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Causal links between patents and economic growth: empirical evidence from OECD countries[1]

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Abstract

Objective of the Study: This paper empirically investigates the reciprocal relationship and causality between patents and economic growth.

Methodology/Approach: Utilizing the Generalized Method of Moments (GMM) Panel Vector Autoregression (PVAR) and panel VAR-Granger Causality frameworks, the study concentrates on Organisation for Economic Co-operation and Development (OECD) economies where a high fraction of global innovative activities take place.

Originality/Relevance: The relationship and causality between patents and economic growth are investigated and evaluated by distinguishing the former variable into patent applications and grants.

Main Results: The findings from the GMM panel VAR approach indicate that patent applications and grants significantly affect economic growth, whereas economic activities do not influence patent-related variables. The estimations from the panel VAR-Granger approach confirm these findings by presenting a unidirectional causality from patent applications and grants to economic growth. The impulse-response functions (IRFs) exhibit parallel findings, and further checks validate the stability of the findings obtained. The outcomes of this study point out two crucial implications. First, the impacts of patent applications and grants affect economic growth similarly while the impact of patent grants lasts longer. Second, while patents cause higher economic activity, the latter does not induce innovative activity through patents in the OECD.

Theoretical/Methodological Contributions: It would be useful to conduct separate analyses for a selected product, sector, or country by including research and development (R&D) expenditures for different periods, country groups, and analysis methods.

Social/Management Contributions: Countries should prioritize the establishment of an effective patent management system that will increase the pace of innovation and the implementation of incentive policies for the development of high-value-added technology products.

Keywords: patent applications; patent grants; economic growth; panel VAR; panel VAR-granger causality

JEL Classifications: O34, O40, O50, C23

Relações causais entre patentes e crescimento econômico: evidências empíricas dos países da OCDE

Resumo

Objetivo do Estudo: Este artigo investiga empiricamente a relação recíproca e a causalidade entre patentes e crescimento econômico.

Metodologia/Abordagem: Utilizando o Método Generalizado de Momentos (MGM) no Painel Vetorial Autorregressivo (PVAR) e as estruturas de Causalidade VAR-Granger no painel, o estudo se concentra nas economias da Organização para a Cooperação e Desenvolvimento Econômico (OCDE), onde uma alta fração das atividades inovadoras globais ocorre.

Originalidade/Relevância: A relação e a causalidade entre patentes e crescimento econômico são investigadas e avaliadas distinguindo a variável anterior em pedidos de patentes e concessões.

Principais Resultados: Os resultados da abordagem MGM no painel VAR indicam que os pedidos de patentes e as concessões afetam significativamente o crescimento econômico, enquanto as atividades econômicas não influenciam as variáveis relacionadas às patentes. As estimativas da abordagem VAR-Granger no painel confirmam esses achados, apresentando uma causalidade unidirecional dos pedidos de patentes e concessões para o crescimento econômico. As funções de resposta ao impulso (FRI) exibem resultados paralelos, e verificações adicionais validam a estabilidade dos achados obtidos. Os resultados deste estudo apontam para duas implicações cruciais. Primeiro, os impactos dos pedidos de patentes e concessões afetam o crescimento econômico de maneira semelhante, enquanto o impacto das concessões de patentes dura mais. Segundo, enquanto as patentes causam maior atividade econômica, esta última não induz atividade inovadora através de patentes na OCDE.

Contribuições Teóricas/Metodológicas: Seria útil realizar análises separadas para um produto, setor ou país selecionado, incluindo os gastos em pesquisa e desenvolvimento (P&D) para diferentes períodos, grupos de países e métodos de análise.

Contribuições Sociais/Gerenciais: Os países devem priorizar o estabelecimento de um sistema de gestão de patentes eficaz que aumente o ritmo da inovação e a implementação de políticas de incentivo para o desenvolvimento de produtos tecnológicos de alto valor agregado.

Palavras-chave: pedidos de patentes; concessões de patentes; crescimento econômico; painel VAR; causalidade VAR-Granger no painel

Classificações JEL: O34, O40, O50, C23

Vínculos causales entre patentes y crecimiento económico: evidencia empírica de los países de la OCDE

Resumen

Objetivo del Estudio: Este documento investiga empíricamente la relación recíproca y la causalidad entre patentes y crecimiento económico.

Metodología/Enfoque: Utilizando el Método Generalizado de Momentos (MGM), el Modelo de Vector Autoregresivo (VAR) en panel y los marcos de Causalidad de Granger en panel VAR, el estudio se concentra en las economías de la Organización para la Cooperación y el Desarrollo Económico (OCDE), donde se lleva a cabo una alta fracción de las actividades innovadoras globales.

Originalidad/Relevancia: La relación y causalidad entre patentes y crecimiento económico se investiga y evalúa al distinguir la primera variable en aplicaciones de patentes y concesiones de patentes.

Resultados Principales: Los hallazgos del enfoque GMM panel VAR indican que las solicitudes de patentes y las concesiones afectan significativamente el crecimiento económico, mientras que las actividades económicas no influyen en las variables relacionadas con patentes. Las estimaciones del enfoque panel VAR-Granger confirman estos hallazgos al presentar una causalidad unidireccional de las solicitudes de patentes y concesiones hacia el crecimiento económico. Las funciones de respuesta al impulso (FRI) exhiben hallazgos paralelos, y verificaciones adicionales validan la estabilidad de los resultados obtenidos. Los resultados de este estudio destacan dos implicaciones cruciales. Primero, los impactos de las solicitudes de patentes y las concesiones afectan el crecimiento económico de manera similar, mientras que el impacto de las concesiones de patentes dura más. Segundo, mientras que las patentes causan una mayor actividad económica, esta última no induce actividad innovadora a través de patentes en la OCDE.

Contribuciones Teóricas/Metodológicas: Sería útil realizar análisis separados para un producto, sector o país seleccionado, incluyendo gastos en investigación y desarrollo (I&D) para diferentes períodos, grupos de países y métodos de análisis.

Contribuciones Sociales/De Gestión: Los países deben priorizar el establecimiento de un sistema de gestión de patentes eficaz que aumente el ritmo de la innovación y la implementación de políticas de incentivo para el desarrollo de productos tecnológicos de alto valor añadido.

Palabras Clave: solicitudes de patentes; concesiones de patentes; crecimiento económico; panel VAR; causalidad de Granger en panel VAR

Clasificaciones JEL: O34, O40, O50, C23

Introduction

Over the last thirty years, the importance of the creation and diffusion of knowledge for economic growth has been well recognized, and many economists have emphasized that knowledge is the source of economic growth (Romer, 1990). Innovation is accepted to be at the core of the creation of knowledge, and thus, it has been at the center of many growth theories. Karl Marx argues that the path to economic growth is through inventions resulting from R&D activities (Marx, 2011). Endogenous growth theories, introduced in the 1980s by some economists who criticized the assumptions of the neoclassical model, emphasize the role of innovations in economic growth (Yıldırım & Kantarcı, 2018). These models point out the significance of some factors including physical and human capital, and protection of patent rights (Grossman & Helpman, 1994). According to Philippe Aghion and Peter Howitt, an entrepreneur who successfully innovates obtains a patent. The inventor has monopolistic power in the market until the patent expires. Although the patent right lasts forever, monopoly power continues until a new technological innovation is made (Aghion & Howitt, 1992). According to the model developed by Paul

M. Romer, firms that develop new knowledge and products through R&D activities monopolize by protecting this new knowledge and technology through patents (Romer, 1990). Neoclassical growth models, in broad terms, emphasized that economic growth depends on technological progress. Joseph A. Schumpeter emphasized that innovations are an endogenous phenomenon and suggested that innovations are the driving force of growth, so he pioneered many growth models due to this view (Schumpeter, 2014).

Innovative activities are proxied by various economic variables including R&D expenditures or activities, number of patents, patent expansion, trademarks, technological adaptation, skill structure, and education level of labor (Thamhain, 2003). Moreover, the vast of the literature examining the innovation and economic growth nexus concentrates on other measures of innovation, such as R&D, exports and imports, and foreign direct investment (FDI) (Göçer, 2013; Zachariadis, 2003; Falk, 2009). Among these, R&D and patents play a key role in the relevant literature. R&D expenditures induce R&D activities that result in innovation and technological development which in turn contribute positively to the economic growth process (Bilbao-Osorio & Rodríguez-Pose, 2004). However, relatively fewer studies concentrate on the role of patents, as an innovation mechanism, for economic growth in the literature (Cantner & Malerba, 2006; Hasan & Tucci, 2010). While R&D activities are crucial to ensure economic growth, they serve as only inputs for innovative activities. Patents, on the other hand, are mostly considered to be the output of such activities. Indeed, patents can be criticized in that they are incapable of quantifying efforts throughout the invention and production process. Still, they present the final version of the entire R&D effort. For this reason, patents are the most concrete indicator of innovation. Endogenous growth economists also point out patents as being a 'direct function of R&D activities' (Pakes & Griliches, 1984). Countries with similar R&D intensity or patenting activity may have different technology portfolios, which may have different effects on their growth (Fagerberg, 1987; Dosi, 1988; Castellacci, 2011). An important indicator of technological innovation is intellectual property (IP), an umbrella term for patents, copyrights, and other creative expressions (Raghupathi & Raghupathi, 2017). Patents not only cover a successful technological invention, but a patent also restrict others from using the covered technology for a certain period. Patents are one of the most important indicators for the output of technology-oriented innovation processes (Grupp, 1998).

Economic research on patents is not new, but the number of studies focusing on them has increased significantly in recent years. According to the World Intellectual Property Organization (WIPO), 'a patent is an exclusive right granted for an invention, which is a product or a process that provides, in general, a new way of doing something or offers a new technical solution to a problem' (WIPO, 2022).

Among the most important objectives of the patent system are to encourage inventors to invent and create new technology, and to reveal and disseminate new knowledge. The reasons why patents are important for an economy can be listed as follows. First, patents provide inventors with public recognition and financial rewards. Third parties or companies may be resulting in new inventions inspired by these inventions. This encourages and spreads further innovation (Pacra, 2008). In this context, patents reduce duplication of research and motivate researchers to improve existing inventions. Patents provide the inventors with the right to prevent third parties from reproducing, using, selling, and importing for commercial purposes or exporting (Prodan, 2005). Thus, technological developments are protected. Patents are becoming an important element in corporate business management as they provide a longer-lasting competitive advantage for firms (Bloom & Reenen, 2002). 'Increasing numbers of patenting in companies have facilitated cooperation between companies via market-based knowledge exchanges' (OECD, 2004). Since patents are a national industrial property rights system that prevents the imitation of any invention with commercial value, it can be said that the ultimate purpose of patents is to encourage invention and innovation (Prodan, 2005; Plant, 1934). Research shows that patents indicate technological innovation (Ayerbe, Lazaric, Callois, & Mitkova, 2014). More R&D activity means more innovation and technology and consequently more potential for patenting (İdris, 2002). The technological capabilities of firms and countries result in patent output. In the context of economic growth, technology does not only mean increased technological intensity or deeper knowledge of existing technologies. Technology also means emerging new technologies and recombining existing knowledge in new directions (Arthur, 2009).

Another important factor in the matter is patent protection. When the patent system is considered a roof, all actors and patent-related issues in the economy are protected under this roof. The main goals of the patent system are to foster innovation in the economy and to advance society by providing economic and technological development (Barton, 1998; Saraç, 2001). Firms need strong patent protection to be able to disclose their technology freely. In the absence of a patent system, firms would be reluctant to share their know-how due to the risk of imitation. Without the patent system, the technology and/or knowledge behind the invention is free to use by everyone. On the other hand, in countries where there is no strong patent protection, companies avoid transferring technology to that country for fear of imitation. This situation negatively affects foreign direct investments (Gökovalı & Bozkurt, 2006). According to Erdost (1982), technology can be internationally transferred through many channels, namely; 'agreements based on intellectual property (license, patent and know-how agreements), foreign capital investments, imports, information about patents, technical plans, projects, the interaction between countries (travel, migration, congress, seminar, student and expert exchange, etc.), international cooperation' (Erdost, 1982). Thus, the existence of a strong patent system encourages national and international technology transfer which leads to technological progress, and thus, economic growth.

This paper examines the reciprocal relationship and causality between patents and economic growth in OECD economies. While a positive relationship between economic growth and patents is well-known in the literature. OECD countries especially attach importance to innovation and make efforts to increase the number of patents. Thus, this study specifically concentrates on OECD economies. Covering a period from 1990 to 2019, this study employs the GMM panel VAR approach and panel VAR-Granger causality approaches in its empirical strategy. This study aims to contribute to the literature by distinguishing patents into patent applications and patent grants. As patent grants are the outcomes of solid innovative activities that are certified to be unique, they may be affecting economic growth more severely compared to patent applications. Thus, this study seeks an answer to the following research question: Do patents and economic growth are subject to a mutual relationship when patents are distinguished into applications and grants?

The paper is organized as follows: Section two reviews the literature; section three describes the data set, econometric model, and methodology; section four presents empirical findings; section five has a discussion on the outcomes of this study and shares some policy recommendations, and section six concludes.

Empirical Literature Review

There has been an increasing number of studies on the relationship between innovation and economic growth over the last few decades. Patents mostly take place in such studies as an indicator of innovation, intellectual property rights (IPRs), and particularly R&D (Gülmez & Akpolat, 2014; Sungur, Aydın, & Eren, 2016). In empirical studies, patents are frequently used in several applications, while the role of patent grants is mostly neglected.

Many studies in the literature that examine the relationship between R&D expenditures and economic growth within the context of innovation reach a general conclusion that R&D expenditure results in a rise in economic growth (Luh & Chang, 1997; Griliches, 1998; Freire-Serén, 1999). Investigating the R&D expenditures and patent applications for 121 firms in the United States (U.S.) from 1968 to 1975, Pakes and Griliches (1984) evidence a statistically significant impact of R&D expenditures on patent applications. Covering the period between 1981 and 1997 for 20 OECD and 10 non-OECD countries, Ülkü (2004) analyzes the relationship between patent applications, R&D expenditures, and economic growth and evidences a strong and positive association between innovation and national income per capita in both OECD and non-OECD countries. Similarly, Bilbao-Osorio and Rodríguez-Pose (2004) include patents in their analysis and examine the relationship between the number of patents, economic growth, and R&D expenditures in the European Union (EU) between 1990 and 1998. The findings of their study indicate that a higher number of patents significantly and positively affect. They also demonstrate a stronger association of patents with R&D expenditures compared to that with economic growth. Besides these, Freire-Serén (2000) analyzes the impact of R&D expenditures on economic growth using pooled horizontal cross-sectional data from 1965 to 1990 and for 21 OECD countries. Their findings reveal a strongly positive relationship between total R&D expenditures and gross domestic product (GDP) growth. Gülmez and Akpolat (2014) examine the relationship between innovation and economic growth using data from 2000 and 2010 data for Turkey and 15 EU countries demonstrating a statistically significant impact of patents and R&D expenditures on economic growth.

Raghupathi (2017) investigated the relationship between economic development and innovation represented by patents for the years 2000–2010 and OECD countries. As a result of the study, while it was expected that countries that ranked high in R&D expenditures would also be the most innovative, this was not the case. One explanation could be that while some countries innovate by increasing their R&D investments, others do so by taking advantage of already-established know-how. Another is that R&D is only one of the indicators of innovation (Güloğlu & Tekin, 2012).

Various studies investigate the effects of patent and IPR protection on economic growth in the analyses covering developed and developing countries. Covering 110 countries and the period between 1960 and 1999, Park and Ginarte (1997) found that lagged R&D investment rates provide stronger patent protection in developed economies. While R&D activities encourage richer economies to secure strong patent rights, they do not have such an effect in poorer countries. This is because much of the R&D in poorer economies is publicly funded and they are unlikely to be patented. On the other hand, some of the R&D in less developed economies may be imitative. Park (1999) investigates the factors affecting the patenting decision abroad in 16 source countries and 40 target countries between 1975 and 1990. According to the findings of the study, stronger intellectual property protection has the potential to improve economic growth. The results also show that IPRs are crucial for the R&D activities in developed economies, whereas it is not the case for the others. Chen and Puttitanun (2007) investigated the relationship between innovation and growth in developing countries from 1975 and 2000. They conclude that innovation in a developing country increases with tighter IPRs. In an economy with an IPR system where the rules are applied without inflexibility, there could be an optimal level of IPRs, which is the trade-off between facilitating the imitation of developed advanced technologies and providing incentives for domestic innovations (Zigic, 1998). There may be domestic innovative activities that would rise under tighter IPRs.

Significant results were obtained from the above in studies where technology-related variables were included. Gould and Gruben (1996), Park (2008), and Chen and Iyigun (2011) advocate that as technology develops in countries with strong patent protections, firms are encouraged to invest heavily in R&D and more patents may emerge. Alper (2017) analyzes the causality between economic growth, R&D expenditures, number of patents, and exports of high-tech products using data from 1990 to 2015 for Turkey, including exports of high-tech products. While the findings indicate a one-way causality from patents to economic growth, they do not present causality in the opposite direction. Gyedu et al. (2021) analyze the impact of technological innovation on economic growth in G7 and BRICS countries for the period 2000-2017 using the GMM panel VAR estimator. According to the empirical findings, the main determinants of innovation such as patents, R&D expenditures, and trademarks have a positive relationship with economic growth in these country groups. Fan (2011) also examines the impact of technological innovation on the GDP growth of China and India between 1981 and 2004. This study reveals that R&D expenditures are one of the main drivers of economic development for both countries.

Many studies in the related literature have examined whether patents are beneficial for innovation and some of the studies conclude that the existence (or a stronger) patent system leads to an increase in patenting (Lerner, 2002; Hall & Ziedonis, 2001). Studies emphasize that patenting should encourage investment in R&D and innovation through patent policies that favor stronger protection. Allocating more resources to R&D activities generates more innovation activities and more patents as an output. A positive relationship between these two variables evidenced in various studies in the literature empirically validates this theoretical information.

The existing studies on patents and economic growth nexus in the literature mostly use patent applications to proxy patents. Despite its significance, patent applications only quantify attempts to have an exclusive right. However, it is also crucial to consider whether such a right is obtained. Thus, the role of patent grants on the relevant nexus is critical and worthwhile for examination. This study aims to contribute to the literature by distinguishing patents into patent applications and patent grants and investigating the mutual relationship between patents and economic growth in the OECD. Therefore, this study aims to find out whether innovative attempts to have an exclusive right (patent applications) and obtaining such a right (patent grants) are interconnected with economic activity distinctly.

Data and Methodology

Data

The empirical analysis covers a panel of 38 OECD economies[2] and 30 years from 1990 to 2019. The beginning of the period is 1990 due to the availability of data and the ending period is 2019 to exclude the impact of COVID-19 that severely influenced economies in 2020. This study specifically concentrates on OECD countries as they have a dominant share of patenting worldwide. Thus, they are accepted as innovation-leading countries.

The study distinguishes patent data into patent applications and patent grants as the contribution of these two on economic growth may vary. The fact that the patenting process is not the same between countries creates a problem in the only use of numbers of patent applications in the analysis. Also, the time lag between patent applications and grants can be exceptionally long. On the other hand, not all inventions result in patents, and not all patent applications are accepted. For these reasons, to strengthen the analysis, the granted patent data is also included in the analysis (Encaoua, Guellec, & Martinez, 2006). Thus, the study examines the impact of patent applications and patent grants on economic growth separately. Patent applications and grants data were gathered from WIPO (2022) and they include direct and PCT national phase entries that are considered for residents plus non-residents for the former variable. For the economic growth variable, the study utilizes the World Bank's (2022) GDP with constant 2015 US$ prices data. Data sources and explanations for variables are presented in Table 1.

[2] Member countries as of 2021. They are Austria, Australia, Belgium, Canada, Chile, Colombia, Costa Rica, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

Table 1

Variables and Data Sources

Variables	Abbreviation	Source	Unit
Dependent Variable			
Gross Domestic Product	GDP	World Bank	2015 Constant US$
Independent Variable			
Patent Application* (resident + non-resident)	PA	WIPO	Number of patent applications
Patent Grants** (direct and PCT national phase entries, counted by applicant's origins)	PG	WIPO	Number of patents granted

Source: Authors' own calculations.
* Exogenous variable used in Model 1
** Exogenous variable used in Model 2

Table 2

Descriptive Summary Statistics

	GDP	PA	PG
Obs	1100	1112	1117
Mean	1.07e+12	30370.1	16103.87
Std. Dev.	2.53e+12	91156.38	37135.3
Min	9.13e+09	22	1
Max	1.99e+13	621353	333012

Source: Author's calculations.

Note: GDP is in constant 2015 US$ prices. PA and PG are the number of patent applications and grants, respectively.

Table 2 shows the summary statistics for the whole panel. The number of observations varies for all variables signifying breaks in the dataset. The variables used in the study are expressed in their natural logarithms since they show geometric characteristics. The descriptive statistics of the logarithmic variables lnGDP, lnPA, and lnPG are presented in Table A1 in the appendix section.

Methodology

Among the panel data analysis methods, this study employs Panel VAR and panel-VAR Granger causality analyses to examine the two-way causality between patents and economic growth. The empirical analysis starts with M. Hashem Pesaran's (2004) cross-sectional dependence (CD) test to determine the cross-sectional dependency between units. As the findings point out cross-sectional dependence, the study then utilizes Pesaran's Cross-Sectional Augmented Dickey-Fuller (CADF) unit-root test that falls into the category of second-generation unit-root tests. After these preliminary checks, the study employs the GMM estimator of the panel VAR approach, and the panel Granger causality test developed by Arellano and Bond (1991) for panel VAR and causality analyses.

To analyze the mutual relationship between patents and economic growth in the OECD, this study seeks answers to the following two research questions (RQ):

RQ1: Do patents affect economic growth?

RQ2: Does economic growth affect patents?

Each research question is then distinguished for patent applications and patent grants. Accordingly, the models estimated are presented as follows:

Model 1a: $lnGDP_{it} = lnPA_{it} + \beta_1 lnGDP_{i(t-1)} + u_{it}$ (1)

Model 1b: $lnGDP_{it} = lnPG_{it} + \beta_1 lnGDP_{i(t-1)} + u_{it}$ (2)

Model 2a: $lnPA_{it} = lnGDP_{it} + \beta_1 lnPA_{i(t-1)} + u_{it}$ (3)

Model 2b: $lnPG_{it} = lnGDP_{it} + \beta_1 lnPG_{i(t-1)} + u_{it}$ (4)

where lnGDP is gross domestic product, lnPA is patent applications, lnPG is total patent grants, and 'u' is the error term. 'I' represent OECD countries and 't' represents the time period between 1990 and 2019. All the variables are expressed in their natural logarithms, as presented with the letter 'l' in front of each variable.

Empirical Findings

Cross-Sectional Dependence and Unit-Root Test

The first step in panel VAR and causality analyses is to apply unit root tests to check the stationarity of the variables. A panel cross-sectional dependence test is performed to see whether a shock affecting a unit will spread to all other units in the panel (Öztürk & Öz, 2016). Since the number of cross-sections (38 OECD countries) is larger than the number of time-sections (30 years), i.e., N>T, the Pesaran-CD (2004) test is used to check the cross-sectional dependence. The findings of this test are also used to determine which generation unit-root test should be applied as a next step.

Table 3

Findings from Panel Cross-Sectional Dependence (Pesaran's CD) Test

Variable	CD-Test	p-value	corr	abs(corr)
lnGDP	131.79	0.000*	0.939	0.939
lnPA	2.69	0.007*	0.019	0.327
lnPG	86.00	0.000*	0.602	0.668

Source: Authors' own calculations.

* indicates significance levels at the 5%.

Table 3 shows that all the analysis series are cross-sectionally dependent. Thus, second-generation unit-root tests should be chosen over first-generation tests. Considering the panel used in the research is unbalanced, this study employs Pesaran's CADF test to examine the stationarity of the series.

Table 4

Findings from Panel Unit-Root (Pesaran's CADF Unit Root) Test

		Constant		Constant & Trending	
		Z[t-bar]	P-value	Z[t-bar]	P-value
lnGDP	Level	3.130	0.999	-2.314	0.010*
	1st difference	-9.171	0.000*	-6.446	0.000*
lnPA	Level	-1.104	0.135	-1.294	0.098
	1st difference	-14.170	0.000*	-13.197	0.000*
lnPG	Level	-3.802	0.000*	-4.426	0.000*

Source: Authors' own calculations.

* indicates significance levels at the 5%.

The findings in Table 4 show that lnGDP and lnPA are non-stationary at the level, while both variables are stationary in the first differences. On the other hand, lnPG is stationary at the level. These findings can summarized as follows: lnGDP is I(1), lnPA is I(1), and lnPG is I(0). For this reason, the first differences of lnGDP (dlnGDP) and lnPA (dlnPA) variables and the level of lnPG are used in the GMM panel VAR and panel VAR-Granger causality analyses.

Panel VAR Analyses

The first step in panel VAR analysis is determining the lag length of the model. In this methodology, model and moment selection criteria (MMSC) depend on various criteria including the coefficient of determination (CD), Hansen's J statistic, minimisation of modified Bayesian Information Criteria (MBIC), modified Akaike Information Criteria (MAIC), and modified Hannan Quinn Information Criteria (MQIC). Among the lag lengths with valid over-identifying restrictions, the one that minimizes MAIC, MBIC, and MQIC is chosen as the optimal lag length (Tatoğlu, 2020).

Table 5

PVAR Model Selection Results

Patent Applications						
Lag	**CD**	**J**	**J pvalue**	**MBIC**	**MAIC**	**MQIC**
1	.1916093	15.69238	.4746288	-88.20768	-16.30762	-44.17452
2	.2179401	8.50237	.7447432	-69.42267	-15.49762	-36.3978
3	-2.148634	2.303033	.9702841	-49.647	-13.69697	-27.63042
4	-5.890038	1.901615	.7538482	-24.0734	-6.098385	-13.06511
Patents Granted						
Lag	**CD**	**J**	**J pvalue**	**MBIC**	**MAIC**	**MQIC**
1	.9918522	21.84854	.1481498	-82.38687	-10.15146	-38.12148
2	.9920591	6.024482	.9148429	-72.15207	-17.97552	-38.95303
3	.981648	2.250731	.972344	-49.86697	-13.74927	-27.73428
4	.981761	2.280327	.6843531	-23.77852	-5.719673	-12.71218

Source: Authors' own calculations.

Table 5 shows the estimated CD, Hansen's J statistics, p-values for Hansen's J statistics, MBIC, MAIC, and MQIC for the patent application and patent granted models. The lag length that minimizes

MBIC, MAIC, and MQIC is lag 1 for both patent applications and patent granted models. Thus, the optimal lag length is selected as 1 lag for both models.

Table 6

Findings from GMM PVAR (1) Analysis

Patent Applications		Patents Granted	
	Coefficient [Std.Error]		Coefficient [Std.Error]
dlnPA		lnPG	
$dlnPA_{t-1}$	0.025* (0.067)	$lnPG_{t-1}$	0.000* (0.022)
$dlnGDP_{t-1}$	0.512 (0.426)	$dlnGDP_{t-1}$	0.826 (0.889)
dlnGDP		dlnGDP	
$dlnPA_{t-1}$	0.045* (0.004)	$lnPG_{t-1}$	0.009* (0.001)
$dlnGDP_{t-1}$	0.000* (0.057)	$dlnGDP_{t-1}$	0.000* (0.058)

Source: Authors' own calculations.

***** indicates significance levels at the 5%. Values in parentheses are standard errors. The letters 'd's in front variables show the first differences of variables.

Table 6 presents the findings from the GMM panel VAR approach on the mutual relationship between patents and economic growth. The estimations for the patent applications and economic growth model indicate that lagged patent applications significantly affect economic growth, while association in the opposite direction is not significant. The findings also show that the lagged patent application and lagged economic growth influence their current values in a significant way. The findings for patent grants and economic growth present similar evidence. Thus, the estimation in Table 6 points out that while patents affect economic growth, the latter does not result in a significant impact on economic activity. These findings demonstrate that the association between patents and economic growth does not present distinct outcomes when patents are differentiated into patent applications and grants in the OECD during the period examined.

Table 7 presents the eigenvalue and modulus of the findings and Figure 1 exhibits roots of the companion matrice both of which are generated from the GMM panel VAR estimations. These outcomes show the stability of the findings in Table 6.

Table 7

Stability of the Findings

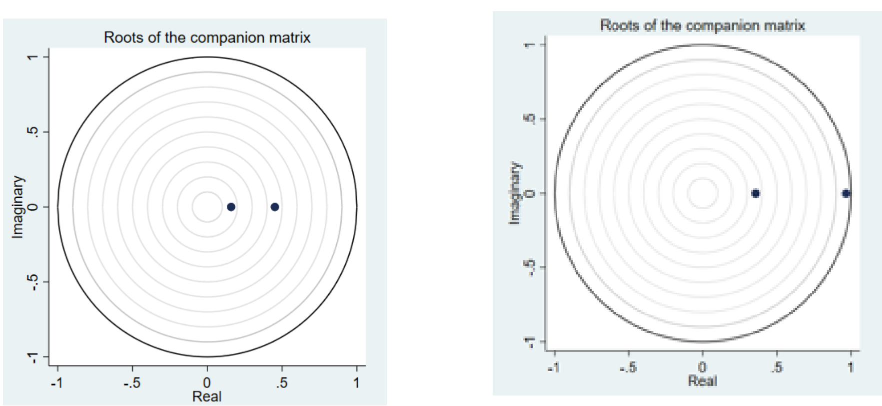
Patent Applications, dlnPA			Patent Grants, lnPG		
Eigenvalue		Modulus	Eigenvalue		Modulus
Real	Imaginary		Real	Imaginary	
0.4516963	0	0.4516963	0.9662332	0	0.9662332
0.1591063	0	0.1591063	0.3569186	0	0.3569186

Source: Authors' own calculations.

Note: Based on the findings from the GMM Panel-VAR approach.

Figure 1

Roots of the Companion Matrices



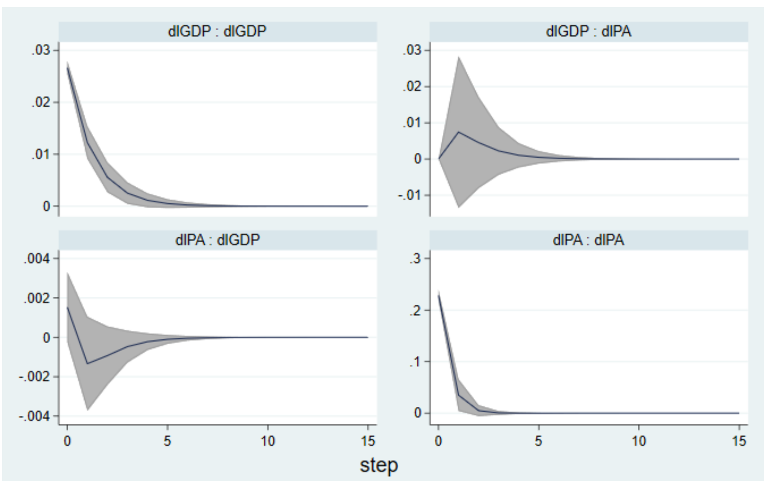
Source: Authors' own calculations.
Note: Based on the findings from the GMM Panel-VAR approach. Patent applications and economic growth are on the left, patent granted and economic growth are on the right.

Table 7 shows that the eigenvalues are less than 1 and Figure 1 shows that all the roots are inside the unit circle with values smaller than 1. These findings exhibit that the PVAR estimates generated in this study meet the stability condition.

The PVAR analysis method uses IRFs to measure the impact of a standard deviation shock on any variable on itself and other variables in the model. Figures 2 and 3 indicate the IRFs calculated using 200 Monte Carlo simulations for economic growth and total patent applications, and economic growth and total patent grants models, respectively.

Figure 2

IRFs for Economic Growth and Patent Applications



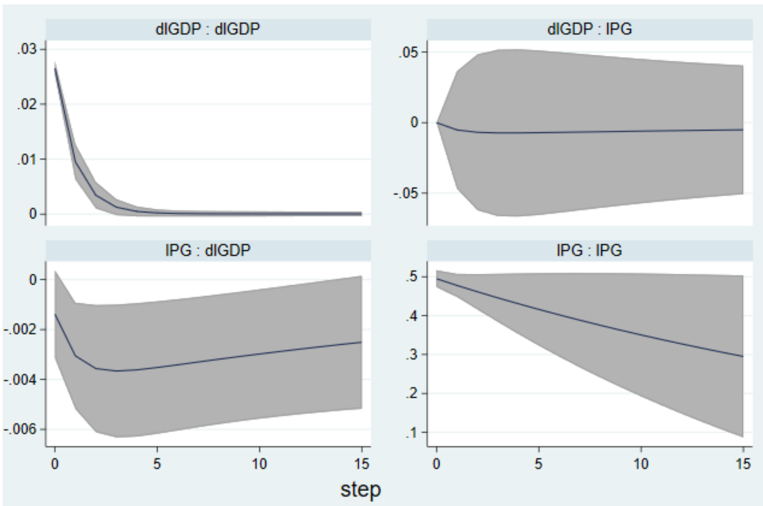
Source: Authors' own calculations.

Note: Impulse: Response

Figure 2 demonstrates that the response of economic growth to a standard deviation shock applied to patent applications (bottom-left panel) is positive first, then turns negative and the effect disappears after five periods. The impact of economic growth on patent applications (upper-right panel) is not significant. The response of economic growth to a standard deviation shock applied to economic growth (upper-left panel) is statistically significant and positive in the first four periods, declining afterward. Finally, the response of patent applications to a standard deviation shock in the patent applications (bottom-right panel) is statistically significant, it decreases and disappears after the first two to three periods. Thus, the IRFs confirm the findings from the GMM panel VAR approach for the economic growth and patent application nexus.

Figure 3

IRFs for Economic Growth and Patent Grants



Source: Authors' own calculations.
Note: Impulse: Response

Figure 3 shows that economic growth does not significantly affect patent grants (upper-right panel) as the confidence intervals contain all parts of the zero line. On the other hand, the response of economic growth to a standard deviation shock applied to patent grants (bottom-left panel) is negative and significant. The impulse of economic growth on itself (upper-left) indicates a positive impact that disappears in approximately five years. Finally, the one standard deviation shock applied to the patent grants on itself (bottom-right panel) was significantly positive. Accordingly, the IRFs in Figure 3 confirm the findings for economic growth and patent grants estimated by the GMM panel VAR approach. However, they present a crucial finding that the impact of patent grants on economic growth lasts longer compared to that of patent applications. While a shock to patent applications on economic growth fades away after approximately five periods (Figure 2, bottom-left panel), a shock to patent grants stays much longer (Figure 3, bottom-left panel).

Granger Causality Test

After examining the dynamic relationship between variables utilizing the GMM panel VAR approach, the study employs the panel-VAR Granger test to examine the causality between the variables in question. Relevant findings are presented in Table 8.

Table 8

Findings from Panel VAR-Granger Causality Wald Test

Direction of Causality			chi2	prob>chi2
dlnGDP	↛	dlnPA	0.430	0.512
dlnGDP	↛	lnPG	0.048	0.826
dlnPA	→	dlnGDP	4.010*	0.045
lnPG	→	dlnGDP	6.797*	0.009

Source: Authors' own calculations.

Notes: ***, **, and * indicate rejection of the null hypothesis of no causality at the 1%, 5%, and 10% levels

The findings in Table 8 indicate that patent applications significantly Granger cause economic growth, while the causality in the opposite direction is not significant. Similar evidence is observed for patent grants and economic growth. Thus, the estimations indicate unidirectional causalities from patent applications and patent grants to economic growth, failing to validate reciprocal causality between patents and economic growth in the OECD during the examined period.

The findings of the Granger causality analysis can be summarized as follows: Patent applications → GDP and Patents granted → GDP

Discussion and Policy Recommendations

Almost all OECD member countries, which is the selected country group, are advanced and have high-income levels. Already, OECD countries encourage innovation by investing in R&D and support policies emphasizing market size's importance for effective R&D sectors (Acemoğlu & Linn, 2004). For these reasons, the conclusion reached in this study that patents have an impact on economic growth in OECD countries is not surprising. Statistical figures support this conclusion; according to the WIPO, the R&D expenditures of OECD countries amount to approximately 772 billion US dollars. Globally, 1.5 million patents are granted per year (WIPO, 2020). The average number of patent applications was 30.370 and the average number of granted patents was 16.103 in OECD countries between 1990-2019 (WIPO, 2022). During these three decades, 53% of patent applications were granted in OECD countries. Approximately 62% of the patent applications filed worldwide were filed by OECD countries in the analyzed 30-year period. The findings of this study are broadly like the results of the related studies in the literature. In the study of patents, Schmookler's contribution is often regarded as the root of all work on this topic and is one of the most comprehensive studies of the relationship between patents and economic growth. Schmookler does not doubt that patents are an important part of economic growth (Vershinin, 2021). Fagerberg (1994) analyzed by compiling studies testing the validity of economic growth theories. Among the findings of this analysis, he mentioned that patents have a strong positive relationship with economic growth as a result of appropriate policies. Ülkü (2004) analyzed the relationship between patent applications, R&D expenditures, and economic growth and found that there is a strong and positive relationship between innovation and national income per capita. Bilbao-Osorio and Rodríguez-Pose (2004), in their study on the relationship between the number of patents, economic growth, and R&D expenditures in EU countries, conclude that a higher number of patents positively affects economic growth.

The role of patents in economic growth is case-specific, both because of variations by industries and differences between countries. Differences in patent activity are due to differences between countries in variables such as population, R&D expenditures, and GDP (WIPO, 2022). Since patenting is a direct function of innovation activities, patents depend on the level of R&D activities. Innovations (R&D expenditures) are mostly concentrated in developed industrial countries, and most of the progress in less developed countries consists of adapting technologies from more developed countries to the conditions of the developing world (Stiglitz, 1999). For this reason, the income level and economic development of countries also have an impact on patents. Thus, the findings of this study indicating causal links from patents to economic growth are in line with all these theoretical foundations and statistical data.

Considering the relevant theory and the existing studies in the literature, the limitation of the present study is that R&D expenditures are not included in the examination. This may be the reason for obtaining a one-way causality only from patents to economic growth, rather than a reciprocal relationship.

Most patent offices have experienced a surge in patent applications in the past two decades, with the largest contribution to growth being made by new technologies (ICT, biotechnology) (OECD, 2004). The fact that patent trends differ between firms, sectors, and countries requires comparative analysis across these units. Therefore, it would be useful to conduct separate analyses for a selected product, sector, or country and with different periods, country groups, variables, and analysis methods.

On the other hand, as mentioned at the beginning of our study, as indicators of technological activity, patents have certain weaknesses. Patents do not reflect all of the research and innovative efforts behind an invention. Desrochers (1990) notes that numerous groundbreaking technological inventions never have their patent applications submitted to patent offices because of lengthy patenting procedures, high expenses, or a lackluster acknowledgment of the ideas' merit. In addition to the fact that not all innovative products are patented, not every patented invention may have a commercial value. Nevertheless, the inventor may patent an invention that may not be commercialized to prevent competitors from using that idea (Kleinknecht, Montfort, & Brouwer, 2002). In conclusion, it is possible to say that the use of patents has certain weaknesses and drawbacks.

Patents are becoming increasingly important for innovation and economic performance. Therefore, most countries' demand for patents has been rapidly expanding since the mid-1990s (WIPO, 2008). In line with this, economists have begun to participate in policy discussions on patents only recently. There have been tremendous changes in the patent system over the past two decades in expanding and strengthening protection. Countries have different social, political, and economic characteristics that affect patents (Encaoua, Guellec, & Martinez, 2006).

Patent systems should be used more systematically to encourage innovation and technology diffusion. Increasing the level of knowledge and awareness of companies about the issues and processes related to patents and IPRs can be considered the first step in the patent system. So, to design a patent system that increases the rate of innovation would be effective. Any knowledge that is currently being used is an important resource for future innovation. Therefore, know-how is critical for a firm or an economy to develop innovations. It is important to strengthen the high-technology sectors with high value-added. With high-technology products, countries can foster technology transfer and encourage new foreign investment. For this reason, to encourage R&D investments, tax incentives can be provided for R&D expenditures. Economists emphasize that innovation activities and technological development are of great importance for sustainable growth. In the late 1970s, patent data began to be used to investigate the relationship between technology and trade. Since then, the drivers of competitiveness, both nationally and internationally, have continued to diversify along with technology and patents (Archibugi, 1992). That's why governmental policies should aim to shift the innovation system towards technologies able to trigger strong economic growth (Yoruk, Radosevic, & Fischer, 2023). The number of patents, which is an indicator of the inventions made by the countries, is important in terms of showing the R&D capacity of the country and measuring the output based on R&D. Patents are powerful tools to encourage the creation of new technologies and industries. In this context, it will be possible to talk about sustainability if innovation and patents are encouraged and made an important element of economic policies. It is important to provide incentives for innovation and protection of IPRs, especially in knowledge-based economies. In addition, it should be aimed to establish strategic goals for the effective management of patents, since patents contribute to a company's balance sheet and have a monetary value that increases the value of the enterprise.

The formation of new products and new technologies because of the expenditures on innovation in a country will improve the production capacity of not only that country but also other countries (Altıntaş & Mercan, 2015). Therefore, patents have a power that affects the whole. It will be beneficial for countries to cooperate to use and develop this power. Incentives should be provided by governments to entrepreneurs so that they can innovate and stimulate other entrepreneurs. In this way, new investments will emerge and spread to other sectors. In recent years, in OECD countries (e.g., Germany, the Netherlands, Norway) special funds have been created to finance research in priority areas. As a result of R&D activities, new products emerge, and innovations occur with the development of more efficient production methods and processes. In this context, economic growth is realized with innovations in the Schumpeter sense (Taban, 2008). Considering that innovations are the output of qualified manpower; the development of education and educational institutions should be given importance and scientific research should be supported. Increasing qualified manpower will increase the welfare level of the country and accelerate economic growth.

As a result of the fact that patent grants have a more significant impact on economic growth, it can be interpreted that not all patent applications are accepted, and the most effective is the quality of patents. In other words, quality is more important than quantity in the impact of patents on growth. This empirical study reveals once again how innovation and patents are important for economic growth.

Conclusion

This paper examines the causal links between patents and economic growth. Distinguishing patents into patent applications and patent grants, this study utilizes GMM panel VAR and Granger causality analyses in its methodology for a panel of 38 OECD countries between 1990 and 2019.

Preliminary checks of the empirical investigation point out the existence of cross-sectional dependency in the data. Thus, the study employs the CADF unit-root test, from second-stage stationarity tests. The outcomes of the GMM panel-VAR approach indicate a one-way causality from patent applications and patent grants to economic growth. The eigenvalue stability conditions confirm the stability of the findings. IRFs provide parallel findings to that from GMM panel-VAR estimations, also pointing out that the impact of patent grants on economic growth stays longer than that of patent applications. While a shock to patent applications on economic growth fades away after approximately five periods, a shock to patent grants stays much longer.

Evidence from Granger causality analysis also presents similar findings by indicating a one-way causality from patent applications and patent grants to economic growth, rather than a reciprocal causality. Such findings show that while patents cause economic growth, the latter does not result in any innovative impact through patents.

The study generally shares common features with R&D-based endogenous growth models and Schumpeter's innovation approach model. Various studies in the literature show that the findings of this study are similar to the other research findings in the literature (Ülkü, 2004; Gülmez & Akpolat, 2014; Sungur, Aydın, & Eren, 2016; Alper, 2017). In addition to the findings in the literature, this study also concludes that structural shock shocks that occur in patent granted are more significant on gross domestic product than patent applications.

Author Contributions

Contribution	Yıldız, Ö.Ö.Y	Görkey, S.G
Contextualization	X	X
Methodology	X	X
Software	X	-
Validation	X	X
Formal analysis	X	-
Investigation	X	-
Resources	X	-
Data curation	X	X
Original	X	-
Revision and editing	X	X
Viewing	X	X
Supervision	X	X
Project management	X	-
Obtaining funding	-	-

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Appendix

Table A1

Variables and Data Sources

	lnGDP ($)	lnPA	lnPG
Obs	1100	1112	1117
Mean	26.36006	7.9589	7.058001
Std. Dev.	1.578799	2.133073	2.593215
Min	22.9363	3.091033	0
Max	30.6232	13.33982	12.73552

Source: Authors' own calculations.

Notes: The variables are in their natural logarithms