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GOVERNMENT AND BUSINESS FUNDING OF SOURCES OF FUNDS FOR R&D AT UNIVERSITIES: COMPLEMENTS OR SUBSTITUTES?

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Abstract

The paper examines the relationship between different sources of funding for research and development at universities. Following the European Commission methodology, we distinguished between government, business and abroad financing of research and development (R&D) in the higher education sector. The paper aims to test short-run and long-run relationships between different funding sources. We are focused on the relationship between government and business funding of R&D at universities. Based on panel data for EU countries, we applied the Granger causality tests and General methods of moments to examine short-run causality and cointegrating regression to search for potential long-run relationships. Our results suggest that government funding of R&D act as a complement to business funding. Hence, rising government financial support for research in higher education can, lead to higher funding from the business sector. Founding from abroad seems to have a similar effect on business funding in the long run.

Keywords*: research and development; funding; higher education; university; Europe.*

JEL classification*: C23, I22.*

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1. Introduction

The intensity of research and development is seen as one of the most important factors supporting innovation in the country. These issues are closely related to higher education institutions and their activities. Especially research in universities is a crucial knowledge-generating factor for the innovation process. This is also true in the case of basic research. According to the Frascati Manual basic research is considered as experimental or theoretical work undertaken primarily to acquire new knowledge without any particular application or use in view (OECD 2015). However, usually, more emphasis is on the direct impact of R&D expenditures in higher education on business activities. Universities are more motivated to foster links with businesses and improve technology transfer channels. This is often referred to as their "third mission" (Etzkowitz et al. 2000). Moreover, in the recent decade, there has been arising political pressure on universities to improve their connections with businesses and try to enhance their research funding options due to the constraints of public budgets (Muscio, Quaglione, and Vallanti 2013). Cooperation between academia and business is also very important when developing business innovation partly or fully based on previous research and development (R&D) expenditures in the higher educational sector. The government still finances a significant share of R&D activities in higher education in most countries. Despite this fact, business funding in higher education is also important. Universities are directly motivated to examine applied research tasks that are important for a business. They have an additional financial resource based on their research activities for the business sector. This could lead to a useful exchange of information between academia and business in several areas. Moreover, firms can use already developed research infrastructure and human capital funded mostly from the public sector, which could reduce their R&D costs. Based on the field the R&D expenditures can be classified into natural sciences, engineering and technology, medical sciences, social science, and humanities. Another classification considers the sector of usage as well as the sector from which financial sources come. Using this approach R&D and classified into business enterprise sector, government, higher education, and privet non-profit sector. Moreover, non-domestic R&D funds are mostly labelled as "From abroad" or "Rest of the world" (OECD 2015). Our analysis is focused on the higher education sector as the sector of usage while considering different sources of funds for other sectors.

The paper aims to identify potential short-run and long-run relationships between different sources of funds for R&D expenditures at universities.

Following the European Commission methodology, we distinguished between government, business and abroad financing of R&D activities in the higher education sector. We examine the structure of funds for R&D at universities and the development of the most significant financial sources.

Due to the importance of cooperation between business and academia, there is still a growing need for increasing business R&D funding of research activities in higher education. Hence, we focus our attention, especially on this source of funds for R&D in higher education. Based on the paper's goal, we tested the assumed long-run and short-run causalities between different sources of funds. We aim to test whether the changes in government R&D funding and funding from abroad could affect business funding of R&D in higher education.

On the one hand, we assume that better government financial R&D support for academia could result in better basic research and better research infrastructure, which could, especially in the long run, lead to more applied research and generate more funding from the business sector. Thus, better public funding of research could improve the quality of research at universities and positively affect the probability of cooperation with the private sector and participation in research directly usable by the business. This potential effect could likely be especially evident in the long run. If the government increases its funding, there will likely be some delays in adoption. Increasing the research infrastructure and human capital takes some time.

Furthermore, improvements in academia-business cooperation that can potentially lead to business funding of R&D in higher education takes time. The effect in the opposite direction is true when the government decides to decrease its funding. Our main research question is whether government funding and funding from abroad decrease or increase the business funding of R&D in higher education. Based on the main aim, we also constructed two main research hypotheses, which we present in the text.

H1: There is a positive effect of government funding of higher education research on business funding of higher education research. This hypothesis will be tested based on its two components which uses different time frame as follows:

H1a: There is a short-run positive effect of government funding of higher education research on business funding of higher education research.

H1b: There is a long-run positive effect of government funding of higher education research on business funding of higher education research.

H2: There is a positive effect of financial sources from abroad on business funding of higher education research. Again, this hypothesis has two partial components as follows:

H2a: There is a short-run positive effect of financial sources from abroad on business funding of higher education research.

H2b: There is a long-run positive effect of financial sources from abroad on business funding of higher education research.

The paper is organized as follows. After the brief introduction, in the second chapter, relevant literature is discussed. Research hypotheses are developed based on the literature review in the third chapter. The applied methodology, along with a description of observed variables, is described in the fourth chapter. The analysis results are presented and discussed in the fifth chapter, whereas the sixth chapter concludes the paper.

2. Literature review

Research is considered one of the main missions of higher education, and its intensity and focus can be significantly affected by funding and financial motivation. According to Bégin-Caouette, Schmidt, and Field (2017), all types of funding streams appear to positively affect the academic output based on the sample of Nordic Countries. However, competitive funding schemes have, in general, the most positive consequences. They also stated that further research on interactions between different funding sources could be beneficial.

Basic research performed mainly by universities enhances the knowledge available to society. However, as mentioned by Tavoletti (2010), funding sources for universities are almost entirely domestic and primarily governmental in most countries. Despite some recent shifts to business funding, government funding is still the most important financial source for university research. Due to this fact, the criteria and targets of public funding play the most important role in setting the research aims and general focus of university research (Auranen and Nieminen 2010). Moreover, public budget limitations and rising focus on efficiency pose more stress on monitoring and evaluation of research outputs in higher education (Jonkers and Zacharewicz 2016).

According to Mohrman, Ma, and Baker (2008), universities are trying to diversify their financial sources. Except for government financial support, they are still often looking for funding from businesses, competitive grants, and the creation of commercially successful businesses as spin-offs of research enterprises.

There is a vivid discussion in the economic literature about the potential consequences of the shift from government funding towards business funding of R&D in higher education. Some authors argue that this change in financial resources could lead to unintended negative consequences, such as decreased basic research output (Geuna 1999). On the contrary, more studies emphasize the positive effect of business academic research funding. More financial resources from the business sector may lead to research on a more socially relevant research topic. This will lead to more applicable knowledge, which seems necessary for changing the global knowledge economy (e.g. Etzkowitz and Leydesdorff 2000). Perkmann and Walsh (2009) showed that industry involvement in university research has several benefits for the production of scientific research under certain conditions. According to Harman (2001), academics in Australia mostly considered university-industry collaboration as a useful opportunity to enhance resources and career opportunities.

On the contrary, academics are concerned about their research autonomy and other undesirable consequences. Mohrman, Ma, and Baker (2008) argue that research universities in the 21st century should have diversified funding. Hence, we can say that increasing business funding for research in higher education will likely have several positive consequences for both academia and business. If the substitution effect is present, the cuts in government financial support could motivate universities to cooperate on research contracts with the private sector. Beath et al. (2003) stated that universities have incentives to focus more on applied research and consultancies with the business sector under limited financial support. This will also generate additional financial resources and help them to ease their budget constraints. However, most research-oriented universities cannot shift from government to business financial support without serious problems. Altbach and Peterson (2009) stated that universities with an emphasis on basic science could be very difficult after the cuts because non-governmental players are more interested in research with quick applicability to the market. Furthermore, Strehl, Reisinger, and Kalatschan (2007) found that cuts in government funding of universities have a negative effect on basic R&D and the quality of research in general.

Economic literature has not discussed the relationship between different financial sources of university research. Hence, our research aims especially on this topic. However, several studies have focused on similar research problems using a different methodology. Especially the potential relationship between government and business funding is often discussed. The basis of this discussion originates from the question about the potential substitution or complementarity of different R&D funding sources in general. Several studies examine the relationship between business and government R&D funding concerning firms and commercial innovation (e.g. David, Hall, and Toole 2000). David, Hall, and Toole (2000) support the existence of complementarity between these two types of financial sources. They argue that publicly subsidized R&D activities for private enterprises have a positive effect and firms can dispose of advanced scientific knowledge and increase their efficiency in their R&D activities.

Moreover, public funding is often available for building some test facilities, acquiring durable research equipment, and assembling specialized research teams. In some circumstances, this could lower firms' costs for their R&D and improve innovation performance. According to Kristkova (2018), private and public R&D can collaborate in synergy. Public support for private R&D can further generate higher public R&D investments and vice versa due to the spill-over effect between the two sectors. Lanahan, Graddy-Reed, and Feldman (2016) found that government research funding is crucial for further private research investments. Based on the sample of US universities, they conclude that funding from the federal government is complementary to every other funding source. They estimated that a 1% increase in federal research funding is linked with an additional 0.468% increase in funding from industry and a 0.41% increase in non-profit research funding.

The relationship between university research funding sources can be somewhat similar but has some specifics. Despite the traditional main focus of universities on basic research, the interaction between firms and the higher education sector is desirable. This cooperation is, of course, most likely in the case of applied research. Hence, the mixed government and business research funding of universities can be expected just in applied research. According to Muscio, Quaglione, and Vallanti (2013), business funding can be expected whenever firms must rely on the infrastructure of universities and the expertise of researchers previously accumulated due to public funding. Government support is necessary for basic research activities and acquiring human capital and costly infrastructure.

Furthermore, based on the results of several studies, government funding and its extent may play a signalling role in the quality of universities (Blume-Kohout, Kumar, and Sood 2014). These quality signals could help the university develop better relations with businesses and obtain additional external funding. Similarly, the positive effect of signals from government funding on business funding has also been supported by Diamond (1999).

The relationship between government and business financial sources can be, to some extent, described as the positive effect of initial government funding on business funding. This means that both types of funding are complements rather than substitutes. Some other empirical studies have supported the complementarity between both funding sources of university research (Dechenaux, Thursby, and Thursby 2011; Muscio, Quaglione, and Vallanti 2013). Muscio, Quaglione, and Vallanti (2013), based on their sample of Italian universities, concluded that public funding and private funding from research contracts and consultancies are positively linked, and these two forms should be perceived as strategic complements. On the other hand, several studies also found a negative substitution effect of government research funding on business funding in higher education (Santos 2007). This is often explained by a shift in universities' financial resource allocations and the crowding-out effect. Firstly, universities and their staff could stop seeking alternative financial resources once they have enough funding from the government. Secondly, government financial support may crowd out private investments in research in higher education. As can be seen, there is no consensus in the literature on the exact relationship between government and business funding of research in higher education. Hence, we will examine this problem in more detail based on the analysis of empirical data.

3. Methodology

We analyze the secondary data capturing the share of different sources of funds for R&D expenditures at universities. All variables used in the analysis are described in Table 1. We used two different forms of gross intramural R&D expenditures (GERD) in higher education. Firstly, we have GERD in price purchasing power standard per capita. Secondly, we also used the share of GERD in higher education on total GDP. These two measures have been used mostly to test the robustness of our results.

Moreover, we also compared the differences in both types of variables. Besides the variables capturing R&D expenditures in higher education funded from different sources, we also used GDP per capita

Table 1. Description of variables used in the analysis

Variable	Description	Source
Business per capita (Funding in PPS per capita)	Intramural R&D expenditure (GERD) in the higher education sector funded by the business enterprise sector - in price purchasing power standard (PPS) per inhabitant at constant 2005 prices	Eurostat database. *Intramural R&D expenditure (GERD) by sectors of performance and source of funds* [rd_e_gerdfund]
Business – GDP (Funding as % of GDP)	Intramural R&D expenditure (GERD) in the higher education sector funded by the business enterprise sector - calculated as a percentage of GDP	
Government per capita (Funding in PPS per capita)	Intramural R&D expenditure (GERD) in the higher education sector funded by the government sector - in price purchasing power standard (PPS) per inhabitant at constant 2005 prices	
Government-GDP (Funding as % of GDP)	Intramural R&D expenditure (GERD) in the higher education sector funded by the government sector - calculated as a percentage of GDP	
Abroad per capita (Funding in PPS per capita)	Intramural R&D expenditure (GERD) in the higher education sector funded from abroad - in price purchasing power standard (PPS) per inhabitant at constant 2005 prices	
Abroad- GDP (Funding as % of GDP)	Intramural R&D expenditure (GERD) in the higher education sector funded from abroad - calculated as a percentage of GDP	
GDP per capita	*GDP per capita* (at price purchasing power parity - PPS) (in international dollars)	World Bank - World development indicators

Source: Authors based on the data from Eurostat and the World Bank database.

Note: Intramural R&D expenditures are all expenditures for R&D performed within a statistical unit or sector of the economy during a specific period, whatever the source of funds.

control variables. GDP per capita and the economic output should directly affect the business funding of R&D.

Descriptive statistics of the variables used in the analysis are shown in Appendix in Table A1.

Our dataset consists of panel data. Thus, all variables include a cross-sectional (country) dimension and a time dimension. It includes the data for EU27 countries in the period 1999 – 2019. However, due to data unavailability in certain countries, we used only data from 23 EU countries (Italy, Greece, Luxembourg and Malta were excluded from the sample). Hence by this step, we get a balanced panel.

The paper's research hypotheses related to short-run effects (H1a and H2a) are tested using the panel General Methods of Moments (GMM) model. In the first stage, initially, we will use pooled ordinary least squares (OLS) and fixed-effect OLS models. We decided to use the GMM approach to eliminate the potential endogeneity problem. It is expected that every 1% increase in government spending on research and development in tertiary education will lead to an increase in business spending in the short run.

On the other hand, research hypotheses dealing with the long-run effect (H1b and H2b) are tested by calculating the long-run coefficient from the panel GMM and cointegrating regression models where the dependent variable will be business financing as % of gross domestic product (GDP). We assume, that the expected effect of government funding could likely be more evident in the long than in the short run. The methodology of hypothesis testing and the identified relationships between variables are shown in the diagram on the Figure A2 in Appendix.

At the beginning of the analysis, all variables were tested for weak stationary by using the Levin, Lin, and Chu (2002), Im, Pesaran, and Shin (2003) and Breitung (2000) tests, as well as the Fisher ADF and PP tests defined by Choi (2001) as well as Maddala and Wu (1999). Results are shown in the Appendix in Table A3. Variables that appear stationary at levels have been used in fixed effects and GMM models. On the other hand, variables capturing the share of funding on GDP become stationary at their differences. These have been used for cointegration tests and in cointegrating regression.

In the next research phase, we tested the short-run causalities in the Granger sense by panel Granger causality tests. Furthermore, pooled OLS fixed-effect and OLS have been applied to stationary variables. Although these two models can be used for a robustness check of the results, they have been primarily used to determine the more suitable model out of difference and system General methods of moments (GMM). GMM represents the dynamic model, which is currently extensively used in economic research in general. One of the first applications of GMM in finance dates back to the 80ties when this approach was used by Hansen and Hodrick (1980) and has been widely used since now. This model has been applied to test the dynamic linkages between business, government and abroad funding of research and development at universities. Based on the archived results, we focused primarily on the system GMM estimator, which appears to be more suitable than different GMMs.

A system GMM estimator has been proposed by Arellano and Bover (1995) and Blundell and Bond (1998), who argue that this approach is significantly less biased and more consistent than pooled OLS and fixed-effects regression. Furthermore, it eliminates the potential endogeneity problem (Nickell 1981), which is also very useful in our case. GMM estimator is consistent if the condition of no serial correlation between error terms and instruments is met. This can be tested by using Arellano and Bond's (1991) approach. One of the main problems related to GMM estimation stems from the number of instruments. Because this number grows exponentially with the periods included in the sample, this can lead to several problems related to finite sample bias. In our case, the period dimension is slightly lower than the cross-sectional dimension, which can be problematic. Hence, to achieve a sufficient reduction in the number of instruments, we decided to present results with a collapsed instrument matrix. We also focused our attention on the results of the Hansen test (Hansen 1982). In our case, we also used both one-step and two-step estimations of coefficients to compare the results. After estimating the statistically significant short-run coefficient of government funding, we also used this result to calculate the potential long-run effects of this variable on business funding. As reported, we assume potential causalities should be more evident in the long run. To further focus mainly on long-run causalities, we apply panel cointegration analysis. The long-run equations will be further estimated as follows:

$$\text{BUSINESS\_funding}_{it} = f(\text{GOVERNMENT\_funding}_{it}, \text{ABROAD\_funding}_{it}) \quad (1)$$

After we successfully demonstrated the same level of integration for selected variables by unit root tests, we tested for cointegration by panel cointegration tests. Cointegration between the dependent and independent variables has been tested using panel cointegration tests developed by Pedroni (2004), both widely used in the empirical literature. Both test the null hypothesis of no cointegration between selected variables. The Pedroni (2004) cointegration tests use seven different statistics. Four of them are panel cointegration statistics based on the within the approach, and three are group-mean panel cointegration statistics based on the between approach.

The panel cointegration tests allow us to identify the presence of cointegration but cannot estimate any long-run coefficients by themselves. For this purpose, we use panel cointegrating regression models. The fully modified OLS (FMOLS) and the dynamic OLS (DOLS) panel cointegration estimators estimate the long-run parameters.

Here we briefly describe the essence of both estimators. Both FMOLS and DOLS are based on standard OLS, considering the simple fixed-effects panel regression model that can be written as:

$$Y_{it} = \alpha_i + \beta_i X_{it} + u_{it}, i = 1, \dots, N, t = 1, \dots, T \quad (2)$$

where Y_{it} is a vector of the dependent variable, β is a vector of coefficients, α_i is an individual fixed effect, and u_{it} is the stationary disturbance term. It is assumed that X_{it} is an integrated process of order one for all i. The FMOLS estimator is then written as follows:

$$\hat{\beta}_{FMOLS} = \left[\sum_{i=1}^{N}\sum_{t=1}^{T}(x_{it} - \overline{x}_i)'\right]^{-1}\left[\sum_{i=1}^{N}\left(\sum_{t=1}^{T}(x_{it} - \overline{x}_i)\,\hat{y}_{it}^{+} + T\hat{\Delta}_{\epsilon\mu}^{+}\right)\right] \quad (3)$$

where $\hat{\Delta}^{+}_{\epsilon\mu}$ is a serial correlation term that gives the covariance matrix of the residuals corrected for autocorrelation and $\hat{y}^{+}_{it}$ is the transformation of the dependent variable y_{it} to achieve the endogeneity correction.

On the other hand, the DOLS estimator is obtained from the following equation:

$$y_{it} = \alpha_i + \beta X_{it} + \sum_{j=q_1}^{q_2} c_{ij}\Delta X_{i,t+j} + u_{it}, \tag{4}$$

where c_{ij} is the coefficient relating to the leads and lags of the first differenced independent variables.

We can estimate β, the long run coefficient, by the following equation:

$$\hat{\beta}_{DOLS} = \sum_{i=1}^{N}\left[\sum_{t=1}^{T} z_{it} z_{it}'\right]^{-1}\left[\sum_{t=1}^{T} z_{it}\,\hat{y}^{+}_{it}\right] \tag{5}$$

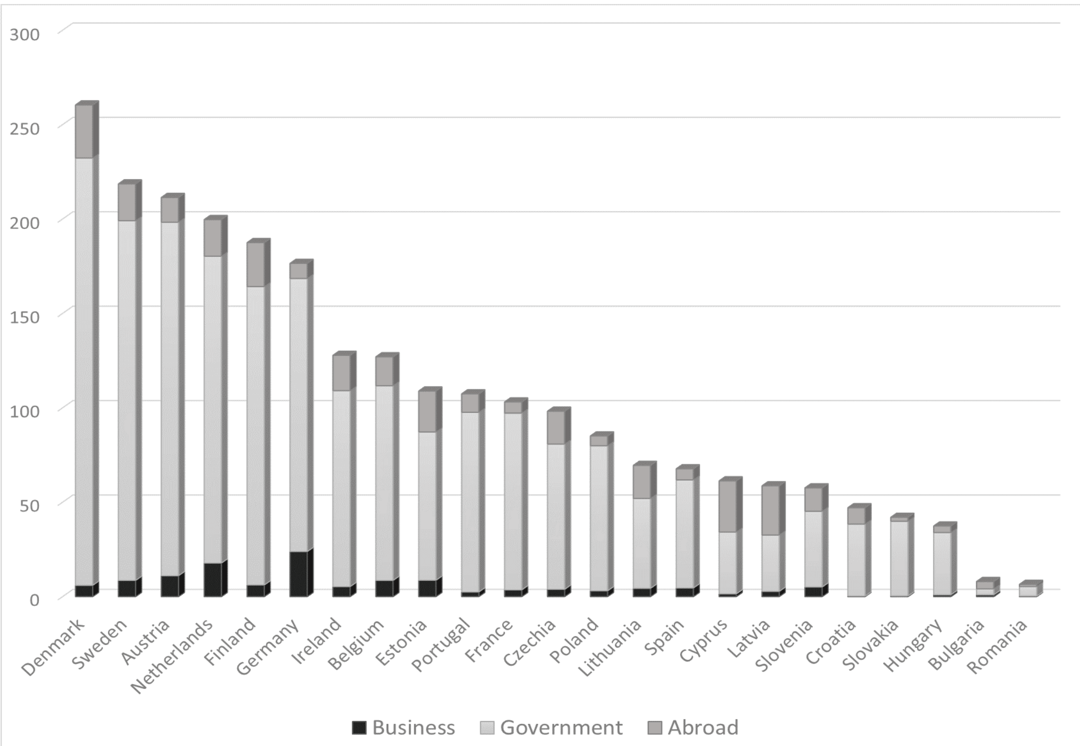
where $z_{it} = (x_{it} - \bar{x}_i\,, \Delta x_{it-q}, \ldots, \Delta x_{it+q})$ is a 2(q+1)×1 vector of regressors.

Both types of estimators have been used in their two forms: pooled and group-mean estimators. While pooled estimators are based on the "within dimension" of the panel, the group-mean estimators are based on the "between the dimension of the panel". The pooled FMOLS estimator is proposed by Phillips and Moon (1999), and the group-mean FMOLS estimator is developed by Pedroni (2000). The pooled DOLS estimator is introduced by Kao and Chiang (2000), and the group-mean estimator is extended from FMOLS to DOLS by Pedroni (2001). Both estimators are robust for the potential problems of serial correlation and endogeneity, which are potential problems with common OLS panel data estimators. The FMOLS estimator solves this by nonparametric corrections, while the DOLS estimator uses parametric correction, adding leads and lags of differenced regressors into the regression.

5. Results and discussion

In the first part of our analysis, we examine the structure of R&D funding in the higher education sector. We also look closely at the development of the most important sources during the selected period. This will allow us to compare financial sources among EU countries and capture some trends in its development. In Figure 1, we can see the size of overall R&D funding in the higher education sector per capita and its most important sources in 2019. Denmark, Sweden and Austria have the highest funding per capita in the EU in the selected year.

Figure 1. Most important sources of funds for R&D expenditures in higher education based on subjects in the EU countries (in PPS per capita) in 2019



Source: Authors based on the data from Eurostat and the World Bank database.

On the other hand, Bulgaria, Romania and Hungary are performing very poorly in this indicator. Fund structure differs from country to country, and governments are the most important funders in most countries. However, funding from abroad and from the business sector represent important financial sources in several countries, and funding from other higher education institutions or non-profit organizations is mostly negligible. Hence, we decided not to take these two sources into account.

In line with the paper's goal, we further examine the potential relationship between funding sources of R&D funding in higher education with a special focus on business and government funding. We applied the Granger causality test to capture the direction of potential causality in the Granger sense. The results are shown in Table 2. In this case, we fail to find almost any statistically significant Granger causalities between selected variables. There is some evidence of potential Granger causality of government funding on business funding as well as on funding from abroad. These relationships will be crucial in our research. The aim is to examine the potential effect of public funding on the business funding of universities.

After getting the results from Granger causality tests, we look more in detail at the potential short-run effect of government funding on funding from the business sector. As we stated, we assume that there could be a potential effect from initial government funding on R&D in the higher education sector business funding. In the first stage, we used pooled OLS and fixed-effect OLS models. However, in these two cases, we still deal with correlations rather than causalities due to the potential problem of endogeneity. To eliminate this problem, we decided to use the GMM approach. All models are based on variables capturing funding in PPS per capita in their log forms. Since the coefficient of the lagged dependent variable obtained by one-step difference GMM is significantly lower than the one estimated by fixed-effects regression, we prefer the system GMM model. The system GMM is represented by both one-step and two-step estimationand the results can be directly compared. Table 3 reports the results of the relationship between business founding government funding, funding from abroad and GDP per capita. The potential effect of government funding on business funding is statistically significant, at least a 10% level in every model used in our set. Hence, our results seem to be rather robust concerning the different types of models. We also calculated the long-run coefficient for government funding and its statistical significance. The fourth model is used without the control variable capturing GDP per capita to check for robustness.

Table 2. Results of Pairwise panel Granger causality tests

	Number of lags		
	1	2	3
H0: Government funding (per capita) does not Granger cause Business funding (per capita)	1.31	0.99	0.59
H0: Business funding (per capita) does not Granger cause Government funding (per capita)	0.86	0.16	0.54
H0: Government funding (%GDP) does not Granger cause Business funding (% GDP)	4.68**	2.37*	1.89
H0: Business funding (% GDP) does not Granger cause Government funding (% GDP)	2.71	0.74	0.51
H0: Abroad funding does (per capita) not Granger cause Business funding (per capita)	2.23	2.07	2.08
H0: Business funding (per capita) does not Granger cause Abroad funding (per capita)	1.72	0.75	0.49
H0: Abroad funding (per capita) does not Granger cause Government funding (per capita)	0.48	0.15	0.24
H0: Government funding (per capita) does not Granger cause Abroad funding (per capita)	11.66***	4.37***	3.62**
Observations	460	436	413

Source: Authors based on the data from Eurostat and the World Bank database.

Note: *** 1% significance level; ** 5%; * 10%.

Table 3. Results of pooled OLS, Fixed-Effects OLS and GMM models

	Dependent variable: log(business (PPS per capita))						
	Period: 1999-2019						period: 2000-2019
	Pooled OLS	**Fixed Effects**	**One-step difference GMM**	**One-step system GMM**	**One-step system GMM**	**Two-step System GMM**	**One-step system GMM**
$\log(\text{business})_{it-1}$	0.907***	0.729*** (6.97)	0.505** (2.12)	0.621*** (3.14)	0.498** (2.11)	0.494** (2.11)	0.479* (1.91)
Log $(\text{government})_{it}$	0.069***	0.18*** (3.26)	0.382* (2.05)	0.232* (1.68)	0.397** (2.14)	0.373* (1.98)	0.401** (2.10)
$\text{Log}(\text{abroad})_{it}$	0.061***	0.105 (1.69)	0.189* (1.79)	0.081 (1.11)	0.172 (1.35)	0.194 (1.32)	0.190* (1.8)
$\text{Log}(\text{GDP per cap})_{it}$	-0.052**	-0.09** (-2.27)	-0.209* (-1.85)		-0.204 (-1.63)	0.193 (-1.55)	-0.187 (-1.58)
Const	0.432*	0.731**	1.61 (1.66)	-0.244 (-1.45)	1.55 (1.43)	1.47 (1.28)	1.39 (1.35)
No. of obs.	455	455	432	455	455	455	433
No. of groups		23	23	23	23	23	23
No. of instruments			23	23	23	23	22
AR(1) z-stat			-2.65***	-2.84***	-2.64***	-1.77*	-2.4**
AR(2) z-stat			1.39	13.38	1.39	1.22	1.36
Sargan J-test [p-value]			25.4 [0.115]	31.56** [0.035]	26.17* [0.096]	26.17* [0.096]	22.42 [0.169]
Hansen J-test [p-value]			20.51 [0.305]	20.52 [0.364]	20.49 [0.306]	20.49 [0.306]	18.30 [0.370]
R^2	0.93	0.93					
F stat./			150.8***	303.3***	141.2***	152.0***	129.2***
Long-run coefficient log (Government)			0.771*** (4.48)	0.58*** (3.40)	0.79*** (4.42)	0.738*** (3.20)	0.769*** (4.47)

Source: Authors based on the data from Eurostat and the World Bank database.

Note: Standard errors are robust concerning heteroscedasticity; numbers in brackets denote t-statistics or z-statistics; *** 1% significance level; ** 5%; * 10%. The long-run GMM coefficient of log(government) has been calculated as follows: $b2(\log(\text{government}_{it}) / (1-b1(\log(\text{business})_{it-1})$.

The first six models have been estimated on a whole sample of 23 countries and 21 years. We decrease the time dimension to 20 years in the seventh estimation to get fewer instruments than groups. The estimator seems to be fully consistent as the Hansen test's null hypothesis checking the instruments' validity is not rejected. The results also show, on the one hand, the presence of first-order serial correlation and, on the other hand, the absence of second-order serial correlation. The interpretation of the results is rather straightforward. The significance and value of the lagged-dependent variable prove a dynamic relationship which further justifies our choice of GMM as the suitable estimator. The current level of business funding for university research and development is affected by its previous levels.

Regarding our main independent variable, we can conclude that a 1% increase in government funding will lead to approximately, on average, a 0.23-0.4% increase in business funding for research and development in tertiary education. In the long run, the intensity of this effect can even further rise to approximately 0.58-0.79%. The potential positive effect of funding from abroad has been significant only at a 10% significance level and only in two models. Thus, we cannot make firm conclusions about the potential effect of this type of funding on business.

In the next part of our analysis, we further examine potential long-run causalities between selected variables. As already mentioned, the expected effect of government funding could likely be more evident in the long run. Business funding has been used as a dependent variable, and government funding and funding from abroad were applied as independent variables. We assume that there is some long-run relationship between government, business and foreign funding of R&D in higher education. To identify this kind of relationship, we first used the results of the panel unit-root test. The results suggest that variables capturing the share of business funding, government funding and abroad funding of R&D in higher education on GDP have the same order of integration. Pedroni and Johansen-Fisher panel cointegration tests test the existence of cointegration between these three variables. All results are shown in Appendix in Table A4 and Table A5.

Most tests from both types confirm the existence of statistically significant cointegration between business funding, government funding and abroad funding. Hence, we can proceed to cointegrating regression analysis and examine long-run causal relationships. This estimation is based on two types of cointegrating regression estimates: fully modified OLS (FMOLS) and dynamic OLS (DOLS). Using two different estimators should again improve the robustness of our results and allow us to compare the results. Both estimators are robust for endogeneity problems which are especially important in our case. As reported in the methodology section, both estimators can be used in their polled or group mean forms. There is also an opportunity to include constants and trends in the equation. As can be seen in Table 4, we used different cointegrating regression models with different specifications. We used both within-dimension (pooled),

Table 4. Results of cointegrating regression models

Dependent variable: Business financing as % of GDP					
Pooled estimator (within dimension)					
	(1) A	(2) B	(3) C	(4) D	(5) E
Government financing (% of GDP)	0.04*** (3.84)	0.03*** (4.57)	0.03** (2.01)	0.02*** (2.62)	0.04*** (3.17)
Abroad financing (% of GDP)	0.05*** (2.59)	0.05* (1.73)	0.09** (5.09)	0.09*** (6.40)	0.07*** (3.08)
R^2	0.84	0.83	0.88	0.88	0.85
Adj. R^2	0.82	0.82	0.87	0.87	0.80
Long-run variance	0.0001	0.0001	8.1x10-5	4.78x10-5	9.9x10-5
Observations	459	459	459	459	421
Group-mean estimator (between dimensions)					
	(6) F	(7) G	(8) H	(9) I	(10) J
Government financing (% of GDP)	0.05*** (4.91)	0.05*** (4.34)	0.04*** (4.63)	0.05*** (3.55)	0.05*** (2.69)
Abroad financing (% of GDP)	0.06** (2.15)	0.18*** (4.72)	0.03*** (0.99)	0.09** (2.02)	0.17** (2.46)
Long-run variance	5.08x10-5	4.02x10-5	1.72x10-5	5.09x10-5	5x10-5
Observations	459	459	459	441	442

Source: Authors' work.

Notes: *** 1% significance level; ** 5%; * 10%.; long-run variances calculated based on Bartlett kernel and Newey-West bandwidth have been used for coefficient covariances; A - FMOLS (pooled estimator), constant included, coefficient covariance matrix with homogenous variances; B - FMOLS (pooled estimator), constant included, coefficient covariance matrix with heterogeneous variances; C - FMOLS (pooled estimator), constant & linear trend, coefficient covariance matrix with homogenous variances; D - FMOLS (pooled estimator), constant & linear trend, coefficient covariance matrix with heterogeneous variances; first-stage residuals use heterogeneous long-run coefficients; E- DOLS (pooled estimator), constant included, lags and leads included based on the AIC; F - FMOLS (group-mean estimator), constant included; G - FMOLS (group-mean estimator), constant & linear trend included; H - FMOLS (group-mean estimator), constant & quadratic trend included; I - DOLS (group-mean estimator), constat, lags and leads included based on the AIC; J - DOLS (group-mean estimator), constant &linear trend, lags and leads included based on the AIC.

and between-dimension (group-mean) approaches. However, the results are rather similar in all models.

Variable capturing government financing of R&D on GDP is statistically significant at a 5% significance level for all models used in our set. Almost the same is also true for funding from abroad. The only exemption is one model where the coefficient is still significant at 10%. Both variables appear to have a positive long-run effect on the business funding of R&D in higher education. Thus, we found strong evidence of a long-run relationship between the three selected variables. The effect of government and funding from abroad on business funding of tertiary education research appears to be positive in the long run. Regarding our two main research hypotheses and their components, we can make several conclusions.

Based on the results, we cannot reject the first research hypothesis. We found a short-run positive effect of government funding of higher education research on business funding of this research. Regarding the second hypothesis, our results are rather ambiguous in this case. Even though we found some relatively weak evidence about the positive effects of funds from abroad, we cannot come to any certain conclusions. However, we can say the short-run positive impact of financial sources from abroad on business funding is possible. According to the calculation of the long-run coefficient from GMM and especially based on the cointegrating regressions, our results strongly suggest a long-run positive effect of government funding of higher education research on business funding of this research. Therefore, the third hypothesis of the paper can be validated. The results of cointegrating regressions suggest a long-run positive effect of government funding of higher education research on business funding of this research. Even though this effect is less statistically significant in some models, the results are more convincing in the long run compared to the short-run effect indicating the acceptance of the fourth hypothesis.

We can conclude there is a complementarity between government funding and business funding of higher education research in the short and long run. The same applies to funding from abroad. The long-run results are valid for the GMM panel regressions using long-run log coefficients and cointegration regression models. Our results align with the findings of several previous studies (Muscio, Quaglione, and Vallanti 2013; Dechenaux, Thursby, and Thursby 2011). Despite this, our research is unique due to capturing the short-run and the long-run relationships based on a sample of EU countries. The positive effect of government research funding on business research funding can be explained by the development of necessary infrastructure and human capital that can be further used in applied research and cooperation with businesses, as reported by Muscio, Quaglione, and Vallanti (2013). Good quality basic science funded mostly by the government is necessary for further applied research, as argued by Guellec and Van Pottelsberghe de la Potterie (2004). Moreover, according to Blume-Kohout, Kuman, and Sood (2014) and Diamond (1999), better government funding could play an important signalling role in business cooperation. Contrary to Santos (2007), we fail to find any support for the substitution effect between government and business funding.

Despite our best afford to maintain the robustness of our results, our approach also has several limitations. First of all, we cannot use more control variables in the models due to the chosen methods. The availability of data for potential control variables, such as the number of researchers at universities, is limited in selected 23 countries during all 21 years. Moreover, the GMM is more suitable for datasets with higher cross-sectional dimensions and lower time dimensions. Every additional variable used as an instrument will inflate the number of instruments over the threshold value, even with the collapse option. Cointegrating regression has a very similar problem as well. The number of variables used in the model is often rather small because all variables in the model should be cointegrated. Hence, these limitations do not allow us to increase the number of model variables.

Moreover, in our case, it appears to be inappropriate to select only one best model of cointegrating regression. Hence, we decided to apply models with different specifications and compare the results. This approach allows us to capture any potential changes. However, our results remain robust in every specification used in our set of models.

5. Conclusions

Research and development in higher education are often inevitable for the creation of innovation. There are several possible sources of funding for this research. In EU countries, the government remains the most important subject in funding R&D in higher education, and business funding is much less common in the EU. Still, it can increase the total R&D expenditures in higher education and motivate universities to be more active in applied research. Likely, government funding and other sources of funding, such as funding from abroad, could potentially affect the amount of business funding. Hence, the paper aims to identify the correlations and causalities between business funding and other sources of R&D funding in the higher education sector.

Based on our results, we can make several conclusions and policy implications. Our results suggest a significant positive correlation between government funding and business funding in the short run. The Granger causality tests first indicated this relationship. In the next step, this relationship has been further confirmed by the results of GMM. It is expected that every 1% increase in government spending on research and development in tertiary education will lead to another increase, on average, in business spending of 0.23 % to 0.4% in the short run. Based on the results, we also assume that in the long run, this effect can multiply business spending on university research by more than 0.7%, which can be considered a substantial increase. This supported our hypotheses.

If the government funding increases, there is likely a time needed to adapt, increasing research infrastructure and human capital. Furthermore, improvements in academia-business cooperation that can potentially lead to an increase in business funding of R&D in higher education are long-term processes. The opposite direction is true when the government decides to decrease its funding. Hence, it is more likely that there is a certain long-run relationship between different sources of R&D funding in academia. Thus, we decided to examine long-run causal effects by using cointegrating regression models. We found empirical evidence for this assumed long-run relationship based on the results panel cointegration test and FMOLS and DOLS estimates. There appears to be a positive long-run effect of government funding on business funding of R&D in higher education. The same is true for funding from abroad. An increase in either government financial support or funding from abroad is leading to a significant increase in business funding of R&D in the higher education sector. This positive effect of government funding can be interpreted by improvement in basic research, development of research infrastructure and enquiring of human capital, as reported by Muscio, Quaglione, and Vallanti (2013). Moreover, government funding has an important signalling role in business cooperation, as stated by Blume-Kohout, Kumar, and Sood (2014).

Despite some methodological limitations, especially in the case of long-run models, our results are robust enough and remain the same when changing the variables and estimation techniques.

Based on our results, it is possible to make certain recommendations for policies in the field of higher education and support for research and development. The findings confirm the importance of government funding of R&D in higher education. It is not only the most important financial source for academic R&D, but it also complements the funding from the business sector to higher education. Hence, for EU countries we are recommending at least keeping the level of government financial support or if possible, even increasing the support. This can be a key tool to generate more funding from businesses, especially in the long run. It can enhance the cooperation between universities and private sector. A similar effect can also be seen in funding from abroad. However, this time the results can be more visible in the long run. This type of funding mostly comes from EU sources such as Horizon Europe. Hence, funds from these programs are not only supporting the research at universities and research organisations but can also indirectly generate further financial support for the research from the business sector. We can say that improving financial support from the government and EU can be seen as an effective tool for motivation and increasing the financial participation of businesses in R&D activities at European higher education institutions.

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APPENDIX

Table A1. Descriptive statistics of variables used in the models, observations = 184

Variable	Mean	SD	Min.	Max.
Business per capita (Funding in PPS)	5.623	0.399	0.3	23.9
Business - GDP (Funding as % of GDP)	0.0238	0.002	0.01	0.09
Government per capita (Funding in PPS)	82.39	4.72	2	233.4
Government- GDP (Funding as % of GDP)	0.319	0.014	0.02	0.81
Abroad per capita (Funding in PPS)	12.45	0.67	0.7	55.3
Abroad- GDP (Funding as % of GDP)	0.056	0.003	0.01	0.028
GDP per capita	37973	937	16328	87380

Source: Authors based on the data from Eurostat and the World Bank database.

Figure A2 Diagram showing the methodology and found effects

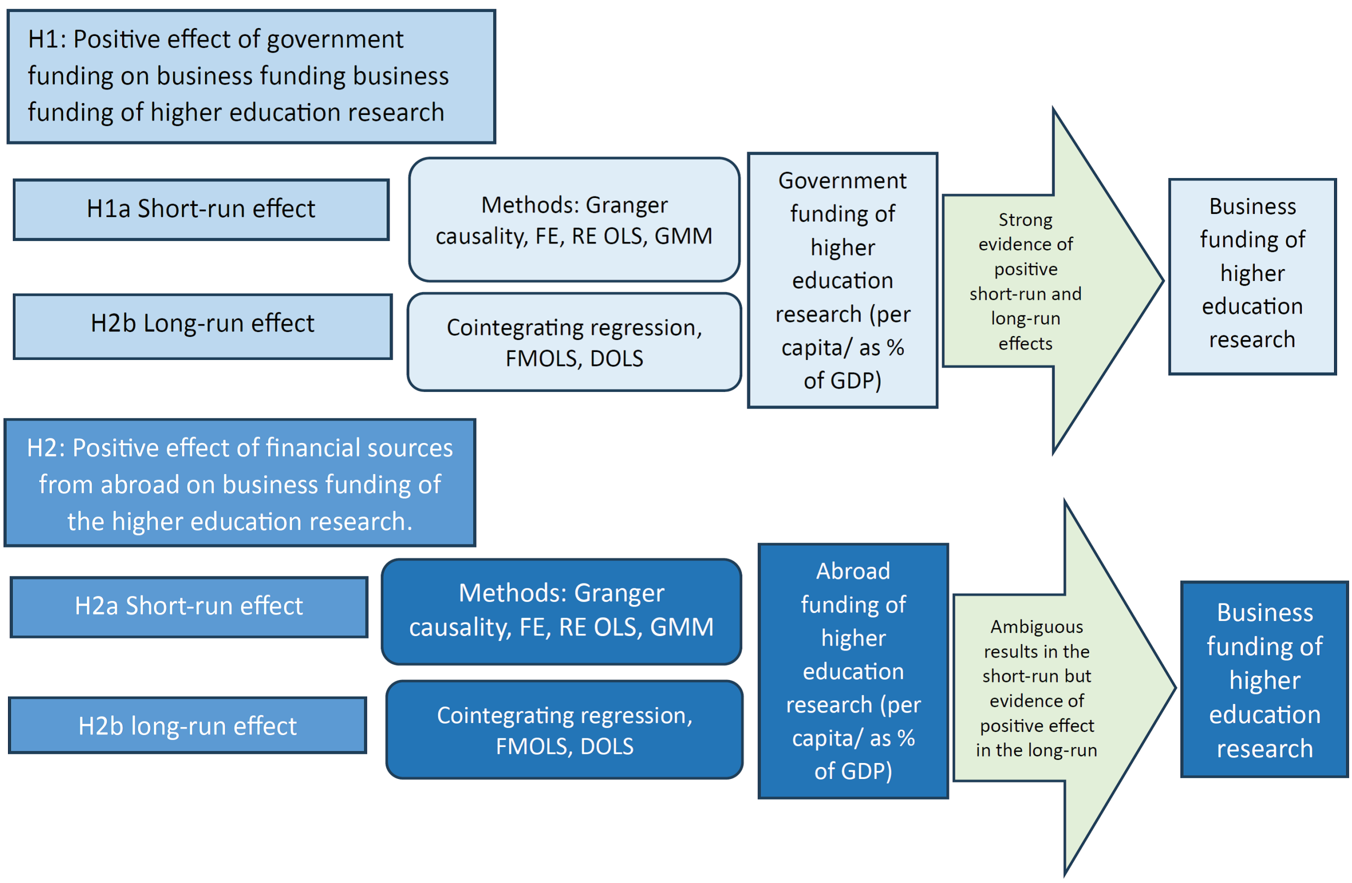

Table A3. Panel unit root tests of selected variables used in the models

Variable	Levin, Lin & Chu	Im, Pesaran & Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-square
Log (Business per capita)	-3.05***	-1.53*	72.11***	83.46***
Log (Government per capita)	-4.66***	-1.96**	72.18***	76.28***
Log (Abroad_ per capita)	-2.17**	-2.17**	77.88***	76.89***
Business (%GDP)	-1.44*	-0.83	58.8**	58.9**
ΔBusiness (%GDP)	-14.8***	-14.7***	253.3***	493.3***
Government (% GDP)	-1.99**	-0.76	53.84	42.03
ΔGovernment (% GDP)	-12.7***	-10.4***	192.1***	205.5***
Abroad (% GDP)	0.06	1.66	41.3	51.8
ΔAbroad (% GDP)	-16.6***	-16.7***	295.5***	367.4***

Source: Authors based on the data from Eurostat and the World Bank database.

Note: *** 1% significance level; ** 5%; * 10%.

Table A4. Results of Pedroni panel cointegration tests

Cointegration: Business funding (%GDP) Government funding (%GDP) Abroad funding (%GDP)			
Pedroni tests (Engle-Granger based) – individual intercept & trend, lag length selection based on SBC	Panel v-Statistic (within dimension)	-23555	0.46
	Panel rho-Statistic (within dimension)	-0.69	-1.93**
	Panel PP-Statistic (within dimension)	-2.05**	-5.09***
	Panel ADF-Statistic (within dimension)	-2.28**	-5.53***
	Group rho-Statistic (between dimensions)	-0.36	
	Group PP-Statistic (between dimensions)	-4.60**	
	Group ADF-Statistic (between dimensions)	-4.18**	

Source: Authors' work.

Note: *** 1% significance level; ** 5%; * 10%.

Table A5. Results of the Johansen-Fisher panel cointegration test

Cointegration: Business funding (%GDP) Government funding (%GDP) Abroad funding (%GDP)		
	Fisher Stat. (from trace test)	Fisher stat (max. eigenvalue test)
None	133.4***	112.8***
At most 1	57.40**	38.06
At most 2	84.95***	84.95***

Source: Authors' work.

Note: *** 1% significance level; ** 5%; * 10%.