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The Impact of R&D and Innovation on National Income*

Ar-Ge ve İnovasyonun Milli Gelire Etkisi

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A B S T R A C T

In this study we empirically investigate the influence of several indicators of R&D and innovation on GDP for OECD countries by utilizing an unbalanced panel for the years of 1995-2021. Two distinct measures of patent applications, two different measures of trademark applications, researchers in R&D, and technicians in R&D are the proxies for R&D and innovation. We also added inflation, productivity, investment, and education into our model as control variables. Selection between fixed effect model and random effect model is made via Hausman test. According to the estimation results, we identified statistically significant positive impact of two distinct measures of patent applications, two different measures of trademark applications, researchers in R&D, and technicians in R&D variables on gross domestic product for the sample of OECD countries during the period of 1995-2021. Regarding the control variables, whenever they are statistically significant then we observed positive coefficient estimations for the variables of productivity, investment, and education and negative coefficient estimation for the variable of inflation.

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ÖZ

Bu çalışmada, 1995-2021 yılları için dengesiz panel veri setini kullanarak OECD ülkeleri için çeşitli Ar-Ge ve yenilik göstergelerinin GSYİH üzerindeki etkisini ampirik olarak incelemekteyiz. İki farklı patent başvurusu ölçütü, iki farklı marka başvurusu ölçütü, Ar-Ge'de yer alan araştırmacı sayısı ve Ar-Ge'de yer alan teknisyen sayısı çalışmamızda Ar-Ge ve yeniliğin temsilcileri olarak kullanılmıştır. Ayrıca enflasyon, verimlilik, yatırım ve eğitim değişkenlerini de kontrol değişkenleri olarak modelimize ekledik. Sabit etki modeli ile rassal etki modeli arasındaki seçim Hausman testi ile yapılmıştır. Tahmin sonuçlarına göre, 1995-2021 döneminde OECD ülkeleri örneklemi için patent başvurularının iki farklı ölçütünün, ticari marka başvurularının iki farklı ölçütünün, Ar-Ge'de yer alan araştırmacı sayısı ve Ar-Ge'de yer alan teknisyen sayısı değişkenlerinin gayrisafi yurtiçi hasıla üzerinde istatistiksel olarak anlamlı pozitif etkisi olduğunu tespit ettik. Kontrol değişkenleri ile ilgili olarak, istatistiksel olarak anlamlı oldukları durumlarda, verimlilik, yatırım ve eğitim değişkenleri için pozitif katsayı tahminleri ve enflasyon değişkeni için negatif katsayı tahminleri elde ettik.

1. Introduction

Growth brings about improvements in living standards and development. According to economic theory, even small differences in growth values can lead to radical changes in the welfare level of those countries. The only way to achieve the high growth rate desired by each country is to use and develop information and information technologies effectively and sufficiently. The processes of developing new products and new production techniques, obtaining many outputs with the same input, and contributing to economic growth with more efficient and faster production methods cannot reach the desired goal without R&D (Bozkurt, 2015: 188).

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Innovation has become a word heard more frequently in recent years. Innovation means using new methods in social, cultural and administrative environments. The innovation process includes all inputs used for planning, organizing and emergence of new information. Patent documents are obtained so that products and goods developed by inventions or brands are registered by the state and individuals do not lose their rights. The formation of a competitive environment has made it necessary for countries and companies to use the many advantages brought by innovation and technological efficiency (Börü and Çelik, 2019:197).

Research and development are the creative work carried out within a certain plan and the bringing together of new products and services to be developed. The aim of R&D is to develop new products that create value, to increase each development produced, to provide cost advantage for production functions and to provide superiority in competitive markets (Börü and Çelik, 2019: 198). Adam Smith stated in his work 'The Wealth of Nations' that the growth process is not only realized with capital flows but also with technological progress, social factors and investments. He advocated the protection of production standards by including machines in the production system. David Ricardo wrote as the pioneer of the Classical school and included the basic data of the game called "Principles of Political Economy and Taxation" and his views on the status of economic growth and social development. He studied the current, profitable, rents, scope issues of functional income with the law of diminishing returns. Solow, on the other hand, touched upon the transition from technological innovation and change as the pioneer of the growth process in his article 'Contribution to the Theory of Economic Growth'. He advocated the idea that savings, technology, production and capital have a positive effect in the long term. In other words, investment equals savings, the economy is at full employment, perfect competition conditions prevail, the offer is closed, the workforce is fixed. According to Marx, innovation movements contribute to the economy as they increase savings (Börü and Çelik, 2019: 198).

Grossman and Helpman (1991), Aghion and Howitt (1992), Barro and Sala-i Martin (2004) are recent studies that emphasize the importance of the link between growth and R&D. According to Grossman and Helpman (1994), industrial innovation resulting from R&D investments is considered the main driver of growth. High profit margins encourage companies to invest in R&D activities. This will provide superior companies with more resources for R&D activities and the innovation process will accelerate, thus achieving higher productivity. On the other hand, Aghion and Howitt (1992) assumed that growth is compatible with technological development and that this is a result of competition between R&D-oriented companies focused on innovation. According to Barro and Sala-i Martin (2004), technological development is modeled as the enrichment of intermediate goods in the production process (Bayraktar et al. 2022: 894).

There are two modern growth theories: exogenous and endogenous growth. The Harrod-Domar model and the Neoclassical Growth model are useful exogenous growth theories. In exogenous growth models, production is done by labor and capital using appropriate technologies, but these models do not detect technological progress (Kalın, 2023:40).

In the R&D-based endogenous growth model, long-term Growth can be achieved by supporting firms' innovative activities. Howitt observed that R&D incentives support long-term growth (Sungur, et al. 2016: 176).

The preceding brief discussion on the importance of R&D and innovation for an economy (particularly for economic growth) encouraged us to analyze the association between national income and R&D and innovation. In this sense, this study focuses on how R&D and innovation, which are seen as an important source of the economic growth process, affect gross domestic product (GDP) in OECD countries by utilizing an unbalanced panel data for the years of 1995-2021. According to the estimation results, we identified the statistically significant positive effect of R&D and innovation on GDP of OECD countries.

Section two provides a short literature review; section three explains data and methodology used in the analyses; section four reports and discusses estimation results; and the last part concludes.

2. Literature Review

The relationship between R&D expenditures, innovation and per capita income is critical. To achieve innovation development, effective technology policies should be implemented, R&D expenditures should be used effectively, which will ultimately contribute to economic growth. There are many studies investigating the relationship between R&D expenditures, innovation development and per capita income.

Bakari (2021) used the panel ARDL model to investigate the relationship between economic growth and innovation, considering the importance of the Internet, with data from 1995 to 2016 in a sample of 76 developed and developing countries. Our findings provided empirical evidence on the positive role of innovation and the Internet in economic growth and the positive role of economic growth and the Internet in innovation.

Bayraktar et al. (2022) examines the relationship between R&D expenditures and growth in Brazil, Russia, India, China, South Africa and Turkey (BRICS-T) countries during the period 2000-2018. In this direction, Dumitrescu-Hurlin's causality test, Impulse-Response and Variance Decomposition analyses were used together with the VAR approach. According to the causality test, a bidirectional causality relationship was determined between R&D expenditures and growth in BRICS-T countries.

Duman and Aydın (2018) the existence of the relationship between R&D expenditures and GDP in Turkey between 1998-2015 was tried to be proven by analyzing with ADF root test, Causality and VAR tests. As a result of the analysis, ıt was determined that there is a linear and one-way relationship between R&D expenditures and GDP in Turkey and because of the Causality test, it was determined that the increase in R&D expenditures caused positive increases in GDP, while decreases caused a decrease in GDP.

Falk (2007), tried to estimate the impact of R&D investments on long-term economic growth in OECD countries using panel data with dynamic empirical growth model between 1970 and 2004. Using GMM estimator, it is found that both the ratio of firms' R&D expenditures to GDP and the share of R&D investment in high-technology sector have strong positive effects on GDP per capita and GDP per hour worked in the long run.

Kalın (2023) in a group of developing and newly developed economies (Brazil, Chile, Colombia, Indonesia, India, Peru, Republic of Korea, Russian Federation, Singapore, Thailand and Turkey), the ratio of GDP to R&D expenditures was calculated using annual data between 2000-2020. The relationship between the ratio and GDP was examined using the fixed effects model and panel data analysis using gross domestic product per capita as the dependent variable. When the analysis result is examined, it is seen that there is a significant and positive relationship between economic growth and R&D.

Kıngır and Kamacı (2016) tested the relationship between R&D expenditures and economic growth in four Central Asian Republics (Kazakhstan, Kyrgyzstan, Tajikistan and Azerbaijan) and Turkey using panel data analysis. In this direction, Levin-Lin and Chu (LLC) Panel Unit Root Test and then Pedroni Cointegration and Panel Granger Causality tests were applied to test the stability of the data. When the analysis result was examined, a one-way causal relationship from economic growth to R&D expenditures was determined and it was determined that there was no causal relationship from R&D expenditures to economic growth.

Külünk (2018) examined the relationship between Turkey's R&D expenditures, exports and GDP series between 1996 and 2016 using multiple linear regression analysis. When the analysis results were examined, it was seen that R&D expenditure had a positive effect on exports, exports had a positive effect on growth and there was no direct relationship between R&D expenditures and GDP.

Özden and Uysal (2020) established the relationship between innovation and economic growth in Turkey between 1990 and 2017 within the scope of time series analysis with vector autoregressive model (VAR). According to the analysis result, a positive relationship was found between economic growth and innovation in Turkey.

Rahmi (2016) examined the effect of R&D expenditures on high-technology exports of 7 Newly Industrialized Countries in the period 1996-2013 using panel data analysis. It was observed that there was a one-way causality relationship from R&D expenditures to high-technology exports.

Sametı et al. (2010) tested the effects of government-financed economic growth, open trade and R&D expenditures on R&D intensity in OECD countries between 1996 and 2008 using panel data analysis. According to the analysis results, it was determined that government-financed economic growth, open trade and R&D expenditures had a positive effect on R&D intensity, while open trade had a more positive effect than the others.

Sökmen and Açcı (2017) examined whether the ratio of R&D expenditures to gross domestic product in BRICS-T countries (Brazil, Russia, India, China, South Africa, Turkey) affected the growth rate in the period 1999-2015 using panel data method. Panel co-integration tests showed that there is a long-term relationship between R&D expenditures and economic growth.

Sözen and Tufaner (2020) the relationship between R&D expenditures, high-technology product exports and patent application numbers was examined using panel data analysis for 25 OECD member countries between 1997 and 2016. According to the analysis results, a mutual causality relationship was found between R&D expenditures and at least one unit of high-technology product exports and between R&D expenditures and patent applications.

Tanrıverdi and Öztürk (2023) used ARDL and Granger Causality analysis to produce different econometric models for the effects of R&D expenditures, number of researchers, scientific publications and patents on national income in Turkey between 2001-2016. According to the causality analysis results, there is a one-way causality from economic growth to patents and when the ARDL analysis was examined, it was revealed that there was a positive and 2.5% relationship between R&D and economic growth. In long-term analyses, no significant result was achieved between R&D and growth.

Wu and Zhou (2007) tested the relationship between R&D expenditures and economic growth for the Chinese countries for the period 1953-2004 by using cointegration and causality analysis. As a result of the study, a long-term cointegration relationship and a dual causal relationship were determined between R&D and GDP.

3. Data and Methodology

This study empirically examines the impact of R&D expenditure and several indicators of innovation on GDP for OECD countries. The study uses an unbalanced panel dataset covering the period of 1995-2021.

The following multivariate fixed effect (FEM) models are estimated.

$GDPit=\beta0i+\beta1PATENT1it+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+uit$ (1.A)

$GDPit=\beta0i+\beta1PATENT2it+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+uit$ (1.B)

$GDPit=\beta0i+\beta1RESEARCHERit+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+uit$ (1.C)

$GDPit=\beta0i+\beta1TECHNICIANit+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+uit$ (1.D)

$GDPit=\beta0i+\beta1TRADEMARK1it+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+uit$ (1.E)

$GDPit=\beta0i+\beta1TRADEMARK2it+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+uit$ (1.F)

Additionally, the following multivariate random effects (REM) models were estimated.

$GDPit=\beta0+\beta1PATENT1it+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+\varepsilon i+uit$ (2. A)

$GDPit=\beta0+\beta1PATENT2it+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+\varepsilon i+uit$ (2.B)

$GDPit=\beta0+\beta1RESEARCHERit+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+\varepsilon i+uit$ (2.C)

$GDPit=\beta0+\beta1TECHNICIANit+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+\varepsilon i+uit$ (2.D)

$GDPit=\beta0+\beta1TRADEMARK1it+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+\varepsilon i+uit$ (2.E)

$GDPit=\beta0+\beta1TRADEMARK2it+\beta2INFLATIONit+\beta3PRODUCTIVITYit+\beta4INVESTMENTit+\beta5EDUCATIONit+\varepsilon i+uit$ (2.F)

The subscript *it* represents the observed value of the relevant variable in the *i.th* country in year *t*, the notation $\beta 0i$ represents country-specific factors, the notation εi represents time-independent country-specific stochastic factors, and the notation *uit* stands for the error term of the regression model.

In addition to the R&D and innovation indicators, four control variables (INFLATION, PRODUCTIVITY, INVESTMENT, and EDUCATION) were used in the models. While the INFLATION variable is expected to decrease GDP, the PRODUCTIVITY, INVESTMENT and EDUCATION variables are anticipated to increase GDP. Logarithmic forms of all variables were used in the models, so each model is a full-logarithmic (log-log) model and therefore the partial slope coefficients obtained give the elasticities.

Definitions and sources of the dependent and independent variables used in the models are given in Table 1 below.

Table 1. Variable Definitions and Sources

Variables	Source	Source
GDP	GDP (constant 2015 US$)	WDI
INFLATION	Inflation, consumer prices (annual %)	WDI
PRODUCTIVITY	GDP per person employed (constant 2017 PPP $)	WDI
INVESTMENT	Gross capital formation (% of GDP)	WDI
EDUCATION	School enrollment, tertiary (% gross)	WDI
PATENT1	Patent applications, residents	WDI
PATENT2	PCT, patents, applications/million pop.	Global Competitiveness Index
TRADEMARK1	Trademark applications, nonresident, by count	WDI
TRADEMARK2	Trademark applications, resident, by count	WDI
RESEARCHER	Researchers in R&D (per million people)	WDI
TECHNICIAN	Technicians in R&D (per million people)	WDI

4. Estimation Results

4.1. Estimation Results for PATENT1 Variable

The variable PATENT1 shows the value of domestic patent applications. The estimation results using PATENT1 are reported in Table 2. In the relevant table, the results obtained from the fixed model are shown in Panel A, and the results obtained from the random effect model are shown in Panel B. When the Hausman test result is examined, the fixed effect model is selected, the results will be interpreted according to the results in Panel A. We got positive statistically significant coefficient estimation for PATENT1, PRODUCTIVITY, INVESTMENT, and EDUCATION variables but no significant coefficient estimation for INFLATION variable. It is seen that a 1% increase in domestic patent application leads to a rise in GDP by 0.0258%. We can state that a 1% jump in productivity augments GDP by 0.9810%, a 1% rise in investments enhances GDP by 0.1832%, and a 1% jump in human capital education level increases GDP by 0.2251%. The F-statistic value obtained for the fixed effect model is statistically significant and therefore the fixed effect model is statistically significant. Having a very high R-square value (i.e., 0.9975) for the FEM model points out that the explanatory power of the independent variables on the GDP is very high.

Table 2. Estimation Results for PATENT1 Variable

Variables	Panel A: Fixed Effect Model				Panel B: Random Effects Model			
	Coeff.	Std. Err.	t-stat.	P value	Coeff.	Std. Err.	t-stat.	P value
C	13.6634	0.3106	43.9878	0.0000	13.6626	0.3299	41.4155	0.0000
PATENT1	0.02580	0.0077	3.3362	0.0000	0.0382	0.0076	4.9930	0.0000
INFLATION	0.0141	0.0104	1.3600	0.1742	0.0151	0.0104	1.4562	0.1457
PRODUCTIVITY	0.9810	0.0299	32.7558	0.0000	0.9843	0.0298	33.0729	0.0000
INVESTMENT	0.1832	0.0218	8.4051	0.0000	0.1826	0.0218	8.3802	0.0000
EDUCATION	0.2251	0.0174	12.9398	0.0000	0.2166	0.0173	12.5186	0.0000
	Panel A: Fixed Effect Model				Panel B: Random Effect Model			
R-squared	0.9975				0.8422			
F-stat.	7279.6800				868.1135			
P-value(F-stat.)	0.0000				0.0000			
Hausman Test Stat.	118.0047							
P-value (Hausman)	0.0000							
Selected Model	FEM							
Number of Years	26							
Number of Countries	38							
Number of Observations	819							

4.2. Estimation Results for PATENT2 Variable

The estimation results using PATENT2 are reported in Table 3. Since the Hausman test result picks the random effect model, the results will be interpreted according to the results in Panel B. We have statistically significant positive coefficient estimations for PATENT2, PRODUCTIVITY, and INVESTMENT variables but no significant coefficient estimations for INFLATION and EDUCATION variables. A 1% rise in patent application enhances GDP by 0.0566%, a 1% jump in productivity causes an increase in GDP by 1.2841%, and a 1% increase in investment leads to a rise in GDP by 0.1519%. It is concluded that the F-statistic value obtained for the random effect model is statistically significant and therefore the random effect model is statistically significant. We observe that the explanatory power of the REM model is quite high given the R-square value of 0.7855.

Table 3. Estimation Results for PATENT2 Variable

Variables	Panel A: Fixed Effect Model				Panel B: Random Effects Model			
	Coeff.	Std. Err.	t-stat.	P value	Coeff.	Std. Err.	t-stat.	P value
C	11.4092	0.7816	14.5965	0.0000	11.5011	0.8210	14.0095	0.0000
PATENT2	0.0557	0.0139	4.0165	0.0001	0.0566	0.0139	4.0853	0.0001
INFLATION	0.0006	0.0102	0.0541	0.9569	0.0003	0.0102	0.0315	0.9749
PRODUCTIVITY	1.2916	0.0775	16.6666	0.0000	1.2841	0.0772	16.6391	0.0000
INVESTMENT	0.1500	0.0328	4.5784	0.0000	0.1519	0.0327	4.6424	0.0000
EDUCATION	-0.0320	0.0320	-1.0005	0.3185	-0.0302	0.0319	-0.9459	0.3453
	Panel A: Fixed Effect Model				Panel B: Random Effect Model			
R-squared	0.9978				0.7855			
F-stat.	19272.9100				150.1857			

P-value(F-stat.)	0.0000	0.0000
Hausman Test Stat.	3.6703	
P-value (Hausman)	0.5978	
Selected Model	REM	
Number of Years	6	
Number of Countries	37	
Number of Observations	211	

4.3. Estimation Results for TRADEMARK1 Variable

Estimation Results for TRADEMARK2 Variable the TRADEMARK1 variable is trademark applications of nonresidents. The estimation results using the TRADEMARK1 variable are reported in Table 4. The estimation results will be interpreted according to the findings in Panel A as the Hausman test selects FEM model. Positive and statistically significant coefficient estimations were obtained for TRADEMARK1, PRODUCTIVITY, INVESTMENT, and EDUCATION variables whereas negative and statistically significant coefficient estimation was obtained for INFLATION variable. It is seen that a 1% increase in the trademark applications of non-residents expands GDP by 0.0623%. It can be said that a 1% rise in productivity enhances GDP by 1.4841%, a 1% jump in the level of education of human capital increases GDP by 0.1460%, and a 1% increase in investments induces a rise in GDP by 0.1724%. On the other hand, if inflation goes up by 1% then GDP drops by 0.0383%. Meanwhile the F-statistic value obtained for the fixed effect model is statistically significant and hence the fixed effect model is statistically significant. The FEM model possesses a very high R-square value and confirms that the explanatory power of FEM model is very high.

Table 4. Estimation Results for the TRADEMARK1 Variable

Variables	Panel A: Fixed Effect Model				Panel B: Random Effects Model			
	Coeff.	Std. Err.	t-stat.	P value	Coeff.	Std. Err.	t-stat.	P value
C	8.1522	0.4435	18.3813	0.0000	8.1858	0.4752	17.2255	0.0000
TRADEMARK1	0.0623	0.0080	7.8076	0.0000	0.0648	0.0080	8.1391	0.0000
INFLATION	-0.0383	0.0103	-3.7384	0.0002	-0.0385	0.0103	-3.7538	0.0002
PRODUCTIVITY	1.4841	0.0391	37.9684	0.0000	1.4915	0.0390	38.2664	0.0000
INVESTMENT	0.1724	0.0224	7706646.0000	0.0000	0.1693	0.0224	7.5718	0.0000
EDUCATION	0.1460	0.0191	7.6318	0.0000	0.1431	0.0191	7.4850	0.0000
	Panel A: Fixed Effect Model				Panel B: Random Effect Model			
R-squared	0.9992				0.8263			
F-stat.	14157.5800				419.4943			
P-value(F-stat.)	0.0000				0.0000			
Hausman Test Stat.	46.4715							
P-value (Hausman)	0.0000							
Selected Model	FEM							
Number of Years	17							
Number of Countries	33							
Number of Observations	447							

4.4. Estimation Results for TRADEMARK2 Variable

The TRADEMARK2 variable indicates trademark applications of residents. The estimation results using TRADEMARK2 are given in Table 5. The estimation findings will be discussed based on the results on Panel A since the Hausman test chooses FEM model. As seen from Panel A of Table 5, we have positive and statistically significant coefficient estimations for TRADEMARK2, PRODUCTIVITY, INVESTMENT, and EDUCATION variables while we have negative and statistically significant coefficient estimation for INFLATION variable. If the trademark applications of residents increase by 1% then GDP enlarges by 0.0721%. We can state that a 1% rise in productivity causes an increase in GDP by 1.3791%, a 1% jump in investments leads to an increase in GDP by 0.2177%, and a 1% increase in the level of education of human capital increases GDP by 0.1455%. Presence of statistically significant F-statistic value for the FEM model implies that the fixed effect model is statistically significant. Meanwhile the explanatory power of the FEM model is very high given the R-square value of 0.9992.

Table 5. Estimation Results for the TRADEMARK2 Variable

Variables	Panel A: Fixed Effect Model				Panel B: Random Effects Model			
	Coeff.	Std. Err.	t-stat.	P value	Coeff.	Std. Err.	t-stat.	P value
C	9.0425	0.4274	21.1577	0.0000	8.8864	0.4343	20.4622	0.0000
TRADEMARK2	0.0721	0.0112	6.4597	0.0000	0.1014	0.0110	9.2453	0.0000
INFLATION	-0.0284	0.0104	-2.7144	0.0069	-0.0265	0.0104	-2.5417	0.0114
PRODUCTIVITY	1.3791	0.0382	36.1190	0.0000	1.3876	0.0379	36.6381	0.0000
INVESTMENT	0.2177	0.0212	10.2640	0.0000	0.2065	0.2118	9.7500	0.0000
EDUCATION	0.1455	0.0198	7.3374	0.0000	0.1248	0.0198	6.3165	0.0000
	Panel A: Fixed Effect Model				Panel B: Random Effect Model			
R-squared	0.9992				0.7786			
F-stat.	13577.7600				310.2518			
P-value(F-stat.)	0.0000				0.0000			
Hausman Test Stat.	207.6080							
P-value (Hausman)	0.0000							
Selected Model	FEM							
Number of Years	17							
Number of Countries	33							
Number of Observations	447							

4.5. Estimation Results for the RESEARCHER Variable

The estimation results using the RESEARCHER variable are shown in Table 6 above. Since the random effect model was selected according to the Hausman test result, the estimation results will be interpreted according to the findings in Panel B. While positive statistically significant coefficient estimates were obtained for the RESEARCHER, PRODUCTIVITY, INVESTMENT and EDUCATION variables, no significant coefficient estimate was obtained for the INFLATION variable. A 1% increase in the number of researchers in R&D causes a 0.1341% increase in GDP. As can be seen from Panel B of Table 6, a 1% increase in productivity increases GDP by 0.8105%, a 1% jump in investments expands GDP by 0.2269% and a 1% increase in the education level of human capital increases GDP by 0.1296%. The significant F-statistic value shows that the REM model is statistically significant. Considering that the R-squared value is 0.9989, it is seen that the explanatory power of the REM model is quite high.

Table 6. Estimation Results for the Variable RESEARCHER

Variables	Panel A: Fixed Effect Model				Panel B: Random Effects Model			
	Coeff.	Std. Err.	t-stat.	P value	Coeff.	Std. Err.	t-stat.	P value
C	14.9537	0.2844	52.5746	0.0000	15.0597	0.3613	41.6876	0.0000
RESEARCHER	0.1350	0.0135	9.9943	0.0000	0.1350	0.0135	9.9418	0.0000
INFLATION	0.0008	0.0055	0.1632	0.8704	0.0008	0.0052	0.1571	0.8752
PRODUCTIVITY	0.8100	0.0299	27.0776	0.0000	0.8105	0.0299	27.1353	0.0000
INVESTMENT	0.2272	0.0170	13.3806	0.0000	0.2269	0.0170	13.3682	0.0000
EDUCATION	0.1291	0.0186	6.9330	0.0000	0.1296	0.0186	6.9705	0.0000
	Panel A: Fixed Effect Model				Panel B: Random Effect Model			
R-squared	0.9989				0.8982			
F-stat.	10576.7300				891.0578			
P-value(F-stat.)	0.0000				0.0000			
Hausman Test Stat.	6.5991							
P-value (Hausman)	0.2522							
Selected Model	REM							
Number of Years	19							
Number of Countries	38							
Number of Observations	511							

4.6. Estimation Results for the TECHNICIAN Variable

The TECHNICIAN variable is an indicator of R&D and number of technicians in R&D in terms of per million people. The estimation results using the TECHNICIAN variable are exhibited in Table 7. According to the Hausman test result, the REM model was chosen and thus interpretation of the estimation findings is relied on the results of REM model. Positive statistically significant coefficient estimation for TECHNICIAN, PRODUCTIVITY, INVESTMENT, and EDUCATION variables were obtained but no significant coefficient estimation for INFLATION variables. It is seen that a 1% increase in the number of technicians in R&D enhances the GDP by 0.0688%. It can be concluded that a 1% jump in productivity leads to an increase in the GDP by 0.8754%, a 1% rise in investments induces a jump in the GDP by 0.1534%, and a 1% increase in the level of human capital education causes an increase in the GDP by 0.1556%. We see that the REM model is statistically significant given the F-test results. Also, high R-square value indicates that the REM model's explanatory power is very high.

Table 7. Estimation Results for the TECHNICIAN Variable

Variables	Panel A: Fixed Effect Model				Panel B: Random Effects Model			
	Coeff.	Std. Err.	t-stat.	P value	Coeff.	Std. Err.	t-stat.	P value
C	14.7696	0.3581	41.2486	0.0000	14.9602	0.4451	33.6101	0.0000
TECHNICIAN	0.0692	0.0108	6.4322	0.0000	0.0688	0.0107	6.4044	0.0000
INFLATION	-0.0009	0.0055	-0.1560	0.8762	-0.0009	0.0055	-0.1594	0.8734
PRODUCTIVITY	0.8750	0.0374	23.3744	0.0000	0.8754	0.0374	23.4388	0.0000
INVESTMENT	0.1535	0.0199	7.7280	0.0000	0.1534	0.0199	7.7226	0.0000
EDUCATION	0.1556	0.0219	7.1137	0.0000	0.1556	0.0218	7.1281	0.0000
	Panel A: Fixed Effect Model				Panel B: Random Effect Model			
R-squared	0.9989				0.9038			
F-stat.	8439.0680				676.6530			
P-value(F-stat.)	0.0000				0.0000			
Hausman Test Stat.	6.9129							
P-value (Hausman)	0.2272							
Selected Model	REM							
Number of Years	19							
Number of Countries	32							
Number of Observations	447							

5. Conclusion

In this study, the effect of R&D and innovation on gross domestic products was empirically examined by using some innovation indicators and R&D indicators. An unbalanced panel data set of OECD countries was employed in the study and the sample covers the period of 1995-2021. Six different indicators of R&D and innovation (i.e., two distinct measures of patent applications, two different measures of trademark applications, researchers in R&D, and technicians in R&D) are employed in the analysis. Selection between fixed effect model and random effect model is made via Hausman test. In addition to R&D and innovation indicators, four control variables (i.e., INFLATION, PRODUCTIVITY, INVESTMENT, EDUCATION variables) were used in the models. While the INFLATION variable was expected to decrease GDP, the PRODUCTIVITY, INVESTMENT, EDUCATION variables were anticipated to increase GDP.

It was observed that indicators of R&D and innovation have an increasing effect on GDP. Statistically significant estimation results reveal that; a 1% jump in domestic patent application leads to a rise in GDP by 0.0258%, a 1% rise in patent application enhances GDP by 0.0566%, a 1% increase in the trademark applications of nonresidents expands GDP by 0.0623%, a 1% rise in the trademark applications of residents augments GDP by 0.0721%, an increase in the number of researchers in R&D by 1% induces to a rise in GDP by 0.1341%, and a 1% increase in the number of technicians in R&D expands the GDP by 0.0688%. Meantime the indicator with the largest influence on GDP is the number of researchers in R&D whereas the indicator with the smallest impact on GDP is the domestic patent application.

Regarding the control variables, whenever they are statistically significant then we obtained positive coefficient estimations for the variables of productivity, investment, and education and negative coefficient estimation for the variable of inflation. Meantime each one of the estimated models is statistically significant based on F-test results and has very high explanatory power given high R-square values.

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