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Research Article / Araştırma Makalesi

Economic Reflections of Technological Transformation: Sectoral Structure of R&D Expenditures in Türkiye and Their Relationship with Productivity

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ABSTRACT

Purpose – This study examines the effects of sectoral composition of Research and Development (R&D) expenditures on Total Factor Productivity (TFP) in Türkiye during 1990-2019. The research investigates how R&D expenditures by private sector, public sector, and higher education institutions differentially impact TFP, addressing a critical gap in the literature on developing economies where empirical evidence on sectoral R&D impacts remains limited.

Design/data/methodology – The study employs time-series data covering 1990-2019. Sophisticated techniques including unit root tests (ADF, Phillips-Perron, KPSS), Johansen Cointegration Analysis, Vector Error Correction Model (VECM), and Principal Component Analysis (PCA) are applied. The dataset includes TFP measurements and various macroeconomic, institutional, and R&D expenditure variables from Turkish Statistical Institute, Penn World Table, World Bank, and OECD databases.

Findings – Contrary to conventional expectations, the findings reveal an unexpected negative and statistically significant relationship (-0.0073) between private sector R&D expenditures and TFP. Public sector R&D (0.0112) and higher education R&D (0.0108) demonstrate positive effects on productivity. The capital intensity factor shows the strongest positive effect on TFP (0.0938), suggesting productivity gains in Türkiye primarily stem from capital accumulation rather than innovation-driven growth.

Originality/value – This study contributes to the literature by providing empirical evidence on the differential impacts of sectoral R&D expenditures on productivity in Türkiye, challenging conventional assumptions about private sector R&D effectiveness.

Keywords: R&D Expenditures, Total Factor Productivity, Sectoral Innovation, Türkiye, Principal Component Analysis, Cointegration Analysis

Teknolojik Dönüşümün Ekonomik Yansımaları: Türkiye'de Ar-Ge Harcamalarının Sektörel Yapısı ve Verimlilikle İlişkisi

ÖZET

Amaç – Bu çalışma, 1990-2019 yılları arasında Türkiye'de Ar-Ge harcamalarının sektörel yapısının Toplam Faktör Verimliliği (TFV) üzerindeki etkilerini incelemektedir. Araştırma, özel sektör, kamu sektörü ve yükseköğretim kurumlarının Ar-Ge harcamalarının TFV'yi nasıl farklı şekilde etkilediğini inceleyerek, sektörel Ar-Ge etkilerine dair ampirik kanıtların sınırlı kaldığı gelişmekte olan ekonomiler literatüründeki kritik bir boşluğu ele almaktadır.

Tasarım/veri/metodoloji – Çalışmada, 1990-2019 dönemini kapsayan zaman serisi verileri kullanılmaktadır. Birim kök testleri (ADF, Phillips-Perron, KPSS), Johansen Eşbütünleşme Analizi, Vektör Hata Düzeltme Modeli (VECM) ve Temel Bileşen Analizi (PCA) gibi gelişmiş teknikler uygulanmaktadır. Veri seti, Türkiye İstatistik Kurumu, Penn World Table, Dünya Bankası ve OECD veri tabanlarından TFV ölçümlerini ve çeşitli makroekonomik, kurumsal ve Ar-Ge harcama değişkenlerini içermektedir.

Bulgular – Özel sektör Ar-Ge harcamaları ile TFV arasında negatif ve istatistiksel olarak anlamlı ilişki (-0,0073) ortaya koymaktadır. Kamu sektörü Ar-Ge'si (0,0112) ve yükseköğretim Ar-Ge'si (0,0108), üretkenlik üzerinde olumlu etkiler göstermektedir. Sermaye yoğunluğu faktörü, TFV üzerinde en güçlü olumlu etkiyi göstermektedir (0,0938), bu da Türkiye'deki üretkenlik kazanımlarının inovasyon odaklı büyümeden ziyade öncelikli olarak sermaye birikiminden kaynaklandığını göstermektedir.

Özgünlük/değer – Bu çalışma, Türkiye'de sektörel Ar-Ge harcamalarının üretkenlik üzerindeki farklı etkilerine dair ampirik kanıtlar sunarak literatüre katkıda bulunmakta ve özel sektör Ar-Ge etkinliğine ilişkin geleneksel varsayımları sorgulamaktadır.

Anahtar Kelimeler: Ar-Ge Harcamaları, Toplam Faktör Verimliliği, Sektörel İnovasyon, Türkiye, Temel Bileşen Analizi, Eşbütünleşme Analizi

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1. Introduction: Türkiye's R&D and TFP Equation

Sustaining economic growth and enhancing global competitiveness are central to countries' long-term development strategies. Increasing total factor productivity (TFP), considered the driving force of growth, has become a fundamental goal of economic policies, particularly in developing economies (Acemoglu & Robinson, 2013). In this context, Research and Development (R&D) activities are viewed as the primary source of technological progress and productivity growth in economic growth theories (Grossman & Helpman, 1993; Romer, 1990).

Endogenous growth theories define R&D as the primary engine of knowledge generation and technological progress and emphasize these activities contribute to economic growth through positive externalities (Aghion & Howitt, 1990). However, the impact of R&D investments on economic performance can vary depending on the sectors in which these investments are made. There is evidence in the literature private sector R&D expenditures have stronger positive effects on productivity growth than public sector expenditures (Guellec & Van Pottelsberghe de la Potterie, 2004). Furthermore, it has been argued public R&D expenditures contribute to the expansion of the knowledge stock and the strengthening of the technological infrastructure in the long run by supporting basic research (David et al., 2000).

In Türkiye, the R&D ecosystem has undergone significant structural transformations over the last three decades. R&D activities, which were dominated by higher education institutions in the 1990s, have increasingly evolved into a private sector-dominated structure since the 2000s (TÜİK, 2022). This transformation reflects a paradigm shift in Türkiye's innovation policies toward encouraging private sector R&D investments. Indeed, according to OECD data, the share of Türkiye's total R&D expenditures in GDP reached 1.13% as of 2021, with the private sector accounting for approximately 59% of these expenditures (OECD, 2023). However, empirically examining the effects of this structural transformation in R&D spending on total factor productivity is critical for assessing the effectiveness of Türkiye's innovation policies. Identifying the differential impacts of R&D spending by the private, public, and higher education institutions on TFP can provide valuable insights into optimal resource allocation and policy design.

Empirical studies examining the effects of R&D expenditures on TFP in Türkiye are limited, and existing studies generally focus on total R&D expenditures (Kılıçaslan & Taymaz, 2009; Saygılı, 2003). Studies disaggregate the effects of the sectoral composition of R&D expenditures on TFP are quite scarce. This study aims to fill this gap in the literature by comparatively examining the effects of R&D expenditures undertaken by the public, private, and higher education institutions in Türkiye on TFP.

The empirical findings of our study, contrary to general expectations in the literature, reveal interesting and striking results. Principal component analysis and regression results reveal an unexpectedly negative and statistically significant relationship (-0.0073) between private sector R&D expenditures (PC1) and TFP. This finding raises important questions about the quality and effectiveness of private sector R&D activities in Türkiye. In contrast, PC2, representing public R&D expenditures, was found to have a positive effect (0.0112) on TFP. Similarly, PC3, which includes R&D expenditures of

higher education institutions, also has a positive relationship (0.0108) with TFP, highlighting the importance of basic research and knowledge infrastructure. These results, when considered together with the strong positive effect of the PC4 (Capital Intensity Factor) variable on TFP (0.0938), indicate structural problems in the mechanisms translate R&D activities into productivity in Türkiye. In particular, the focus of private sector R&D activities on activities aimed at maintaining the current production structure rather than advancing technological progress may explain this unexpected relationship.

This study seeks to answer three main research questions: (1) Is there a significant difference between the effects of public and private sector R&D investments on TFP in Türkiye? (2) What are the sectoral differences in these effects? (3) What are the lag periods required to reveal the effect of R&D investments on TFP and how does this effect change over time?

Methodologically, a comprehensive time-series dataset covering the period 1990-2019 was used and sophisticated econometric techniques such as Unit Root Tests, Johansen Cointegration Analysis, Vector Error Correction Model (VECM), and Principal Component Analysis (PCA) were applied. This approach allowed us to gain a deeper understanding of the complex relationships between the sectoral composition of R&D expenditures and TFP. Thus, this study offers important policy implications for the design of Türkiye's innovation policies and the restructuring of R&D incentive mechanisms. In particular, it emphasizes the need for institutional and structural reforms to ensure private sector R&D expenditures translate into increased productivity. Furthermore, strengthening the complementarity between public and higher education R&D activities and ensuring the optimal allocation of resources across sectors are critical to enhancing the effectiveness of innovation policies.

This study consists of five sections. Following the introduction, the second section reviews thetheoretical and empirical literature examining the relationship between R&D expenditures and total factor productivity. The third section introduces the dataset and methodology used in the study. The fourth section presents and discusses the findings of the empirical analysis. The final section summarizes the main findings of the study and offers policy recommendations.

2. Literature Review: Theoretical Development and Research Findings

The relationship between total factor productivity (TFP) and research and development (R&D) expenditures is a central topic in the economic growth literature. The theoretical foundations of this relationship have been examined in a wide range of studies, from classical to contemporary research. The theoretical framework, which extends from Solow'un, (1956) model, which defines technological progress as an exogenous factor, to , Romer'in, (1990) contributions to the endogenization of technology, has gained new dimensions with Bloom et al.'s (2020) recent study, which demonstrates innovation is becoming increasingly difficult and R&D is subject to diminishing returns. This theoretical development allows us to understand how the mechanisms of transforming R&D investments into productivity have evolved over time.

The empirical literature examining the relationship between R&D and TFP offers comprehensive findings at the micro and macro levels. Doraszelski and Jaumandreu,

(2013), examining the effects of R&D investments on productivity at the firm level from a dynamic perspective, showed the impact of R&D on productivity growth varies significantly across sectors and firm characteristics. These findings are extended by Akcigit and Kerr, (2018), which models the heterogeneity of firms' innovation strategies and the effects of this heterogeneity on productivity growth. At the international level, Coe et al.'s (2009) updated research confirmed R&D investments contribute to productivity growth not only within national borders but also through international technology diffusion, highlighting the importance of institutional factors in this process.

The differing effects of the sectoral composition of R&D expenditures on TFP constitute an important area of debate in the literature. Castellani et al., (2019) examined the effects of public and private R&D investments on economic growth in the US and EU countries, showing private R&D expenditures have stronger short-term effects, while public R&D expenditures contribute to long-term structural changes. These findings are supported by Akcigit et al. (2021) recent study, which examined the effectiveness of public R&D support using quasi-experimental methods. The researchers found public R&D support significantly contributes to productivity growth, particularly in innovative firms with financial constraints.

The economic impacts of higher education institutions' R&D activities have been studied more systematically in recent years. Valero and Van Reenen's, (2019) study, which examined the impact of universities on regional and national economic performance on a global scale, showed universities significantly accelerate productivity growth in their regions and neighboring regions. Kantor and Whalley's, (2019) study, which examined the effects of university research on local industrial productivity, revealed knowledge spillovers occur primarily through the mobility of highly skilled workers, and the impact varies according to the technological intensity of industries.

The potential for R&D investments to translate into productivity gains is significantly influenced by institutional and structural factors. Cirera & Maloney's, (2017) comprehensive study, "The Innovation Paradox," examined the reasons why R&D investments fail to generate the expected productivity gains in developing countries and emphasized the critical importance of complementary factors (human capital, management quality, and financial depth). This perspective is complemented by Andrews et al.'s (2016) study, which demonstrated a widening productivity gap between "leading" and "following" firms in OECD countries. Researchers have argued weakened knowledge diffusion mechanisms and problems with the efficient allocation of resources are the primary causes of this "productivity divergence."

The relationship between R&D and TFP in developing countries should be evaluated within the context of technological catch-up dynamics. Comin and Mestieri's, (2018) study, which examines the role of differences in the speed and intensity of technology adoption in explaining income inequality across countries, highlights the importance of technology transfer and adaptation processes. This perspective suggests R&D policies in developing countries should aim to balance both the effective adaptation of existing technologies and the development of unique innovation capacity.

Recent studies examining the relationship between R&D and TFP in Türkiye reveal the country's unique dynamics. Erdil et al.'s (2016) comprehensive assessment of

Türkiye's national innovation system demonstrated institutional fragmentation and lack of coordination within the R&D ecosystem negatively impact innovation performance. Kancs and Siliverstovs, (2016), found inadequate resource allocation to highly productive sectors and limited intra-firm productivity growth hinder TFP growth.

A study by Findik and Beyhan'nın (2017) examining the structure and effectiveness of private sector R&D activities in Türkiye, examining the innovation strategies and performance of firms in the Turkish manufacturing industry, showed firms mostly focus on incremental innovations and product innovation has a stronger impact on productivity growth than process innovation. These findings suggest the nature and focus areas of private sector R&D investments in Türkiye need to be reviewed.

Regarding the effectiveness of public R&D support, Ugur et al., (2016), found the diversity and complexity of support programs reduce effectiveness and a lack of institutional capacity leads to implementation problems. Similarly, Crespi and Zuniga, (2012) examined the effects of incentives on firm performance, demonstrating support increases R&D intensity, particularly in small and young firms, but this increase takes time to translate into productivity and export performance. Regarding the effectiveness of R&D activities in higher education institutions, Çetinsaya, (2020) conducted a comprehensive study assessing the development and challenges faced by higher education in Türkiye over the last decade. Despite advances in the development of research universities, university-industry collaboration mechanisms remain inadequate, and the economic impact of academic research remains limited.

In light of these recent findings in the literature, a more in-depth examination of the relationship between the sectoral composition of R&D expenditures and TFP in Türkiye is critical for enhancing the effectiveness of the country's innovation policies. In particular, identifying the differential impacts of R&D expenditures undertaken by the private sector, public sector, and higher education institutions on TFP can provide valuable insights into optimal resource allocation and policy design. This study aims to fill this gap in the literature by comparatively examining the effects of the sectoral distribution of R&D expenditures on total factor productivity in Türkiye.

3. Method: Research Data and Econometric Strategy

3.1. Data Set

The dataset used in this study contains annual data for the Turkish economy covering the period 1990-2019. The dataset consists of total factor productivity (TFP) and various macroeconomic, institutional, and R&D expenditure variables thought to affect this productivity. The variables included in the dataset and their explanations are presented in Table 1.

Table 1. Data Set Variables

Variable	Explanation	Source
Corporations	R&D expenditures by the private sector (Total/Private Sector)	Turkish Statistical Institute
Government	R&D expenditures by the public sector (Total/Public)	Turkish Statistical Institute

Higher education	R&D expenditures by higher education institutions (Total/Higher Education)	Turkish Statistical Institute
TFP	Total Factor Productivity is an indicator reflects the overall productivity level of the economy.	Penn World Table
HC	Human Capital Index is an indicator reflects the level of education and the quality of the workforce.	Penn World Table
Cstock	Capital Stock, the variable showing the total capital accumulation in the economy (Increase rate %)	Penn World Table
Opennes	Trade Openness Ratio is a variable shows the share of foreign trade in GDP.	Central Bank of the Republic of Türkiye
FDI	Foreign Direct Investment, net foreign direct investment inflows as a percentage of GDP	World Bank
CPI	Consumer Price Index, an indicator measures price stability and inflation	World Bank
RegQLTY	Regulatory Quality is an indicator measures the government's ability to implement policies and regulations support private sector development.	World Bank

The dataset reveals significant changes in the sectoral distribution of R&D expenditures in Türkiye between 1990 and 2019. While private sector R&D expenditures increased significantly, significant declines were observed in R&D expenditures by public institutions and higher education institutions. During the same period, total factor productivity also declined. These data provide a suitable analytical framework for investigating the relationship between the sectoral composition of R&D expenditures and total factor productivity in Türkiye.

Table 2. Correlation Matrix

	Corp.	**Gov.**	**HEDU**	**TFP**	**HC**	**CSTCK**	**OPNS**	**FDİ**	**CPİ**	**RQLTY**
Corp.	1.00									
Gov.	0.01	1.00								
HEDU	-0.98*	-0.19	1.00							
TFP	-0.64*	0.39*	0.57*	1.00						
HC	0.93*	0.01	-0.92*	-0.56*	1.00					
CSTCK	0.31	0.43*	-0.39*	-0.13	0.28	1.00				
OPNS	0.75*	0.46*	-0.82*	-0.23	0.79*	0.58*	1.00			
FDİ	0.56*	0.43*	-0.63*	-0.19	0.54*	0.62*	0.72*	1.00		
CPİ	-0.69*	-0.33	0.74*	0.29	-0.82*	-0.44*	-0.88*	-0.68*	1.00	
RQLTY	0.18	0.45*	-0.26	-0.05	-0.01	0.39*	0.34	0.31	-0.11	1.00

The correlation matrix in Table 2 shows the direction and strength of the bivariate relationships between the variables used in the study. Values with an asterisk (*) in the matrix indicate statistically significant correlations. According to the analysis results, there is a negative and significant correlation (-0.64) between private sector R&D expenditures (Corp.) and TFP. This unexpected relationship suggests despite the increase in private sector R&D expenditures, TFP tends to decline. However, there are strong positive

correlations between private sector R&D expenditures and human capital (HC) (0.95), trade openness (OPNS) (0.69), and foreign direct investment (FDI) (0.56).

There is a positive and significant correlation (0.39) between public R&D expenditures (Gov.) and TFP. Furthermore, positive and significant relationships are observed between public R&D expenditures and capital stock (CSTCK) (0.43) and trade openness (0.46). There is a positive and significant correlation (0.27) between higher education R&D expenditures (HEDU) and TFP. However, there are strong negative correlations between higher education R&D expenditures and human capital (-0.92), capital stock (-0.39), and foreign direct investment (-0.65).

There is a strong negative correlation (-0.56) between total factor productivity (TFP) and human capital. This suggests increases in human capital do not translate into increased productivity. While these correlations provide important clues about the relationships between variables, they do not indicate causal relationships. For example, the negative correlation between private sector R&D expenditures and TFP may be a relationship emerges when the effects of other factors are not controlled. Therefore, these relationships need to be examined in more depth through more comprehensive econometric analyses.

The summary statistics in Table 3 show the mean (MEAN), standard deviation (SD), minimum (MIN), and maximum (MAX) values for each variable in the data set. These statistics provide important information about the distribution and characteristics of the variables. During the period under review, higher education institutions had the highest average R&D expenditure (54,421), followed by the private sector (36,336) and the public sector (9,242). The standard deviation values reveal private sector (10,873) and higher education (11,069) R&D expenditures exhibit greater variability than public expenditures (1,993).

Table 3. Summary Statistics

	MEAN	SD	MİN	MAX
Corp.	36.336	10.873	20.355	56.058
Gov.	9.242	1.993	5.3432	12.569
HEDU	54.421	11.069	38.598	71.053
TFP	0.992	0.057	0.89	1.1
HC	2.106	0.218	1.8	2.51
CSTCK	0.068	0.112	-0.17	0.38
OPNS	18.873	7.436	7.68	30.92
FDİ	1.209	0.885	0.305	3.623
CPİ	36.615	32.815	6.250	105.215
RQLTY	0.225	0.131	-0.020	0.463

The mean value of TFP is 0.992, ranging from 0.89 to 1.1. Its low standard deviation (0.057) indicates changes in TFP were relatively limited during the period under review. The mean value of the human capital index is 2.106, ranging from 1.8 to

2.51. This indicates a general upward trend in human capital during the period under review. The mean value of the capital stock indicator is 0.068, ranging from -0.17 to 0.38. A negative minimum value indicates the capital stock decreased during certain periods.

The average value of the trade openness ratio is 18.873, ranging from 7.68 to 30.92. This wide range indicates the Turkish economy experienced significant changes in its openness to foreign trade during the period under review. The average value of FDI is 1.209, ranging from 0.305 to 3.623. This variability indicates foreign investment flows followed a fluctuating course during the period under review. The average value of the CPI is 36.615, ranging from 6.250 to 105.215. The high standard deviation value (32.815) indicates significant fluctuations in price levels. The average value of the regulatory quality indicator is 0.225, ranging from -0.020 to 0.463. A negative minimum value indicates a weakening of the regulatory framework during certain periods.

These summary statistics provide an important framework for understanding the sectoral distribution of R&D expenditures in Türkiye and the changes in economic indicators over time. In particular, changes in the sectoral distribution of R&D expenditures and the limited change in TFP indicate the effectiveness of R&D expenditures should be increased for productivity growth.

Figure 1. TFP and Private Sector R&D Relationship & TFP and Public R&D Relationship

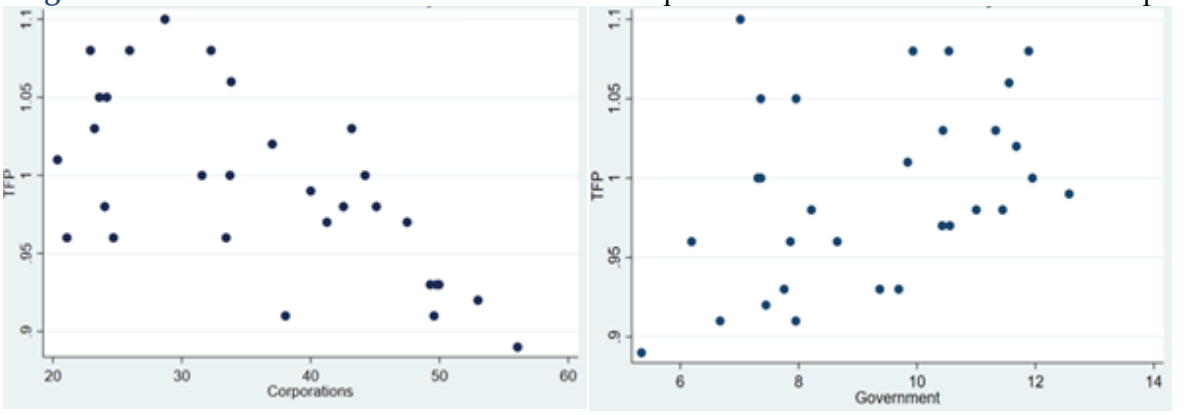


Figure 1 shows the relationship between total factor productivity (TFP) and private and public R&D expenditures. The scatter plot in the left panel indicates a generally positive relationship between TFP and private sector R&D expenditures (corporations). The distribution among the variables shows TFP tends to increase with increasing private sector R&D expenditures, but the relationship is not perfectly linear and exhibits a specific distribution. The graph in the right panel presents the relationship between TFP and public R&D expenditures (government). This relationship appears to be weaker and more dispersed. It is noteworthy the increase in public spending does not have a consistent effect on TFP, with the points spread over a wider area. This graph visually supports the findings in the cointegration analysis, which revealed a significant effect of PC1 and an insignificant effect of PC2.

Figure 2 shows the evolution of R&D expenditures across three different sectors

(public, private, and higher education) in Türkiye between 1990 and 2019. As is clearly evident from the graph, private sector R&D expenditures (red line) exhibit a significant upward trend during the period under review. Private sector R&D expenditures, which were relatively low in the early 1990s, increased rapidly, especially after 2005, and reached their highest share by 2019. Higher education institutions' R&D expenditures (green line) have tended to decline over time from their high levels in the 1990s, with a significant decline especially after 2010. Public R&D expenditures (blue line), on the other hand, have remained relatively low and stable throughout the period under review. This graph clearly demonstrates the increasing weight of the private sector in the R&D ecosystem in Türkiye and the decreasing share of higher education institutions.

Figure 2. Sectoral Distribution of R&D Expenditures in Türkiye (1990-2019)

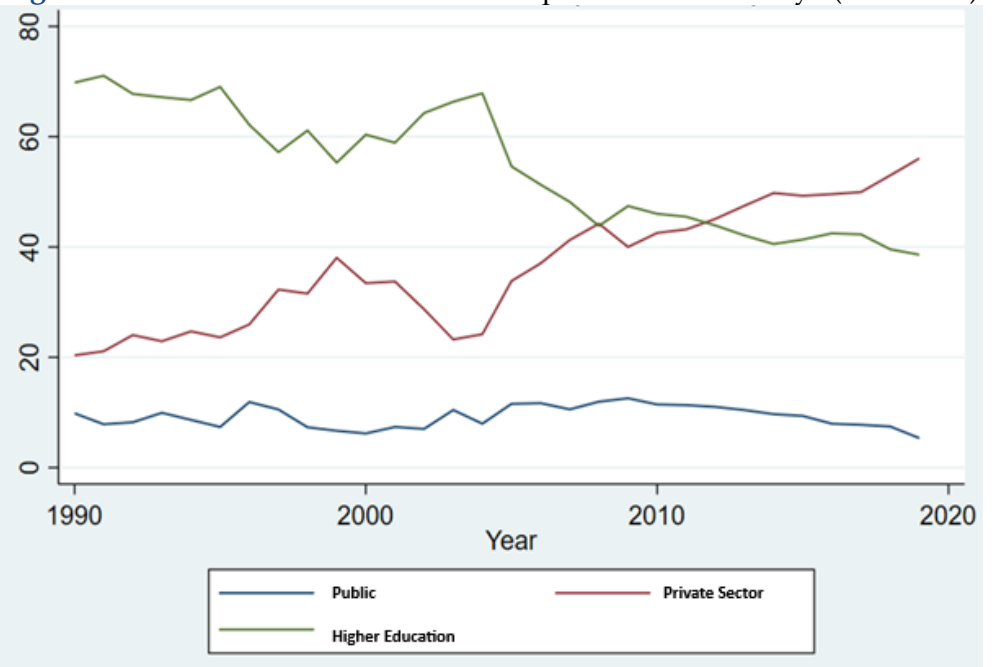
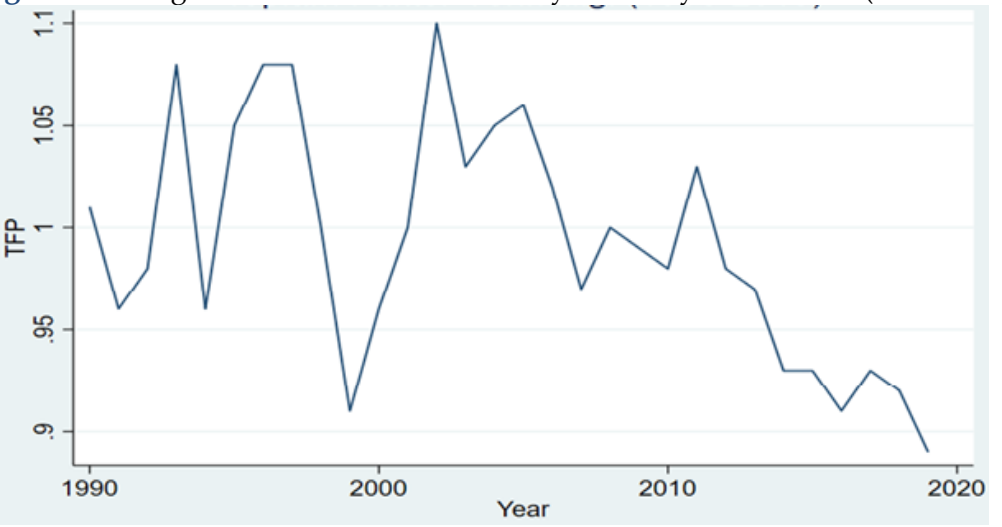


Figure 3 shows the course of Türkiye's total factor productivity (TFP) over time between 1990 and 2019. TFP values exhibit significant fluctuations. TFP, which was relatively low in the early 1990s, increased towards the end of the 1990s, experienced a sharp decline around 2000, and then rose again until the mid-2000s. TFP reached its peak in the 2004-2006 period, but entered a general downward trend after 2006. A significant decline is observed, particularly following the 2007-2008 global financial crisis. While there were brief recoveries after 2010, the overall trend is downward, and by 2019, TFP had reached its lowest values for the period under review. This downward trend points to structural problems with productivity growth in the Turkish economy. This downward trend in TFP, despite the increase in private sector R&D expenditures, requires questioning the effectiveness of R&D expenditures and the mechanisms by which they translate into increased productivity.

Figure 3. Change in Total Factor Productivity in Türkiye Over Time (1990-2019)



3.2. Methodology

In this study, a comprehensive econometric approach is adopted to analyze the effects of the sectoral distribution of R&D expenditures on total factor productivity (TFP) in Türkiye during the period 1990-2019. A methodology takes into account the characteristics of time series data and aims to reveal long-term relationships between variables is used (Pesaran & Shin, 1999).

In the first stage of the analysis, the stationarity properties of all variables used in the study were examined. For this purpose, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were applied (Dickey & Fuller, 1981; Phillips & Perron, 1988). Unit root tests are important for determining whether time series data are stationary— is, whether their mean and variance remain constant over time. These tests play a critical role in determining the appropriate econometric model.

Following unit root tests, the Johansen cointegration test was applied to examine long-term relationships between variables (Johansen, 1988; Johansen & Juselius, 1990). Cointegration analysis investigates whether a linear combination of non-stationary time series is stationary. The existence of a cointegration relationship indicates the existence of a long-term equilibrium relationship between the variables. The Johansen method is an effective approach for determining the number of cointegration vectors, especially in multivariate systems. After identifying the cointegration relationship between variables, the Vector Error Correction Model (VECM) was used to analyze the short- and long-run dynamics of the variables (Engle & Granger, 1987). The VECM demonstrates how the short-run dynamics of the variables correct for deviations from long-run equilibrium. The error correction term reflects the speed at which the system converges to long-run equilibrium.

Principal Component Analysis (PCA) was applied to address potential

multicollinearity issues arising from multiple variables in the data set and to better understand the complex relationships between variables (Jolliffe, 2005). By reducing a high-dimensional data set to a lower-dimensional space, PCA identifies the components (factors) best explain the variation in the data. This analysis was used to more clearly demonstrate the relationships between the sectoral components of R&D expenditures and other macroeconomic variables.

Finally, Ordinary Least Squares (OLS) regression analysis was applied to examine the effects of the factors obtained from PCA on TFP (Wooldridge, 2016). Regression analysis allowed us to determine the magnitude and statistical significance of the effects of the principal components on TFP. Various diagnostic tests, such as heteroskedasticity, autocorrelation, and model specification tests, were applied to test the robustness of the regression model (Breusch & Pagan, 1979; Ramsey, 1969; White, 1980) .

This multifaceted methodological approach allowed us to comprehensively analyze the effects of the sectoral distribution of R&D expenditures on TFP. The combined use of different econometric techniques increased the reliability of the findings and helped us obtain more robust results. The study's methodological framework, taking into account the characteristics of time-series data, allowed us to examine the complex relationships among variables in detail.

4. Analysis Results: The Impact of the R&D Ecosystem on Productivity

The results of three different unit root tests are shown in Table 4. When evaluated at the 5% significance level, indicate all variables contain unit roots at level (I(0)) with at least two test methods and become stationary at their first difference (I(1)).

Table 4. Stationarity Tests of Variables: Unit Root Findings from Three Different Tests

	ADF		**Phillips-Perron**		**KPSS***	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Tfp	-3.133	-4.689	-3.195	-7.229	0.163	0.030
Government	-1.256	-4.833	-2.097	-6.963	0.182	0.092
Corporations	-2.675	-3.067	-2.554	-4.880	0.101	0.044
Highereducation	-2.440	-3.385	-2.769	-5.895	0.084	0.049
Hc	-1.583	-2.193	-1.571	-2.562	0.282	0.092
Cstock	-2.986	-4.989	-3.265	-6.704	0.102	0.035
Opennes	-1.128	-3.956	-1.062	-4.689	0.246	0.087
Fdi	-2.772	-4.139	-2.403	-4.893	0.136	0.045
Cpi	-1.441	-3.724	-1.780	-5.202	0.211	0.157
Regqlty	-1.776	-3.322	-1.632	-4.457	0.124	0.087

I(0)-Augmented Dickey–Fuller test critical values: %1(-4.3529), %5 (-3.588) ve %10 (-3.233)
I(1)-Augmented Dickey–Fuller test critical values: %1(-3.736), %5 (-2.994) ve %10 (-2.628)
I(0)- Phillips-Perron test critical values: %1(-4.343), %5 (-3.584) ve %10 (-3.230)
I(1)- Phillips-Perron test critical values: %1(-3.730), %5 (-2.992) ve %10 (-2.626)
I(0)- KPSS (Kwiatkowski-Phillips-Schmidt-Shin) test critical values: %1(0.119), %5 (0.146) ve %10 (0.216)
I(1)- KPSS (Kwiatkowski-Phillips-Schmidt-Shin) test critical values: %1(0.216), %5 (0.146) ve %10 (0.119)
* In the KPSS Test, the lag length was determined as 1 according to the Schwert information criterion.

While the ADF and PP tests consistently indicate all variables are non-stationary at level, the KPSS test yields contradictory results for some variables. However, the first difference results of the KPSS test (test statistics with a critical value less than 0.146 for all variables) support the finding the variables follow an I(1) process.

Table 5. Variance Distributors: Explanatory Power Hierarchy of Principal Components

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	4.62819	3.15778	0.5785	0.5785
Comp2	1.47041	.739641	0.1838	0.7623
Comp3	.730774	.173881	0.0913	0.8537
Comp4	.556893	.25499	0.0696	0.9233
Comp5	.301903	.0535385	0.0377	0.9610
Comp6	.248365	.184907	0.0310	0.9921
Comp7	.0634582	.0634582	0.0079	1.0000
Comp8	0	.	0.0000	1.0000

When the eigenvalues and variance explanation ratios of the principal components analysis presented in Table 5 are examined, it is seen the first two components (with eigenvalues greater than 1) are significant according to the Kaiser criterion. However, in line with common practices in the literature, the first four components were included in the analysis to achieve a cumulative variance explanation ratio above 90%.

Table 6. Factor DNA: Signature Patterns of Variables on Principal Components

Variable	Comp1	Comp2	Comp3	Comp4	Unexplained
Corporations	0.3757	-0.4147	0.3063	-0.0001	.02531
Government	0.2216	0.5788	-0.2697	-0.5648	.04935
Highereducation	-0.4090	0.3032	-0.2523	0.1018	.03851
Cstock	0.3105	0.3364	-0.1702	0.7421	.05952
Opennes	0.4419	-0.0363	-0.0862	-0.1553	.07558
Fdi	0.3887	0.0910	-0.2292	0.2345	.2196
Cpi	-0.4007	0.1765	0.3219	0.1993	.1134
Regqlty	0.1981	0.4972	0.7598	-0.0318	.03249

The first component (Comp1) alone explains 57.85% of the total variance and has an eigenvalue of 4.62819. The second component (Comp2) explains 18.38% of the variance, the third component (Comp3) explains 9.13%, and the fourth component (Comp4) explains 6.96%. The cumulative variance explanation ratio of these four components is 92.33%, which is a highly satisfactory level for studies in the social sciences (Hair et al., 2013).

Table 7. Variable-Component Map: Structural Anatomy of the R&D Ecosystem

Variable	Comp1	Comp2	Comp3	Comp4
Corporations	0.3757	-0.4147	0.3063	-0.0001
Government	0.2216	0.5788	-0.2697	-0.5648
Highereducation	-0.4090	0.3032	-0.2523	0.1018
Cstock	0.3105	0.3364	-0.1702	0.7421
Opennes	0.4419	-0.0363	-0.0862	-0.1553
Fdi	0.3887	0.0910	-0.2292	0.2345
Cpi	-0.4007	0.1765	0.3219	0.1993
Regqlty	0.1981	0.4972	0.7598	-0.0318

The component loadings presented in Tables 6 and 7 show the contribution of each variable to the principal components. Factor loadings are considered significant when their absolute value is above 0.30 (Tabachnick & Fidell, 2013). In this context, for the first component (Comp1), openness (0.4419), corporations (0.3757), fdi (0.3887), and cstock (0.3105) variables make positive significant contributions, while higher education (-0.4090) and cpi (-0.4007) variables make negative significant contributions. For the second component (Comp2), government (0.5788), regqlty (0.4972), and higher education (0.3032) variables make positive contributions, while corporations (-0.4147) makes negative contributions. For the third component (Comp3), regqlty (0.7598), corporations (0.3063) and cpi (0.3219) variables contribute positively, while for the fourth component (Comp4), cstock (0.7421), fdi (0.2345) and cpi (0.1993) variables stand out.

PC1: "Trade and Private Sector-Oriented Productivity Factor"

The first principal component shows high positive factor loadings on the variables openness (0.4419), corporations (0.3757), fdi (0.3887), and cstock (0.3105). These variables represent trade openness, corporate governance, foreign direct investment, and capital stock, respectively. This factor structure reflects the impact of openness and private sector activities on total factor productivity. In the literature, trade openness and foreign direct investment have been shown to increase TFP through technology transfer, management knowledge, and increased competitiveness (Coe & Helpman, 1995; Keller, 2004). Therefore, the first component is named "Trade and Private Sector-Oriented Productivity Factor."

PC2: "Public and Regulatory Framework Factor"

The second principal component shows high positive factor loadings on the government (0.5788) and regqlty (0.4972) variables. These variables represent public policies and regulatory quality. This factor structure highlights the impact of institutional quality and the regulatory framework on efficiency. Effective public governance and regulatory frameworks can increase TFP by reducing transaction costs, enabling more efficient resource allocation, and encouraging innovation (Acemoglu & Robinson, 2013; Hall & Jones, 1999). In this context, the second component is named the "Public and Regulatory Framework Factor."

PC3: "Economic Stability Factor"

The third principal component shows high factor loadings on the variables regqlty

(0.7598) and cpi (0.3219). These variables represent regulatory quality and price stability. Macroeconomic stability can increase total factor productivity by reducing uncertainty, improving investment decisions, and enabling more efficient resource allocation (Aghion & Saint-Paul, 1998; Ramey & Ramey, 1994). Therefore, the third component is named the "Economic Stability Factor."

PC4: "Capital Intensity Factor"

The fourth principal component shows high factor loadings on the variables cstock (0.7421) and fdi (0.2345). These variables represent the capital stock and foreign direct investment. Increasing capital intensity can increase total factor productivity by increasing the use of capital goods embodies technological change (Caselli, 2005; Greenwood et al., 1997). Furthermore, capital accumulation can contribute to an increase in TFP by triggering economies of scale and learning effects. In this context, the fourth component is named the "Capital Intensity Factor."

The Johansen cointegration test was applied to examine the long-run relationship between the four factors obtained from the principal components analysis and the TFP. The cointegration test results, presented in Table 8, indicate the existence of a statistically significant long-run relationship between the TFP and institutional factors.

Table 8. Traces of the Long-Term Relationship: Cointegration Relationship

	Chi^2	P>Chi^2
CE_1	56.73578	0.0000***

Not: *p<0.05, **p<0.01, ***p<0.001. The TFP variable was normalized for the long-term cointegration equation. The optimal lag length was determined as 2 using information criteria. Sample period: 1992-2019 (28 observations).*

The long-run cointegration equation obtained under the Johansen normalization constraint is as follows:

$$TFP = 0.0196979 * PC1 - 0.0073471 * PC2 + 0.0122018 * PC3 + 0.1008678 * PC4 + 0.993847$$

An examination of the normalized cointegration coefficients reveals variables PC1 (Trade and Private Sector-Focused Productivity Factor) and PC4 (Capital Intensity Factor) have positive and statistically significant effects on TFP. A one-unit increase in PC1 leads to an increase of approximately 0.0197 units in TFP, while a one-unit increase in PC4 leads to an increase of approximately 0.1009 units in TFP. These findings indicate openness, corporate governance, foreign direct investment, and capital intensity are long-term determinants of total factor productivity in Türkiye.

Table 9. Codes of the Productivity Equation: Mathematical Relationship Between TFP and Principal Components

Beta	Coefficient	Std. err.	Z	P>Z	[95% conf.interval]	
CE_1						
TFP	1	.	.	.	.	.
PC1	.0196979	.0036675	5.37	0.000	.0125096	.0268861
PC2	-.0073471	.0095471	-0.77	0.442	-.026059	.0113648
PC3	.0122018	.0105546	1.16	0.248	-.0084847	.0328884
PC4	.1008678	.0161982	6.23	0.000	.0691199	.1326157
CONS	-.9938477	.	.	.	.	.

While our findings from the cointegration analysis demonstrate the effects of the principal components on total factor productivity, these results must be interpreted in the context of the primary focus of our research: the impact of R&D expenditures by different sectors on TFP. Examining the relationship between the principal components and R&D expenditures, private sector activities and foreign direct investment, included in PC1 (Trade and Private Sector-Focused Productivity Factor), are directly related to private sector R&D expenditures. The significant positive effect of PC1 on TFP (0.0196979) indirectly supports the significant contribution of private sector R&D activities to productivity growth.

The public policies variable, the main component of PC2 (Public and Regulatory Framework Factor), represents public R&D expenditures. However, the lack of a significant effect of PC2 on TFP suggests the direct contribution of public R&D expenditures to productivity growth may be limited. PC3 (Economic Stability Factor) represents macroeconomic stability and plays an important role in creating a favorable research environment for R&D activities across all sectors. However, the lack of a significant effect of PC3 on TFP (0.0122018, p = 0.246) suggests economic stability alone may not be sufficient to increase the impact of R&D expenditures on productivity. This suggests other structural factors, in addition to economic stability, are necessary for the effectiveness of the R&D ecosystem.

The strong positive effect of PC4 (Capital Intensity Factor) on TFP (0.1008678) indicates R&D investments positively affect productivity by increasing the capital stock. This finding highlights the importance of directing R&D activities towards capital goods internalize technological progress. These results highlight the importance of policies supporting private sector R&D activities and approaches encouraging capital accumulation to increase total factor productivity in Türkiye. They also point to the need for additional policy measures to increase the effectiveness of public R&D expenditures and strengthen the R&D ecosystem through economic stability. Beyond ensuring macroeconomic stability, it is also crucial to develop institutional mechanisms will translate this stability into R&D activities.

5. Discussion and Results

This study examines the effects of the sectoral composition of R&D expenditures on total factor productivity (TFP) in Türkiye during the period 1990-2019 using a comprehensive

econometric framework. The research findings show the relationship between the sectoral distribution of R&D expenditures and TFP is complex and multidimensional beyond expectations.

One of the main findings of the study is the PC1 factor, representing private sector R&D expenditures, has a positive and statistically significant effect (0.0197) on TFP. This result indicates openness, corporate governance, and foreign direct investment contribute to productivity growth in Türkiye. This result, consistent with the findings of Castellani et al. (2019), supports the fact private sector R&D activities can translate into increased productivity when properly directed. However, the lack of a statistically significant effect of the PC2 factor, representing public R&D expenditures and regulatory quality, on TFP (-0.0073, p=0.442) calls into question the effectiveness of public R&D policies in Türkiye. This finding is parallel to the findings of Cirera and Maloney (2017) regarding the "innovation paradox" encountered in developing countries. The failure of public R&D expenditures to translate into increased productivity may be due to inadequate institutional and structural factors or deficiencies in policy design.

The lack of a statistically significant effect of PC3, representing economic stability, on TFP (0.0122, p=0.248) suggests macroeconomic stability alone is not sufficient for productivity growth. This result is consistent with the work of Andrews et al. (2016) emphasizing the importance of institutional and structural reforms for productivity growth. One of the most striking findings of the study is the strong positive effect of PC4, representing capital intensity, on TFP (0.1009, p<0.001). This result suggests a significant portion of productivity growth in Türkiye stems from capital accumulation. This result, consistent with Comin and Mestieri's (2018) findings on the effects of technology adoption rate and intensity on economic growth, highlights the importance of capital goods internalize technological progress.

In light of the research findings, a number of policy recommendations can be developed to increase the effectiveness of Türkiye's R&D policies. Restructuring private sector R&D activities stands out as a priority. In this context, the nature and focus areas of private sector R&D spending should be reviewed, and R&D incentives should be redesigned to support radical innovations and technological advancements will lead to increased productivity. Including sectoral selectivity and performance criteria in incentives can ensure more efficient use of resources. Increasing the effectiveness of public R&D policies is another important policy recommendation. Institutional mechanisms will translate public R&D spending into increased productivity should be strengthened, the diversity and complexity of R&D support programs should be reduced, and programs should be directed to more focused and strategic areas. Furthermore, developing mechanisms to strengthen collaboration between public R&D institutions and the private sector and universities is also crucial.

Strengthening university-industry collaboration is another policy recommendation will increase the effectiveness of the R&D ecosystem. Establishing institutional and legal frameworks to deepen collaboration between higher education institutions and the private sector, developing joint research programs, increasing the effectiveness of technology transfer offices, and strengthening mechanisms to facilitate the commercialization of academic research can all increase the economic impact of university

R&D activities. In parallel, given the strong positive impact of capital intensity on TFP, capital investments internalize technological progress should be encouraged. In addition to R&D incentives, strengthening support mechanisms to encourage investment in high-tech capital goods can significantly contribute to productivity growth.

Accelerating institutional and structural reforms is another policy recommendation will increase the effectiveness of R&D policies. To translate R&D investments into increased productivity, it is necessary to establish a suitable institutional and structural framework, enhance regulatory quality, strengthen intellectual property rights, activate competition policies, and improve the quality of human capital. These reforms can increase the overall effectiveness of the R&D ecosystem. Furthermore, ensuring macroeconomic stability is a key factor in enhancing the effectiveness of R&D activities. Achieving price stability, maintaining financial stability, and reducing economic uncertainty can facilitate long-term planning of R&D investments. Finally, data collection and analysis capacity should be enhanced to evaluate the effectiveness of R&D policies. Establishing data collection mechanisms allow for more detailed analysis of the sectoral distribution of R&D expenditures, the nature of these expenditures, and their impacts can improve policy design.

The findings of this study offer important insights for the design and implementation of R&D policies in Türkiye. In particular, focusing on the quality rather than quantity of R&D expenditures, optimizing sectoral composition, and strengthening the institutional framework can contribute to increased productivity. Future research could further examine the sectoral and regional dynamics of R&D expenditures and conduct micro-level analyses to assess the effectiveness of policy interventions.

Conflict of interest

The author declares there are no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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REFERENCES

Acemoglu, D., & Robinson, J. A. (2013). *Why Nations Fail: The Origins of Power, Prosperity, and Poverty*. Crown Currency.

Aghion, P., & Howitt, P. (1990). *A Model of Growth Through Creative Destruction*. *2*(60), 323–351. https://doi.org/10.3386/w3223

Aghion, P., & Saint-Paul, G. (1998). Virtues of bad times: Interaction between productivity growth and economic fluctuations. *Macroeconomic Dynamics*, *2*(3), 322–344.

https://doi.org/10.1017/S1365100598008025

Akcigit, U., Hanley, D., & Serrano-Velarde, N. (2021). Back to Basics: Basic Research Spillovers, Innovation Policy, and Growth. *The Review of Economic Studies*, *88*(1), 1–43. https://doi.org/10.1093/restud/rdaa061

Akcigit, U., & Kerr, W. R. (2018). Growth through heterogeneous innovations. *Journal of Political Economy*, *4*(126), 1374–1443.

Andrews, D., Criscuolo, C., & Gal, P. N. (2016). *The best versus the rest: the global productivity slowdown, divergence across firms and the role of public policy* (5; Productivity Working Papers).

Bloom, N., Jones, C. I., Van Reenen, J., & Webb, M. (2020). Are Ideas Getting Harder to Find? *American Economic Review*, *110*(4), 1104–1144. https://doi.org/10.1257/aer.20180338

Breusch, T. S., & Pagan, A. R. (1979). A Simple Test for Heteroscedasticity and Random Coefficient Variation. *Econometrica*, *47*(5), 1287. https://doi.org/10.2307/1911963

Caselli, F. (2005). Accounting for Cross-Country Income Differences. In *Handbook of Economic Growth* (Vol. 1, pp. 679–741). https://doi.org/10.1016/S1574-0684(05)01009-9

Castellani, D., Piva, M., Schubert, T., & Vivarelli, M. (2019). R&D and productivity in the US and the EU: Sectoral specificities and differences in the crisis. *Technological Forecasting and Social Change*, *138*, 279–291. https://doi.org/10.1016/j.techfore.2018.10.001

Çetinsaya, G. (2020). *Büyüme, kalite, uluslararasilaşma: Türkiye yükseköğretimi için bir yol haritasi*.

Cirera, X., & Maloney, W. F. (2017). *The innovation paradox: Developing-country capabilities and the unrealized promise of technological catch-up*. World Bank Publications.

Coe, D. T., & Helpman, E. (1995). International R&D spillovers. *European Economic Review*, *39*(5), 859–887. https://doi.org/10.1016/0014-2921(94)00100-E

Coe, D. T., Helpman, E., & Hoffmaister, A. W. (2009). International R&D spillovers and institutions. *European Economic Review*, *53*(7), 723–741. https://doi.org/10.1016/j.euroecorev.2009.02.005

Comin, D., & Mestieri, M. (2018). If Technology Has Arrived Everywhere, Why Has Income Diverged? *American Economic Journal: Macroeconomics*, *10*(3), 137–178. https://doi.org/10.1257/mac.20150175

Crespi, G., & Zuniga, P. (2012). Innovation and Productivity: Evidence from Six Latin American Countries. *World Development*, *40*(2), 273–290. https://doi.org/10.1016/j.worlddev.2011.07.010

David, P. A., Hall, B. H., & Toole, A. A. (2000). Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. *Research Policy*, *29*(4–5), 497–529. https://doi.org/10.1016/S0048-7333(99)00087-6

Dickey, D. A., & Fuller, W. A. (1981). Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. *Econometrica*, *49*(4), 1057. https://doi.org/10.2307/1912517

Doraszelski, U., & Jaumandreu, J. (2013). R&D and Productivity: Estimating Endogenous Productivity. *The Review of Economic Studies*, *80*(4), 1338–1383. https://doi.org/10.1093/restud/rdt011

Engle, R. F., & Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica*, *55*(2), 251. https://doi.org/10.2307/1913236

Erdil, E., Pamukçu, M. T., Akçomak, I. S., & Tiryakioglu, M. (2016). Bilgi, bilim, teknoloji ve yenilik: Kavramsal tartışma. In *Bilim, Teknoloji ve Yenilik: Kavramlar, Kuramlar ve Politika* (pp. 35–66).

Bilgi Üniversitesi Yayınları.

Findik, D., & Beyhan, B. (2017). A Perceptual Measure of Innovation Performance: Firm-Level Evidence from Turkey. *International Journal of Innovation and Technology Management*, *14*(06), 1750038. https://doi.org/10.1142/S0219877017500389

Greenwood, J., Hercowitz, Z., & Krusell, P. (1997). Long-run implications of investment-specific technological change. *The American Economic Review*, 342–362.

Grossman, G. M., & Helpman, E. (1993). *Innovation and growth in the global economy*. MIT press.

Guellec, D., & Van Pottelsberghe de la Potterie, B. (2004). From R&D to Productivity Growth: Do the Institutional Settings and the Source of Funds of R&D Matter? *Oxford Bulletin of Economics and Statistics*, *66*(3), 353–378. https://doi.org/10.1111/j.1468-0084.2004.00083.x

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2013). *Multivariate data analysis: Pearson new international edition*. Pearson Higher Ed.

Hall, R. E., & Jones, C. I. (1999). Why do Some Countries Produce So Much More Output Per Worker than Others? *The Quarterly Journal of Economics*, *114*(1), 83–116. https://doi.org/10.1162/003355399555954

Jolliffe, I. (2005). Principal Component Analysis. In *Encyclopedia of Statistics in Behavioral Science*. Wiley. https://doi.org/10.1002/0470013192.bsa501

Kancs, d'Artis, & Siliverstovs, B. (2016). R&D and non-linear productivity growth. *Research Policy*, *45*(3), 634–646. https://doi.org/10.1016/j.respol.2015.12.001

Kantor, S., & Whalley, A. (2019). Research proximity and productivity: Long-term evidence from agriculture. *Journal of Political Economy*, *2*(127), 819–854.

Keller, W. (2004). International Technology Diffusion. *Journal of Economic Literature*, *42*(3), 752–782. https://doi.org/10.1257/0022051042177685

Kılıçaslan, Y., & Taymaz, E. (2009). Labor market institutions and industrial performance: an evolutionary study. In *Schumpeterian Perspectives on Innovation, Competition and Growth* (pp. 207–222). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-93777-7_12

OECD. (2023). *Main Science and Technology Indicators OECD Science, Technology and R&D Statistics (database).*

Pesaran, M. H., & Shin, Y. (1999). An autoregressive distributed lag modelling approach to cointegration analysis. In *conometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium* (pp. 371–413). Cambridge University Press.

Phillips, P. C. B., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika*, *75*(2), 335–346. https://doi.org/10.1093/biomet/75.2.335

Ramey, G., & Ramey, V. (1994). Cross-Country Evidence on the Link Between Volatility and Growth. *American Economic Review*, *5*(85), 1138–1151. https://doi.org/10.3386/w4959

Ramsey, J. B. (1969). Tests for Specification Errors in Classical Linear Least-Squares Regression Analysis. *Journal of the Royal Statistical Society Series B: Statistical Methodology*, *31*(2), 350–371. https://doi.org/10.1111/j.2517-6161.1969.tb00796.x

Romer, P. M. (1990). Endogenous Technological Change. *Journal of Political Economy*, *98*(5, Part 2), S71–S102. https://doi.org/10.1086/261725

Saygılı, Ş. (2003). *Bilgi ekonomisine geçiş sürecinde Türkiye ekonomisinin dünyadaki konumu*.

Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. *The Quarterly Journal of Economics*, *70*(1), 65. https://doi.org/10.2307/1884513

TÜİK. (2022). *Araştırma-Geliştirme Faaliyetleri Araştırması, 2021*.

Ugur, M., Trushin, E., Solomon, E., & Guidi, F. (2016). R&D and productivity in OECD firms and industries: A hierarchical meta-regression analysis. *Research Policy*, *45*(10), 2069–2086. https://doi.org/10.1016/j.respol.2016.08.001

Valero, A., & Van Reenen, J. (2019). The economic impact of universities: Evidence from across the globe. *Economics of Education Review*, *68*, 53–67. https://doi.org/10.1016/j.econedurev.2018.09.001

White, H. (1980). A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. *Econometrica*, *48*(4), 817. https://doi.org/10.2307/1912934

Wooldridge, J. M. (2016). *Introductory Econometrics: A Modern Approach* (5th ed.). South-Western Cengage Learning.