VERİMLİLİK DERGİSİ
JOURNAL OF PRODUCTIVITY

The Impact of R&D Expenditures on Economic Growth in Türkiye: New Evidence from Machine Learning Method

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ABSTRACT

Purpose: This study analyzes the impacts of R&D expenditures on economic growth in Türkiye.

Methodology: In this study, we explore the impact of R&D expenditure on economic growth in Türkiye. Annual time series from 1990 to 2021 are considered for this research examination based on the data availability. R&D expenditure, Gross Domestic Product (GDP) per capita, gross fixed capital formation, labor force, and tertiary ratio variables are used for the analysis and obtained from the World Bank. Based on machine learning, analyses were conducted using the Kernel Regularized Least Square method.

Findings: The empirical analysis using KRLS shows that higher spending on research and development leads to a significant boost in economic growth. Furthermore, labor force participation, school enrolment (tertiary) ratio, and gross fixed capital formation are all significantly and positively associated with economic growth in Türkiye.

Originality: The contribution of the paper is twofold: (1) it provides new scientific evidence based on the machine learning econometric method, the Kernel Regularized Least Square (KRLS); (2) many papers in the literature have only examined the relationship between R&D expenditures and economic growth, without controlling for other variables. We have used possible control variables such as labor force participation rate, school enrolment (tertiary) ratio, and gross fixed capital formation, which are also linked to economic growth models.

Keywords: Productivity, KRLS method, Research and Development, Economic Growth, Innovation.

JEL Codes: O47, O32, O38.

Türkiye'de Ar-Ge Harcamalarının Ekonomik Büyüme Üzerindeki Etkisi: Makine Öğrenmesi Yönteminden Yeni Kanıtlar

ÖZET

Amaç: Bu çalışma, Türkiye'de Ar-Ge harcamalarının ekonomik büyüme üzerindeki etkilerini analiz etmektedir.

Yöntem: Bu çalışmada, Türkiye'de Ar-Ge harcamalarının ekonomik büyüme üzerindeki etkisi araştırılmaktadır. Veri mevcudiyetine bağlı olarak bu araştırmada 1990'dan 2021'e kadar olan yıllık zaman serileri kullanılmıştır. Ar-Ge harcaması, kişi başına Gayri Safi Yurtiçi Hasıla (GSYH), gayri safi sabit sermaye oluşumu, işgücü ve okula kayıt (yükseköğretim) oranı değişkenleri Dünya Bankası'ndan temin edilmiştir. Makine öğrenimine dayalı olarak, analizler Kernel Düzenlenmiş En Küçük Kare yöntemi kullanılarak gerçekleştirilmiştir.

Bulgular: KRLS kullanılarak yapılan ampirik analiz, araştırma ve geliştirmeye yapılan daha yüksek harcamaların ekonomik büyümede önemli bir artışa yol açtığını göstermektedir. Ayrıca, işgücüne katılım, okula kayıt (yükseköğretim) oranı ve gayrisafi sabit sermaye oluşumu Türkiye'deki ekonomik büyüme ile anlamlı ve pozitif bir şekilde ilişkilidir.

Özgünlük: Bu makalenin katkısı iki yönlüdür: (1) makine öğrenimi ekonometrik yöntemi olan Kernel Düzenlenmiş En Küçük Kare (KRLS) yöntemine dayalı yeni bilimsel kanıtlar sunmaktadır; (2) literatürdeki birçok makale, diğer değişkenleri kontrol etmeden sadece Ar-Ge harcamaları ve ekonomik büyüme arasındaki ilişkiyi incelemiştir. Bu çalışmada, ekonomik büyüme modelleriyle bağlantılı olan işgücüne katılım oranı, okullaşma (yükseköğretim) oranı ve gayrisafi sabit sermaye oluşumu gibi olası kontrol değişkenleri de analizde kullanılmıştır.

Anahtar Kelimeler: Verimlilik, KRLS yöntemi, Araştırma ve Geliştirme, Ekonomik Büyüme, İnovasyon.

JEL Kodları: O47, O32, O38.

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DOI: 10.51551/verimlilik.1344757
Research Article |Submitted: 17.08.2023 |Accepted: 07.12.2023
Cite: Acar, Y. ve Kesici, İ. (2024). "The Impact of R&D Expenditures on Economic Growth in Türkiye: New Evidence from Machine Learning Method", *Verimlilik Dergisi,* Productivity for Innovation (SI), 107-118.

1. INTRODUCTION

Innovation, Research and Development (R&D) are pivotal drivers of economic growth in the modern world. They form a dynamic relationship, where innovation acts as a catalyst for technological advancements, and R&D serves as the engine that fuels these innovations. Innovation refers to the process of creating novel products, services, or processes that offer significant value to individuals, businesses, or society as a whole. It involves the application of new ideas, technologies, and methodologies to enhance efficiency, quality, and sustainability. Innovation is a driving force behind economic growth as it promotes productivity gains and fosters a competitive edge for nations, industries, and businesses (Stokey, 1995).

Innovation leads to the development of new industries and the revitalization of existing ones. This generates jobs, stimulates demand, and encourages entrepreneurship (Pessoa, 2010). Furthermore, innovative solutions often address societal challenges, such as climate change, healthcare, and poverty, yielding additional economic and social benefits. R&D is the systematic and scientific exploration of new knowledge, leading to the development of innovative products, services, or processes. It serves as a bridge between theoretical concepts and practical applications, transforming ideas into tangible advancements. Governments, businesses, and academia invest in R&D to expand their knowledge base, improve existing technologies, and discover new ones. These investments spur a cycle of innovation by enabling the creation of cutting-edge products and services, propelling economic development and growth. This relationship has been theoretically analyzed by many models (Griliches, 1979; Romer, 1990; Aghion and Howitt, 1990; Grossman and Helpman, 1991: 15-16). R&D has been crucial in industries like pharmaceuticals, technology, and renewable energy, where constant innovation is fundamental for long-term success.

The expansion and increase in economic activity in a country over a given period is called economic growth. This phenomenon typically signifies the overall worth of products and services generated during a specific timeframe. Over time, the growth phenomenon has been theorized, and growth theories have emerged. The Solow Growth Model, which was put forward by Solow (1956) and is the predecessor of growth theories, deals with the fundamental growth factors of the economy. Theory suggests that economic growth is pushed by factor accumulation (capital and labor) and exogenous technological development. While factor accumulation has diminishing returns at a certain point (law of diminishing returns), sustainable growth, in the long run, is realized through technological progress that increases total factor productivity. Economic growth theories have evolved and have been enriched with more comprehensive approaches, especially endogenous growth theories that have addressed technological the source and sustainability of technological progress in detail. Romer (1986) laid the foundation of R&D-based growth models. This study is constructed related to endogenous growth theories by examining R&D expenditures.

Increasing economic welfare in a country is through sustainable economic growth, which increase the number of resources individuals can utilize and thus the welfare they will gain from using these resources. The type of economic growth directly affects welfare. For example, an economic growth model in which the increase in welfare is felt only by a particular population segment may lead to social unrest by increasing inequality. In addition, another view shaped around the ideas of Kuznets (1955) is that income inequality will increase in the initial phases of economic growth; however, income inequality will begin to fall after a certain point. In conclusion, in spite of its ethical controversies, economic growth is seen as the most crucial resource of welfare increase. Therefore, it is targeted by almost all countries.

Technological development is one of the most important ways of achieving sustainable economic growth. It has been analyzed by many economists since Solow (1957) in terms of its effects on economic growth. Hence, countries formulate strategies to accelerate technological developments to sustain economic growth and maintain competitive advantages. R&D expenditures, at the center of these strategies, are recognized as one of the strongest drivers of innovation and technological progress. In its most general definition, R&D is the generation of knowledge and ideas about new ways of organizing or using new materials or compounds and preparing innovative designs for new goods and services (Griliches, 1991). R&D expenditures realized through public and private sector investments cover areas such as discovering new knowledge, improving existing technologies, and developing innovative solutions. Countries that prioritize R&D generally gain significant advantages such as increasing their technological capabilities, becoming competitive in the universal market, and raising the living standards of their citizens.

R&D expenditures are key to ensuring and sustaining technological development and innovation, and thus economic growth. The effects of R&D expenditures on economic growth are pretty diverse. These expenditures foster a continuous innovation cycle, enabling the development of new products, services, and processes that support economic growth. Moreover, new technologies and knowledge diffuse across different sectors of the economy, increasing productivity and competitiveness; therefore, R&D investments improve overall productivity, especially in the long run. As technological advances increase, economies begin to achieve higher levels of output, income, and employment, thereby improving the living standards of society (Jones and Williams, 2000; Grossman and Helpman, 1994). While the relationship between R&D expenditure and economic growth is widely recognized, the magnitude and mechanisms of their interaction vary in different contexts. Factors such as the quality of institutions, the effectiveness of intellectual property protection, the availability of skilled human capital and the extent of cooperation between academia, industry and government institutions all shape the outcomes of R&D investments. As a result, R&D expenditures will increase the technological development potential of countries, enabling the production of new goods and services, resulting in higher levels of income and economic growth.

In sum, as the global economy becomes increasingly dependent on knowledge and innovation, the role of R&D expenditures in supporting economic growth becomes more prominent. This paper investigates the relationship between R&D expenditures and economic growth in Türkiye. In doing so, it underlines the significance of R&D investments as a transformative force that promotes not only technological progress but also social welfare via economic growth.

The contribution of the paper is twofold: (1) it provides new scientific evidence based on the machine learning econometric method, the Kernel Regularized Least Square (KRLS); (2) many papers in the literature have only analyzed the relationship between R&D expenditures and economic growth without using control variables. Therefore, we have used possible control variables, such as labor force participation rate, school enrolment (tertiary) ratio, and gross fixed capital formation.

The rest of the paper is structured as follows: the second section provides the theoretical background of the study; the third section briefly summarizes related literature, section four presents data and methodology; the fifth section reports empirical analysis and discussion; finally, the sixth section concludes the study and proposes relevant policy implications.

2. THEORETICAL BACKGROUND

Economic growth, which in its most basic definition can be characterized as an increase in the quantity or value of goods and services produced, has been one of the primary economic goals of societies and one of the main areas of study for economists throughout history. However, growth theories emerged in the post-World War II period when economic growth was badly needed. These theories aimed to analyze what affects a country's potential output in the long run, how these factors trigger economic growth and which factors are more determinant for growth. Economic growth theories can be categorized into two main groups: exogenous and endogenous growth theories. This distinction is made according to whether technological developments are affected by factors of production or not. Under the assumption that technological developments are not affected by factors of production, we talk about exogenous growth models, whereas in the opposite case, we talk about endogenous growth models.

The model proposed by Solow (1956), which can be considered as the predecessor of the exogenous growth models, examines how capital accumulation and technological development, which are considered as exogenous, and population and labor force growth affect economic growth. According to this model, economic growth is in a certain interaction with production inputs and an increase in these inputs will increase economic growth. However, the source of economic growth in the long run is technological developments. There are certain assumptions in this model. These can be characterized as the diminishing efficiency of capital, perfect competition and full employment conditions, a closed single-good market and perfect substitution between production inputs (Ehrlich, 1990). Through this model, the differences in GDP per capita between countries and the "convergence hypothesis" explained that these differences would tend to decrease over time. This model, which remained valid until the 1980s, was later abandoned due to the realization that the assumption of diminishing returns to capital is not always valid and the acceptance that technological developments are not an exogenous factor. In this period, new economic growth theories emerged in which technological developments were taken as an endogenous variable. Starting with Romer (1986) and later developed by economists such as Lucas (1988), Barro (1990), Aghion and Howitt (1990) and Grossman and Helpman (1991: 15-18), endogenous growth models have altered the perspective on economic growth. In this period, unlike Solow, a growth model that takes technological developments as an endogenous variable was developed. Again, unlike previous growth theories, factors such as government intervention, human capital accumulation and R&D activities were added to endogenous growth theories and the impact of these factors on economic growth was analyzed.

Romer (1986), inspired by Arrow's (1962) "learning by doing" approach, emphasized the importance of knowledge accumulation. According to this approach, the accumulation of knowledge over time leads to an increase in the quality of goods and services produced and a decrease in their costs. Romer emphasized that this effect can be considered as an extra input that will increase economic growth. Therefore, according to Romer's model, the accumulation and spill-over of knowledge through production and investment processes is the most important driver of economic growth in the long run.

Lucas (1988), on the other hand, used the concept of human capital, which can be characterized as a measure of the quality of the labor force, to explain the economic growth process. According to this approach, the way to achieve economic growth in the long run is determined by the human capital level of the labor force and the investments made in human capital. On the other hand, Barro (1990) investigated the effect of public expenditure on productive areas on economic growth. According to Barro's findings, public spending and investments in productive sectors are believed to contribute to long-term economic growth by creating positive externalities.

Schumpeter (1942: 81-86) can be considered as the first economist who aimed to endogenize technological developments, the source of the "creative destruction" process, which he characterized as the continuous improvement of goods and services produced, in the economic growth model. Aghion and Howitt (1990) and Grossman and Helpman (1991:15-18) furthered this effort and included technological developments as an endogenous variable in their economic growth models. Accordingly, the continuity of economic growth in the long run can only be realized through R&D activities that will ensure technological development. Countries with intensive R&D activities will be able to grow faster than other countries by gaining comparative advantages over time. Another important point here is the adjustments to be made by the public sector in resource allocation through incentives for R&D activities. Countries that can effectively allocate resources to R&D activities that will accelerate technological developments can achieve long-term and stable growth.

3. LITERATURE REVIEW

Many researchers have analyzed R&D expenditures regarding their effect on economic growth. Some researchers have found a positive and significant relationship between R&D expenditures and economic growth (Ali et al., 2021; Gumus and Celikay, 2015; Horowitz, 1967; Falk, 2007; Guloglu and Tekin, 2012; Moustapha and Yu, 2021; Wu and Zhou, 2007; Peng, 2010; Ulku, 2004; Bayarçelik and Taşel, 2012). For example, Ali et al. (2021) examined the impact of R&D expenditures on economic growth in 100 countries with the most significant economic size for 1995-2015. They showed that R&D investments have a positive association with economic growth in the long run, but this effect is higher in developed countries. Similarly, Gumus and Celikay, using data from 52 countries for the period 1996-2010, concluded that R&D expenditures have a positive and significant effect on economic growth in the long run for all countries. Horowitz (1967) found that R&D increase correlated positively with regional economic growth in various U.S. states from 1920 to 1964. Falk (2007), in his study on OECD countries for the period 1970-2004, found that the share of firms' R&D expenditures in GDP and the ratio of R&D expenditures in high-tech sectors in total expenditures have a strong and positive effect on GDP per capita and GDP per hour worked. Similarly, Moustapha and Yu (2021) analyzed the impact of R&D expenditures on economic growth in 35 OECD countries over the 2000-2016 period. They found that a 1% increase in R&D expenditures would lead to a 2.83% increase in real GDP growth rate. Guloglu and Tekin (2012) also found that R&D expenditures and economic growth have a positive and significant relationship for the period 1991-2007 for thirteen OECD high-income countries. Wu and Zhou (2007) examined the cointegration and causality relationship between R&D expenditures and economic growth in China for the period 1953-2004. They found that there is a long-run cointegration relationship between R&D and GDP and that there is a bidirectional causal relationship from R&D to GDP and vice versa in the long run. Peng (2010), on the other hand, found a long-run relationship between R&D expenditures and economic growth in China for the period 2000-2007. Analysis results uncovered that when R&D expenditures increase by 1%, GDP will increase by 0.9243%. In a study conducted by Ulku (2004), an examination of patent and R&D information for twenty OECD countries and ten non-OECD countries revealed a favorable correlation relating GDP per capita and innovation. Lastly, Bayarçelik and Taşel (2012) concluded that R&D expenditures and the number of employees in R&D have a positive and significant effect on economic growth.

The impact of R&D expenditures on economic growth, on the other hand, may vary across countries as well as income levels. Some researchers discovered a negative or no significant relationship between R&D expenditures and economic growth in specific contexts. For example, in their study Samimi and Alerasoul (2009) conducted in thirty developing countries between 2000 and 2006, concluded that there is no significant relationship between R&D expenditures and economic growth since R&D expenditures remain low in these countries. For developed countries, Susanto et al. (2023) conducted a study using the data of five countries (USA, China, Japan, Germany, and the United Kingdom) from 1996 to 2018 showed that R&D expenditures had no significant impact on economic growth within these countries. Similarly, Sylwester (2001) analyzed the relationship between R&D expenditures and economic growth in 20 OECD countries and G-7 countries and found no strong relationship for OECD countries but a positive relationship between industrial R&D expenditures and economic growth for G-7 countries.

When the studies conducted for Türkiye are analyzed, it is observed that similar results are obtained. Altin and Kaya (2009) analyzed the period 1990-2005 and found no relationship between R&D expenditures and economic growth in the short term. However, in the long term, a causality relationship was found from R&D expenditures to growth. Taban and Şengür (2014), on the other hand, utilizing data for the period 1990-2012, found that R&D expenditures and the number of employees in R&D positively affect economic growth in long term. Similarly, Korkmaz (2010) explored a long-run cointegration between R&D expenditures and economic growth in the 1990-2008 period, showing they affect each other. Yaylalı et al. (2010) examined the relationship between R&D expenditures and economic growth in Türkiye for the period 1990-2009. In this study where cointegration test was applied, a unidirectional relationship was found from R&D expenditures to economic growth. Akıncı and Sevinç (2013), on the other hand, found a unidirectional causality from R&D expenditures to economic growth for Türkiye between 1990-2011.

However, some studies do not directly examine the relationship between R&D expenditures and economic growth but provide insights into its impact on economic growth. For example, the spillover effects of R&D expenditures were examined and it is found that a significant and positive relationship between R&D expenditures and total factor productivity exist in the long run (Coe and Helpman, 1995). Wakelin (2001) examined the relationship between productivity growth and R&D expenditures in 170 firms in the UK and found that a firm's R&D expenditures have a positive and important role in affecting productivity growth. Similarly, Zachariadis (2003) found a positive and significant relationship between R&D expenditures and technological development. Some studies have examined the factors affecting innovation. Griffith et al. (2004) examined different sectors in 12 OECD countries and found that R&D is crucial for both technological catch-up and innovation. Schmookler (1966) concluded that technologists and R&D expenditures are related to the number of patents, which is an important indicator of innovation.

In conclusion, the economic literature shows that R&D expenditures positively and significantly impact economic growth in many countries. However, this impact may vary inversely or insignificantly depending on factors such as the income level of countries and the source of R&D financing.

4. DATA and METHODOLOGY

4.1. Data

In this study, we explore the impact of R&D expenditure on economic growth in Türkiye. Annual time series from 1990 to 2021 are considered for this research examination based on the availability of data. R&D expenditure, GDP per capita, labor force, gross fixed capital formation, and tertiary ratio variables are gathered from the WDI (World Bank Data Indicator). We include the control variables based on the economic growth models and related literature, considering the main drivers of economic growth in an economy. Hence, we use labor force and capital formation as the key factors of production. Additionally, we add school enrolment (tertiary) variable as a proxy of human capital (Tsai et al., 2010; Ogunleye et al., 2017). Data sources and other details are displayed in Table 1. Furthermore, we converted all the series into natural logarithms to mitigate heteroskedasticity and interpret the coefficients into a percentage.

Table 1. Variable *description*

Code	*Indicator Name*	*Source*
EG	GDP per capita (constant $ 2010)	World Bank
RD	Research and Development Expenditure (% of GDP)	World Bank
L	Labor force participation rate	World Bank
K	Gross fixed capital formation (% of GDP)	World Bank
H	School enrolment, tertiary (% gross)	World Bank

4.2. Methodology

In the current study, we use Kernel-based Regularized Least Squares (KRLS) method, which has been recently developed by Hainmueller and Hazlett (2014). Kernel-based Regularized Least Squares (KRLS) is a machine learning method recently used in econometrics and statistics for regression analysis. It is an extension of the standard linear regression that incorporates the concept of kernel methods for modeling non-linear relationships between variables.

In traditional linear regression, the relationship between the independent variables (features) and the dependent variable (target) is assumed to be linear. However, many real-world relationships are not strictly linear. On the contrary, Kernel methods offer a means of capturing non-linear connections by converting the initial feature space into a higher-dimensional space through the use of a mathematical kernel function.

The KRLS method provides a flexible and convenient modeling approach that bridges the gap between the constrained GLMs frequently used by researchers and the more flexible but often less clear machine learning methods (Hainmueller and Hazlett, 2014). At the same time, KRLS is user-friendly and helps researchers protect their conclusions from bias due to incorrect specifications without requiring them to sacrifice the interpretability and statistical properties they assess. This methodology falls into a model category that exhibits well-behaved and easily attainable marginal effects due to a continuously differentiable solution surface, which is determined through closed-form estimation. Furthermore, it readily permits the application of statistical inference through closed-form expressions and exhibits favorable statistical characteristics even with reasonably moderate assumptions. Enabling more comprehensive interpretations, the resulting model is directly interpretable, similar to linear regression. The estimator generates individual estimates of partial derivatives, which describe the isolated effects of each independent variable at each specific data point within the covariate space. Researchers have the option to examine the distribution of these individual estimates at specific points to gain a deeper understanding of the variation in marginal effects. Alternatively, they can calculate an average from these estimates to obtain an average partial derivative, which is akin to a β coefficient obtained from linear regression.

KRLS is also used for estimating models that may have complex relationships between variables. KRLS draws inspiration from machine learning techniques to address regression and cataloging tasks without being constrained by linearity or additivity assumptions. This approach builds an adaptable hypothesis space that employs kernels as radial basis functions. It identifies the optimal-fitting surface within this space by minimizing a least squares problem that considers complexity penalties (Wilson and Wright, 2017). This method is particularly fitting for inquiries in the realm of social science due to its ability to circumvent rigid parametric assumptions. Simultaneously, it facilitates an interpretation framework reminiscent of generalized linear models. Moreover, it allows for intricate interpretations to explore nonlinearities, interactions, and heterogeneous effects. The strengths of KRLS encompass its capacity to mitigate misspecification bias through a versatile and intelligible machine-learning methodology.

Kernel regression is a non-parametric approach based on linear and non-linear least squares regression. It is a generalization of linear regression that uses kernel functions to map the input data into a higher-dimensional space (Ferwerda et al., 2017). The kernel function is used to weight the contribution of each data point in the regression. On the flip side, linear regression represents a parametric method, presupposing a linear connection between the input and output variables. It estimates the parameters of the model employing least squares (LS) optimization.

Hence, the KRLS method can furnish more precise estimations compared to parametric models as well as specific non-parametric models. In this manner, it emerges as a robust substitute for other econometric models ie OLS. Therefore, we can basically express the model as in Equation 1.

$$y = g(x) + \varepsilon \tag{1}$$

In this context, "y" represents per capita GDP, "$g(.)$" represents an undisclosed functional relationship, " x " represents a set of factors influencing economic growth, such as R&D expenditures, labor force participation rate, gross fixed capital formation, and tertiary enrollment ratio, and " ε " represents a unique error term. The choice of variables aligns with previous research in the field (e.g. Minviel and Bouheni, 2022; Blanco and Prieger, 2016). The KRLS method presupposes that the target function *g(x)* can be estimated or approximated in the following manner (Equation 2):

$$g(x) = \sum_{i=1}^{N} c_i k(x, x_i) \tag{2}$$

Here, $k(x, x_i)$ represents similarity measurement, denoted as x, and *N* input, denoted as x_i, while c_i signifies the weight associated with each input pattern. Please take into account that equation (2) shares some resemblance with generalized linear models (GLMs) to a certain extent. It is important to highlight that KRLS holds a higher degree of naturalness and potency compared to GLM (Hainmueller and Hazlett, 2014). Similarity measurement can be computed thanks to a Gaussian kernel function (Equation 3):

$$k(x, x_i) = \exp\left(-\frac{\|x - x_i\|^2}{\sigma^2}\right) \tag{3}$$

where $\|x - x_i\|$is the Euclidian distance between the covariate vectors x and x_i and $\sigma^2 \in R^+$ is the bandwidth of the kernel function. Tikhonov regularization estimates the model, enabling the selection of the optimal function that aligns with the data, in accordance with the following principle (Equation 4):

$$\underset{g \in H}{\operatorname{argmin}} \sum_i \big(V(g(x_i), y_i)\big) + \lambda R(g) \tag{4}$$

Here, $V(f(x_i), y_i)$ denotes a loss function that quantifies the discrepancy of the function at each observation, while R represents a "regularizer" that gauges the intricacy of the function *g*. The scalar parameter $\lambda \in \mathbb{R}+$ influences the balance between fitting the model and its complexity. Elevated λ values lead to greater penalization for function complexity, prioritizing model fit, whereas lower λ values yield the opposite outcome. *H* symbolizes a flexible function space associated with a specific kernel choice, often referred to as the reproducing kernel Hilbert spaces. When utilizing squared loss for *V* and the square of the L_2 norm for the "regularizer," the resultant Tikhonov regularization problem is formulated as in Equation 5.

$$\underset{g \in H}{\operatorname{argmin}} \sum_i (g(x_i) - y_i)^2 + \lambda \|g\|_K^2 \quad (5)$$

with $\|g\|_K^2 = \sum_i \sum_j c_i c_j k(x_i, x_j)$, where x_i and x_j are vectors of continuous independent variables. λ is selected via cross-validation (CV) criterion.

In the study, we examine the role of R&D expenditures on economic growth in Türkiye, taking into account labor force participation, school enrolment (tertiary) rate, and gross fixed capital formation. Similar to Warsame et al. (2023), who also benefit from KRLS method in time series setting, the model specification of the paper is as in Equation 6.

$$EG_t = \beta_0 + \beta_1 RD_t + \beta_2 LF_t + \beta_3 H_t + \beta_4 K_t + \varepsilon_t \quad (6)$$

5. EMPIRICAL RESULTS and DISCUSSION

5.1. Descriptive statistics

Table 2 provides an overview of the statistical summaries for the variables. It reveals the mean values of per capita GDP (8.9); R&D expenditures (-0.5), labor force participation rate (17.02), tertiary ratio (3.7), and gross fixed capital formation ratio (3.2). The labor force participation rate has a lesser variation (0.17), whereas the tertiary ratio has a higher variation (0.71) than other variables.

Table 2. Summary statistics

Variable	*Obs*	*Mean*	*Std.Dev.*	*Min*	*Max*
Ingdppc	32	8.965	.291	8.567	9.499
Inrd	32	-.556	.464	-1.446	.122
Inlaborforce	32	17.028	.174	16.794	17.33
Intertiary	32	3.697	.717	2.576	4.779
Incapital	32	3.225	.132	2.888	3.396

The results of Pairwise correlations indicate that GDPpc is positively associated with R&D expenditure, labor force, tertiary ratio, and capital stock, as shown in Table 3. Similarly, R&D has a positive correlation with the labor force and tertiary ratio, as expected.

Table 3*.* Correlation matrix

	Ingdppc	*InR&D*	*Inlaborforce*	*Intertiary*	*Incapital*
Ingdppc	1.0000				
InR&D	0.9429	1.0000			
Inlaborforce	0.9626	0.9096	1.0000		
Intertiary	0.9860	0.9466	0.9789	1.0000	
Incapital	0.7092	0.5263	0.6045	0.6463	1.0000

5.2. The KRLS estimation result

The outcomes of the KRLS estimation are displayed in Table 4. Unlike the Ordinary least square (OLS), which assumes constant marginal effects, the KRLS observes pointwise marginal coefficients for each variable. Consequently, it becomes feasible to assess whether the impact of each independent variable on economic growth fluctuates across different time periods. The model fit of the result is good, as indicated by R^2. R&D expenditures, labor force participation, school enrollment (tertiary ratio), and gross fixed capital are statistically significant.

The average marginal effect estimate suggests that one unit increase in R&D expenditure contributes to economic growth by about 0.16% on average. R&D expenditure increases economic growth by 0.09%, 0.18%, and 0.21% in the 25th, 50th, and 75th percentiles, respectively. R&D expenditure has increasing marginal effects on economic growth. It plays a crucial role in increasing economic growth. This result is pertinent to previous studies concluding that R&D expenditure leads to higher economic growth such as Bozkurt (2015) in Türkiye, and Gumus and Celikay (2015) in cross-country analysis.

On average, labor force participation positively and significantly affects economic growth. A 1% increase in labor force participation causes an increase in economic growth by about 0.40%. LF also has increasing marginal effects on per capita GDP, meaning that the labor force is the main driver of economic activity. LF has the highest significant effect on economic growth in Türkiye compared to other regressors.

An average increase in school enrolment (tertiary ratio) increases economic growth by 0.11%. This variable is used as a proxy for human capital in our study. Hence, H increases per capita GDP by about 0.07%, 0.10%, and 0.15% in the 25th, 50th, and 75th percentiles, respectively. It is found that human capital promotes economic growth in Türkiye. Human capital refers to the skills, knowledge, abilities, and experiences that individuals accumulate through education, training, work experiences, and personal development. It plays a vital role in promoting economic growth in several way, ie. increased productivity, innovation and technological advancement, and knowledge spillovers. This finding is parallel to the results of Chatterji (1998) who investigates the potential importance of tertiary education in the growth process. Similarly, Karaalp (2017) noted that human capital, which is also proxied by tertiary education, fosters economic growth in Türkiye.

Furthermore, gross fixed capital formation (K) is positively linked to economic growth. An average increase in capital formation exerts an increase in per capita GDP by 0.20%. Gross fixed capital formation has a constructive role in increasing per capita GDP by about 0.005%, 0.32%, and 0.47% in the 25th, 50th and 75th percentiles, respectively in Türkiye. Gross Fixed Capital Formation (GFCF) refers to the total value of investments made in physical assets such as buildings, machinery, equipment, and infrastructure that contribute to the expansion of a country's productive capacity. GFCF plays a critical role in driving economic growth for several reasons such as increased productive capacity, higher productivity, and job creation. This finding corroborates with ample studies that produced the same result. For instance, Abbas et al. (2020) reported that capital fixed formation in twenty-four emerging economies boost economic growth.

To ensure the reliability and stability of the results, we conducted various post-estimation examinations, including assessments for tolerance, lambda, goodness-of-fit, and looloss, as detailed in Table 4. The results of these tests, as reported in Table 4, demonstrate the absence of serial correlation and heteroskedasticity in the study's results. Furthermore, the model's stability, evaluated in Table 5, proves favorable. This assertion is supported by the fact that the test statistic is smaller than the 1% critical value, and the CUSUM curve depicted in Figure 1 remains within the confidence bands on the graph. Consequently, it can be deduced that there is no discernible structural discontinuity within the dataset.

Table 4. KRLS estimation result

	Average	*SE*	*T-statistics*	*P-value*	*P25*	*P50*	*P75*
lnRD	0.160134	0.020393	7.852	0.000	0.094965	0.180612	0.217551
lnLF	0.408165	0.058317	6.999	0.000	0.276121	0.418962	0.550455
LnH	0.115481	0.012273	9.410	0.000	0.078301	0.104772	0.153712
LnK	0.209305	0.053187	3.935	0.000	0.005312	0.325755	0.477381
Obs	32						
Lambda	0.07841						
Tolerance	0.032						
Sigma	4						
Eff.df.	12.49						
R^2	0.9947						
Looloss	0.1337						

Table 5. Parameter stability test

Type	*Test statistic*	*1% Critical Value*	*5% Critical Value*	*10% Critical Value*
recursive	0.9247	1.1430	0.9479	0.8499

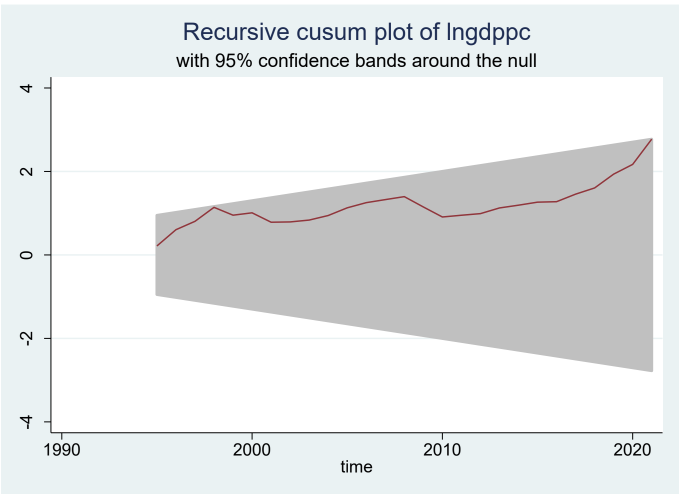

Figure 1. CUSUM test

6. CONCLUSION

Technological developments have become one of the most critical inputs of economic growth for the last 30 years. Technological breakthroughs made by countries increase social welfare through their economic effects. In this context, R&D expenditures stand out as the most significant source of technological development. To drive innovation, economic growth, and global competitiveness can also be maintained via R&D expenditures. They foster a culture of creativity, exploration, and problem-solving that propels societies forward and ensures their adaptability in an ever-evolving world.

R&D activities are important since it involves the creation of new knowledge, technologies, and processes. They drive innovation productivity by leading to the development of novel products, services, and solutions that can revolutionize industries and improve overall quality of life. Furthermore, R&D investments contribute to increased innovation productivity by enhancing efficiency, optimizing processes, and fostering the creation of new industries and markets. This, in turn, boosts economic growth as more efficient and innovative methods lead to higher output. Moreover, R&D activities provide opportunities for researchers, scientists, and engineers to advance their skills and knowledge. This contributes to a country's human capital development and positions it as a hub for expertise and innovation.

In the context of this study, we investigate the relationship between R&D expenditures and economic growth in Türkiye for the period from 1990 to 2021, with a focus on endogenous growth models. Our analysis reveals that R&D expenditures in Türkiye have a noteworthy and statistically significant positive influence on economic growth. Specifically, a 1% increase in R&D expenditures leads to an average economic growth increase of 0.16%. Furthermore, our empirical results, obtained through the KRLS method, indicate that factors such as labor force participation, tertiary school enrollment ratio, and gross fixed capital formation are all significantly and positively associated with economic growth in Türkiye. A particularly intriguing discovery is that R&D expenditure exhibits increasing marginal effects on economic growth, underscoring its pivotal role in stimulating and enhancing economic growth in the country. Our findings are in line with Wu and Zhou (2007) and Bayarçelik and Taşel (2012) who also reported positive association between R&D expenditure and economic growth, whereas contradicts with the results of Samimi and Alerasoul (2009), studying 30 developing countries' and claim that R&D expenditures have no direct effect on economic growth.

The rise in economic growth attributed to increased R&D expenditures underscores the significance of investing in research and development. To attain sustainable economic growth in Türkiye, it is imperative to foster collaborative R&D initiatives involving both the public and private sectors while also providing support to individual researchers. Promoting economic growth through increased research and development (R&D) expenditures in Türkiye requires a comprehensive approach that involves various stakeholders, policies, and strategies. For instance, the government should allocate a higher percentage of the national budget to R&D activities and offer tax incentives or subsidies to businesses that invest in R&D. From the educational perspective, Türkiye should strengthen education systems to produce a skilled workforce in science, technology, engineering, and mathematics (STEM) fields. Also, schools should support programs that encourage students to pursue careers in R&D.

In conclusion, providing financial support and incentives for startups and small businesses engaged in R&D will support innovation productivity and economic growth. Implementing these measures collectively can create an ecosystem that fosters innovation and R&D, contributing to sustainable economic growth in Türkiye. It's crucial for policymakers, industry leaders, and academia to work together to create an environment that supports long-term research and development initiatives. By doing so, we can catalyze a sustainable economic growth cycle, leveraging the high potential for future returns associated with R&D investments.

Our current study discusses the relationship between R&D expenditures and economic growth in a broader perspective taking the whole R&D expenditures. The future studies can handle this topic taking into account the details of R&D expenditures in several sectors.

Acknowledgements
We thank the anonymous reviewers for their careful reading of our manuscript and many insightful comments and suggestions that improved the paper.

Author Contributions
Yasin Acar: Conceptualization, Methodology, Analysis, Writing-original draft, Modelling, Writing-review and editing *İbrahim Kesici*: Literature Review, Conceptualizaton, Data Curation, Writing-review and editing

Conflict of Interest
No potential conflict of interest was declared by the authors.

Funding
Any specific grant has not been received from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with Ethical Standards
It was declared by the authors that the tools and methods used in the study do not require the permission of the Ethics Committee.

Ethical Statement
It was declared by the authors that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.

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