggests that other factors besides university-industry R&D collaboration also play a significant role in determining startup ecosystem performance. The F-statistic shows a p-value of 0,0000, indicating that the overall regression model is statistically significant, reinforcing that the independent variable (UI_RD_C) reliably predicts the outcome variable (GSEI).

The regression analysis in Table 3 demonstrates that university-industry R&D collaboration positively and significantly impacts startup ecosystem performance. While the effect size is notable, the moderate R-squared value implies that there are additional factors influencing GSEI that are not captured by UI_RD_C alone. Nonetheless, enhancing university-industry collaboration could be a key driver for improving startup productivity and ecosystem strength.

4.3. Spline modelling to identify knots and gap intervals

Firstly, the graph of median spline was built to visualize the line of spline, its form and interval for showing the relationship between the factor and outcome investigated variables (Figure 3).

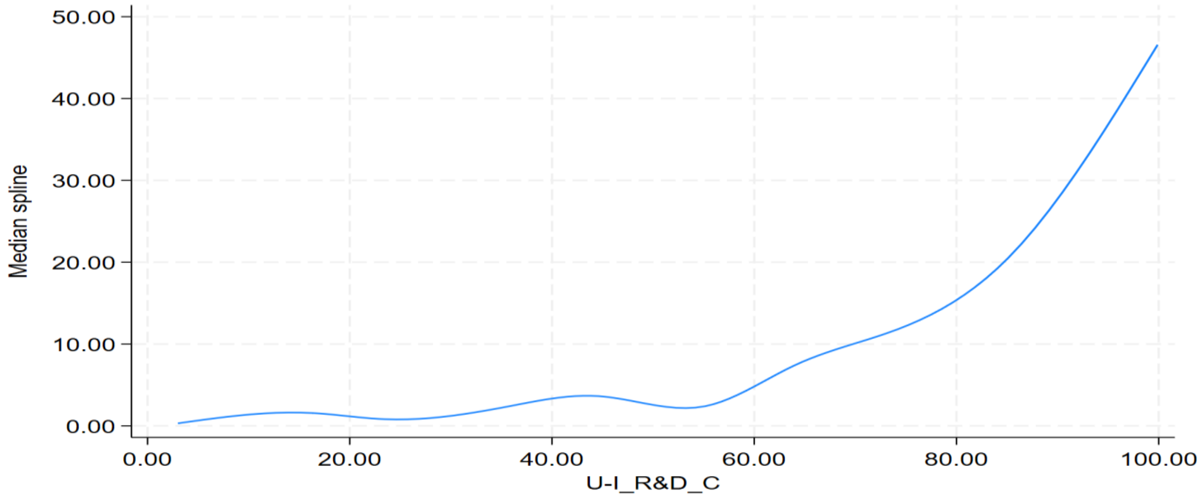

Figure 3. Median spline of relationship between scores of Global Startup Ecosystem Index (GSEI) and University-Industry R&D Collaboration Index (UI_RD_C)
Source: *own compilation*

As can be seen from the graph above, the line does not contain steep peaks, it is not very curved, but instead is relatively smooth, close to a straight line. Therefore, in further spline modelling, it is advisable to abandon the construction of a cubic spline in favour of modelling a linear spline.

Figure 4 demonstrates scatter plot overlayed on median spline also to show the interconnection between the factor and outcome variables.

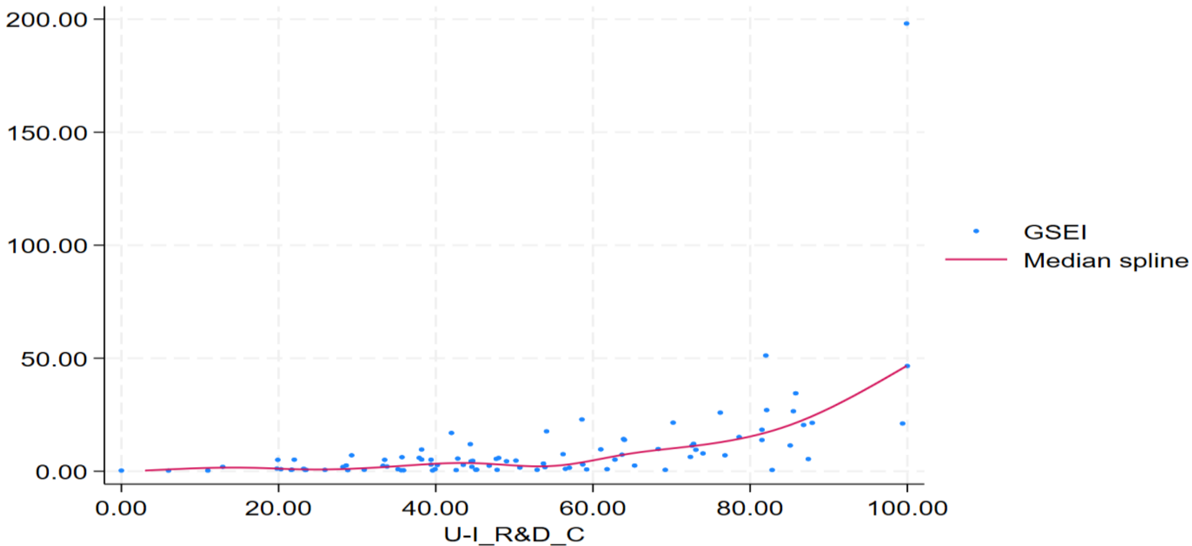

Figure 4. Scatter plot of interconnection between scores of Global Startup Ecosystem Index (GSEI) and University-Industry R&D Collaboration Index (UI_RD_C)
Source: *own compilation*

Secondly, 5 new variables of UI_RD_C were generated within determination of 4 knots (one fewer knots than newly formed variables) (Table 4).

Table 4

Knots displaying

	Knot1	Knot2	Knot3	Knot4
UI_RD_C	30.58	43.22	56.32	73.28

Note: UI_RD_C – University-Industry R&D Collaboration Index (score)

Source: *own compilation*

These new spline variables (critical points) are the following: pctUI_RD_C1, pctUI_RD_C2, pctUI_RD_C3, pctUI_RD_C4, and pctUI_RD_C5). They correspond to the four generated knots at the 20th, 40th, 60th, and 80th percentiles of the data (option 'pctile displayknots').

Since there is no highly curved function in the case of this study, as evidenced by the results of previous iterations of the study, the cubic spline was not applied. A linear spline regression model was chosen to examine the non-linear effects of university-industry collaboration on startup performance. Spline regression enables dividing the predictor variable (UI_RD_C) into segments or 'knots,' allowing for varying relationships between the predictor and outcome within each segment.

Table 5 presents the results of a regression analysis based on a linear spline that incorporates identified knots and gap intervals.

Table 5

The results of regression analysis based on linear spline, determined knots and gaps.

Source	*SS*	*df*	*MS*		
Model	19490.1893	5	3898.03787	F (5,87)	13.54
Residual	25052.13	87	287.955517	Prob > F	0.0000
Total	44542.3193	92	484.155645	R-squared	0.4376
				Root MSE	16.969

Gap interval of UI_RD_C	*GSEI*	*Coefficient*	*Std. err.*	*t*	*p>|t|*	*[95% conf. interval]*
< knot1	pctUI_RD_C1	-.0272818	.9407034	-0.03	0.977	-1.897032 1.842468
knot1 – knot2	pctUI_RD_C2	0	(omitted because of collinearity)			
knot2 – knot3	pctUI_RD_C3	.1452501	1.066446	0.14	0.892	-1.974427 2.264927
knot3 – knot4	pctUI_RD_C4	-.362966	.7211194	-0.50	0.616	-1.7962269 1.70337
> knot4	*pctUI_RD_C5*	*2.439902*	*.7492737*	*3.26*	*0.02*	*.9506397 3.929165*

Note: GSEI – Global Startup Ecosystem Index (score); UI_RD_C – University-Industry R&D Collaboration Index (score); pctUI_RD_C1 – pctUI_RD_C5 – critical points due to spline construction based on percentiles knots displaying.

Source: *own compilation*

The analysis demonstrates the relationship between the Global Startup Ecosystem Index (GSEI) and the University-Industry R&D Collaboration Index (UI_RD_C). Specifically, the table provides coefficient estimates for different segments of the collaboration index, which are divided into five segments based on percentiles. The results indicate that the regressor coefficient is statistically significant only at the fifth segment (> knot4), where the p-value is 0.02, suggesting a high reliability of this outcome. The model shows an R-squared value of 0.4376, indicating that approximately 43.76% of the variance in the GSEI is explained by the model, and the overall model is statistically significant (Prob > F = 0.0000). This suggests that collaboration between universities and industries has a strong influence on startup performance only when it reaches a certain intensity.

A key finding from this analysis is that an increase of 1% in the UI_RD_C, within the range between critical points of 73.28 and 100, correlates with an average increase in startup productivity by 2.44%. This emphasizes the impact of business and education collaboration on enhancing the global startup ecosystem performance.

The insignificance of other knots in the spline regression model means that changes in the UI_RD_C within those particular intervals (or knots) do not significantly affect the performance of startup ecosystems, as measured by the GSEI.

This lack of significance could suggest several things:

1. The impact of university-industry collaboration on startup productivity might not be constant across all levels of the UI_RD_C. The relationship could be stronger or weaker at different points, indicating that only a certain range (the significant knot) has a substantial effect. Spline regression breaks the data into pieces and fits different functions in each segment. This is what we have already done, and it is a powerful method for capturing non-linear relationships.

2. It may imply that only after reaching a certain level of university-industry collaboration (between the significant knot range of 73.28 and 100) does this collaboration begin to significantly drive startup performance. Below this threshold, the effect might be too weak or inconsistent to register as significant.

3. The GSEI is influenced by multiple factors beyond university-industry collaboration. At lower or intermediate levels of collaboration, the effect might be overshadowed by other variables (e.g., funding availability, market conditions, policies), thus making the impact of UI_RD_C on GSEI less clear or insignificant.

The lack of significance in other intervals indicates that moderate or low levels of university-industry collaboration have no clear or consistent effect on startup performance, highlighting the need for a threshold level of collaboration to yield tangible benefits for startup ecosystems. The scatter plot with an overlaid spline line (Figure 4) demonstrates a relatively smooth curve, with a stronger upward trend in the upper quartile of the UI_RD_C index. This visualization supports the conclusion that only high levels of university-industry collaboration are significantly associated with higher GSEI scores.

5. RESULTS, LIMITATIONS, AND DISCUSSION

Research results show that generally within the sample of 93 countries represented both in Global Startup Ecosystem Index rating and the University-Industry R&D Collaboration Indicator as an element of Global Innovation Index, a 1% increase in business-education collaboration (estimated as a score of University-Industry R&D Collaboration Indicator) could led to an average 0,46% increase of startup performance and productivity (estimated as a score of Global Startup Ecosystem Index).

However, the results of the regression analysis using spline modelling and the selection of 4 knots based on percentiles in the range of indicators of business-education collaboration give reason to assert that ensuring a 1% increase in the collaboration index (on the interval between the critical points from 73,28 to 100) will contribute to an average increase in the productivity indicator of startups by 2,44%.

So, reaching the score of the University-Industry R&D Collaboration Indicator on the interval between the critical points from 73,28 to 100 has a great potential to achieve the maximum statistically significant influence on the indicator of startups productivity (in average 2,44% increase).

The conclusions closely related to the obtained results were highlighted in the previously published works of the authors. In particular, it was proven that increasing the studied indicator of business and education collaboration in R&D by 1 position causes an increase in the overall assessment of sustainable development by 0,7 (the maximum statistically significant result at the time of the study), if the indicator is in the range of knots 62.04 and 68.96 (Samoilikova et al., 2023a). The strongest university-industry R&D collaboration contributes to more robust sustainable development in 60% of studied countries and also shrinking informal economy in 4 out of 40% countries (Samoilikova et al., 2023b). The combination of the results of previous and this research allows to form a comprehensive confirmation of the importance of strengthening cooperation between business and education in R&D and, accordingly, a vision of targeted quantitative values, the achievement of which can become a strategic vector in the further development of the countries of the world.

The presented study contains certain limitations. Firstly, when constructing the spline, there was an abstraction from the influence of other factors, in combination with which it is potentially possible to achieve a faster and greater effect. Secondly, the sample of countries was selected based on the author's approach, and in the future, when expanding the database, it can be supplemented with data on individual countries (up to 7 countries). Thirdly, in further research, it is advisable to follow the change in the obtained results by building splines for different time periods, which will enable the identification of inhibitors and catalysts of innovative development and the commercialization of its results through the implementation of startups.

6. CONCLUSION

The research purpose was identifying the impact of university-industry R&D collaboration on startups performance, taking into account existing knots and gap intervals.

The range of values of the University-Industry R&D Collaboration Index was divided by four percentile orientated knots (such as 30.58, 43.22, 56.32 and 73.28) into certain intervals that demonstrate cross-country gaps in innovation development. The maximum statistically significant value of the indicator of startups productivity is predicted in the case of positioning university-industry R&D collaboration between critical points 73.28 and 100. Being on this interval, country with a 1% increase in providing business and education collaboration index could receive an average increase in the productivity startups by 2,44%.

The obtained results confirm the importance of an entrepreneurial university concept for innovation transfer and their commercialization and provide a view of targeted value of the University-industry R&D collaboration on average at the world level.

These findings underscore the importance of strengthening university-industry R&D collaboration to improve startup ecosystems. Policymakers and educational institutions should aim to increase collaboration to reach the critical range where its impact on startup productivity is maximized.

Further scientific research in this direction is planned to be aimed at tracking changes in the obtained results in dynamics by constructing splines for different time intervals, which will allow not only to carry out a more comprehensive and comparative analysis, but also to identify inhibitors and catalysts of innovation development and commercialization of its results through the introduction of startups, as well as offer ways to improve the innovation and business climate. The current model only considers the relationship between UI_RD_C and GSEI, without accounting for other possible influencing factors such as market conditions, policy environment, or venture capital availability. Future studies could incorporate these factors to provide a more comprehensive understanding of the drivers of startup ecosystem performance.

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