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PUBLIC, PRIVATE OR UNIVERSITIES?: THE EFFECTIVENESS OF R&D EFFORTS IN OECD COUNTRIES

The aim of this study is to investigate the differential impacts of business, government and higher education sectors' research and development expenditures (R&D) on innovation in OECD countries. Although the business sector has the largest share of the R&D sector due to its profit motive, there are also some efforts made by public and higher education sectors. On the other hand, for decades, the literature of economics is in doubt about the efficiency of the public sector. The study deals with the issue by making a panel data analysis covering 18 OECD countries over the 1981-2016 period and aims to examine the separated effects of these sectoral R&D expenditures on innovation performance. Since most of the existing literature mostly focused on the R&D-GDP relationship, the present study aims to contribute to a relatively untouched point. To obtain robust findings, recent econometric tests and estimators have been used. The previous studies in the existing literature ignored the possibility of cross-sectional dependence problem within the country samples. Ignoring this problem may yield biased and inconsistent results. The present study considers the existence of cross-sectional dependence between selected countries and checks the robustness of each test and estimator via recent econometric techniques. The findings reveal firstly that there is a cointegrating relationship between the number of domestic

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patents (innovation) and the other three R&D indicators. Secondly, the long-run estimation results imply that increases in the R&D expenditures made by business sector significantly raise innovation while there is no statistically significant evidence on the impact of R&D expenditures made by the government and higher education sectors. The findings reveal that the R&D efforts made by the government and higher education sectors cannot turn into innovation and do not contribute to the knowledge spillover mechanism.

Key words: research and development, innovation, OECD, panel data analysis.

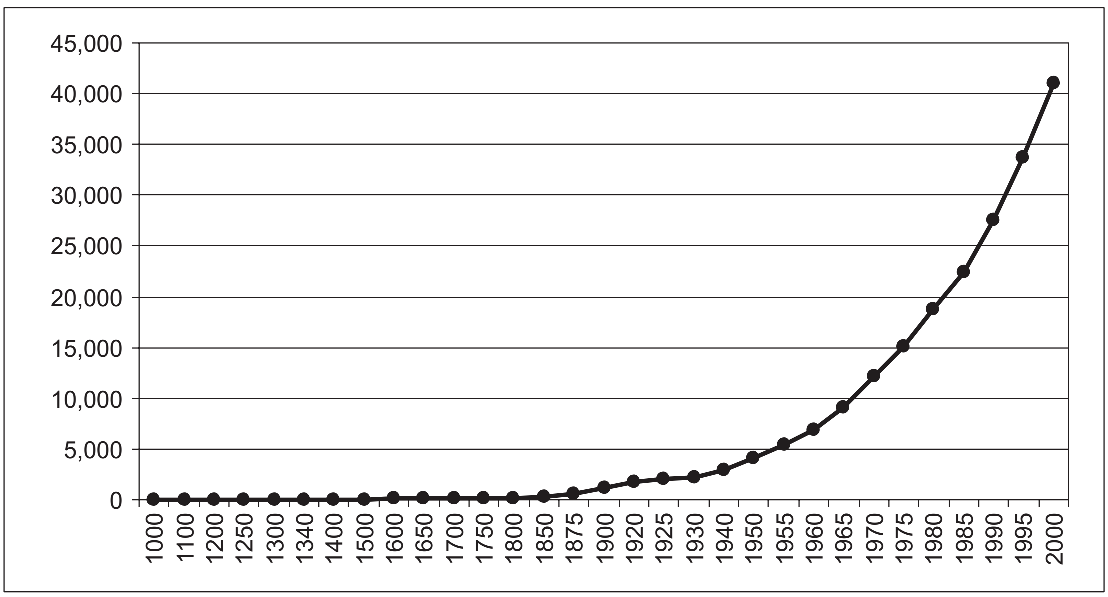
1. Introduction

Economic growth is one of the leading goals of policymakers. To satisfy the needs of the rising population and raise the life quality of society, economic growth is an essential condition. Due to its importance, there have been extensive debates on the sources of economic growth in the literature of economics. The early discussions on the sources economic growth in the literature have presented a quite limited discourse. In a more systematic framework, studies propounded in after the 20th century, have investigated the sources and issues related to economic growth in detailed. The first-generation theories, both Keynesian and Neo-Classical ones, suggested that economic growth is a process which mainly depends on the capital accumulation efforts (i.e. Harrod, 1939; Domar, 1946; Solow, 1956; Swan, 1956 etc.). Of course, the models of Keynesian and Neo-Classical approaches differ from each other with respect to the main assumptions on production factors. Their common ground is both approaches assumes that the investing behavior (saving rates) and technological progress are exogenous factors. Technical improvements are regarded as "*manna from heaven*".

Although economic growth has always been taken place in history, there have been very low rates until the mid-18th century; the beginning of the industrial revolution. Figure 1 shows the World Real GDP over the 1000-2000 period. DeLong (1998) provides the data starting from 1,000,000 BC but to serve the purpose of the present study, we limited the depiction for the last millennium. Until 1750, the real GDP increases by about 5-10 $ per "hundred years". However, starting from the industrial revolution, it is seen from the figure that the total world GDP exponentially increases over the periods. This is an explicit sign for the augmenting role of technology on economic growth. So, the "manna from heaven" dramatically rose in the post-18th century. For sure, economists did not ignore this increase; there was an obvious breakpoint starting with the industrial revolution. Realizing this fact, in the mid-1980's, some studies suggested a newer framework in which technical progress such as knowledge and technology are assumed as an endogenous factor. Inspired by the framework of some older studies such as Arrow (1962) and Uzawa (1965), the newer studies mad a substantial progress only in a decade (i.e. Romer, 1986; Lucas, 1988; Romer, 1990; Rebelo, 1991; Grossman and Helpman, 1991; Aghion and Howitt, 1992 etc.). According to these models, technological progress is an endogenous process and its sources lie behind the whole economic process. Therefore, any factors determining the technological progress came into prominence.

Figure 1.

TOTAL WORLD REAL GDP (BILLIONS OF 1990 INTERNATIONAL DOLLARS)



Source: Depicted by using the data collected by De Long (1998).

Since the 1980's, the empirical analyses examining the impact of technology are sure about a growth-enhancing impact of R&D investments. Developing countries that try to achieve a higher development path and catch up with developed countries on an international basis, certainly need to invest in R&D. However, R&D activities do not directly influence economic growth but with an indirect mechanism through innovation. Thus, to understand and observe the impact of R&D activities on economic growth, it is necessary to deal with the issue in a two-stage framework; and the first one is obviously the innovation stage.

Observing countries' increasing efforts on technical progress and the importance of technology on countries' growth performance have oriented researchers to investigate the sources of technological improvement. According to Romer (1986) and Romer (1990), technology is improved by new ideas. So, there are two questions at this point; "what is an idea?" and "what determines new ideas?".

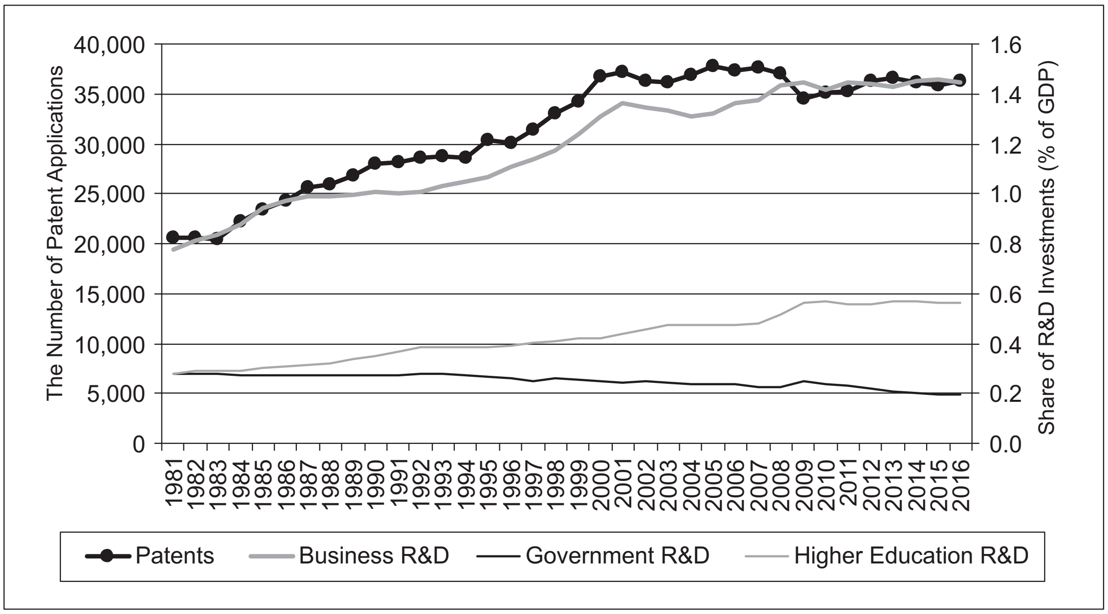
Since they grant to the owner the right to use the new knowledge, patents constitute a good proxy for ideas and number of patents is an efficient and simplest measure of new ideas. In such a framework, simply, patents are the output while R&D activities are the input for their production (see Jones, 1998: 84; Griliches, 1998; etc.). The functional form of this relationship will be explained more extensively in the methodology section.

The main hypothesis of this study suggests that R&D efforts handled by business sector is more applicable rather than the public sector and the higher education sector. Thus, we will examine whether the R&D expenditures made by the business sector is more efficient than the public and higher education sectors or not. Figure 2 depicts the average values of domestic patent applications, the share of business R&D expenditures, the share of government R&D expenditures and the share of higher education R&D expenditures in the selected OECD countries over the 1981- 2016 period.[1] Due to the lack of data, the analysis covers 18 OECD countries. For all the analysis period, interestingly, it is seen that the business R&D expenditures shows a dramatic increase. In 1981, the share of business R&D expenditures was around 0.77%, but until the end of the analysis period, it goes beyond 1.45%. The share of government R&D expenditures, on the other hand, is nearly constant around 0.25% while the share of higher education R&D expenditures rose from about 0.27% to 0.56% over 36 years. Although the R&D effort of higher education sector shows a substantial increase, the volume is still well below the R&D activity of the business sector. The mean number of domestic patent applications per year exceeds 36,200 which was about 20,500 in 1981. More importantly, there is a co-movement of the trends of the business R&D expenditures and the number of domestic patent applications which might be considered as the first signal of a statistical correlation. One may suggest from the preliminary findings that during the post-1980 period, the selected 18 OECD countries decided to invest more in R&D and reaped the fruits (patents) of these investments over the 36 years.

[1] The countries in the analysis are Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, United Kingdom, and United States.

Figure 2.

DOMESTIC PATENTS AND R&D EFFORTS IN OECD COUNTRIES
(1981-2016)



Note: Author's own depiction. The series are the average values of the OECD countries. The data are obtained from the *OECD.Stats* database of *OECD* and the *World Development Indicators* database of the *World Bank*

The augmentative role of R&D investments on economic growth mentioned in the theory treats with an indirect mechanism which comes up with innovation, and the figure suggests that innovation mainly emerges from the R&D efforts of the business sector. However, these preliminary implications need to be proved by further, reliable statistical findings. Therefore, in the empirical analysis part of this study, the question will be examined via more extensive panel data methods.

The existing literature on R&D activities mainly focuses on the effects of R&D intensity on economic growth. Moreover, most of the studies tackled the issue on a micro basis. Studies mostly investigated how do the R&D efforts of firms and industries affect their innovation performance. Although this is a significant question and these studies provided remarkable evidence for firms and industries, the R&D-innovation relationship on a macroeconomic basis is also important for policymakers. In the present study, we will mainly focus on how the public, private and higher education sectors' R&D investments influence innovation performance (patents) of countries.

Griliches (1986) have examined the R&D-productivity relationship with a large data-set for U.S. manufacturing firms in the 1970's. The findings obtained from several estimations imply that R&D expenditures have an obvious positive impact on productivity level and private R&D expenditures are more effective than the R&D expenditures made by the government.

Griliches (1989) have investigated the impacts of R&D expenditures made by companies and universities on patent applications in the U.S. over the 1953-1987 period. The findings of the analysis imply that increases both in company-financed R&D and university R&D expenditures significantly raise the number of patent application in U.S. The estimated coefficients, on the other hand, show that the effect of company-financed R&D is stronger than university R&D expenditures. Moreover, the results of the study suggest that the number of patent applications decreases as the cost of R&D activities increases.

Lichtenberg (1992) states that to observe the underlying reasons of the productivity differences between countries, physical investments provide insufficient information. Since technological progress has an important impact on the production process, it is necessary to focus also intangible assets and as R&D investments. To examine the hypothesis, a cross-country analysis covering 1960-1985 period has been made by Lichtenberg (1992). The findings of the study show that per capita output increases 0.07% as private research capital increases by 1%. Moreover, it was found that R&D activities made by the government have a much lower marginal return relative to the private ones.

Zachariadis (2003) has made an analysis to investigate the relationships between R&D intensity, innovation, technological progress and economic growth for the U.S. manufacturing industry over the 1963-1988 period. The findings obtained from the empirical analysis suggest that each variable in this chain has a positive effect on the next one; in other saying, R&D activities raise innovation, innovation raises technological progress, and finally, technological progress raises economic growth as expected. Bilbao-Osorio and Rodrigues-Pose (2004) have investigated the interactions between R&D, innovation and economic growth for peripheral and non-peripheral regions of Europe in the 1990's. The findings suggest that private R&D investments raise innovation both in peripheral and non-peripheral regions while R&D investments made by the higher education sector raise innovation only in peripheral regions. Especially the latter is a sign implying in peripheral regions, the higher education sector has an important role since the size of the total R&D market is relatively low. But in non-peripheral regions, due to the bigger size of the total R&D market, private R&D investments are the main driver of innovation. The peripheral and non-peripheral differences also might be seen between developed and developing countries. Prodan (2005) have made separated regression analyses examining the impacts of total R&D expenditures and business R&D expenditures on patent applications. The findings show that both total R&D and business R&D expenditures have positive effects on patenting activities; but in developed countries, the number of patent applications mainly depends on business R&D expenditures. Similarly, but on a cross-country basis, Guloglu and Tekin (2012) have examined the causalities between R&D expenditures, patent numbers and economic growth for 13 high-income OECD countries over the 1991-2007 period. Their results show that there is a bidirectional relationship between R&D expenditures and innovation which implies successful inventions made in the R&D sectors might feedback the sector in the future. Moreover, the results imply that there is also a bidirectional relationship between innovation and economic growth. Thus, each of the three variables has the potential to affect each other in some way.

The empirical evidence in the existing literature mostly suggests that business R&D expenditures are more effective than the R&D expenditures made by government or higher education sectors. On the other hand, the existence of government in the innovation market does not have to appear always in the form of innovation. To raise the innovation capability of the nation, governments can support business R&D sector by using public funding. However, some studies suggest that if these kinds of subsidies support some firms which already have high innovation and production capacity, the funding mechanism will yield a crowding-out situation for small firms in the R&D sector (e.g. David et al., 2000; Klette et al., 2000 etc.). There are also many empirical findings showing that public funding in R&D sectors does not always yield the same results. Busom (2000), for example, dealt with the issue for Spain and found some partial situations implying crowding-out. Lach (2002) examined the hypothesis for Israel and found statistically insignificant impact for the full sample while rejecting the crowding-out hypothesis for small firms. Hu (2001) have investigated the direct and indirect effects of public and private R&D expenditures on productivity levels of 813 Chines firms in 1995. The findings firstly show that there is an obvious, positive impact of private R&D investments on productivity level. Secondly, a direct positive impact of government R&D expenditures is not observed while there is an indirect mechanism through public R&D – private R&D channel. According to the estimation results, public incentives on the R&D market stimulate private R&D investments and hence raise productivity level. Guellec and Van Pottelsberghe de la Potterie (2003) also found the same evidence for 17 OECD countries but they also found that defense research made by the government and the higher education sectors creates a crowding-out effect in the R&D market. Additionally, their results imply that other research activities made within the government sector do not have any statistically significant impact on business R&D sector. Duguet (2004) examined the crowding-out hypothesis for French firms over the 1985-1997 period and found that public support does not cause crowding-out in the market.

The existing literature on the issue, mainly suggests that business R&D expenditure is the main driver of innovation. However, some other studies discuss the existence of public and higher education sectors in the R&D market might yield some positive impacts via indirect mechanisms through inducing business R&D sector. The new contribution of the present study can be described as follows: first, the present study considers the existence of cross-sectional dependence between selected countries and checks the robustness of each test and estimator via recent econometric techniques; secondly, the time dimension of the panel data set is as wide as possible and the most recent data is used. Since some countries do not have R&D data after 2016 and some of them do not have patent data after 2016, the dataset of the analysis covers a period until 2016. Such a limitation was necessary because some estimation and test techniques require "balanced data" with no lacks. Let us continue to the next section with the theoretical model and data, and then present the empirical findings in the third section.

2. Model and data

The theory of economic growth suggests that technology has an augmentative role on economic growth and technology is considered either as exogenous or endogenous in the existing literature as mentioned in the previous section. Following Jones (1998), we start with a basic Cobb-Douglas production function based on the Romerian framework (see Romer, 1990) and assuming constant returns to scale;

$$Y = K^{\alpha}(AL)^{1-\alpha} \tag{1}$$

where $\alpha < 1$.

The A term in Equation (1) represents the level of technology (number of ideas) while Y, K, and L stand for total production, capital stock and labor respectively. In such a framework, it is clear to suggest that any increase in the level of technology will raise labor productivity and hence, will raise total production. Let us assume that the level of technology grows at a constant rate; $\dot{A}/A = g$. Of course, the level of technology implies more than accumulated innovation or patenting activities or total knowledge; but to keep it simple and compatible with our case let us assume that A is total knowledge stock. Now, we can define how the knowledge stock accumulates;

$$A_{t+1} = PATR_t + A_t \tag{2}$$

Here, it is assumed that any innovation is added to the current knowledge stock and so the total knowledge is accumulated;

$$\frac{\dot{A}}{A} = \frac{(A_{t+1} - A_t)}{A_t} = \frac{PATR_t}{A_t} = g \tag{3}$$

The logic here is very similar with the capital accumulation formula of Solow (1956) but note that to keep the framework simple, we do not assume that there is a depreciation in knowledge. The *PATR* variable, the number of domestic patents, is the only augmenter component of the technology in this model and investigating the sources of this variable is the key to raise the level of technology. Thus, the question now is what determines or what raises the patenting activities?

The study assumes a basic function to be analyzed via the selected panel data methods. We assume that innovation -or the number of domestic patent applications is a function of business, government and higher education sectors' R&D investments;

$$PATR = f(BERD, GOVERD, HERD)$$

where *PATR*, *BERD*, *GOVERD,* and *HERD* are the number of domestic patent applications, the share of business R&D expenditures, the share of government R&D expenditures and the share of higher education R&D expenditures respectively. To investigate the impacts of the two R&D efforts on innovation, the implicit function given above can be written in a panel data form as below;

$$PATR_{it} = \beta_0 + \beta_1 BERD_{it} + \beta_2 GOVERD_{it} + \beta_3 HERD_{it} + \varepsilon_{it} \tag{4}$$

Here, the β_0 and ε_{it} are constant and error terms while the *i* and *t* indices stand for cross section and time dimensions respectively.

Before the empirical analysis, it will be useful to mention descriptive statistics on the data. The data for patents (*PATR*) are obtained from the World Development Indicators database of the *World Bank* and mainly released by the World Intellectual Property Organization (WIPO). The data represents the number of patent applications those which the applicants are the resident of the region or state. R&D data is obtained from the *OECD* statistical database. The Business enterprise expenditure on R&D (*BERD*) data consists of all the R&D expenditures made by the business sector. The government expenditure on R&D (*GOVERD*) consists of all the R&D expenditures made by central, regional or local government units. The higher education expenditure on R&D (*HERD*) consists of all the R&D expenditures made by universities, any institutions providing tertiary education, research institutes, clinics and experimental stations (OECD, 2015).

The analysis covers selected 18 OECD countries. We tried to include more OECD countries in the analysis but for many countries, the data starts from 1995. Since the empirical techniques require longer time dimensions, we could not include some important countries such as South Korea, Turkey, Israel etc. However, since the available sample has countries with different economic and technological characteristics, we may suggest that the selected sample reflects important notions in OECD countries.

Table 1.

DESCRIPTIVE STATISTICS

	Mean	**Std. Dev.**	**Min**	**Max**	**Observations**
Number of Domestic Patent Applications	31387	80281	14	384201	648
Business R&D Expenditures	1.186	0.638	0.060	3.031	648
Government R&D Expenditures	0.250	0.127	0.048	0.730	648
Higher Education R&D Expenditures	0.425	0.171	0.055	1.006	648

Note: Authors own calculations.

According to the values given in Table 1, over the 1981-2016 period, the range of the number of domestic patent applications is between 14 and 384,201 which implies that the sample contains observations with very little and very high innovation capacities. For example, the minimum value, 14 is the number of Iceland's patent applications in 1981. Nevertheless, for the advancing years, countries like Iceland and Portugal have relatively lower domestic patent applications as against the other countries in the analysis. However, the sample also includes countries with very high domestic patent applications such as Japan and the Unites States. Another noticeable fact in Table 1 is the differences between the share of the business, government, and higher education sectors' R&D expenditures. The mean value of the share of business R&D is 1.18% while the mean values of the shares of government and higher education R&D expenditures are only 0.25% and 0.42%

respectively. Moreover, the maximum value of government R&D in the sample is about 0.73% and the maximum value of higher education R&D in the sample is 1.00% which belong to Iceland in 1998 and Denmark in 2013 respectively. On the other hand, the maximum share of business R&D expenditures is about 3.03% which belongs to Sweden in 2001. This might be found interesting but in the post-2000 period, the two other Nordic countries, Denmark and Finland raised their business R&D share up to 1.8%. However, for Norway, the ratio is still about 1.08% recently. The other leading advanced economies such as Japan, United States and Germany have ratios above 1.5% over the whole period; and recently, the ratios in Germany and United States are about 1.95% while in Japan it is about 2.47%. Although South Korea does not take part in the analysis due to data constraints, it is important to state that South Korea has the highest share of the world which is about 3.2%.

After presenting the preliminary descriptive statistics on the sample, now let us deal with the issue by making some further, econometric analyses.

3. Empirical methodology and results

The preliminary findings in the previous section imply that there might be a significant relationship between business R&D expenditures and innovation. The average trends in Figure 2 indicate a co-movement of these two variables. Notice that, from this point on, for all the tests and calculations, the variables are used in their natural logarithm. So, *LPATR*, *LBERD*, *LGOVERD,* and *LHERD* abbreviations are the natural logarithmic form of domestic patents, the share of business R&D expenditures, the share of government R&D expenditures and the share of higher education R&D expenditures respectively.

The study uses panel data analysis which utilizes both time and cross-sectional dimensions of the data. Using both dimensions raise the number observation and the degree of freedom which finally raise the efficiency of econometric analyses (Hsiao et al., 1995). Since a panel data sample includes more than one unit, there might be heterogeneity within the sample. In such cases, the inferences obtained by the results of the panel data analyses do not reflect the behavior of each individual unit or the whole panel. Therefore, to be able to interpret the test statistics and any other estimations in the analysis, first, one must examine whether the model has slope homogeneity or not. This is an important step because all the further methods should be chosen by considering the status of the homogeneity. Pesaran and Yamagata (2008) developed a test to examine this issue. Under the null hypothesis, the test statistics suggest slope homogeneity which implies the coefficients obtained from the whole panel data reflects each unit's behavior ($\beta_1 = \beta$).

Table 2.

THE TEST RESULT FOR SLOPE HOMOGENEITY

Test Statistics	Value	Probability
$\tilde{\Delta}$	1.395	0.081
$\tilde{\Delta}_{adj}$	1.500	0.067

Note: Under the null hypothesis, the model has slope homogeneity.

Both test statistics shown in Table 2 cannot reject the null hypothesis of slope homogeneity at 5% statistical significance level. Thus, we may assume that the sample is homogenous. This is most likely caused by the similarities of the selected 18 OECD countries.

Secondly, in panel data analyses, increasing interaction between cross sections (here countries) may cause a *cross-sectional dependence* problem. In other saying, the units of the panel may affect each other even they constitute a homogenous sample. Ignoring the existence of cross-sectional dependence between the units may reduce the power of the test statistics and estimators; and cause misleading results in the further steps of the analysis such as unit root and cointegration tests. For macroeconomic analyses covering open economies with relatively higher interaction in the post-1980 era, the probability of cross-sectional dependence is considerably high. Therefore, examining this issue as before all the further tests is an important step.

Table 3.

THE TEST RESULTS FOR CROSS-SECTIONAL DEPENDENCE

	LPATR		LBERD		LGOVERD		LHERD		MODEL	
Test Statistics	**Value**	**Prob.**	**Value**	**Prob.**	**Value**	**Prob.**	**Value**	**Prob.**	**Value**	**Prob.**
Breusch-Pagan LM	1713.1	0.00	2437.9	0.00	2065.7	0.00	3941.3	0.00	1270.1	0.00
Pesaran scaled LM	89.1	0.00	130.6	0.00	109.3	0.00	216.5	0.00	63.8	0.00
Bias-corrected scaled LM	88.9	0.00	130.3	0.00	109.1	0.00	216.3	0.00	63.6	0.00
Pesaran CD	13.9	0.00	32.9	0.00	1.35	0.17	62.1	0.00	2.1	0.03

Note: The null hypothesis for each test statistics simply indicates cross-sectional independence. The first four columns show test statistics for domestic patents, business R&D expenditures, government R&D expenditures, and higher education R&D expenditures while the last column shows the test statistics for the residuals obtained from the base model given in Equation (4).

Table 3 shows the four test statistics examining the existence of cross-sectional dependence which are Breusch-Pagan's (1980) LM Test, Pesaran's (2004) scaled LM Test, Baltagi, Feng and Kao's (2012) Bias-corrected scaled LM and Pesaran's (2004) CD Test statistics. The null hypothesis for each test statistics is "*no cross-sectional dependence*". We applied the mentioned tests for the main variables of the study and the residuals of the base model given in Equation (4). The results imply that except the Pesaran CD Test, we can reject the null hypothesis for each variable and for the model at 5% statistical significance. So, there is cross-sectional dependence between selected countries. However, the Pesaran CD Test results suggest that, for government R&D expenditures, the null hypothesis cannot be rejected. Moreover, the Pesaran CD Test cannot even reject the null hypothesis for the residuals of the base model at 1% significance level. In short, although there are some weak evidence suggesting no cross-sectional dependence, we have stronger evidence implying the existence of cross-sectional dependence. In short, we are now in doubt for the case; there might be cross-sectional dependence problem in the sample. Thus, we will apply for the further steps both older methods ignoring cross-sectional dependence and also newer methods which allow cross-sectional dependence in the sample.

To make a cointegration analysis, the variables should be integrated of order one which implies they should be non-stationary at level but stationary at their first differences. In the recent econometric literature, the panel unit root tests are in two categories; the first-generation panel unit root tests and the second-generation panel unit root tests. The first-generation panel unit root tests such as Harris and Tzavalis, 1999; Maddala and Wu, 1999; Breitung (2000); Hadri, 2000; Choi, 2001; Levin, Lin and Chu, 2002; Im, Pesaran and Shin, 2003 assume cross-sectional independence. The second-generation panel unit root tests, on the other hand, considers cross-sectional dependence and give more powerful test results in case of such an issue (i.e. Bai and Ng, 2001; Choi, 2002; Phillips and Sul, 2003; Moon and Perron, 2004; Pesaran, 2007).

Table 4.

PANEL UNIT ROOT TEST RESULTS

Test Statistics (Level)	LPATR	LBERD	LGOVERD	LHERD
Levin, Lin & Chu	0.504	1.521	-0.158	-0.926
Breitung t-stat	3.192	3.734	1.896	0.353
Im, Pesaran and Shin	2.357	1.207	0.534	-0.526
ADF-Fisher	28.754	38.710	44.447	43.487
PP-Fisher	28.305	22.508	37.966	26.255
CIPS	-2.168	-1.785	-2.417	-2.075
Test Statistics (First Difference)	**LPATR**	**LBERD**	**LGOVERD**	**LHERD**
Levin, Lin & Chu	-18.795***	-13.917***	-17.995***	-15.437***
Breitung t-stat	-12.851***	-10.556***	-13.148***	-11.835***
Im, Pesaran and Shin	-18.872***	-12.440***	-16.987***	-14.462***
ADF-Fisher	319.779***	202.218***	287.993***	236.878***
PP-Fisher	348.593***	211.603***	339.973***	481.904***
CIPS	-5.514***	-4.395***	-5.062***	-4.849***

Note: *, **, *** denote statistical significance at 10%, 5% and 1%. The first five test statistics are called "first-generation panel unit root tests" which are not robust under cross-sectional dependence. The lag lengths for these tests are automatically selected by the Schwarz Information Criteria (SIC). The CIPS test statistics is a "second-generation panel unit root test" and allow for cross-sectional dependence. The lag length of this test is automatically selected by the F-joint test.

Since the cross-sectional dependence test results in Table 3 brought us into doubt, we applied unit root tests from both generations which are shown in Table 4. As first-generation tests, we applied Levin, Lin & Chu, Breitung, Im, Pesaran and Shin, ADF-Fisher and PP-Fisher panel unit root tests. Notice that the ADF-Fisher and PP-Fisher tests are modified versions of Augmented Dickey-Fuller and Phillips-Perron test which have been developed by Maddala and Wu (1999) and Choi (2001). From the second-generation tests, the cross-sectionally augmented Im-Pesaran-Shin panel unit root test (CIPS) of Pesaran (2007) is applied. The CIPS test statistics is the group-specific average of the cross-sectionally augmented ADF (CADF) test results of Pesaran (2007). For each panel unit root test in Table 4, the null hypothesis is that "all the series are stationary" while the alternative hypothesis is "at least one of the series in the panel is non-stationary (has unit-root)". All the test statistics in Table 4 suggest that the series are non-stationary at level. The bottom panel in Table 4 implies that all the test statistics suggest that series are stationary at their first differences. The test results obtained both from the first and second-generation panel unit root tests are consistent with each other. Therefore, the series are integrated of order one and now we are able to proceed to the cointegration analysis.

To examine the co-movement of the series that are integrated of order one, cointegration tests are applied. For the cointegration analysis, we applied cointegration tests both not allowing cross-sectional dependence and allowing cross-sectional dependence. Table 5 presents the test results for Pedroni (2004) and Kao (1999) panel cointegration tests. The null hypothesis of both tests is that the series are not cointegrated. According to the Pedroni (2004) test results on Panel A, both panel and group test statistics cannot reject the null which implies the series are not cointegrated. Similarly, the Kao (1999) test result shown on Panel B suggests that the null hypothesis of cointegration cannot be rejected. In short, both the Pedroni and Kao cointegration test results do not imply the existence of cointegration. But remember that the series and the base model have cross-sectional dependence problem; and both cointegration tests applied above do not allow correlation between cross-sectional units. So, there might be still a cointegration relationship between the variables.

Table 5.

THE TEST RESULTS FOR PEDRONI (2004) AND KAO (1999) PANEL COINTEGRATION TESTS

Panel A: Pedroni (2004) Panel Cointegration Test					
Within Dimension			**Between Dimension**		
Statistics	**Value**	**p-value**	**Statistic**	**Value**	**p-value**
Panel v-Statistic	-2.159	0.98			
Panel rho-Statistic	1.870	0.96	**Group rho-Statistic**	3.253	0.99
Panel PP-Statistic	0.512	0.69	**Group PP-Statistic**	1.552	0.93
Panel ADF-Statistic	0.146	0.55	**Group ADF-Statistic**	0.723	0.76
Panel B: Kao (1999) Panel Cointegration Test					
Statistics	**Value**		**p-value**		
ADF	1.218		**0.11**		

Note: The null hypothesis of the test statistics is that the variables are not cointegrated. The lag length is selected by Schwarz Information Criterion (SIC).

In case of cross-sectional dependence, the Westerlund (2007)'s Error-Correction Based Panel Cointegration test and Westerlund and Edgerton (2007)'s Panel Bootstrap Cointegration tests give more reliable and consistent test results. Table 6 shows the test results obtained from both methods. Panel A shows the results for Westerlund (2007) cointegration test. The Ga, Gt, Pa and Pt test statistics are calculated for the group-means and for the whole panel. The robust probability values for the Pt and Pa test statistics which are obtained by applying bootstrap replications reject the null hypothesis at 1% statistical significance and imply the existence of a cointegrating relationship. By recalling the evidence favoring slope homogeneity on Table 2 and considering the Pt and Pa test statistics, one may suggest the existence of a cointegrating relationship for the whole panel. Panel B shows the results for Westerlund and Edgerton (2007)'s cointegration test. Note that the null hypothesis of this test is that the series are cointegrated. It is clearly seen that the null hypothesis for this test cannot be rejected. Since the Westerlund (2007) and Westerlund-Edgerton (2007) panel cointegration tests provide more power as against to the previous tests and confirm each other, we may now suggest that the variables are cointegrated.

Table 6.

WESTERLUND (2007) AND WESTERLUND-EDGERTON (2007) PANEL COINTEGRATION TEST RESULTS

Panel A: Westerlund (2007) Error-Correction-Based Panel Cointegration Test			
Test Statistics	**Value**	**Z-value**	**Robust p-value**
Gt	-2.194	2.484	0.392
Ga	-4.155	6.004	0.204
Pt	-6.418	4.285	0.008
Pa	-4.484	4.280	0.008
Panel B: Westerlund and Edgerton (2007) Panel Bootstrap Cointegration Test			
Test Statistics	**Value**	**Asymptotic p-value**	**Robust p-value**
LM Test	5.092	0.000	0.296

Note: The null hypothesis of the Westerlund (2007) cointegration test is "no cointegration" while the Westerlund and Edgerton (2007) test examines the null hypothesis of cointegration. The test statistics regressions are estimated with trend and constant. The lag length criteria decision of the model has been made via the Akaike Information Criterion (AIC) and the kernel bandwidth is determined according to the rule $4(T/100)^{2/9}$. The robust p-values are calculated by making 500 bootstrap replications. For more details, please see Persyn and Westerlund (2007) for Panel A and Westerlund and Edgerton (2007) for Panel B.

The evidence favoring the existence of cointegration only reveal a co-movement of the selected variables. To observe the impact of business, government and higher education sectors' R&D on domestic patents, the next step is estimating the long-run coefficients. In order to check the robustness of the results, the long-run coefficients of the model are estimated via five different econometric estimators. These results are seen in Table 7. As asymptotically unbiased and more efficient methods compared to OLS, firstly, the Fully Modified OLS (FMOLS) method proposed by Phillips and Hansen (1990) and the dynamic OLS (DOLS) method proposed by Saikkonen (1992) and Stock and Watson (1993) are used. The findings obtained from the FMOLS and DOLS estimators show that the number of patent applications increases 0.44% and 0.48% respectively as business R&D expenditures increases by 1%. From these two estimators, only the FMOLS estimation results imply that the government sector's R&D expenditures significantly raise domestic innovation. There is no statistically significant evidence on the impact of higher education sectors' R&D expenditures. However, these two estimators are not as robust as CCEMG and AMG estimators in case of cross-sectional dependence. The CD tests applied on the residuals obtained from these the FMOLS and DOLS estimations imply that there is still a cross-sectional dependence problem in the models.

The last three columns in Table 7 shows the estimation results applied via the mean group estimators. Firstly, the mean group (MG) method of Pesaran and Smith (1995) which does not concern cross-sectional dependence is used. The coefficient obtained from the MG estimator also confirms the previous results with a minor difference. The MG estimation results suggest that the R&D activities made by the business sector have a statistically significant positive effect on patenting activities while the R&D efforts of the government and higher education sectors do not have any statistically significant effect. However, since the sample of the study have some concerns with cross-sectional dependence, checking the results with some further methods that consider cross-sectional dependence will relieve the concerns about this issue. Within this purpose, the Common Correlated Effects Mean Group estimator (CCEMG) which has been developed by Pesaran (2006) and the Augmented Mean Group estimator (AMG) has been developed by Bond and Eberhardt (2009) and Eberhardt and Teal (2010) are used. Besides verifying the findings of the previous findings, the estimated coefficients via these two methods are very close to each other. One may now clearly suggest that even if there might be a cross-sectional dependence between selected countries, the estimation results are almost the same. The CEE-MG and the AMG estimation results also confirm the FMOLS and DOLS results and suggest that as business R&D expenditures increase by 1%, the number of patent applications increases by 0.39% and 0.37% respectively. The coefficients obtained from these two estimators also suggest that both government and higher education sectors' R&D expenditures have no significant impact on patenting activities (innovation). Moreover, the CD test results show that the AMG estimator is the most resistant technique for this sample on allowing the cross-sectional dependence problem.

Table 7.

THE LONG-RUN ESTIMATION RESULTS

Dependent Variable: Number of Domestic Patent Applications					
Variable	**FMOLS**	**DOLS**	**MG**	**CCE-MG**	**A-MG**
Business R&D	0.448*** (0.064)	0.480*** (0.080)	0.429*** (0.099)	0.395** (0.186)	0.370*** (0.113)
Government R&D	0.092* (0.049)	-0.061 (0.070)	-0.094 (0.141)	-0.078 (0.106)	-0.112 (0.102)
Higher Education R&D	-0.027 (0.064)	0.085 (0.090)	-0.038 (0.212)	0.144 (0.094)	0.002 (0.111)
Observation	612	608	648	648	648
Country	18	18	18	18	18
CD Test (prob.)	0.035	0.083	0.000	0.033	0.288

Note: Standard errors are in parentheses. *, **, *** denote statistical significance at 10%, 5% and 1%. The null hypothesis of the CD Test implies that the residuals have no cross-sectional dependence problem.

By combining all the five estimation results, we can suggest that increases in the share of business R&D expenditures significantly raise domestic innovation while increases in the share of government and higher education sectors' R&D expenditures do not have any statistically significant effects in OECD countries. It is seen from all the models that the standard errors of the government R&D and higher education R&D are very high which lead to insignificance. The range of the business R&D coefficient is between 0.370 and 0.480. The results explicitly reveal that the main source of domestic innovation is R&D efforts made by the business sector. It seems that the government sector's and higher education sector's R&D efforts do not contribute to domestic innovation. Only the FMOLS estimator which cannot produce consistent results in case of cross-sectional dependence, suggests that also government R&D expenditure has a significant impact on domestic innovation. The obstruction in government and higher education sectors' R&D efforts might be caused by the nature and institutional structures of government and the higher education sector. Their R&D perception and priorities are more different than the business sector which mainly acts by focusing the profit-motive. As it is widely discussed in the economic growth literature, the spillover mechanism has an important role in knowledge accumulation. The R&D activities made by government sector are usually performed in line with the needs of the government sector and this may cause some obstacles in the knowledge spillover mechanism within the whole economy. However, the main purpose of the business sector is profit maximization which leads to the R&D efforts made by the business sector mainly based on the needs of the market and society; and this brings about a knowledge spillover mechanism within the business sector (between the firms).

4. Conclusion

This study aimed to examine the effects of business, government and higher education sectors' R&D expenditures on domestic innovation performance. The modern theory of economic growth puts a premium on innovation and technological progress which implies countries investing in new technologies and ideas will grow faster and catch up the frontier countries. Thus, investigating the sources of innovation has importance in the empirical economic literature. On the other hand, there are some preliminary inferences showing the relative success of the business sector in innovation performance. Within this purpose, the study presented some empirical evidence obtained from a panel data analysis covering 18 OECD countries over the 1981-2016 period.

In the empirical part of the study, the number of domestic patent applications, the share of business R&D expenditures, the share of government R&D expenditures and the share of higher education sector's R&D expenditures are employed. The diagnostic test results showed that there are evidence implying the data has a cross-sectional dependence problem. Therefore, by using newer and powerful techniques, robustness checks have been made for all the tests and estimators. The cointegration test results obtained from two different methods allowing cross-sectional dependence suggested that the series are cointegrated. Then, to estimate how the sectoral R&D expenditures affect the number of patent applications, five different estimators have been used. The first two estimations (FMOLS and DOLS) suggested that business R&D expenditures have a statistically significant and positive impact on domestic patents. The FMOLS results also suggest that R&D expenditures made by the government sector have a significant impact on domestic patents while both FMOLS and DOLS results do not show any significant evidence for higher education sectors' R&D expenditures. The third one, the mean group estimator (MG) implied that increases in business R&D expenditures significantly raise domestic innovation while increases in government and higher education sector's R&D expenditures do not affect domestic innovation. However, the first three estimators are not resistant to cross-sectional dependence problem. For this reason, the augmented version of the mean group estimator (CCEMG and AMG) are employed to consider the existence of dependence. The CCEMG and AMG results did not confirm the significant coefficient of government R&D estimated by MG estimator and suggested that the only driver of innovation from these three R&D investment types is business R&D. Moreover, all the models implied that the elasticity of business R&D investment is about 0.37-0.48; which is very remarkable.

The empirical evidence obviously suggests that the main driver of innovation is the business sector's R&D investments. This is probably due to the profit motive of the business sector. Making the R&D effort by expecting a palpable profit for the future, probably determines the success rate of R&D investment. Since the effectiveness in the government sector and the profit motive in the higher education sector cannot compete with the business sector, the situation most probably will not become reversed even in the future. On the other hand, policymakers and governments should absolutely realize the driving force of the business R&D sector and should implement incentive policies to raise private R&D investments rather than investing in R&D by itself or by its institutions. Further research may focus this point either on a macro or micro basis.

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JAVNO, PRIVATNO ILI SVEUČILIŠTE?: UČINKOVITOST ISTRAŽIVANJA I RAZVOJA U DRŽAVAMA OECD-a

Sažetak

Cilj ovog rada je istražiti diferencijalne utjecaje ulaganja u istraživanje i razvoj u sektorima gospodarstva, vlade i visokog obrazovanja na inovacije u zemljama OECD-a. Iako poslovni sektor ima najveći udio u području istraživanja i razvoja zbog profitnih interesa, također postoje i napori javnog sektora i visokog obrazovanja. S druge strane, ekonomska literatura desetljećima sumnja u učinkovitost javnog sektora. Istraživanje se bavi izradom panel analize podataka koja obuhvaća 18 zemalja OECD-a tijekom razdoblja od 1981. do 2016. godine i ima za cilj ispitati odvojene učinke ovih sektorskih izdataka za istraživanje i razvoj na inovacijske performanse. Budući da je većina postojeće literature uglavnom usmjerena na odnos istraživanja i razvoja i BDP-a, ova studija ima za cilj pridonijeti relativno neistraženoj temi. Kako bi se dobili čvrsti nalazi, korištena su recentna ekonometrijska testiranja i procjene. Prethodne studije u postojećoj literaturi ignorirale su mogućnost problema međusektorske ovisnosti u uzorcima zemlje. Zanemarivanje ovog problema može dovesti do pristranih i nedosljednih rezultata. Ova studija polazi od pretpostavke o međusektorskoj ovisnosti između odabranih zemalja i analizira robusnost svakog testa i procjenitelja putem recentnih ekonometrijskih tehnika. Rezultati otkrivaju prvo kako postoji kointegracijski odnos između broja domaćih patenata (inovacija) i ostalih triju pokazatelja istraživanja i razvoja. Drugo, dugoročni rezultati procjene ukazuju na to da povećanje izdataka za istraživanje i razvoj u poslovnom sektoru značajno povećava inovacije, dok ne postoje statistički značajni dokazi o utjecaju izdataka za istraživanje i razvoj od strane vlade i sektora visokog obrazovanja. Rezultati ukazuju kako se napori vlade i sektora visokog obrazovanja vezano uz istraživanje i razvoj ne mogu pretvoriti u inovacije i ne doprinose mehanizmu prelijevanja znanja.

Ključne riječi: istraživanje i razvoj, inovacije, OECD, panel analiza