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The Relationship between R&D Expenditures and Economic Growth in BRICS-T Countries

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BRICS-T Ülkelerinde Ar-Ge Harcamaları ve Ekonomik Büyüme Arasındaki İlişki

Öz

Teknolojik gelişmenin temel belirleyicilerinden olan Ar-Ge ülkeler arasında gelişmişlik farklarının belirlenmesinde kritik bir role sahiptir. Gelişmiş ülkelerin yanı sıra gelişmekte olan ülkelerin de Ar-Ge harcamalarına daha fazla fon ayırmaya başlaması, bu konudaki literatürün güncelliğini korumasına yol açmaktadır. Bu çalışmanın amacı, 2000-2018 döneminde Ar-Ge harcamaları ve büyüme arasındaki ilişkiyi Brezilya, Rusya, Hindistan, Çin, Güney Afrika ve Türkiye (BRICS-T) için incelemektir. Bu kapsamda panel VAR yaklaşımıyla birlikte Dumitrescu-Hurlin (2012) nedensellik testi, Etki-Tepki ve Varyans Ayrıştırma analizleri kullanılmıştır. Dumitrescu-Hurlin (2012) nedensellik testine göre BRICS-T ülkelerinde Ar-Ge harcamaları ile büyüme arasında çift yönlü nedensellik ilişkisi vardır.

Anahtar Kelimeler: Ar-Ge Harcamaları, Büyüme, Panel VAR, BRICS-T

JEL Kodları: O32, O40, I25

The Relationship between R&D Expenditures and Economic Growth in BRICS-T Countries

Abstract

R&D, which is one of the main determinants of technological development, has a critical role in determining the development differences between countries. The fact that developing countries as well as developed countries start to allocate more funds to R&D expenditures causes the literature on this subject to remain up-to-date. The aim of this study is to examine the relationship between R&D expenditures and growth in the period of 2000-2018 in Brazil, Russia, India, China, South Africa, and Turkiye (BRICS-T). In this context, Dumitrescu-Hurlin's (2012) causality test, Impulse-Response and Variance Decomposition analyzes are used together with the panel VAR approach. According to Dumitrescu-Hurlin (2012) causality test, there is a bidirectional causality relationship between R&D expenditures and growth in BRICS-T countries.

Keywords: R&D Expenditures, Growth, Panel VAR, BRICS-T

JEL Codes: O32, O40, I25

Araştırma ve Yayın Etiği Beyanı	Bu çalışma bilimsel araştırma ve yayın etiği kurallarına uygun olarak hazırlanmıştır.
Yazarların Makaleye Olan Katkıları	Yazarlar çalışmaya eşit oranda katkı sağlamıştır.
Çıkar Beyanı	Yazarlar açısından ya da üçüncü taraflar açısından çalışmadan kaynaklı çıkar çatışması bulunmamaktadır.

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1. Introduction

R&D is the creative work carried out to ensure that the stock of human and social knowledge is used to develop new applications (Arond and Bell, 2010). In this framework, R&D studies are accepted as well-organizing the process of producing, disseminating and applying knowledge (Wang, 2007). According to Godin and Lane (2012), research is an academic category, while development is an industrial category. According to Hall (2006), research and development are activities carried out by individual entrepreneurs, companies or institutional organizations to create new or improved products and processes. According to Gaillard (2010), R&D is creative activities that are systematically applied to increase the stock of knowledge in order to develop new applications.

R&D investments are among the main determinants of increasing the development and competitiveness of a country (Bor, et al. 2010). In general, technological innovation leads to economic growth in the long-run. Because innovation positively affects total factor productivity (TFP), which shows total output growth (Surani et al. 2017). The role of industrial innovation processes in growth has been frequently discussed since Schumpeter. In this context, Schumpeter is one of the early economists examining the relationship between industrial innovation and economic growth at the macro level (Hasan and Tucci, 2010). By the middle of the 20th century, the Neoclassical growth model, known as the Solow (1956) and Swan (1956) model, focused on the role of capital accumulation, technological progress, population growth and productivity in long-term economic growth. Although the model emphasizes the positive effect of technology on growth, technological development has been accepted as an exogenous variable. In the late 1980s, endogenous growth models supported by the pioneering work of Romer (1986) and Lucas (1988) accepted R&D as an endogenous variable in economic growth models (Li, 2010).

Grossman and Helpman (1991), Aghion and Howitt (1992), Barro and Sala-i Martin (2004) are recent studies emphasizing the importance of R&D in growth. Grossman and Helpman (1994) considered industrial innovation resulting from R&D investments as the basic engine of economic growth. High-profit margins are the incentive for companies to invest in R&D activities. This motive will lead companies to open up more resources for R&D activities; innovation process will be accelerated and higher efficiency will be achieved. Aghion and Howitt (1992) have argued that growth is based on technological development and that this is the result of competition between research firms that focus on innovation. Barro and Sala-i Martin (2004) modeled technological progress as enrichment of intermediate goods for the production process.

In the following periods, the relationship between R&D and growth has been discussed in many studies. The findings in the literature generally indicate that R&D investment expenditures positively affect growth in the short or long term. In addition, most of the studies have examined panel cointegration or causality as a panel data method. This study differs from other studies in that it uses the panel VAR method on the relationship between R&D expenditures and growth for BRICS-T countries.

In this study, the relationship between R&D expenditures and economic growth is discussed using the panel VAR analysis method the period of the 2000-2018 in BRICS-T countries. The remaining plan of the study is as follows: In the second section, R&D expenditures in BRICS-T countries are presented. In the third section, data and methods are given. In the fourth section, the analysis findings are discussed.

2. R&D in BRICS-T Countries

Technological progress is a determining factor in many sectors of production and has a strong effect on changing the consumption patterns of society. As a result of increasing competition with the effect of globalization, companies need quantitative and qualitative R&D planning in order to stay strong and progress. On the other hand, it is known that countries that give more place to R&D expenditures have made significant progress in scientific and technological terms. As a matter of fact, research and development activities in developed economies play an important role in areas such as national security, agriculture, transportation, economic growth, industrial competitiveness, job creation, energy, environmental protection, public health and welfare, and expanding the boundaries of human knowledge understanding (Sargent, 2018). In this context, R&D activities have tended to increase in developing countries in recent years. These activities for technological innovations are sometimes mediated by the internal resources of the countries and sometimes by foreign direct investments. For example, some developing countries with strong infrastructures, skilled workforce, intellectual property rights, and attractive domestic markets in Asia and the Pacific have attracted significant foreign direct investments for their R&D activities. Accordingly, these countries have tried to maximize the degree of technological diffusion from foreign direct investments and to encourage the participation of local firms in R&D (United Nations, 2005).

In Brazil, one of the BRICS countries, The National Fund for Scientific and Technological Development (FNDCT) was established in 1969 for the development of science and technology and by giving financial autonomy to the national science and technology system with this available budgetary resources and external credit facility, it has been an important step in the creation of incentive policies related to science and technology (De Negri et al., 2006). In Brazil, the turning point in the policy of financing and supporting innovation was the creation of Sectoral Funds in 1999, which channel some taxes to finance R&D. For example, the government has collected a certain tax on petroleum royalties to finance technological development for this sector, and has also taxed other sectors such as biotechnology, health, mining, aviation, and so on. The collected taxes are also intended to be used to fund R&D projects in these sectors (Braga de Andrade, 2020). By the 2000s, Brazil implemented a number of new innovation policy tools based on large amounts of public funds. These changes began with the publication of two very important laws, the Innovation Law in 2005 and the Lei do Bem in 2006. These laws allowed the development of new policy tools and helped direct the sources of innovation funds created in the 90s to businesses (Rocha, 2018).

In Russia, which transitioned to a market economy in 1991 after the collapse of the Union of Soviet Socialist Republics, this process had a significant impact on R&D activities. While the dominance of state-owned enterprises has weakened, the role of industry associations, enterprises, and local governments has increased (Gokhberg, 1999). However, the transition to this market economy negatively affected R&D activities in Russia. Because the percentage of R&D expenditures directly provided by the public in GDP has decreased by approximately 75 percent. This caused half of the scientists and researchers to lose their jobs (Schweiger et al. 2018). However, there was a recovery in R&D activities in the next period. The participation of Russian engineers and scientists in technology projects and international science, the employment of Russian researchers abroad, joint ventures involving Russian and foreign organizations, and the establishment of foreign companies in Russia have led to the strengthening of Russia's technological infrastructure (Gokhberg et al. 1997).

India started the industrial growth process by announcing its first industrial policy in 1948. However, since heavy industry-based industrialization requires high technology, foreign direct investments and technology licensing policy have been encouraged for industry demand (Aggarwal, 2001). At the end of the liberalization process that has accelerated since the beginning of the 1990s, R&D expenditures have increased significantly. In this framework, governments have given priority to supporting R&D and encouraged especially industrial sectors to start R&D activities. Various fiscal measures have been put in place, such as general tax incentives, and incentives specific to emerging sectors (Sheeja, 2014: 104). India has started to give more priority to science and technology in recent years, and with the effect of these policies, India ranks third among the most attractive investment destinations in the world for technological investments (IBEF, 2022).

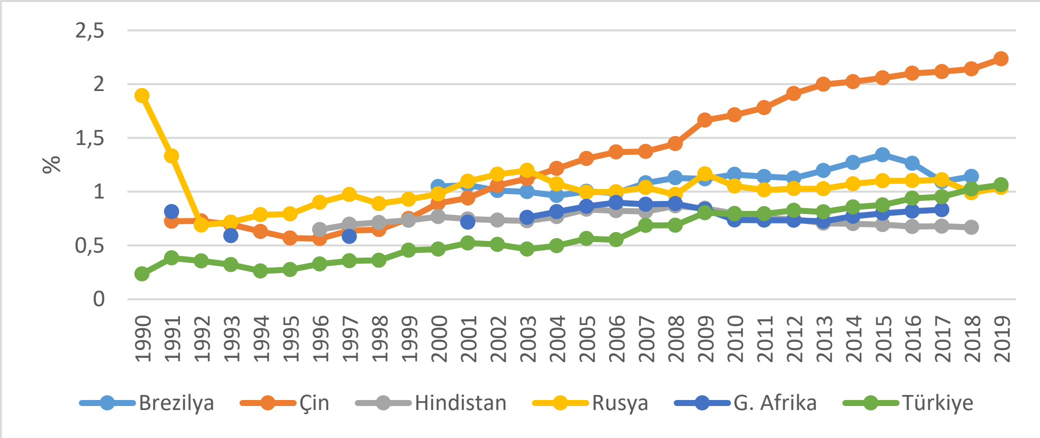
In the early 1980s, China's technological infrastructure was rather weak compared to developed countries. The structural transformation of the Chinese economy in 1978 led to rapid growth in the field of science, and technology (Xie et al., 2014). In this context, the law enacted by the government in the field of science and technology in 1985 contributed positively to the development of the technological infrastructure in China. In addition, the Act Promoting Commercialization of S&T Discoveries and Inventions was enacted in 1996. The focus of these policies has been the commercialization of academic outputs, and the development of R&D and innovation capacity in industrial sectors (Chen et al. 2015). As a result of R&D-oriented policies, China has come to the fore more and more in industries that use scientific and technological knowledge intensively. In March 2021, China's "14. Five-Year Plan (2021–2025)" and "Long-Term Targets Until 2035" programs have renewed support targets for innovation (Yao et al., 2021).

With the regime change in 1994, South Africa started to give priority to policies aimed at opening up. In this context, South Africa could not reach the macroeconomic targets set by the National System of Innovation (NSI) policy in 1996 for innovation policies, but it provided a partial transformation in the country's economy (Mamphiswana, 2022). In addition, the South African government has started to implement a tax incentive policy to encourage the private sector to invest in technological research and development in the country (NTSI, 2021).

In Turkiye, the Five-Year Development Plans, which started in the 1960s, are the period when technology-oriented policies came to the fore. At this point, the establishment of the Scientific and Technological Research Council of Turkiye (TÜBİTAK) with the first Five-Year Development Plan implemented in the 1963-1967 period was a turning point in this sense. By 1983, the establishment of the Supreme Council for Science and Technology (BTYK) was an important step in the long-term determination, execution and coordination of science and technology policies (Karagöl and Karahan, 2014). The structural transformation of the Turkish economy in the 1980s necessitated further strengthening of the technological infrastructure, and in this framework, R&D expenditures began to increase in the 1990s.

In this study, the change in the share of R&D expenditures in GDP over the years in BRICS-T countries is shown in Figure 1. Accordingly, China, along with South Africa and Turkiye, was one of the countries with the lowest R&D expenditures in the second half of the 1990s. However, over the years, China's R&D investments have continuously increased their share of GDP. As a matter of fact, while China's R&D expenditures constituted only 0.5% of GDP in 1996, they reached 2.2% in 2019. In Russia, on the other hand, there has been a significant decrease in R&D expenditures with the disintegration of the USSR. However, it is observed that Russia increased its R&D expenditures, especially in the early 2000s, and fluctuated in the following years. Although Brazil is the country with the highest R&D expenditures after China, it is seen that the share of R&D expenditures has decreased in recent years. India has the lowest R&D expenditure among the BRICS-T countries, and the share of R&D has dramatically decreased in recent years. On the other hand, South Africa and Turkiye have been the countries that have increased their R&D expenditures in recent years.

Figure 1: R&D Investment Expenditures (% of GDP) In BRICS-T countries



Source: World Bank

3. Literature

There is a large literature dealing with the relationship between R&D and economic growth. The general tendency in the relevant literature is that there is a strong relationship between the two variables.

The prominent results in the studies that discuss the relationship between R&D and economic growth in the context of causality are that there is either bidirectional causality between the variables or there is a causal relationship from R&D expenditures to growth. In this context, Genç and Atasoy (2010) found a one-way causality relationship from R&D expenditures to economic growth in 34 countries. Altın and Kaya (2009) argued that there is no relationship between R&D expenditures and growth in Turkiye, but there is a causal relationship from R&D expenditures to growth in the long run. Similarly, Korkmaz (2010) concluded that there is a causality relationship from R&D expenditures to GDP in Turkiye. Genç and Tandoğan (2020) found bidirectional causality between R&D expenditures and economic growth in Turkiye. Türedi (2016) found bidirectional causality between R&D expenditures and economic growth in OECD Countries. Gülmez and Yardimcioglu (2012) found bidirectional causality between R&D and growth in 21 OECD member countries. Dereli and Salğar (2019) reached a cointegration relationship between R&D expenditures and growth in Turkiye and found bidirectional Granger causality between the variables. Ülger and Uçan (2018) argued that the effect of growth on R&D expenditures in Turkiye is quite weak, but the effect of R&D expenditures on growth is strong.

In some studies, it is seen that the findings on the relationship between R&D expenditures and growth differ on the basis of institution/company or other conditions. For example, Lichtenberg (1992) discussed the relationship between private and public sector R&D and growth in 74 countries. According to the study, public sector R&D expenditures are not effective on growth, but there is a significant relationship between private sector R&D expenditures and growth. Wakelin (2001) investigated the relationship between R&D expenditure and productivity for 170 companies in the United Kingdom. In the study, it was concluded that the R&D expenditures of the companies positively affect the productivity and the R&D rate of return is higher for innovative companies than for non-innovative companies. Wang and Wu (2015) investigated the effects of both government R&D expenditures and enterprise R&D expenditures on growth in China. According to the study, all R&D expenditures positively affect economic growth, but while the correlation between Enterprise R&D Expenditure and growth is strong, the correlation between government R&D expenditures and economic growth is weak.

The level of development of countries is determinant in the relationship between R&D expenditures and growth. For example, Goel and Ram (1994) analyzed the effect of R&D expenditures on growth for 18 developing countries and 34 Least-Developed countries. According to the study, there is no relationship between variables in low-income countries and growth, but there is a relationship between variables in high-income countries. Gyedu (2021) investigated the effect of innovation on growth in G7 and BRICS countries. In the study, R&D, patent and trademark were used as innovation indicators. According to the study, these indicators are determinant on growth and this effect is stronger in G7 countries. Sylwester (2001) found that there is no relationship between R&D expenditures and economic growth in OECD countries, but there is a positive relationship between industrial R&D expenditures and growth in G7 countries.

In addition, Ortega and Marin (2011) investigated the relationship between R&D expenditures and productivity in 65 countries. According to the study, R&D expenditures increase total factor productivity in the long run. Gyekye et al. (2012) found that an increase in R&D spending boosted economic growth in selected Sub-Saharan African countries. Khan and Khattak (2014) found that R&D positively affects growth in Pakistan. Similarly, Olaoye et al. (2021), Appiah-Otoo and Song (2021), Mudronja et al. (2019), Mladenovic et al. (2016), Amor and Zina (2015), Meçik (2014) , Blanco et al. (2013), Huda et al. (2020) found that R&D positively affects growth in some African countries, 123 countries, port areas within the European Union, 28 Member States of the European Union, MENA countries, OECD countries, and US States, ASEAN region with the 4 main Asian countries, respectively.

Despite the large literature suggesting a positive relationship between R&D and growth, Akinwale et al. (2012) found that R&D expenditures negatively affect growth in Nigeria. According to the study, corruption, weak institutional infrastructure, and low inter-institutional interaction were the determining factors in obtaining these findings.

Although studies in the literature generally focus on R&D expenditures as an indicator of R&D or innovation, some studies have investigated the growth relationship by using different innovation indicators or by using both R&D expenditures and different innovation indicators. In addition, in some studies, the relationship between R&D and growth has been discussed through the innovation channel. For example, Aali Bujari and Mart´ınez (2016) found that investments in high-tech products, R&D, and patents positively affect growth in Latin America. Pece et al. (2015) investigated the effect of innovation on growth in the Czech Republic, Poland, and Hungary. They used patents, trademarks, and R&D expenditures as innovation indicators. According to the study, innovation affects growth positively. Gülmez and Akpolat (2014) investigated the relationship between R&D activities, innovation, and economic growth in Turkiye and 15 EU countries. According to the study, both R&D and innovation positively affect economic growth. Ulku (2004) found a positive relationship between innovation and growth in 30 OECD and non-OECD countries. In addition, the effect of R&D expenditures on innovation has been investigated and they have found that this effect is significant only in OECD countries with large markets. Bilbao-Osorio and Rodríguez-Pose (2004) examined the relationship between R&D, innovation, and growth in EU countries in two stages. First, the effect of R&D expenditures on innovation was examined and a positive relationship was found between the variables. In the second stage, the effect of innovation on growth was investigated and a positive relationship was found between the two variables.

Some of the studies dealing with the relationship between R&D expenditures and growth are summarized in Table 1.

Table 1: Some Empirical Studies

Researcher	Period	Sample	Method	Result
Lichtenberg (1992)	1964-1989	74 Countries	Panel Data Analysis	There is no relationship between public-sector R&D expenditures and growth but there is a relationship between growth and private-sector R&D expenditures
Goel and Ram (1994)	1960-1985	Developing and Developed countries	Multiple Regression	There is no relationship between R&D spending and growth in low-income countries, but there is in high-income countries.
Wakelin (2001)	1988 - 1992	United Kingdom	Cobb-Douglas Production Function	R&D expenditures of companies positively affect productivity
Altın and Kaya (2009)	1990-2005	Turkiye	Vector Error Correction	R&D is the cause of growth in the long run, but there is no relationship between the variables in the short run
Genç and Atasoy (2010)	1997-2008	34 Countries	Panel Causality	There is unidirectional causality from R&D expenditures to growth
Korkmaz (2010)	1990-2008	Turkiye	Granger Causality Test and Johansen Cointegration Test	There is a long-run relationship between the variables. Besides, there is unidirectional causality from R&D to growth in the short run
Ortega and Marin (2011)	1965-2005	65 Countries	Panel Causality	R&D positively affects total factor productivity in the long run
Gülmez and Yardımcıoğlu (2012)	1990-2010	21 OECD Countries	Panel Cointegration and Panel Causality	There is bidirectional causality between variables
Gyekye et al. (2012)	1997-2007	Some Sub-Saharan African Countries	Panel Data Analysis	R&D expenditures positively affect growth
Khan and Khattak (2014)	1971-2008	Pakistan	Johansen Cointegration Test	There is a long-run relationship between the variables
Meçik (2014)	1990-2012	OECD Countries	Panel Causality	R&D positively affects economic growth

Mladenović et al. (2016)	2002-2012	EU-28	Multiple Regression	R&D expenditures positively affect growth.
Türedi (2016)	1996-2011	OECD Countries	Panel Causality	There is bidirectional causality between R&D and growth
Ülger and Uçar (2018)	1996-2014	Turkiye	VAR Analysis	R&D expenditures positively affect growth.
Dereli and Salğar (2019)	1990-2015	Turkiye	Johansen Cointegration Test and Granger Causality Test	There is a long-run relationship between the variables and in the short run, there is bidirectional causality between R&D and growth
Mudronja et al. (2019)	2002-2015	EU-28	Panel Data Analysis	R&D expenditures positively affect growth.
Genç and Tandoğan	1990-2017	Turkiye	Cointegration Test	There is bidirectional causality between R&D and growth
Gülmez and Akpolat (2014)	2000-2010	15 EU Countries, and Turkiye	GMM	R&D and innovation positively affect growth
Akinwale et al. (2012)	1977-2007	Nigeria	Least Square Method	R&D expenditures negatively affect growth

4. Model and Data

In this study, the relationship between economic growth and R&D expenditures were analyzed in BRICS-T countries during 2000-2018 using the panel VAR method, and Dumitrescu-Hurlin's (2012) causality test. For BRICS-T countries, the starting year of the study was determined as 2000, since data on R&D expenditures have been available since 2000. In addition, due to the limited data on R&D expenditures after 2018, the end year was used. The model established in the study is shown in Table 2.

$$LGROW_{it} = B_0 + B_1 RD_{it} + \varepsilon_{it} \quad (1)$$

The variables, and data sources in the model are given in Table 2.

Table 2: Variables and Sources

Variables	Definition	Sources
LGROW	GDP per capita (constant 2015 US$)	World Bank Indicators
RD	R&D Expenditure (%GDP)	OECD

* L indicates logarithmic form of the variable.

In this study, the relationship between variables are examined using the panel VAR method. The panel VAR approach allows the determination of the internal interaction between R&D expenditures and growth. In other words, it can reveal the lagged effects of R&D expenditures on growth and whether there is feedback from growth to R&D expenditures. In addition, this approach allows to determine the direction of the relationship between variables with Dumitrescu-Hurlin's (2012) causality analysis and helps to evaluate the dynamic links between the variables with the impulse-response analysis.

The panel VAR approach takes into account the static and dynamic interdependencies between variables and also allows to examine the impulse-response functions of different shocks and how they affect other imbalances (Canova and Ciccarelli, 2013).

In its most general form, the econometric model is as follows:

$$Y_{it} = A_1(L)Y_{it} + A_2(L)W_{it} + U_{it} \quad (2)$$

In the above equation, Y_{it} denotes a matrix of endogenous variables or a vector of stationary variables, $A_1(L)$ and $A_2(L)$ represent a matrix polynomial in the delay operator; i used for countries and U_{it} used for the vector of specific errors (Bouvet et al., 2013).

In order to use panel VAR analysis, some assumptions need to be tested. First of all, unit root tests of each series should be used. Cross-section dependency is of great importance for the selection of the unit root test to be used. At this point, depending on whether the time dimension (T) of the data set is larger than the cross-section dimension (N), the cross-sectional dependence between the variables can be tested with the Lagrange Multiplier (LM) test developed by Breusch and Pagan (1980) or the CD test of Pesaran (2004).

The Breusch and Pagan LM test is based on the Lagrange Multiplier (LM) test statistic to test the existence of a dependency between cross-sections, and this statistic is used when T is large and N is small (Tatoğlu, 2020).

$$LM = \mathrm{T}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\acute{\rho}^2 ij \quad (3)$$

The $\acute{\rho}^2 ij$ in Equation 2 shows the sample estimate of the binary correlation of the residuals.

Breusch and Pagan (1980) and Pesaran (2004) scaled up the LM test when the cross-section is too large and extended it as follows:

$$LMs = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\acute{T_\iota}\rho^2 ij - 1 \quad (4)$$

Pesaran (2004) developed the CD test statistic by solving the possible size distortion problem in *LM* and LM_s.

$$CD = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\acute{T_\iota}\rho^2 ij \quad (5)$$

Whether there is a dependency between cross-sections was determined by the following hypotheses:

$$H_0 \ : There\ is\ no\ cross-section\ dependency$$
$$H_1 \ : There\ is\ a\ cross-section\ dependency$$

On the other hand, whether the slope coefficients are homogeneous or not is tested with the Swamy S test and causality tests are determined according to the results of this test. (Tatoğlu, 2020: 247). The Swamy S test is as in equation (6).

$$\hat{S} = X^2_{k(N-1)} = \sum_{i=1}^{N}(\widehat{\beta\iota} - \bar{\beta}^*)'\,\hat{V}\iota^{-1}\,(\widehat{\beta\iota} - \bar{\beta}^*) \quad (6)$$

Pesaran and Yamagata (2008) developed this test of Swamy as the delta (Δ) test. The hypotheses for these tests are as follows:

$$H_0 : \beta\mathrm{i} \ = \ \beta \text{ slope coefficients are homogeneous}$$
$$H_1 : \beta \ \neq \ \beta\mathrm{j} \text{ slope coefficients are not homogeneous.}$$

Pesaran and Yamagata (2008) developed delta and adjusted delta test statistics in equations (7) and (8 to) test the above hypotheses (Pesaran and Yamagata, 2008).

$$\hat{\Delta} = \sqrt{N}\ \left(\frac{N^{-1}\hat{S} - k}{\sqrt{2k}}\right) \quad (7)$$

$$\hat{\Delta}_{adj}= \sqrt{N}\left(\frac{N^{-1}\hat{S}-E(\hat{Z}_{it})}{\sqrt{Var(\hat{Z}_{it})}}\right) \quad (8)$$

Taylor and Sarno (1998) suggested the Multivariate Augmented Dickey-Fuller (MADF) unit root test, one of the second-generation panel unit root tests, which is weak in cases of inter-unit correlation and is similar to the standard single-equivalent ADF unit root test. (Tatoğlu, 2020).

$$y_{it} = \mu_i + \sum_{j=i}^{k} \rho_{ij} y_{it-j} + u_{it} \qquad \text{İ} = 1, \dots, N \text{ and } t = 1, \dots., T \quad (9)$$

In Equation 9, the error term ($u_t = (u_{it}, \dots, u_{Nt})'$) is assumed to be independent normally distributed with the non-scalar covariance matrix.

$$u_{it} \sim IN\ (0, \Lambda) \quad (10)$$

In the MADF unit root test, the following null hypothesis is tested:

$$H_0 = \sum_{j=1}^{k} \rho_{ij} - 1 = 0 \qquad \forall_i = 1, \dots.., N \quad (11)$$

The causal relationship between the variables was tested using Dumitrescu-Hurlin (2012) causality analysis. The hypotheses are as follows:

H_0 : No Granger causality from Y to X

H_1 : *Granger causality from Y to X*

To test these hypotheses, Dumitrescu-Hurlin (2012) developed the panel's $Wald\ (W_{N,T}^{Hnc})$ statistic.

$$Wald\ (W_{N,T}^{Hnc}) = \frac{1}{N} \sum_{\text{İ}=1}^{N} W_{i,T} \quad (12)$$

On the other hand, Dumitrescu-Hurlin (2012) used the Znhc ($Z_{N,T}^{Hnc}$) statistic, which has an asymptotic distribution in case the cross-section size is smaller than the time dimension (N<T) and Ztild (Z_N^{Hnc}) statistics with semi-asymptotic distribution in case the cross-section size is larger than the time dimension (N>T). The statistical calculations of these tests are as follows:

$$(Z_{N,T}^{Hnc}) = \sqrt{\frac{N}{2K}(W_{N,T}^{Hnc} - K)} \quad (13)$$

$$(Z_N^{Hnc}) = \frac{\sqrt{N}\,[W_{N,T}^{Hnc} - N^{-1}\sum_{i=1}^{N} E(W_{i,T})]}{\sqrt{N^{-1}\sum_{i=1}^{N} Var(W_{i,T})}} \ \xrightarrow[N,T\to\infty]{d}\ \text{N}\ (0,1) \quad (14)$$

5. Emprical Results

Which unit root tests will be used for the stationarity tests of the variables used in the study was determined by the cross-section dependency test. As seen in Table 3, the H_0 hypothesis that there is no cross-section dependency in the panel was not accepted. Second-generation unit root tests were used because of the cross-section dependency according to the test result.

Table 3: Cross-Section Dependency Test

Test	Statistic
LM	69.8 ***
LM adj*	23.66 ***
LM CD*	6.369 ***

***<0.01

In order to determine the stationarity of the series, the Multivariate Augmented Dickey-Fuller (MADF) panel unit root test, one of the second-generation panel unit root tests, was used. The results of the MADF panel unit root tests are given in Table 4.

Table 4: MADF Unit Root Test Results

	MADF	Approx 5% CV
LGROW	36.986	45.195
RD	29.737	45.195
ΔLGROW	103.667	49.619
ΔRD	125.069	49.619

Looking at the level values of the series in the stationarity analysis, it is seen that the MADF test statistics for both growth and R&D expenditures are smaller than the critical values. Accordingly, it is seen that the series are not stationary at the level. When the first differences of both variables used in the model are taken, the H_0 hypothesis is accepted at the 95% confidence level, that is, the series become stationary.

In the panel VAR model, first of all, the optimal lag length must be determined. As seen in Table 5, the optimal lag length was determined as 1 according to the MBIC, MAIC, and MQIC information criteria.

Table 5: Optimal Lag Lengths Selection

LAGS	CD	J	J pvalue	MBIC	MAIC	MQIC
1	.5989999	9.351862	.6726191	-42.92864	-14.64814	-25.96934
2	.6246463	8.16288	.4177236	-26.69079	-7.83712	-15.38459
3	.6708354	2.203974	.6983018	-15.22286	-5.796026	-9.569762

In the next step, $\hat{\Delta}\ and\ \hat{\Delta}_{Adj}$ tests were used to test parameter homogeneity. Accordingly, H_0 hypothesis claiming that the model is homogeneous was rejected and it was decided that the parameters were heterogeneous.

Table 6: Homogeneity Test Results

	Statistics	Prob.
$\hat{\Delta}$	4.270	0.000
$\hat{\Delta}_{Adj}$	4.653	0.000

The Dumitrescu-Hurlin (2012) causality test, which takes into account heterogeneity, was used in the study. According to the test findings in Table 7, there is a bidirectional causality relationship between growth and R&D expenditures.

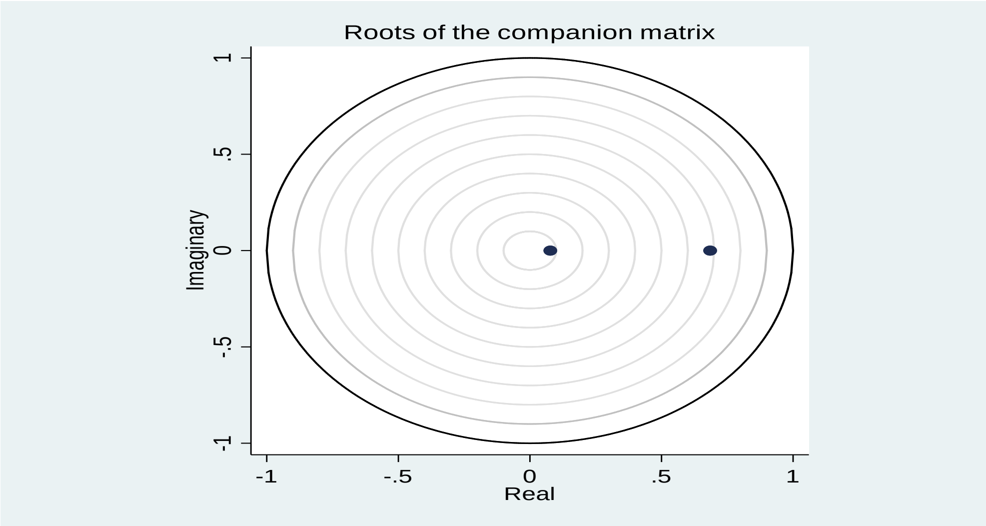
Table 7: Dumitrescu-Hurlin (2012) Causality Test Results

	W-bar	Z-bar	Z-bar tilde
LGROW ⇏ RD	8.6165	8.1035***.	4.9337***
RD ⇏ LGROW	12.6616	7.5012***	1.1774

***<0.01

Whether there is system stability in the panel VAR model is important for the impulse-response functions and variance decomposition analysis to be performed in the next step. In Figure 2, the current eigenvalues of the three variables in the model are less than 1 and are in the circle. In this framework, the panel VAR model provides the stability conditions for the BRICS-T Countries.

Figure 2: System Stability of Panel VAR model in BRICS-T Countries



Variance decomposition is an analysis that shows how much of a change that may occur in the variables in the model is explained by their own delays and how many percent is explained by other variables (Barışık and Kesikoğlu, 2006: 70). The variance decomposition results for the variables used in the panel VAR model are shown in Tables 8 and 9. According to Table 8, 100% of the growth variance in a lagged period is self-explained, in the 2 lagged period, 97% of the variance is explained by itself and about 3% is explained by the R&D variable. By the 10th lag, approximately 94.7% of the variance of the growth variable is explained by itself and 5% is explained by the R&D variable.

Table 8: Forecast Variance Decomposition for Growth

h	LGROW	RD
0	0	0
1	1	0
2	.970309	.029691
3	.9575658	.0424342
4	.9522277	.0477723
5	.9498705	.0501295
6	.9487965	.0512035
7	.9482995	.0517005
8	.948068	.051932
9	.9479597	.0520403
10	.947909	.052091

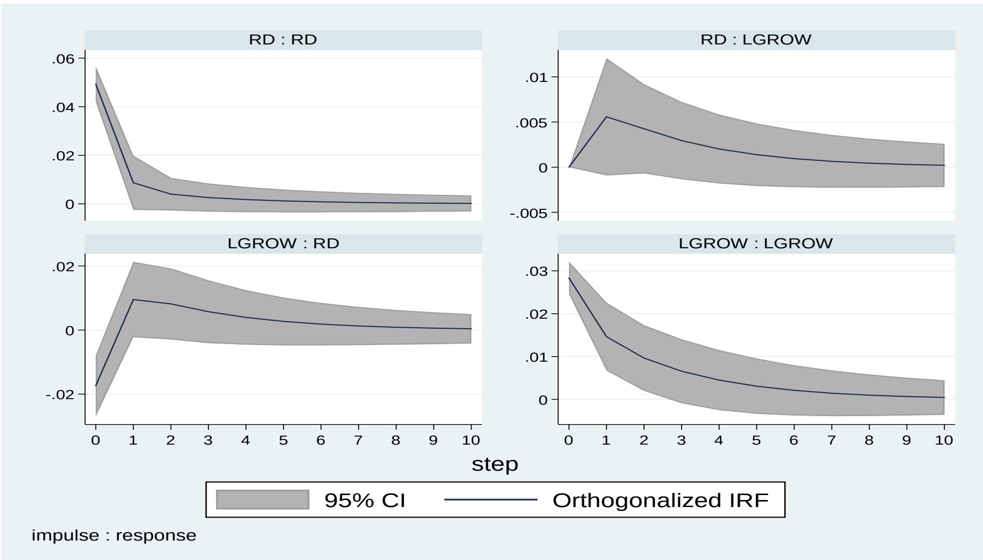
According to Table 9, approximately 88% of the variance of the R&D variable in a lagged period is explained by itself, and approximately 11% of the variance is explained by the growth variable. But by the 10th lag, about 82% of the variance of the R&D variable is explained by itself and 17% by the growth variable.

Table 9: Forecast Variance Decomposition for R&D Expenditures

H	LGROW	RD
0	0	0
1	.1104606	.8895394
2	.1353752	.8646249
3	.1540235	.8459765
4	.1628617	.8371383
5	.1669506	.8330494
6	.168852	.831148
7	.16974	.83026
8	.1701555	.8298444
9	.1703502	.8296497
10	.1704415	.8295585

Impulse response functions indicate the extent of the effects of shocks on variables. Accordingly, shocks in economic growth initially increase R&D expenditures, but then it begins to decrease and the effect of shocks disappears towards the 10th period. On the other hand, shocks in R&D expenditures similarly increase growth at the beginning, but show a decreasing trend after the first period and disappear towards the 10th period.

Figure 3: Panel VAR Impulse Response Functions



6. Conclusion

The technological infrastructure of developed and developing countries is a powerful parameter in explaining the differences in economic growth. One of the prerequisites for technological progress is undoubtedly R&D. In this context, policies towards R&D are also an important determinant of economic growth. Therefore, R&D activities of especially developing countries are one of the main tools for convergence of these countries with developed countries.

In this study, the relationship between R&D expenditures and economic growth is investigated using panel VAR analysis and Dumitrescu-Hurlin's (2012) panel causality analysis during 2000-2018 in BRICS-T Countries. According to the variance decomposition findings for both variables, 100% of the variance of the growth variable in a lagged period is explained by itself, but after two lags, 97% of the variance is explained by itself, and at the 10th lag, approximately 94.7% of the variance is explained by itselfs and 5% is explained by the R&D variable. In a lagged period, 88% of the variance of R&D expenditures is explained by itself, and by the 10th lag, 82% of the variance is explained by itself. Finally, according to the results of the impulse-response analysis, both shocks in economic growth increase R&D expenditures at first and shocks in R&D expenditures increase growth in the first stage. However, the effect of these shocks disappears towards the 10th period.

On the other hand, according to Dumitrescu-Hurlin's (2012) panel causality analysis, there is a bidirectional causality relationship between economic growth and R&D expenditures. In this framework, economic growth is the determinant of R&D expenditures and R&D expenditures are the determinants of economic growth.

When the panel VAR analysis findings are evaluated as a whole, the following results can be expressed: i) In BRICS-T countries, economic growth increases the share of R&D investment expenditures. ii) The increase in the R&D expenditures of the BRICS-T countries positively affects the economic growth of these countries. For this reason, it can be said that R&D expenditures increase the national income and the increasing national income level affects the R&D expenditure level. These findings support the work of Gülmez and Yardimoğlu (2012), Türedi (2016), Dereli and Salğar (2019), Genç and Tandoğan (2020). In this context, increasing the R&D expenditures of the BRICS-T countries will positively affect the growth trends of the countries.

Considering the role of R&D expenditures in economic growth, policies for R&D expenditures gain importance. Therefore, R&D studies should be focused on sectors with suitable technological infrastructure. It should be taken into account that parameters such as corruption and bad governance will weaken the effectiveness of R&D, and it should be transparent in R&D support policies. In addition, since university-industry cooperation will contribute to R&D studies both scientifically and commercially from different perspectives, collaborations on this subject should be supported. In addition, companies and sectors that focus on innovation studies but have funding problems should be given financial support by governments.

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