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# The Relationship between R&D Expenditures, Patent Applications and Growth: A Dynamic Panel Causality Analysis for OECD Countries

# Ar&Ge Harcamaları, Patent Başvuruları ve Büyüme Arasındaki İlişki: OECD Ülkeleri İçin Bir Dinamik Panel Nedensellik Analizi

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## Abstract
*The causality relationship of economic growth with R&D expenditures and patent applications for the 23 OECD member countries is investigated in this study by utilising from the data belonging the period of 1996-2011. To that aim, GMM (Generalized Method of Moments) approach developed by Arellano-Bond (1991) and Wald test are used. Panel causality estimation results put forth a two-way and positive causality between R&D expenditures and economic growth, and a one-way and positive causality from patent applications to economic growth. Hence, on the ground of these results, it can be argued that it is important for the countries aiming to achieve a sustainable and high rate of growth to allocate more resources for R&D activities and establish an efficient patent system.*

**Keywords:** *R&D Expenditures, Patent Applications, Growth, Panel Causality*

## Öz
*Bu çalışmada, OECD üyesi 23 ülkenin 1996-2011 dönemine ilişkin verilerinden yararlanılarak Ar&Ge harcamaları ve patent başvuruları ile ekonomik büyüme arasındaki nedensellik ilişkileri araştırılmıştır. Bu amaçla, Arellano-Bond (1991) tarafından geliştirilen GMM (Genelleştirilmiş Momentler Metodu) yaklaşımı ile Wald testinden yararlanılmıştır. Panel nedensellik tahmin sonuçları, Ar&Ge harcamaları ile ekonomik büyüme arasında çift yönlü ve pozitif, patent başvurularından ekonomik büyümeye doğru tek yönlü ve pozitif bir nedensellik ilişkisinin varlığını ortaya koymuştur. Dolayısı ile bu sonuçlardan hareketle, sürdürülebilir ve yüksek oranlı büyümeyi hedefleyen ülkeler açısından Ar&Ge faaliyetlerine daha fazla kaynak ayırmanın ve etkin bir patent sistemi kurmanın önemli olduğu ifade edilebilir.*

**Anahtar Kelimeler:** *Ar&Ge Harcamaları, Patent Başvuruları, Büyüme, Panel Nedensellik*

## Introduction
Defined by the OECD as a creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications (OECD, 1993, p.29), R&D activities are considered among the key determinants of economic growth in the literature on theoretical and empirical growth. The role of the R&D in the growth process was first discussed in the literature on endogenous growth theories that emerged in the 1980s and regarded growth as a phenomenon that depends on productivity and technological innovations (developments). According to these theories, technological innovations are the result of endogenous factors and arise as a result of R&D activities that use human

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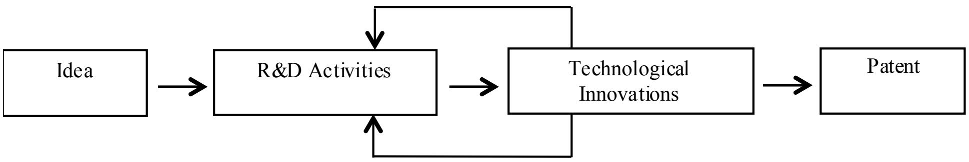
capital and the existing stock of knowledge in the economy to produce new knowledge (Romer, 1986). As a matter of fact, Grossman and Helpman (1994) described the technological innovations emerging as a result of R&D activities and investments as the main force underlying the continuous rise in the standard of living. Thus, it is acknowledged that innovations arising from R&D activities make a positive contribution to economic growth by increasing the competitive power of companies and countries through reducing costs of production, improving the quality of products, and allowing the development of new products and production methods (Üzümcü, 2012, p.237; Rouygari and Kızıltan, 2014, p.33).

The number of patents is another important indicator of technological innovation (i.e., the capacity to create technological innovations) in a country. There is a close relationship between R&D expenditures and patents, which are defined as the right of the owner of an innovation to produce, use, sell, or import the idea or product he or she owns within a particular time period. This relationship is clear in Figure 1, which illustrates the emergence process of a patent. Accordingly, while R&D activities are the input of technological innovation, patents are its output (Saygılı, 2003, p.89). From this perspective, while R&D activities lead to an increase in patents through creating innovations, patents increase profitability by providing monopoly power to inventors and encouraging R&D activities. Therefore, it is possible to say that an effective patent system enhances productivity and accelerates economic growth by contributing to technology production and transfer, the spread of technical knowledge, the expansion of economic activities, and the rise of national and international competitive power, as well as encouraging R&D activities (Zhang, 2014, p.507-508).




Cited by Işık, 2014, p.71 from Ayhan, 2002, p.264.

***Figure 1. The Emergence Process of a Patent***

The number of studies related to the influence of R&D activities, as an input to technological innovations; and patents, as an output of technological innovations, on the growth process of the countries increased in the literature with the acceptance of technological innovations as the driving force behind the sustainable growth by the endogenous growth theories. The aim of this study is to investigate the existence and direction of the causality relationship of economic growth with the R&D expenditures and patent applications for the OECD member countries for the period of 1996-2011. The results derived from the GMM estimations and Wald test applied in this scope verify a statistically significant causality relationship among the mentioned variables. Thus, it is assumed that this study will make a contribution to the literature thanks to its difference from the other studies in the literature stemming from the used estimation method, the period covered and the countries examined. The structure of this paper is organised as follows. Section two provides a brief overview of the recent contributions to the R&D expenditures, patent applications and economic growth literature. Section three describes econometric methodology and data set used analysis. Section fourth proceeds to descriptive statistics and the empirical findings obtained from analysis. The last section provides conclusion and recommendations.

## Literature Review

### R&D Expenditures and Economic Growth Literature

Lichtenberg (1993) investigated the relationship between growth and R&D expenditures in both the private and public sectors of 74 countries during 1964-1989 and reported that there was no relationship between economic growth and R&D expenditures in the public sector, but R&D expenditures in the private sector affected growth positively. Gittleman and Wolff (1995) addressed the relationship between R&D activities and economic growth by using panel data covering the period of 1960-1988 as the real GDP per capita, R&D expenditures, the number of scientists per R&D, and the number of engineers per R&D. Their empirical findings revealed that R&D activities accounted for growth only in developed countries, but did not account for growth in low-income underdeveloped countries. Based on the panel data from 1973-1992, Braconier (2000) conducted a study for ten OECD member countries and determined that rise in per capita income level led to an increase from 1.83% to 2.93% in R&D expenditures. Yanyun and Mingqian (2004) performed a dynamic GMM estimation on eight countries (Indonesia, Malaysia, Japan, Korea, Thailand, Singapore, the Philippines, and China), three of which were ASEAN countries, by using the Cobb-Douglas production function. They found that R&D expenditures in the public sector made a greater contribution to the economic growth than R&D expenditures did in the private sector.

Arguing that R&D expenditures played an important role in growth by creating an increase in innovation and productivity, Samimi and Alerasoul (2009) made a panel data analysis for thirty developing countries including Turkey and found that R&D expenditures in fact did not contribute to growth in developing countries because such expenditures were low. Altın and Kaya (2009) used time series to estimate the relationship between economic growth and R&D investments in Turkey for the period of 1990-2005 and. Based on an empirical analysis using the Johansen-Juselius cointegration and error-correction technique, they determined that there was no relationship between the above-mentioned variables in the short run, but that R&D investments were a cause of economic growth in the long run. Mehran and Reza (2011) performed a comparative examination of the effect of R&D expenditures on economic growth in underdeveloped countries and OECD countries by using the fixed effects panel data technique. They determined that although R&D expenditures made a positive contribution to growth in both country groups, the contribution was larger in OECD countries. Akcay (2011) used the Toda-Yamamoto approach and ascertained that there was a two-way causality relationship between R&D investments and economic growth in the United States. Gyekye et al. (2012) employed the Cobb-Douglas production function to examine the influence of R&D investments on socio-economic development in Sub-Saharan African countries. To this end, they conducted fixed-effects panel regression estimation and found that a rise of 1% in R&D investments contributed to economic growth in the mentioned countries by 0.326%. Akıncı and Sevinç (2013) conducted a study via the least-squares approach and determined that R&D expenditures in the private sector, in higher education, and in total had a positive effect on growth in Turkey in the 1990-2011 period, but R&D expenditures in the public sector had no positive effect on growth in that period.

## Patent Applications and Economic Growth Literature

Crosby (2000) made an empirical analysis and found that patent applications had a positive effect on labour productivity and economic growth in the Australian economy. Claiming that innovation played an important role in economic growth, Sinha (2008) investigated the relationship between the number of patents granted and economic growth in Japan and South Korea via time-series and panel data approaches. The time-series analysis demonstrated that there was no relationship between the two variables in South Korea, but there was a two-way causality relationship between them in Japan. The panel data analysis, on the other hand, revealed that the above-mentioned causality relationship was one-way from growth to the number of patents. Ortiz (2009) performed a regression estimation based on cross-sectional data from 23 countries covering the period of 1820-1990 and determined that there was a strong and positive relationship between the number of patents per person and per capita income in the long run. Kim at al. (2009) carried out a study on the South Korean manufacturing industry, tested the effects of patent applications on total factor productivity (which is a key growth determinant), and determined that non-resident patent applications were more influential on the increase in productivity than resident patent applications.

Josheski and Koteski (2011) used the bound test (ARDL) and Johansen cointegration technique and determined that there was a positive relationship between number of patents and growth in G-7 countries in the long run. They also conducted dynamic relationship estimation and ascertained that there was a one-way causality relationship from number of patents to economic growth. Arguing that economic growth had a critical importance for sustainable development, Saini and Jain (2011) addressed the effects of patent applications on economic growth in nine Asian countries. The findings obtained from the regression analysis showed that patent applications made an insignificant contribution to economic growth in Singapore, Japan, Thailand, and Vietnam; they made a negative contribution to economic growth in China, Indonesia, and Malaysia; but they made a positive contribution to economic growth in India and the Philippines. Guo and Wang (2013) carried out a study on the Chinese economy and determined that patent applications made a positive contribution to growth. A rise of 1% in patent applications increased economic growth in China by 0.26% in the period under examination. Işık (2014) carried out a study in Turkey, determined that patent expenditures were a cause of economic growth, and stated that patent expenditures should be made in an organized way to ensure a sustainable growth.

## Methodology and Data Set

Panel data, which are also referred as longitudinal or cross-sectional time-series data, are composed by bringing together time-series observations concerning such economic units as countries, companies, and households in a cross-sectional form. These data allow us to monitor the changes occurring in these units over time (i.e. we can make multiple observations for each unit). That this method has two dimensions (i.e. cross-section [I] and time-series [t]) makes it well suited for establishing and testing quite complicated behavioural models, especially in comparison to time-series and cross-sectional analyses. Therefore, panel data are widely used in the applied literature (Hsiao, 2003, p.1; Baltagi, 2007, p.28-30; Hsiao, 2006, p.3-7). The model developed by Holtz-Eakin, Newey, and Rosen (1988) is taken as the foundation in estimating the causality relationship of economic growth with R&D expenditures and patent applications based on panel data belonging to 23 countries. This model is as the following:

$$y_{it} = \alpha_0 + \sum_{j=1}^{m} a_j y_{t-j} + \sum_{j=1}^{m} \beta_j x_{t-j} + f_i + \mu_t \quad (1)$$

In equation (1), y and x are the variables between which a relationship is investigated; (i) is the horizontal dimension of the model; (t) is the time dimension of the model; and  refers to the fixed effects of cross-sectional units. Fixed effects in the model need to be eliminated in case they lead to erroneous estimation results. For that reason, these fixed effects are eliminated through taking the difference of the equation. The resulting estimation model can be displayed as follows:

$$\Delta y_{it} = \sum_{j=1}^{m} a_j \Delta y_{t-j} + \sum_{j=1}^{m} \beta_j \Delta x_{t-j} + f_i + \Delta\mu_t \quad (2)$$

In equation (2), there is a correlation between the lagged values of the dependent variable (Δyt-j) and error terms (Δμt). Thus, Holtz-Eakin, Newey and Rosen (1988) and Arellano and Bond (1991) argued that the model had to be estimated by using instrumental variables.Accordingly, whether there is any causality relationship between the variables is decided by estimating equation (2) via the Generalized Method of Moments (GMM), which construes all valid lagged values of dependent and independent variables as instrumental variables, and applying the Wald test to all the obtained independent variable coefficients. The validity of the created instrumental variables is tested through the Sargan test. A balanced panel data set covering the period of 1996-2011 is used in this study aiming to investigate the causality relationship of economic growth with R&D expenditures and patent applications for 23 OECD member countries[1] (provided in Table 1). Detailed information regarding the variables and data sources taken into consideration in the analysis are provided in Table 2.

1 OECD has currently 34 member countries. Due to inadequate observation in the data set, Chile, Estonia, Finland, Greece, Iceland, Italy, Luxembourg, New Zealand, Norway, Sweden and Switzerland aren't covered in the study.

***Table 1. The Countries Included in the Analysis***

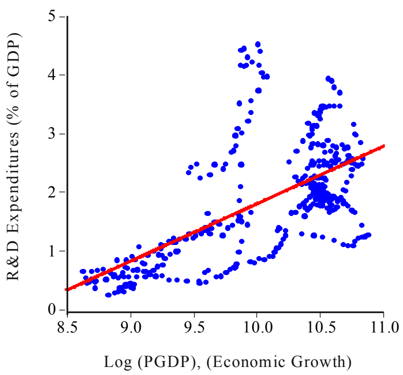
| | | | |
|---|---|---|---|
| Turkey | South Korea | Mexico | France |
| USA | Netherlands | United Kingdom | Germany |
| Czech Republic | Slovak Republic | Portugal | Spain |
| Denmark | Poland | Belgium | Austria |
| Finland | Slovenia | Ireland | Israel |
| Japan | Hungary | Canada | |

***Table 2. Data Descriptions and Sources***

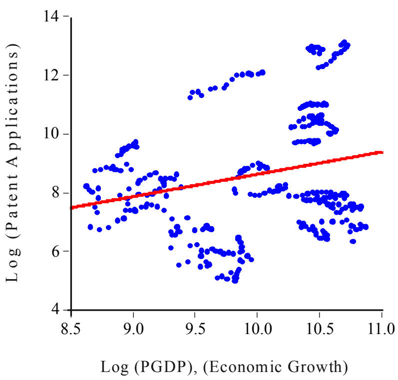
| Variable | Descriptions | Source |
|---|---|---|
| PGDP | Per Capita Gross Domestic Product (constant 2005-USD). It is used in logarithmic values. | World Bank (WDI) |
| R&D Expenditures | The Ratio of Total R&D Expenditures to GDP (% of GDP). It is used in pure values (without calculating its logarithms). | World Bank (WDI) |
| Patent Applications | Total Number of Patent Applications (resident and non-resident). It is used in logarithmic values. | World Bank (WDI) |

## Descriptive Statistics and Empirical Findings

Before proceeding to the econometric analysis, we perform a correlation analysis and construct a scatter diagram to gather some priori information on the direction of the relationship between the variables. The results of the Pearson's correlation analysis show that there is a statistically significant positive relationship, as expected, between PGDP, which represents economic growth, and R&D expenditures and patent applications. According to the two-sided t-test, correlation coefficients indicating the direction and strength of the relationship are 0.63 and 0.24, respectively. On the other hand, despite the irregular distribution of the observations belonging to the variables around of regression lines on the scatter diagrams formed separately for the PGDP and other variables, the positive slope of the regression lines supports the results of the correlation analysis. Finally, we perform a simple panel regression analysis. The results obtained in the regression estimation are parallel to those obtained from the correlation analysis and the scatter diagram. Accordingly, we find that 1% increases in the share of total R&D expenditures in the GDP and patent applications increase GDP per capita (economic growth) 0.40% and 0.07% respectively (Figure 2).




Pearson Correlation = 0.63 (P-value: 0.000)
Log (PGDP)=9.2902 + 0.4003 (R&D Expenditures)




Pearson Correlation = 0.24 (P-value: 0.000)
Log (PGDP)=9.3989 + 0.0723 Log (Patent Applications)

***Figure 2. The Relationship between R&D Expenditures, Patent Applications and Growth***

## Cross-Sectional Dependence and Unit Root Test Results

In this study investigating the causality relationship of economic growth with the R&D expenditures and patent applications, GMM estimator is used as one of the dynamic panel data approaches. Since the variables are assumed stationary in this approach (Jung and Kwon, 2007, p.2), primarily, it is necessary to investigate the stationary of the variables used in the analysis via appropriate unit root tests. When the panel data literature is considered, it is observed that the tests developed to identify the stationary are divided into two as the first and second generation unit root tests. These tests differentiate from each other on the basis of whether there is a relationship among the units forming the panel (cross-sectional dependence). First generation unit root tests, such as Hadri (2000), Choi (2001) Levin et al., Lin and Chu (2002) and Im, Pesaran and Shin (2003) assumes that there isn't a dependence among the cross-sectional units; second generation unit root tests, such as SURADF [(Breuer et al (2002)], MADF [(Taylor and Sarno (1998)], CADF [(Pesaran (2007)] and Bai and Ng (2004) take into account the cross-sectional dependence. In addition, by considering the diversification among first generation unit root tests as homogeneous and heterogeneous, both the homogeneity of the variables and cross-sectional dependence shall be primarily investigated for making a decision about which root test is appropriate for the observation of time series properties of the variables in the panel.

In defining whether the slope coefficients are changing across cross-sectional units, namely, in identifying whether the variables are homogeneous, Delta Tilde ($\tilde{\Delta}$) and Adjusted Delta Tilde ($\tilde{\Delta}_{adj}$) tests developed by Pesaran and Yamagata (2008) are utilised. There are different approaches for estimating the cross-sectional dependence in the panel data applications. Among the mentioned approaches, the ones that are more frequently used in the literature are Breusch and Pagan (1980) LM (Lagrange Multiplier) test and CD test developed by Pesaran (2004). LM test is used when cross- sectional dimension of the model is smaller than the time dimension (N < T), CD test is used when (N > T). In this study, since N=23 and T=16, Pesaran (2004) CD test is preferred. The results of homogeneity and CD test are provided in the Table 3 and Table 4.

***Table 3. Results of Homogeneity Test***

| | Test Statistics | p-value |
|---|---|---|
| Delta Tilde Test ($\tilde{\Delta}$) | 12.739 | 0.000 |
| Adjusted Delta Tilde Test ($\tilde{\Delta}_{adj}$) | 14.568 | 0.000 |

$H_0$: Slope parameters are homogeneous for all cross-sectional units.

According to the results provided in the Table 3, ($\tilde{\Delta}$) and ($\tilde{\Delta}_{adj}$) test statistics are significant at 1%. On the basis of these results, the null hypothesis ($H_0$) is rejected and it is detected that the slope coefficients are changing among the cross- sectional units, namely, variables in the panel data set are accepted heterogeneous.

***Table 4. Results of CD Test***

| Variables | CD Test Statistics | p-value |
|---|---|---|
| Log (PGDP) | 58.27 | 0.000 |
| R&D Expenditures | 26.71 | 0.000 |
| Log (Patent Applications) | 2.08 | 0.037 |

$H_0$: Series are cross-sectionally independent.

CD test results given in the Table 4 are providing proofs for the significant relationship among the cross-sectional units. Hence, by rejecting the null hypothesis ($H_0$) assuming that the series are independent from each other, it is accepted that there is a cross-sectional dependence in PGDP, R&D expenditures and patent applications series of 23 OECD member countries. This means that second generation panel unit root tests taking into account cross-sectional dependence shall be used in the stationary analysis that will be conducted. Therefore, in the study, CADF (Cross-Sectionally Augmented Dickey Fuller) test which is one of second generation panel unit root estimators and developed by Pesaran (2007) is used to test whether the variables are stationary or not.

Pesaran (2007) CADF test is an extended version of the standard Dickey-Fuller (DF) test. To put it more clearly, this approach uses the extended version of the standard DF regression with the first-differences of individual series and lagged cross-sectional averages. This test produces valid results when (T) and (N) are big enough under the conditions of (N > T) and (N < T). Besides, in this approach, stationary of each units can be searched by calculating CADF test statistic for cross-sectional units separately, as well as, stationary for the entire panel can be searched by means of CIPS (Cross-Sectional Augmented IPS) statistic, which is the arithmetic average of the CADF test statistics belonging to cross-sectional units. (Gengenbach et al., 2010, p.113; Pesaran et al., 2013, p.95). The results of the applied panel unit root test are provided in the Table 5.

It is identified that CIPS test statistics reached as a result of the CADF test related to three variables forming the data set are higher than the table critical values provided by Pesaran (2007). Hence, on the basis of these results, the null hypothesis ($H_0$) arguing that the series are non-stationary is rejected and it is accepted that the mentioned three variables are stationary at the level of I (0) at different significance levels, namely they don't include unit root. After the application of unit root test showing the validity of the assumption of the GMM approach regarding the stationary of variables, causality estimations are carried out.

***Table 5. Result of CADF (CIPS) Unit Root Test***

| | | | Table Critical Values | | |
|---|---|---|---|---|---|
| CADF Test | Variables | CIPS Test Statistics | 1% | 5% | 10% |
| Level | Log (PGDP) | -2.138* | -2.320 | -2.150 | -2.070 |
| | R&D Expenditures | -2.177** | -2.320 | -2.150 | -2.070 |
| | Log (Patent Applications) | -2.610*** | -2.320 | -2.150 | -2.070 |

$H_0$: Series are non-stationary. The stationary test is based on the model with a constant.
***, ** and * indicate that test statistics are significant at 1%, 5% and 10% levels, respectively.

## Causality Test Results

This section presents estimation results concerning the causality relationship between the variables under examination. Firstly, we investigate the causality relationship between economic growth (PGDP) and R&D expenditures in the analysis using the GMM technique. The obtained results are presented in Table 6. The Wald test applied to all the independent variable coefficients obtained from Model 1, where PGDP is accepted as the dependent variable, and Model 2, where R&D expenditures are taken as the dependent variable, demonstrates that $\chi^2$ test statistics are statistically significant at 1%. Based on these results, we can say that there is a two-way causality relationship between economic growth and R&D expenditures. In addition, the positive signs of the independent variable coefficients in both models show that these variables affect each other positively.

*Table 6. Results of Panel Causality Test [Log (PGDP) and (R&D Expenditures)]*

| Independent Variables | Dependent Variables [Model 1] Δ Log (PGDP) | | [Model 2] Δ (R&D Expenditures) | |
|---|---|---|---|---|
| | Coefficient | Std. Error | Coefficient | Std. Error |
| Δ Log $(PGDP)_{t-1}$ | 1.1529*** | [0.1601] | 0.4771*** | [0.1122] |
| Δ Log $(PGDP)_{t-2}$ | -0.0504 | [0.1709] | -0.0849 | [0.0844] |
| Δ (R&D $Expenditures)_{t-1}$ | -0.0405 | [0.0451] | 0.6845*** | [0.2324] |
| Δ (R&D $Expenditures)_{t-2}$ | 0.0369*** | [0.0137] | -0.0733 | [0.1092] |
| Wald Test ($\chi^2$ statistics) | 5.1720*** | | 9.1956*** | |
| Sargan Test (p-value) | 0.88 | | 0.35 | |

*** implies level of significance at 1%. Log (PGDP) $_{t-j}$, (R&D Expenditures) $_{t-j}$, (j=2,…,6) and constant factor used as instrumental variables in the analysis.

*Table 7. Results of Panel Causality Test [Log (PGDP) and Log (Patent Applications)]*

| Independent Variables | Dependent Variables [Model 3] Δ Log (PGDP) | | [Model 4] Δ Log (Patent Applications) | |
|---|---|---|---|---|
| | Coefficient | Std. Error | Coefficient | Std. Error |
| Δ Log $(PGDP)_{t-1}$ | 1.1681*** | [0.1176] | 0.6246 | [1.1795] |
| Δ Log $(PGDP)_{t-2}$ | -0.1404 | [0.1137] | -0.3487 | [0.4194] |
| Δ Log (Patent $Applications)_{t-1}$ | 0.0713* | [0.0373] | 0.4501** | [0.2213] |
| Δ Log (Patent $Applications)_{t-2}$ | -0.0373** | [0.0163] | -0.0471 | [0.1024] |
| Wald Test ($\chi^2$ statistics) | 2.7091* | | 0.3935 | |
| Sargan Test (p-value) | 0.74 | | 0.65 | |

***, ** and * imply levels of significance at 1%, 5% and 10% respectively. Log (PGDP) $_{t-j}$, Log (Patent Applications) $_{t-j}$, (j=2,…,6) and constant factor used as instrumental variables in the analysis.

Table 7 presents the results of GMM testing conducted for estimating the causality relationship between economic growth and patent applications. According to these results, the test statistics of the Wald test ($\chi^2$) applied to all the independent variable coefficients are statistically significant only in Model 3, where PGDP is accepted as a dependent variable. When we take into consideration the sign of the sum of the independent variable coefficients, we find a positive one-way causality relationship from patent applications to economic growth in the analysed countries.

## Conclusion and Recommendations

The present study investigates the relationship of the economic growth with the number of patent applications and R&D expenditures in 23 OECD member countries. The study, which employed data from 1996-2011, uses the GMM – a dynamic panel data analysis method. According to the findings obtained from model estimations, there is a positive two-way causality relationship between economic growth and R&D expenditures and a positive one-way causality relationship from patent applications to growth in the countries under examination. The results obtained in the present study support the assumption of endogenous growth theories that R&D activities affect economic growth positively by creating technological innovations and thus increasing productivity. Since innovation is the driving force of economic growth, countries aiming for a high rate of sustainable economic growth should allocate more resources for R&D activities and establish an effective patent system that enables innovations to spread across the economy and encourages new R&D.

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