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Is digital development a factor of university-industry R&D collaboration and vice versa?

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Abstract
The purpose of the article is to determine and characterize relationships and their causality between indicators of digitalization of social relations and level of university-industry R&D collaboration. To conduct the research, a sample was formed for 20 countries of the world leaders in University-Industry R&D Collaboration indicator (as a part of Global Innovation Index) in 2022, which covers the following indices for period from 2011 to 2020: indicators of university-industry R&D collaboration, access to ICT, government online services, online creativity (as assessed by WIPO Global Innovation Index), and export of ICT goods (according to the World Bank). The methodological basis of the study was methods of correlation analysis (Pearson or Spearman, depending on data distribution, for which Shapiro-Wilk test for normal data distribution was previously applied) taking into account possible lags in time, VAR modelling, Granger test, and corresponding toolkit of STATA 18 software. As a result of the research, it was confirmed that the level of university-industry R&D collaboration is affected by such indicators of digitalization of social relations as online creativity (in 16 from 20 sample countries), access to ICT (in 12 countries) and the share of ICT goods exports in total exports (in 11 countries). At the same time, university-industry R&D collaboration is a cause of changes in the level of online creativity (in 15 from 20 sample countries), access to ICT (in 11 countries), public online services (in 10 from 19 sample countries) and the share of ICT goods exports (in 10 from 20 sample countries). The obtained results can be useful for stakeholders in R&D, innovative activities, development of state policy in the innovation and information sphere for making the most effective decisions in the context of stimulating the role of cooperation.

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1. Introduction

Digitalization of social relations, as well as innovation development of the countries all over the world in general, are important drivers of socio-economic and sustainable development. One of the reasons is that scientific and technological progress, transfer and commercialization of innovations, digitalization of economy and public management lead to more efficient use of labor and capital investments, increased productivity and ultimately to economic growth (Habenko, 2023; Alshourah et al., 2023). Moreover, technological progress and, accordingly, digital development has accelerated significantly over the years, and obvious advantages such as speed, flexibility, the ability to manage the process in real time, and the reduction of human errors have become even more in demand in the business environment, government, education, and other fields (Kartanaitė et al., 2021; Kisel'áková et al. 2022; Stacho et al., 2023).

However, new technologies are the result not only of scientific production and the implementation of scientific achievements but the related activities of scientific teams (Fobel and Kuzior, 2019), which involve the collaboration of various stakeholders, including both educational, scientific institutions, businesses etc. Effective cooperation between industry, education, and science in the field of research and development is directly one of the directions and plays an important role in digital development, being also an unconditional component of solving other priority tasks at the micro and macro levels.

Today, education is positioned not only in the social dimension, but also as a driving force of economic growth and the SDG achievement, an important source of innovation. The activities of the university go beyond ensuring only the quality of education (SDG 4), but they form an important basis for the transfer of technologies and the achievement of other SDGs (Artyukhov et al., 2021). Business activities also have a great potential for economic and sustainable development (Djalilov et al., 2015; Brychko et al, 2023; Djamal et al., 2023; Ulewicz and Sethanan, 2020).

Therefore, the purpose of this study is to determine and characterize the causal relationships between the indicators of digitalization of social relations and the level of university-industry R&D collaboration.

2. Literature review

The issue of digital development receives special attention in scientific circles, being the subject of both highly specialized and interdisciplinary research, based on the multifaceted use of digital technologies in various spheres of life. This topic became even more relevant during the covid-19 pandemic, emergencies, and war for objective reasons (Kuzior et al., 2022a; Barvinok and Pudło, 2023; Ogunleye et al., 2023; Pakhnenko and Pudło, 2023). Moreover, it is crucial in the context of Industry 4.0 and Industry 5.0, taking into account new tendencies and challenges (Vasylieva and Kasyanenko, 2013; Kuzior and Zozul'ak, 2019).

The issue of digital technology and data management, the effectiveness of state management of the digital economy was investigated by Yeraliyeva et al. (2023). In this context scholars made a factor analysis of digital development in different spheres (Kuzior et al., 2022b; Kuzior et al., 2023; Pozovna et al., 2023; Yamin and Murwaningsari, 2023; Yu, 2023; Yu et al., 2023).

In particular, the role of digitization in education reforming, digitization of all processes and strengthening of social communication of the university community was studied by Hara (2023), Kaya et al. (2023), Spivakovsky et al. (2023) etc. Digitalization can be a factor in improving the quality of education, and vice versa (Liuta et al., 2021). Melnyk et al. (2023) also put attention on the question of the impact of digital education initiatives. Nevertheless, ICTs and innovation transfer are leadership trends in education. Besides that, modern education in digital era is a competitive advantage for business (Kharchenko, 2023).

In the business sphere Melnyk et al. (2019) studied circular technologies as the basis of business processes for sustainable transformation of the conventional economy into a digital one. The authors proved that scientific justification, design and practical implementation of cyclical business processes create a platform for building a digital economy, for effective communication of economic agents in the main areas of the digital economy and ensure the sustainability of ecosystems in general.

The issue of university-industry collaboration in R&D is also not new in scientific research (Runiewicz-Wardyn and Winogradska, 2023). Many cases of partnership, cooperation, collaboration, coopetition, and various types of interaction take place in order to solve urgent socio-economic problems, such as achieving the goals of sustainable development, ensuring corporate social responsibility, inclusiveness, innovation, cybersecurity etc. (Lyeonov et al., 2021; Kuzmenko et al., 2023; Liu, 2023; Samoilikova et al., 2023; Yarovenko et al., 2023). Nahla (2023) investigated arguments and counter-arguments about the reality of research partnerships between universities and industrial companies, considering the university-company partnership as a part of the university's mission. Moreover, effective interaction today cannot be seen separately from innovative activity and the development of information technologies (Boiko et al., 2023).

However, the issue of interrelationship, causality, and impact of digitalization on the collaboration of business and education in R&D, as well as the reverse impact, remains practically outside the attention of scientists, which determines the relevance of this study. It is important to understand what causes the result for decision-making with the purpose to strengthen digital development and university-industry R&D collaboration.

3. Experimental

To conduct the study, a sample was formed for 20 countries of the world which are leaders in the rating of University-Industry R&D Collaboration Indicator (according to the Global Innovation Index) in 2022 (Dutta et al., 2022). The study covers the following indicators for the period from 2011 to 2020: indicators of university-industry R&D collaboration, access to ICT, public online services, online creativity (according to the Global Innovation Index of the World Intellectual Property Organization) (WIPO, n.d.), and exports of ICT goods (according to the World bank) (World Bank, n.d.).

The methodological basis of the study was the methods of correlation analysis (Pearson (Pearson, 1987) or Spearman (Spearman, 1987) depending on the data distribution, for which the Shapiro-Wilk test for the normal distribution of data was previously applied (Shapiro and Wilk, 1965) taking into account possible time lags, VAR modelling (Stata, n.d.), the Granger test (Granger, 1969) and the corresponding toolkit of the STATA 18 software for calculations.

At the first stage, the data was checked for normal distribution using the Shapiro-Wilk test (Table 1) for the subsequent correct selection of the correlation analysis method to justify the existence of a relationship between the studied indicators, to determine its nature and strength.

In the case of a normal distribution of data (the result of the Shapiro-Wilk test is 0.05 or more), the correlation coefficient should be calculated using the Pearson method, otherwise (the result of the Shapiro-Wilk test is less than 0.05) – using the Spearman method when the data violates the assumption of normality, such as having skewed distributions or outliers, Spearman correlation is typically more appropriate). Also, during the correlation analysis to substantiate the existence of a relationship between the investigated indicators, possible lags in time (up to three years) are taken into account, due to which the correlation coefficient becomes maximum, and accordingly the revealed relationship acquires the greatest statistical significance.

Table 1. Results of testing the input sample for normal distribution of data

Country	Prob>z value (Shapiro-Wilk test) for the indicator:			
	ICT_A	GOS	OC	ICT_G_E
USA	0.30140	0.52647	0.05046	0.12283
Israel	0.12948	0.00000*	0.26381	0.10877
Switzerland	0.46313	0.91874	0.12477	0.00070*
Netherlands	0.22876	0.00000*	0.35612	0.36765
China	0.37081	0.50603	0.06296	0.58102
Ireland	0.05105	0.85564	0.43470	0.02653*
Singapore	0.51722	0.00000*	0.28954	0.19196
Belgium	0.59370	0.76545	0.23004	0.09886
Canada	0.08209	0.81335	0.38174	0.87255
Sweden	0.85024	0.05063	0.48131	0.01846*
Finland	0.07773	0.00087*	0.06720	0.00039*
Qatar	0.05003	0.00004*	0.62267	0.00000*
Indonesia	0.54940	0.44711	0.10801	0.76840
Korea	0.01973*	0.06634	0.32754	0.58757
Denmark	0.79199	0.89568	0.54473	0.60148
Germany	0.40457	0.77408	0.10238	0.83035
Hong Kong	0.03721*	–	0.32591	0.31509
Austria	0.21439	0.00187*	0.03362*	0.46108
Luxembourg	0.11411	0.02957*	0.04737*	0.91944
Norway	0.47300	0.90187	0.08600	0.42985

Note: * – data are not normally distributed; – - the data did not change during the studied period or were absent; UI_RD – assessment of university-industry R&D collaboration (within the Global Innovation Index); ICT_A – assessment of access to ICT (within the Global Innovation Index); GOS – assessment of government online services (within the Global Innovation Index); OC - assessment of online creativity (within the Global Innovation Index); ICT_G_E – the share of the export of ICT goods in the total export (according to the World Bank data).

The generalized results of the assessment of the relationship between the indicator of university-industry R&D collaboration and digitalization indicators are presented in Table 2.

Table 2. Results of the calculation of correlation coefficients / time lags for assessing the strength and nature of the relationship between the indicator of university-industry R&D collaboration and digitalization indicators

Country	UI_RD			
	ICT_A	GOS	OC	ICT_G_E
USA	-0.32 / 3	0.57 / 2	0.73 / 2	-0.19 / 2
Israel	0.90 / 2	0.91 / 3	-0.85 / 2	0.33 / 3
Switzerland	0.43 / 0	-0.36 / 2	0.77 / 2	0.55 / 2
Netherlands	0.90 / 2	0.49 / 3	0.55 / 3	-0.52 / 0
China	-0.67 / 0	-0.68 / 0	0.53 / 2	0.79 / 3
Ireland	0.52 / 0	-0.68 / 3	0.59 / 2	0.35 / 0
Singapore	-0.91 / 3	0.93 / 1	0.83 / 1	-0.98 / 3
Belgium	-0.84 / 2	-0.94 / 2	0.86 / 1	-0.71 / 3
Canada	-0.74 / 0	-0.89 / 0	0.47 / 0	0.75 / 0
Sweden	0.31 / 3	-0.57 / 0	0.82 / 0	0.86 / 0
Finland	0.75 / 1	-0.98 / 0	0.81 / 2	0.29 / 0
Qatar	-0.90 / 3	0.65 / 2	0.90 / 1	-0.81 / 3
Indonesia	0.31 / 0	0.89 / 2	0.56 / 1	0.85 / 3
Korea	-0.85 / 2	0.82 / 0	0.71 / 0	-0.88 / 0
Denmark	-0.41 / 2	0.37 / 3	0.73 / 0	0.35 / 3
Germany	0.57 / 0	0.34 / 1	0.57 / 3	0.30 / 0
Hong Kong	0.41 / 3	–	-0.86 / 2	0.77 / 3
Austria	0.69 / 3	0.95 / 2	-0.93 / 3	-0.82 / 2
Luxembourg	0.55 / 3	0.95 / 2	-0.79 / 2	0.34 / 3
Norway	0.44 / 0	0.54 / 2	0.86 / 2	-0.72 / 2

Note: – - the data did not change during the studied period or are missing; UI_RD – assessment of university-industry R&D collaboration (within the Global Innovation Index); ICT_A – assessment of access to ICT (within the Global Innovation Index); GOS – assessment of government online services (within the Global Innovation Index); OC - assessment of online creativity (within the Global Innovation Index); ICT_G_E – the share of the export of ICT goods in the total export (according to the World Bank data).

The obtained results have statistical significance. The strength of the relationship between each pair of investigated indicators is determined depending on the value of the correlation coefficient by module. It is low if the correlation coefficient is less than 0.19, medium – from 0.2 to 0.49, high – from 0.5 to 0.79, and very high – from 0.8 to 1. Accordingly, the mathematical sign indicates the nature of the relationship: inverse – for a negative correlation coefficient and direct – for a positive correlation coefficient.

Therefore, summarizing the results of the correlation analysis for the entire sample of countries, it is possible to assert the existence of a relationship between the indicator of university-industry R&D collaboration and:

- access to ICT, which is direct in 12 of the 20 sample countries with medium, high, and very high connection strength and a time lag of 0 to 3 years depending on the country under study. Accordingly, the inverse relationship occurs in 8 of the 20 countries of the sample (the strength of the relationship is from medium to very high, with a time lag of 2-3 years or without a time lag);
- the level of public online services, which means a direct interconnection in 12 of the 19 countries of the sample with medium, high, and very high connection strength and a time lag from 0 to 3 years. Inverse connection is in 7 out of 19 sample countries (connection strength from medium to very high, time lag of 2-3 years or no time lag);
- the level of online creativity, which in most countries (16 out of 20 sample countries) is direct with mostly high and very high connection power and a time lag of 0 to 3 years. Accordingly, the inverse relationship is substantiated only in 4 of the 20 countries of the sample (the strength of the relationship is very high, the time lag is 2-3 years);
- the share of the export of ICT goods which means a direct relationship in 12 of the 20 countries of the sample with the strength of the relationship from medium to very high depending on the country under study, mostly without a time lag or with a lag of 3 years. Inverse relationship – in 8 out of 20 countries of the sample with low, high, or very high strength of connection, no time lag, or a time lag of 2-3 years.

However, correlation analysis does not provide an opportunity to establish the direction or causality in the determined relationships, which determines the expediency of conducting a causal analysis using the Granger causality test based on previous VAR modelling. The obtained results of the Granger causality test are given in Appendix A, Table 1.

The results obtained for the USA indicate that the lagged value of the indicator of access to ICT is not the cause of university-industry R&D collaboration (UI_RD), since the value of Prob > chi2 = 0.163, which is greater than 0.05. Similarly, the lagged value of the indicator of university-industry R&D collaboration (UI_RD) is not the cause of the indicator of access to ICT (Prob > chi2 = 0.200, which is greater than 0.05). Instead, the level of government online services (GOS) is determined to be the cause of university-industry R&D collaboration (UI_RD) because the value of Prob > chi2 = 0.000, which is less than 0.05. At the same time, university-industry R&D collaboration (UI_RD) is not the reason for the change in the level of government online services (GOS), as evidenced by the value of Prob > chi2 = 0.131, which is greater than 0.05. According to a similar algorithm, it was established that the indicator of online creativity (OS) affects (is the cause of) university-industry R&D collaboration (UI_RD) (Prob > chi2 = 0.000, which is less than 0.05), and there is a bidirectional causality between these indicators, because the level of cooperation between universities and industry in R&D (UI_RD) is the reason for the level of online creativity (OS) (Prob > chi2 = 0.011, which is less than 0.05). Also, bidirectional causality was found for the relationship between university-industry cooperation in R&D (UI_RD) and the share of ICT goods exports (ICT_G_E) (respectively, Prob > chi2 = 0.000 to assess causality in both directions).

The results of determining causality in the relationships between the studied indicators for all countries of the sample are summarized in Appendix A, Table 2.

4. Results and discussion

It follows from the above that the level of access to ICT is the reason for the change in the level of cooperation between universities and industry in R&D in 12 out of 20 sample countries, reverse causality occurs in 11 out of 20 sample countries, including bilateral causality in 5 countries.

The level of development of public online services is the reason for the change in the level of cooperation between universities and industry in R&D in 7 of the 19 countries of the sample, reverse causality is established in 10 of the 19 countries of the sample, including bilateral causality – in 3 countries.

The assessment of online creativity affects university-industry cooperation in R&D in 16 out of 20 sample countries, reverse causality was found in 15 out of 20 sample countries, including bilateral causality in 12 countries.

The share of exports of ICT goods in total exports affects cooperation between universities and industry in R&D in 11 out of 20 sample countries, reverse causality occurs in 10 out of 20 sample countries, including bilateral causality in 5 countries.

So, it has been confirmed that the level of cooperation between universities and industry in R&D is affected by such indicators of digitalization of social relations as online creativity, access to ICT and the share of ICT goods exports in total exports. At the same time, cooperation between universities and industry in R&D is the reason for changes in the level of online creativity, access to ICT, public online services, and the share of ICT goods exports. That is why the key recommendations for policymakers in the spheres of innovation and digital development should be the following:

1) it is necessary to develop “business-education” collaboration to accelerate the transfer of innovations, technologies, and knowledge, including in the field of digitization. At the same time, business and education should not be considered as competitors in the field of commercialization of innovations, but as partners, from whose effective interaction it is possible to obtain a synergistic effect;

2) in connection with the above, great potential is seen in the functioning of innovation hubs / centres, which will include interested representatives of the business environment and education, and, accordingly, the support of such functioning by the state;

3) collaboration between business and education in the direction of innovation development and digitalization should be declared as one of the strategic directions of state policy;

4) the state should shift emphasis from direct financing of research and development costs in the field of education in favour of a grant approach, in the field of business – to develop tax incentives (benefits) for innovators, etc.

Comparing the obtained results with the achievements of other scientists, the following should be noted. Mursalov et al. (2023) determined the relationships and their nature between the entrepreneurial ecosystem, infrastructure, innovations, and digital development of the economic and social spheres (IT and cyber security) and established that changes in the development of the business ecosystem significantly affect the level of digital development. Instead, this study used other indicators of digital development in relation to university-industry collaboration in R&D.

Cooperation between the university and industry as a driving force of digital transformation was also explored in the work (Evans et al., 2023), in which the authors substantiate their conclusions with personal experience (research activity, joint use of means and equipment, cooperation involving student projects, joint teaching and learning). Instead, in this study, the conclusions are based on statistical data and economic-mathematical calculations for several countries of the world, which proves their impartiality.

Fernandes et al. (2023) tried to find the most success factors (thirty-four) of university-industry R&D collaborations based on literature review and a case study between Bosch Car Multimedia in Portugal and University of Minho. However, among them the author does not clearly single out the digitization factor, which is the key to achieving those indicators that the authors position as critically successful factors. Instead, this study covers several important indicators that characterize digital development as a trend today.

On the example of European countries Ćudić et al (2022) found the links between university-industry collaboration inputs and outputs and based on the statistical analysis, the authors identified the investments in knowledge, networking, and R&D as the most significant determinants. Instead, this study grounds other causal relations and indicators based on countries' sample which includes not only European countries, but countries all over the world according chosen criteria.

This study is not without limitations due to the size of the sample of countries and the time period of the study, which are planned to be expanded in further studies to obtain even more accurate and objective results, taking into account a number of other countries that are currently left out of the sample. The list of variables selected to determine and characterize the causal relationships between the indicators of digitization of social relations and the level of university-industry R&D collaboration can be expanded in further research too.

5. Summary and conclusion

The purpose of the article was to determine and characterize the causal relationships between the indicators of digitalization of social relations and the level of university-industry R&D collaboration.

Therefore, the theoretical and methodological approach to determination and evaluating the cause-and-effect relationships of the digitalization of social relations and the level of cooperation of industry, education, and science in the field of R&D as drivers of socio-economic development has been improved. Unlike the existing ones, it is based on VAR-modelling and testing according to the Granger method for the 20 leading countries of the world according to the indicator of cooperation between universities and industry in the field of R&D for 2011-2020, based on a study of indicators of cooperation between universities and industry in the field of R&D, access to ICT, public online services, online creativity (according to the Global Innovation Index), and exports of ICT goods (according to the World Bank).

As a result of investigation, it has been confirmed that the level of cooperation between universities and industry in R&D is affected by such indicators of digitalization of social relations as online creativity, access to ICT and the share of ICT goods exports in total exports. At the same time, cooperation between universities and industry in R&D is the reason for changes in the level of online creativity, access to ICT, public online services, and the share of ICT goods exports.

The obtained results can be useful for various stakeholders who carry out scientific research and innovative activities, participate in the development of state policy in the innovation and information sphere for making the most effective decisions in the context of stimulating the role of cooperation in the digital environment.

Future research should be directed forward the possible quantitative impact estimation of investigated indicators using regression models.

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Appendix

Appendix A

Table 1. Results of the Granger test for establishing causality in the relationships between the indicator of university-industry R&D collaboration and digitalization indicators

The resulting indicator	Factorial indicator	chi2	df	Prob > chi2
		USA		
UI_RD	ICT_A	3.6223	2	0.163
ICT_A	UI_RD	3.2216	2	0.200
UI_RD	GOS	30.825	2	0.000*
GOS	UI_RD	4.0703	2	0.131
UI_RD	OC	24.52	2	0.000*
OC	UI_RD	9.0822	2	0.011*
UI_RD	ICT_G_E	30.197	2	0.000*
ICT_G_E	UI_RD	24.892	2	0.000*
		Israel		
UI_RD	ICT_A	5.2571	2	0.072
ICT_A	UI_RD	7.8989	2	0.019*
UI_RD	GOS	3.5479	2	0.170
GOS	UI_RD	23.283	2	0.000*
UI_RD	OC	8.3246	2	0.016*
OC	UI_RD	46.537	2	0.000*
UI_RD	ICT_G_E	.50378	2	0.777
ICT_G_E	UI_RD	.56222	2	0.755
		Switzerland		
UI_RD	ICT_A	1.3377	2	0.512
ICT_A	UI_RD	12.039	2	0.002*
UI_RD	GOS	5.6705	2	0.059
GOS	UI_RD	7.0555	2	0.029*
UI_RD	OC	54.262	2	0.000*
OC	UI_RD	.08753	2	0.957
UI_RD	ICT_G_E	15.403	2	0.000*
ICT_G_E	UI_RD	3.8031	2	0.149
		Netherlands		
UI_RD	ICT_A	19.731	2	0.000*
ICT_A	UI_RD	1.2773	2	0.528
UI_RD	GOS	4.5423	2	0.103
GOS	UI_RD	1.196	2	0.550
UI_RD	OC	9.9897	2	0.007*
OC	UI_RD	42.582	2	0.000*
UI_RD	ICT_G_E	22.546	2	0.000*
ICT_G_E	UI_RD	.87521	2	0.646
		China		
UI_RD	ICT_A	3.6595	2	0.160
ICT_A	UI_RD	48.162	2	0.000*
UI_RD	GOS	.10064	2	0.951
GOS	UI_RD	2.7845	2	0.249
UI_RD	OC	9.9482	2	0.007*
OC	UI_RD	14.558	2	0.001*
UI_RD	ICT_G_E	.61658	2	0.735
ICT_G_E	UI_RD	.74958	2	0.687
		Ireland		
UI_RD	ICT_A	7.4771	2	0.024*
ICT_A	UI_RD	9.671	2	0.008*
UI_RD	GOS	4.3659	2	0.113
GOS	UI_RD	1.4806	2	0.477
UI_RD	OC	8.4803	2	0.014*
OC	UI_RD	10.538	2	0.005*
UI_RD	ICT_G_E	25.054	2	0.000*
ICT_G_E	UI_RD	1.4506	2	0.484
		Singapore		

The resulting indicator	Factorial indicator	chi2	df	Prob > chi2
UI_RD	ICT_A	13.362	2	0.001*
ICT_A	UI_RD	1.3871	2	0.500
UI_RD	GOS	20.404	2	0.000*
GOS	UI_RD	.92555	2	0.630
UI_RD	OC	11.599	2	0.003*
OC	UI_RD	98.143	2	0.000*
UI_RD	ICT_G_E	18.658	2	0.000*
ICT_G_E	UI_RD	3.2046	2	0.201
		Belgium		
UI_RD	ICT_A	107.04	2	0.000*
ICT_A	UI_RD	4.5961	2	0.100
UI_RD	GOS	44.264	2	0.000*
GOS	UI_RD	.71994	2	0.698
UI_RD	OC	64.257	2	0.000*
OC	UI_RD	6.6176	2	0.037*
UI_RD	ICT_G_E	26.219	2	0.000*
ICT_G_E	UI_RD	.88451	2	0.643
		Canada		
UI_RD	ICT_A	12.163	2	0.002*
ICT_A	UI_RD	11.629	2	0.003*
UI_RD	GOS	.65597	2	0.720
GOS	UI_RD	1.7263	2	0.422
UI_RD	OC	2.6881	2	0.261
OC	UI_RD	56.158	2	0.000*
UI_RD	ICT_G_E	1.8528	2	0.396
ICT_G_E	UI_RD	4.5198	2	0.104
		Sweden		
UI_RD	ICT_A	3.3801	2	0.185
ICT_A	UI_RD	2.6906	2	0.260
UI_RD	GOS	2.0882	2	0.352
GOS	UI_RD	6.062	2	0.048*
UI_RD	OC	49.66	2	0.000*
OC	UI_RD	4.8807	2	0.087
UI_RD	ICT_G_E	1.2795	2	0.527
ICT_G_E	UI_RD	13.722	2	0.001*
		Finland		
UI_RD	ICT_A	8.9789	2	0.011*
ICT_A	UI_RD	43.008	2	0.000*
UI_RD	GOS	.01827	2	0.991
GOS	UI_RD	19.374	2	0.000*
UI_RD	OC	5.2748	2	0.072
OC	UI_RD	27.222	2	0.000*
UI_RD	ICT_G_E	1.7639	2	0.414
ICT_G_E	UI_RD	60.814	2	0.000*
		Qatar		
UI_RD	ICT_A	9.2409	2	0.010*
ICT_A	UI_RD	13.166	2	0.001*
UI_RD	GOS	7.7231	2	0.021*
GOS	UI_RD	51.392	2	0.000*
UI_RD	OC	51.392	2	0.000*
OC	UI_RD	13.363	2	0.001*
UI_RD	ICT_G_E	2.7479	2	0.253
ICT_G_E	UI_RD	4.9064	2	0.086
		Indonesia		
UI_RD	ICT_A	.70456	2	0.703
ICT_A	UI_RD	29.594	2	0.000*
UI_RD	GOS	19.473	2	0.000*
GOS	UI_RD	9.5577	2	0.008*
UI_RD	OC	5.2637	2	0.072
OC	UI_RD	8.9824	2	0.011*
UI_RD	ICT_G_E	7.1256	2	0.028*
ICT_G_E	UI_RD	35.048	2	0.000*
		Korea		

The resulting indicator	Factorial indicator	chi2	df	Prob > chi2
UI_RD	ICT_A	28.654	2	0.000*
ICT_A	UI_RD	1.0109	2	0.603
UI_RD	GOS	1057	2	0.000*
GOS	UI_RD	357.96	2	0.000*
UI_RD	OC	8.4929	2	0.014*
OC	UI_RD	157.5	2	0.000*
UI_RD	ICT_G_E	6.4962	2	0.039*
ICT_G_E	UI_RD	35.502	2	0.000*
		Denmark		
UI_RD	ICT_A	48.239	2	0.000*
ICT_A	UI_RD	.30173	2	0.860
UI_RD	GOS	46.776	2	0.000*
GOS	UI_RD	.81789	2	0.664
UI_RD	OC	14.753	2	0.001*
OC	UI_RD	.58687	2	0.746
UI_RD	ICT_G_E	5.279	2	0.071
ICT_G_E	UI_RD	12.104	2	0.002*
		Germany		
UI_RD	ICT_A	6.5427	2	0.038*
ICT_A	UI_RD	11.047	2	0.004*
UI_RD	GOS	2.0644	2	0.356
GOS	UI_RD	1.7243	2	0.422
UI_RD	OC	2.7714	2	0.250
OC	UI_RD	2.4341	2	0.296
UI_RD	ICT_G_E	.85831	2	0.651
ICT_G_E	UI_RD	9.207	2	0.010*
		Hong Kong		
UI_RD	ICT_A	4.5502	2	0.103
ICT_A	UI_RD	104.76	2	0.000*
UI_RD	GOS	–	–	–
GOS	UI_RD	–	–	–
UI_RD	OC	17.799	2	0.000*
OC	UI_RD	.88917	2	0.641
UI_RD	ICT_G_E	6.4836	2	0.039*
ICT_G_E	UI_RD	.26085	2	0.878
		Austria		
UI_RD	ICT_A	6.4422	2	0.040*
ICT_A	UI_RD	2.5666	2	0.277
UI_RD	GOS	.76327	2	0.683
GOS	UI_RD	26.06	2	0.000*
UI_RD	OC	7.1771	2	0.028*
OC	UI_RD	7.069	2	0.029*
UI_RD	ICT_G_E	10.495	2	0.005*
ICT_G_E	UI_RD	167.85	2	0.000*
		Luxembourg		
UI_RD	ICT_A	3.5863	2	0.166
ICT_A	UI_RD	1.9479	2	0.378
UI_RD	GOS	4.6862	2	0.096
GOS	UI_RD	37.21	2	0.000*
UI_RD	OC	15.785	2	0.000*
OC	UI_RD	19.962	2	0.000*
UI_RD	ICT_G_E	1.2315	2	0.540
ICT_G_E	UI_RD	26.916	2	0.000*
		Norway		
UI_RD	ICT_A	8.3546	2	0.015*
ICT_A	UI_RD	18.755	2	0.000*
UI_RD	GOS	1.1737	2	0.556
GOS	UI_RD	39.764	2	0.000*
UI_RD	OC	251.4	2	0.000*
OC	UI_RD	8.0682	2	0.018*
UI_RD	ICT_G_E	80.133	2	0.000*
ICT_G_E	UI_RD	13.549	2	0.001*

Note: * causality is established; – - the data did not change during the studied period or were absent; UI_RD – assessment of university-industry R&D collaboration (within the Global Innovation Index); ICT_A – assessment of access to ICT (within the Global Innovation Index); GOS – assessment of government online services (within the Global Innovation Index); OC - assessment of online creativity (within the Global Innovation Index); ICT_G_E – the share of the export of ICT goods in the total export (according to the World Bank data).

Table 2. Generalized results of determining causality in the relationships between the indicator of cooperation between universities and industry in R&D and digitalization indicators

Country	Direction of causality							
	From ICT_A to UI_RD	From UI_RD to ICT_A	From GOS to UI_RD	From UI_RD to GOS	From OC to UI_RD	From UI_RD to OC	From ICT_G_E to UI_RD	From UI_RD to ICT_G_E
USA			+		+	+	+	+
Israel		+		+	+	+		
Switzerland		+		+	+		+	
Netherlands	+				+	+	+	
China		+			+	+		
Ireland	+	+			+	+	+	
Singapore	+		+		+	+	+	
Belgium	+		+		+	+	+	
Canada	+	+				+		
Sweden				+	+			+
Finland	+	+		+		+		+
Qatar	+	+	+	+	+	+		
Indonesia		+	+	+		+	+	+
Korea	+		+	+	+	+	+	+
Denmark	+		+		+			+
Germany	+	+						+
Hong Kong		+	–	–	+		+	
Austria	+			+	+	+	+	+
Luxembourg				+	+	+		+
Norway	+	+		+	+	+	+	+

Note: – - causality cannot be established based on the available data for the studied time period; UI_RD – assessment of cooperation between universities and industry in R&D (within the Global Innovation Index); ICT_A – assessment of access to ICT (within the Global Innovation Index); GOS – assessment of government online services (within the Global Innovation Index); OC – assessment of online creativity (within the Global Innovation Index); ICT_G_E – the share of the export of ICT goods in the total export (according to the data of the World Bank).