“Structural and comparative analysis of R&D funding impact on the level of innovation development: The empirical evidence of GII’s leaders and Ukraine”

AUTHORS	Olena Dobrovolska Ralph Sonntag Wolfgang Ortmanns Iryna Kadyrus Tatyana Rudyanova

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Olena Dobrovolska (Ukraine), **Ralph Sonntag** (Germany), **Wolfgang Ortmanns** (Germany), **Iryna Kadyrus** (Ukraine), **Tatyana Rudyanova** (Ukraine)

STRUCTURAL AND COMPARATIVE ANALYSIS OF R&D FUNDING IMPACT ON THE LEVEL OF INNOVATION DEVELOPMENT: THE EMPIRICAL EVIDENCE OF GII'S LEADERS AND UKRAINE

Abstract

The study aims to determine the influence of the R&D expenditure structure funded by different sectors of stakeholders on the level of innovation development. The data sample involves values of GII and R&D expenditure funded by business, government, higher education, private non-profit sectors, and foreign sources for 10 countries – Ukraine and 9 top countries in GII-2022 for 2011–2020. Pearson/Spearman correlation analysis considers time lags to determine the nature and strength of relationships. For GII's top countries, the relationship with innovation development level is confirmed as direct for funding R&D by business (in 8 from 9 countries), higher education (5 from 7), and foreign sources (5 from 9) with power from moderate to very high and 0-3-year lag. In Ukraine, the direct relationship is for financing by business (very high power and 3-year lag) and foreign sources (high power and 1-year lag). The regression modeling of dependences (Arellano-Bover/Blundell-Bond dynamic model for panel data and linear model for Ukraine) was also applied using STATA 18. In GII's top countries, increasing the share of R&D expenditures financed by business by 1% contributes to increasing GII's score by 0.25%, higher education – 2.47%; government, non-profit sector, and foreign sources – decreasing by 0.89%, 1.68% and 0.81% accordingly. In Ukraine, increasing financing R&D by the government by 1% leads to a similar decrease of GII estimate by 0.19% with a 2-year lag, and the business sector – an increase of 0.16% with a 3-year time lag. Vice versa, in Ukraine, R&D expenditures financed by higher education lead to GII's score decreasing.

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Olena Dobrovolska, Doctor of Economic Sciences, Professor, Department of Finance, Banking and Insurance, Dnipro State Agrarian and Economic University, Ukraine. (Corresponding author)

Ralph Sonntag, Prof. Dr., Rector of the University of Applied Sciences Stralsund, Germany.

Wolfgang Ortmanns, Professor of Business Administration / Management of Banks and Insurance Companies, University of Applied Sciences Dresden, Germany.

Iryna Kadyrus, Ph.D. in Economics, Associate Professor, Department of Marketing, Dnipro State Agrarian and Economic University, Ukraine.

Tatyana Rudyanova, Associate Professor, Department of Computer Science and Software Engineering, University of Customs and Finance, Ukraine.

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JEL Classification H72, M21, M30, O32

INTRODUCTION

Today ICT, artificial intelligence, virtual and augmented reality technologies, e-commerce, the Internet of Things, and blockchain are rapidly developing and becoming an integral part of everyday life (Afaishat et al., 2022; Pakhnenko & Kuan, 2023; Ngo et al., 2023; Chen et al., 2023; Liu, 2023; Mandryka et al., 2023; Ojochide et al., 2023; Blikhar et al., 2023). In such conditions, achieving sustainable development and economic growth is not possible without the innovation development of the country (Melnyk et al., 2022). Developing financial and organizational mechanisms to activate innovation activity is the key driver of economic growth and sustainable development (Berezhnytska et al., 2022). One of the conditions for progressive sustainable development is the creation of a National Program to support the transformation of innovation parks, as well as investment in R&D and new innovational parks (Petrushenko et al., 2021).

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Ukraine took 57th place in the Global Innovation Index 2022, while EU countries demonstrated significantly better results: Sweden – 3rd, the Netherlands – 4th, Germany – 8th, Finland – 9th, Denmark – 10th, and so on (WIPO, 2022). At the same time, EU countries have much higher indicators in R&D funding and differ in funding structure, in particular: in 2020, research and development expenditures in Ukraine were 0.41% of GDP (27.62% – business sector, 48.24% – government sector, 0.09% – higher education sector, 0.06% – private non-profit sector, 23.99% – funds from foreign sources) and, for example, in Germany this indicator was 3.14% of GDP (62.6% – business sector, 29.7% – government sector, 0.4% – private non-profit sector, 7.3% – funds from foreign sources) (World Bank, n.d.d; Eurostat, n.d.).

As the research and development expenditures in Ukraine were only 0.41% of GDP, it was lower 7-8 times than the level of financing R&D in top countries in the Global Innovation Index 2022, in particular in Switzerland – 3.15%, in the United States of America – 3.45%, in Sweden – 3.53%, in Germany – 3.14% and so on (World Bank, n.d.d).

1. LITERATURE REVIEW

The issues of innovation activity and its financing are not new in modern economic science. However, the relevance and urgency of improving innovation policy, as well as the transfer and commercialization of innovations, determine the expediency of further research in this important scientific area.

Triyonowati et al. (2023) substantiated that innovation projects' efficiency can improve companies' efficiency. They proved that innovation performance affects financial results due to science and technology achievements. Innovation efficiency is an optimal combination of innovative contribution and innovative results.

Investments in research and development are defined as the main factor of economic development, which in turn depends on many determinants. Domestic sources of funding are significant for R&D spending (Tvaronaviciene & Burinskas, 2021).

Factors affecting research and development spending in developing countries, among which financial constraints play an important role, were studied by Mallinguh et al. (2022). The results show that approximately 11% of firms investing in R&D export their products/services positively and significantly correlated with R&D expenditures.

In this context, Strielkowski et al. (2022) investigate different instruments and directions of R&D financing, especially at the business level, considering government, business, and foreign sources based on bibliometric, analytical, and trend analyses.

The search for stimulating mechanisms of the relationship and interaction of investment in R&D and bank capital is still relevant. Without bank investments as a source of financing for innovation development, intensive development of the economic system is impossible. However, at the same time, it should be borne in mind that their presence in this form alone is not enough to ensure economic growth (Kozmenko & Vasylieva, 2008).

The impact of countries' research and development expenditures on economic growth was a research subject of Shkarupa et al. (2022). Regression analysis made it possible to obtain an equation for the GDP indicator, taking into account the impact, including R&D expenditures, and to compare the analysis results for the countries of "old" and "new" Europe and Ukraine.

The interconnection of R&D expenditure and economic growth was also studied by Bozkurt (2014), who concluded that the GDP growth rate would increase by 0.26% with an increase of the share of R&D by 1%. The impact of R&D spending on economic growth in the EU was estimated by Sokolov-Mladenović et al. (2016), who showed that a 1% increase in R&D spending would lead to GDP growth by 2.2%.

The impact of various types of R&D expenditure on economic growth was assessed by Ildırar et al. (2016) for OECD countries in 2003–2014. As a result, all types of R&D expenditures were identified as positive factors in case of economic growth.

The impact of R&D expenditure funded by the business sector in the EU countries was assessed by Hunady and Pisar (2020), who focused on a long-term, positive causal effect of R&D expenditure in the business area because according to the authors, this indicator is the most crucial part in the innovation system.

In turn, Šimáková and Pražák (2023) assessed the impact of R&D investments and expenditures on the performance of large companies using regression analysis for 2010–2018. The study concluded that the growth of R&D expenditures and investments had a negative impact on the profitability of firms in the year of implementation.

Çimen and Sağlam (2019) focused on the structural aspect and testing of the structural efficiency of internal R&D spending (for the business enterprise sector, the government sector, the higher education sector, and the private non-profit sector) in the EU for 2000–2017 based on VAR. According to the empirical results, a two-way causal relationship between innovation and economic growth was established. It was substantiated that the business entrepreneurial sector contributes most to innovation and economic growth, and the private non-profit sector is the most endogenous.

It is important not only to consider R&D spending as one aggregate indicator but also to consider the contribution of various R&D funding entities. Since firms are the main innovative actors that create the largest number of innovations in the national innovation system, Pisár et al. (2020) focused on the financing of business R&D. Their results indicate that the main source of funding for business research and development is the business sector, followed by government support and resources from abroad.

Erins and Vitola (2014) analyzed whether changes in spending levels in any sector of R&D significantly impact indicators of the effectiveness of scientific research work or whether an increase in spending in a specific sector of R&D contributes to the improvement of indicators of R&D efficiency. The authors concluded that increased spending in higher education and the public sector would likely increase the number of doctoral students and research staff. In the case of high-tech exports and the number of patent applications, there is no strong relationship between these indicators and spending levels, so improving these indicators must be achieved through targeted public policies.

Having analyzed and summarized the scientific output on the issue of financing R&D costs, it should be noted that in most publications, either the aggregate indicator of costs or their structure is investigated in the context of descriptive statistics or assessment of its impact on economic growth, but not on countries' innovational development. So, a structural and comparative analysis of the impact of R&D funding by different economic sectors on the level of innovation development (as a total score of the Global Innovation Index) was not carried out. Thus, the study aims to ground the influence of the R&D expenditure structure funded by different stakeholder sectors on the innovation development level.

2. METHODS

The research methodology involves basic (abstraction, synthesis, analysis, and comparison) and specific scientific methods (correlation-regression analysis, econometric and mathematical modeling).

Correlation analysis based on Pearson and Spearman methods is used to confirm the relationships between the level of innovation development and shares of R&D expenditure funded by different stakeholders: business, government, higher education, private non-profit sectors, and foreign sources, taking into account possible lags in time when interconnections are the most significant (Pearson, 1896; Pearson & Filon, 1898; Spearman, 1904; Stata, n.d.b; Stata, n.d.d). Before conducting correlation analysis, Shapiro-Wilk test is applied to identify whether the data are normally distributed (Shapiro & Wilk, 1965; Shapiro & Francia, 1972; Stata, n.d.c).

Regression analysis is applied to formalize and estimate the influence of the funding structure of R&D expenditures on the level of innovation development. For the panel of 10 countries, i.e.,

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9 leading countries in GII-2022, in particular, Denmark, Finland, Germany, the Netherlands, the Republic of Korea, Sweden, the United Kingdom, Switzerland, and the United States of America (WIPO, 2022), and Ukraine for the period 2011–2020, Arellano-Bover/Blundell-Bond system dynamic linear panel-data model is built (Arellano & Bover, 1995; Blundell & Bond, 1998; Blundell et al., 2000; Stata, n.d.a). For Ukraine, a linear regression model is also built. All calculations are made in the STATA 18 software package.

The information base involves statistical data from INSEAD, WIPO, Eurostat, World Bank, and State Statistics Service of Ukraine according to the following indicators:

- the level of innovation development as a value of the general score of the Global Innovation Index (GII) (WIPO, 2022; WIPO, n.d.; INSEAD, 2011; INSEAD & WIPO, 2012);
- gross domestic expenditures on R&D (GERD) by the source of funding: government, business enterprise, higher education, private non-profit sectors, and foreign sources (Eurostat, n.d.; Ukrstat, n.d.);
- research and development expenditure as a percent of GDP, % (RD) (World Bank, n.d.d);
- net inflows of foreign direct investment as a percentage of GDP, % (FDI) (World Bank, n.d.a);
- the rate of labor force participation as a percentage of the total population ages 15-64, % (L) (World Bank, n.d.c);
- the level of inflation as annual GDP deflator, % (I) (World Bank, n.d.b).

3. RESULTS AND DISCUSSION

R&D expenditures differ significantly from country to country, as their structure does. Figure 1 shows the results of a dynamic analysis of R&D expenditures in GII's top countries and in Ukraine, including a comparison with the average level of R&D expenditures in the European Union and the world.

In Ukraine, the share of R&D expenditures in GDP is significantly lower not only than the level of the leading countries in the GII but also than

Source: World Bank (n.d.d).

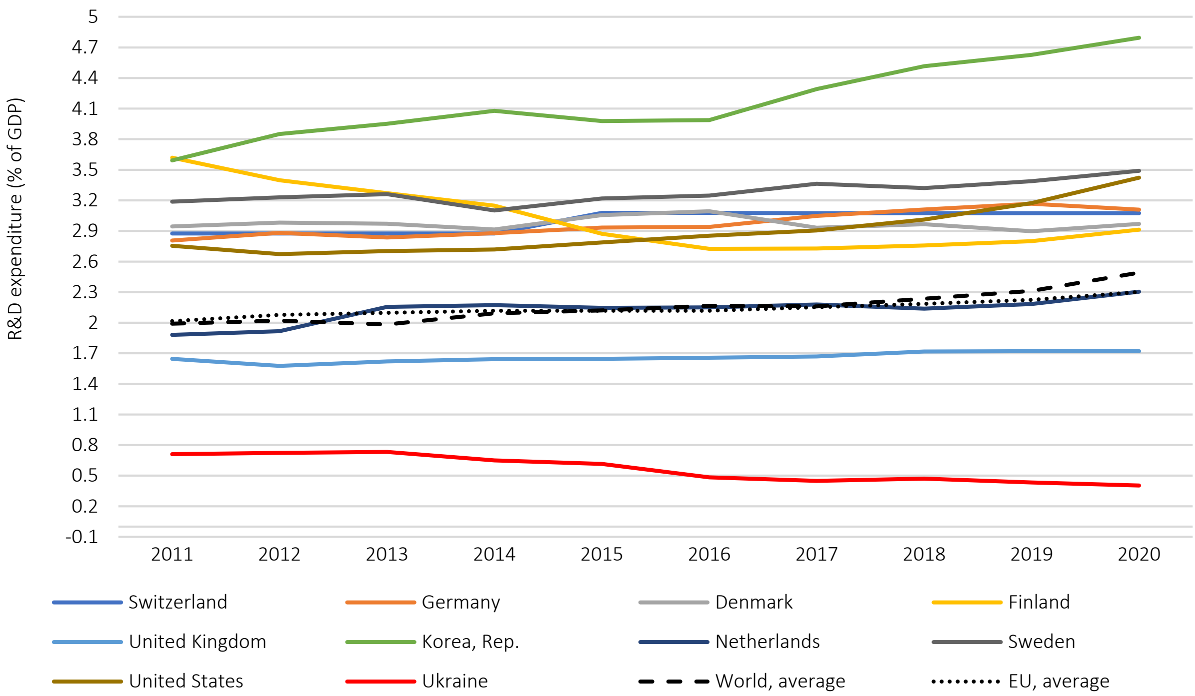

Figure 1. Comparison of dynamics of R&D expenditures in GII's top countries and in Ukraine compared with an average level of R&D expenditures in the EU and all over the world

Source: WIPO (n.d), Eurostat (n.d.), Ukrstat (n.d.).

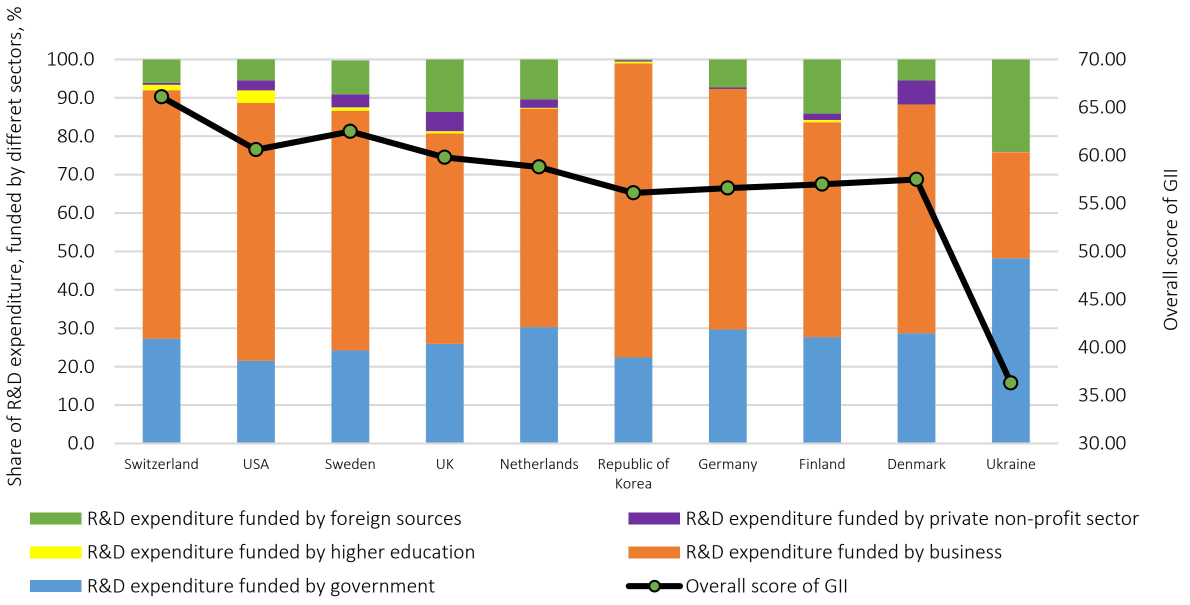

Figure 2. Structural analysis of R&D expenditure funded by different sectors of stakeholders in GII's top countries and in Ukraine in 2020, taking into account a value of the general score of GII

the world average level (as well as the average level for EU countries, which is important for understanding the country's aspirations to join the EU). At the same time, a downward trend is generally observed in Ukraine, in contrast to other studied countries.

Figure 2 presents the results of the structural analysis of R&D expenditure funded by different sectors of stakeholders (histogram) and the level of innovation development as a value of the general score of GII (line).

The great shares in the financing structure of R&D expenditure are allocated to the government and business sectors, but it is obvious that in different countries, the proportional ratio of the elements of the structure differs significantly.

A correlation analysis confirms and characterizes the relationship between financing of R&D expenditures by various stakeholder sectors and the level of innovation development. However, before conducting the correlation analysis, the Shapiro-Wilk test is performed to check whether the data

Table 1. Shapiro-Wilk test

Country name	Prob>z				
	RD_G	RD_B	RD_HE	RD_NS	RD_FS
Switzerland	0.37352	0.22644	0.36228	0.24859	0.98079
The United States of America	0.46082	0.87669	0.44362	0.00021 *	0.16180
Sweden	0.33211	0.20530	0.28533	0.25267	0.80268
The United Kingdom	0.03810 *	0.77125	0.01290 *	0.20772	0.18566
The Netherlands	0.27193	0.07755	0.00271 *	0.00911 *	0.60910
The Republic of Korea	0.79990	0.76695	0.62634	0.23626	0.19372
Germany	0.21638	0.00403 *	n/a	0.84240	0.52002
Finland	0.33704	0.14811	0.49149	0.27037	0.93489
Denmark	0.54345	0.23747	n/a	0.62468	0.28478
Ukraine	0.80528	0.87380	0.70825	0.61791	0.51298

Note: * – the data do not follow a normal distribution (Prob>z is less than 0.05); n/a – not available due to constant data or lack of data; RD_G – the share of R&D expenditure funded by the government sector; RD_B – the share of R&D expenditure funded by the business sector; RD_HE – the share of R&D expenditure funded by the higher education sector; RD_NS – the share of R&D expenditure funded by the non-profit organization sector; RD_FS – the share of R&D expenditure funded by foreign sources.

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Table 2. Correlation analysis of the relationship between financing of R&D expenditures by various stakeholder sectors and the level of innovation development

Country	Correlation coefficient (r) / time lag (t) when it is the most significant									
	GII									
	RD_G		RD_B		RD_HE		RD_NS		RD_FS	
	r	t	r	t	r	t	r	t	r	t
Switzerland	0.53	0	0.32	0	0.49	0	–0.38	0	–0.47	0
The United States of America	–0.87	0	0.80	0	0.67	1	0.87	2	0.72	0
Sweden	0.63	3	0.31	3	0.57	3	0.66	2	–0.94	3
The United Kingdom	0.88	0	–0.79	3	0.82	0	–0.80	3	0.83	2
The Netherlands	–0.64	0	0.51	0	0.29	0	–0.43	1	0.33	1
The Republic of Korea	–0.65	0	0.56	0	–0.58	0	–0.84	0	0.69	0
Germany	–0.85	0	0.36	0	n/a	n/a	–0.72	2	0.79	2
Finland	–0.62	3	0.62	1	–0.79	1	–0.74	3	–0.50	1
Denmark	0.91	3	0.35	1	n/a	n/a	–0.51	1	–0.71	3
Ukraine	–0.71	2	0.86	3	–0.81	3	–0.71	3	0.60	1

Note: n/a – not available due to constant data or lack of data; GII – a value of the general score of the Global Innovation Index; RD_G – the share of R&D expenditure funded by the government sector; RD_B – the share of R&D expenditure funded by the business sector; RD_HE – the share of R&D expenditure funded by the higher education sector; RD_NS – the share of R&D expenditure funded by the non-profit organization sector; RD_FS – the share of R&D expenditure funded by foreign sources.

on the factor variables are normally distributed in order to subsequently choose the necessary method for calculating the correlation coefficient. The results of the Shapiro-Wilk test are shown in Table 1.

The data do not follow a normal distribution (Prob>z is less than 0.05). So, if the test result is less than 0.05, then the Spearman method should be used; otherwise, the Pearson method should be used. The results of correlation analysis are generalized in Table 2.

A positive sign of the correlation coefficient characterizes a direct (positive) relationship, a negative one – an inverse (negative) relationship between the investigated indicators. The value of the correlation coefficient is interpreted as follows: $0 < |r| \leq 0.19$ – low correlation; $0.2 < |r| \leq 0.49$ – moderate correlation; $0.5 < |r| \leq 0.79$ – high correlation; $0.8 < |r| \leq 1$ – very high correlation.

So, in GII's top countries, the relationship between innovation development (as an overall score of GII) and R&D expenditures funded by different sectors (share of every source in total R&D expenditures) is confirmed in the following way:

1) with the share of R&D expenditure funded by the government sector it is inverse (negative) in most sample countries (5 out of 9 countries), mostly without time lag and high or very high power;
2) with the share of R&D expenditure funded by the business sector – direct (positive) in 8 out of 9 sample countries with power from moderate to very high and time lag from 0 to 3 years;
3) with the share of R&D expenditure funded by the higher education sector – direct in 5 out of 7 countries, for which it was possible to confirm correlation, with power from moderate to very high and time lag from 0 to 3 years;
4) with the share of R&D expenditure funded by the non-profit organization sector – inverse in 7 out of 9 sample countries with power from moderate to very high and time lag from 0 to 3 years;
5) with the share of R&D expenditure funded by foreign sources – direct in 5 out of 9 countries, with power from moderate to very high and time lag from 0 to 2 years.

Therefore, in GII's top countries, the relationship with the level of innovation development is confirmed as direct (positive) in the case of funding R&D spending by business, higher education, and foreign sources.

In turn, in Ukraine, the relationship between the level of innovation development and the share of R&D expenditure funded by the government sector is inverse (negative) with high power and 2-year lag, with the share of R&D expenditure funded by the business sector – direct (positive) with very high power and 3-year lag, with the share of R&D expenditure funded by the higher education sector – inverse (negative) with very high power and 3-year lag, with the share of R&D expenditure funded by the non-profit organization sector – inverse (negative) with high power and 3-year lag, and with the share of R&D expenditure funded by foreign sources – direct (positive) with high power and 1-year lag.

So, in Ukraine, the direct relationship with changing the level of innovation development is confirmed only in the case of financing R&D expenditure by the business sector and foreign sources.

To formalize and determine the influence of the funding structure of R&D expenditures on the level of innovation development, the Arellano-Bover/Blundell-Bond systemic dynamic panel data model was built. Besides, in addition to the above indicators of the level of innovation development (as the value of the general score of the Global Innovation Index) (GII) and shares of R&D expenditure funded by different stakeholders (as a percent of total R&D expenditure) (RD_G, RD_B, RD_HE, RD_NS, RD_FS), the following additional indicators were added to the model to increase its quality:

- net inflows of foreign direct investment as a percentage of GDP, % (FDI);
- the rate of labor force participation as a percentage of the total population ages 15-64, % (L);
- the level of inflation as annual GDP deflator, % (I).

This systemic dynamic linear model of panel data estimates assumes that panel-level unobserved effects correlate with time lags of the dependent variable. This estimator takes into account parameters of autoregression and the ratio of the variance of the effect at the panel level to the variance of the idiosyncratic error, the influence of the values of the outcome variable of past periods is also taken into account. This method assumes no autocorrelation in the idiosyncratic errors and requires that the panel-level effects be uncorrelated with the first difference of the first observation of the dependent variable. The following formula is used to construct the model (Arellano & Bover, 1995; Blundell & Bond, 1998; Blundell et al., 2000; Stata, n.d.a):

$$Y_{it} = \sum_{j=1}^{p} a_j y_{i,t-j} + x_{it}\beta_1 + w_{it}\beta_2 + v_i + \varepsilon_{it}, \quad (1)$$
$$i = 1,\ldots,N, \; t = 1,\ldots,T_i$$

where the a_j are p parameters to be estimated; x_{it} is a $1\times k_1$ vector of strictly exogenous covariates; β_1 is a $k1\times 1$ vector of parameters to be estimated; w_{it} is a $1\times k_2$ vector of predetermined or endogenous covariates; β_2 is a $k_2\times 1$ vector of parameters to be estimated; v_i are the panel-level effects; ε_{it} are independent and identically distributed variables over the whole sample with variance σ^2.

Thus, the rate of labor force participation is used as a predetermined variable. All other investigated variables are considered endogenous. The results of regression modeling are shown in Table 3.

The level of significance of the model (Prob > chi2 = 0.0000) and Wald test (Wald chi2(27) = 2468.14) grounded the quality of the built model. The coefficients for investigated indicators with a certain time lag are chosen based on the level of significance of z-statistics (P>|z| is not more than 0.05 or 95% probability).

The obtained regression model is the following:

$$\begin{aligned} GII &= 0.49GII_{t-1} - 0.89RD\_G + \\ &+0.25RD\_B_{t-3} + 2.47RD\_HE - \\ &-1.68RD\_NS - 0.81RD\_FS + \\ &+0.06FDI_{t-2} - 0.12I_{t-1} + 1.35L + 74.88, \end{aligned} \quad (2)$$

where *GII* – a value of the general score of the Global Innovation Index; *RD_G* – the share of R&D expenditure funded by the government sector; *RD_B* – the share of R&D expenditure funded by the business sector; *RD_HE* – the share of R&D expenditure funded by the higher education sector; *RD_NS* – the share of R&D expenditure funded by the non-profit organization sector; *RD_FS* – the share of R&D expenditure funded by foreign

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Table 3. Systemic dynamic panel data modeling of the influence of funding structure of R&D expenditures on the level of innovation development

GII	Coefficient	Std. err.	z	P>|z|	[95% conf. interval]	
Wald chi2(27) = 2468.14 Prob > chi2 = *0.0000*						
GII						
L1.	*.4934308*	.1176945	4.19	0.000	.2627537	.7241078
RD_G						
L0.	–.8908738	.2685607	–3.32	0.001	–1.417243	–.3645046
RD_B						
L0.	–.8815687	.2335329	–3.77	0.004	–1.339285	–.4238527
L1.	.168335	.1336747	1.26	0.208	–.0936626	.4303326
L2.	–.1932472	.1458535	–1.32	0.185	–.4791149	.0926204
L3.	.2521144	.0875851	2.88	0.000	.0804508	.4237781
RD_HE						
L0.	2.47119	1.072932	2.30	0.021	.3682817	4.574099
L1.	–2.304944	1.585853	–1.45	0.146	–5.41316	.803271
L2.	.022918	1.566301	0.01	0.988	–3.046975	3.092811
L3.	.0241785	1.217966	0.02	0.984	–2.362992	2.411348
RD_NS						
L0.	–1.686249	.8197247	–2.06	0.040	–3.29288	–.079618
L1.	–.4480344	.9567022	–0.47	0.640	–2.323136	1.427068
L2.	.8024947	1.22779	0.65	0.513	–1.603929	3.208918
L3.	.7927992	1.079483	0.73	0.463	–1.322948	2.908546
RD_FS						
L0.	–.8081487	.2345178	–3.45	0.001	–1.267795	–.3485022
L1.	.0910643	.1528871	0.60	0.551	–.2085889	.3907174
L2.	.0008932	.1095706	0.01	0.993	–.2138613	.2156477
FDI						
L0.	–.0201259	.0139697	–1.44	0.150	–.047506	.0072542
L1.	.0128699	.0128528	1.00	0.317	–.0123212	.038061
L2.	.0617767	.0137308	4.50	0.000	.0348648	.0886886
L3.	–.0344554	.0230005	–1.50	0.134	–.0795356	.0106248
I						
L0.	–.0498016	.0440245	–1.13	0.258	–.136088	.0364848
L1.	–.1204008	.0386944	–3.11	0.002	–.1962404	–.0445612
L2.	.0278415	.0417907	0.67	0.505	–.0540669	.1097498
L3.	–.036139	.0455348	–0.79	0.427	–.1253855	.0531075
L						
L0.	1.348351	.3099344	4.35	0.000	.7408902	1.955811
L1.	–.9975934	.3165027	–3.15	0.002	–1.617927	–.3772596
_cons	74.88442	23.95766	3.13	0.002	27.92826	121.8406

Note: L0, L1, L2, L3 – without time lag, 1-year, 2-year, and 3-year time lags; GII – a value of the general score of the Global Innovation Index; RD_G – the share of R&D expenditure funded by the government sector; RD_B – the share of R&D expenditure funded by the business sector; RD_HE – the share of R&D expenditure funded by the higher education sector; RD_NS – the share of R&D expenditure funded by the non-profit organization sector; RD_FS – the share of R&D expenditure funded by foreign sources; FDI – net inflows of foreign direct investment as a percentage of GDP; L – the rate of labor force participation as a percentage of the total population ages 15-64; I – the level of inflation as annual GDP deflator.

sources; *FDI* – net inflows of foreign direct investment as a percentage of *GDP*; *L* – the rate of labor force participation as a percentage of the total population ages 15-64; *I* – the level of inflation as annual *GDP* deflator.

So, in GII's leading countries, with an increase in the share of R&D expenditures financed by the government by 1%, the GII overall estimate falls by an average of 0.89% without time lag. Increasing the share of R&D expenditures financed by the business sector by 1% contributes to increasing the GII overall estimate by an average of 0.25% with a 3-year time lag. With an increase in the share of R&D expenditures financed by higher education by 1%, the GII overall also increases – by

Table 4. Linear regression modeling of the influence of funding structure of R&D expenditures on the level of innovation development in Ukraine

Factor variable	Coefficient	t	P>|t|	Prob > F	R–squared	Regression model
L2RD_G	–.1881895	–2.48	0.048	0.0477	0.5065	$GII = 45.17 - 0.19RD\_G_{t-2}$
cons	45.17222	13.29	0.000			
L3RD_B	.160369	3.73	0.014	0.0136	0.7356	$GII = 31.82 + 0.16RD\_B_{t-3}$
cons	31.82089	23.11	0.000			
L3RD_HE	–16.1	–3.11	0.027	0.0266	0.6589	$GII = 39.66 - 16.1RD\_HE_{t-3}$
cons	39.66	43.18	0.000			
L3RD_NS	–12.83333	–2.25	0.075*	0.0746*	0.5024	$GII = 37.45 - 12.83RD\_NS_{t-3}$
cons	37.45	–2.25	0.075			
LRD_FS	.296088	1.98	0.088*	0.0882*	0.3589	$GII = 30.26+0.29RD\_FS_{t-1}$
cons	30.26542	9.30	0.000			

Note: * – obtained results are not statistically significant for 95% probability level; L2, L3 – 2-year and 3-year time lags; GII – a value of the general score of the Global Innovation Index; RD_G – the share of R&D expenditure funded by the government sector; RD_B – the share of R&D expenditure funded by the business sector; RD_HE – the share of R&D expenditure funded by the higher education sector; RD_NS – the share of R&D expenditure funded by the non-profit organization sector; RD_FS – the share of R&D expenditure funded by foreign sources.

an average of 2.47% without time lag. The growth of shares of R&D expenditure funded by the non-profit organization sector and foreign sources contributes to decreasing the GII overall estimate by 1.68% and 0.81% without time lag, respectively.

In comparison for Ukraine for 2011–2020, linear regression models were also built to estimate time series data. The results are presented in Table 4.

So, in Ukraine, with an increase in the share of R&D expenditures financed by the government by 1%, the GII overall estimate falls by an average of 0.19% with a 2-year time lag. Increasing the share of R&D expenditures financed by the business sector by 1% contributes to increasing the GII overall estimate by an average of 0.16% with a 3-year time lag. In turn, with an increase in the share of R&D expenditures financed by higher education by 1%, the GII overall estimate decreases by an average of 16.1% with a 3-year time lag. For other sources in the funding structure of R&D expenditure, the quality of built models was not confirmed, and the obtained results were not statistically significant for a 95% probability level.

Both in GII's top countries and in Ukraine, an increase in the share of R&D expenditure funded by the government leads to a decrease of innovation level (overall score of GII), and an increase in the share of R&D expenditure funded by the business sector leads to an increase of innovation level. A difference in the compositional structure of R&D financing at the expense of the higher education sector was revealed: in the GII's top countries, an increase in the share of expenses financed by higher education leads to an increase in the level of innovative development, while in Ukraine – to a decrease. Besides, during the studied period, it was not possible to formalize the impact of financing R&D by the non-profit sector and by foreign sources with a 95% probability level. The above shows that in Ukraine and the GII's top countries, the increase in the amount of R&D funding at the expense of individual stakeholders affects the level of innovative development in different ways, which can be explained by the difference in the regulatory and legal regulations of this area and the practical transfer and implementation of innovations, especially in the field of education.

The influence of different sources of R&D financing for a panel of countries with similar economic levels and Ukraine was also studied by Rzayev and Samoilikova (2020) but on economic growth, not on the level of innovation development. Nevertheless, the study determined a similar direction of the impact of the share of government and business R&D financing. In particular, it was stated that an increase in the share of R&D expenditures funded by the government leads to a decrease in GDP growth per capita by 0.15% without time lag, in the case of the business sector – to an increase of 0.13% with a time lag of 2 years.

The relationship between R&D expenditures and the GII was also investigated by M. Dritsaki and C. Dritsaki (2023). They revealed a long-term positive relationship. However, they did not estimate the

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funding structure of R&D expenditures, paying attention only to the total volume of R&D expenditures.

The impact of gross R&D expenditures per capita on the aggregate value of GII was also studied by Ivanová and Žárská (2023) but without an emphasis on the funding structure of R&D expenditures. Besides, their results cover only V4 countries.

Some scientists exclusively analyzed specific sources of funding for R&D expenditures and their impact at different levels. Thus, Ali-Yrkkö (2005) studied the influence of government and business financing of R&D in companies. The results proved that government funding of R&D does not displace privately funded R&D, and receiving a positive decision before receiving public funds for R&D increases private financing of R&D.

The potential impact of public financing of R&D expenditures in the context of strategies for companies seeking to combine internal and external R&D expenditures was substantiated by Afcha and López (2014). The study positively assessed the impact of state funding of R&D through the provision of subsidies on the structure of R&D expenditures and especially on the decision to conduct R&D both domestically and abroad.

Berman (1990) tested the effect of exclusively university R&D funded by industry on increased technological innovation based on data from 1953 to 1986. At the same time, the study also looked at time lags and found that increased R&D spending had an average lag of five years.

CONCLUSION

The purpose of the paper was to confirm and estimate the influence of the R&D expenditure structure funded by different sectors of stakeholders on the level of innovation development. This aim was achieved using correlation (Pearson/Spearman) and regression analyses (Arellano-Bover/Blundell-Bond systemic dynamic panel data model). In GII's top countries, the relationship with the level of innovation development is confirmed as direct (positive) in the case of funding R&D spending by business (in 8 out of 9 countries with power from moderate to very high and time lag from 0 to 3 years), higher education (in 5 out of 7 countries with power from moderate to very high and time lag from 0 to 3 years) and foreign sources (in 5 out of 9 countries, with power from moderate to very high and time lag from 0 to 2 years). In Ukraine, the direct relationship with changing the level of innovation development is confirmed only in the case of financing R&D expenditure by the business sector (very high power and a 3-year lag) and foreign sources (high power and a 1-year lag).

Both in GII's top countries and in Ukraine, an increase in the share of R&D expenditure funded by the government leads to a decrease in innovation level (in GII's top countries – by an average of 0.89% without time lag; in Ukraine – 0.19% with a 2-year time lag). An increase in the share of R&D expenditure funded by the business sector leads to an increase in innovation level (in GII's top countries – 0.25% with a 3-year time lag; in Ukraine – 0.16% with a 3-year time lag). A difference in the compositional structure of R&D financing at the expense of the higher education sector was revealed: in the GII's top countries, an increase in the share of expenses financed by higher education leads to an increase in the level of innovation development (2.47% without time lag), while in Ukraine – to a decrease (16.1% with 3-year time lag). In Ukraine, for other sources in the funding structure of R&D expenditure, the quality of built models was not confirmed, and the obtained results were not statistically significant for a 95% probability level. On the panel level, it was found that the growth of shares of R&D expenditure funded by the non-profit organization sector and foreign sources contributes to decreasing the GII overall estimate by 1.68% and 0.81% without time lag, respectively.

Therefore, in Ukraine and the GII's top countries, the increase in the amount of R&D funding at the expense of individual stakeholders affects the level of innovation development in different ways, which can be explained by the difference in the regulatory and legal regulation of this area and the practical transfer and implementation of innovations, especially in the field of education.

Further research on this scientific question should expand the list of sample countries, covering not only the leaders in GII but also countries with a low indicator, as well as expanding a period to improve the quality of the results obtained.

AUTHOR CONTRIBUTIONS

Conceptualization: Olena Dobrovolska, Iryna Kadyrus.
Data curation: Olena Dobrovolska, Wolfgang Ortmanns, Tatyana Rudyanova.
Formal analysis: Olena Dobrovolska, Ralph Sonntag, Tatyana Rudyanova.
Funding acquisition: Olena Dobrovolska, Wolfgang Ortmanns, Iryna Kadyrus, Tatyana Rudyanova.
Investigation: Olena Dobrovolska, Ralph Sonntag, Iryna Kadyrus.
Methodology: Olena Dobrovolska, Ralph Sonntag, Wolfgang Ortmanns, Iryna Kadyrus.
Project administration: Olena Dobrovolska, Tatyana Rudyanova.
Resources: Olena Dobrovolska, Ralph Sonntag, Iryna Kadyrus.
Software: Olena Dobrovolska, Ralph Sonntag.
Supervision: Olena Dobrovolska, Wolfgang Ortmanns, Iryna Kadyrus. Tatyana Rudyanova.
Validation: Olena Dobrovolska, Iryna Kadyrus, Tatyana Rudyanova.
Visualization: Olena Dobrovolska, Ralph Sonntag.
Writing – original draft: Olena Dobrovolska, Ralph Sonntag, Wolfgang Ortmanns, Iryna Kadyrus.
Writing – review & editing: Olena Dobrovolska, Wolfgang Ortmanns, Tatyana Rudyanova.

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