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Research Article

**Trade Openness, Foreign Direct Investment, and Human Capital as Drivers of
Total Factor Productivity: Evidence from Türkiye**

İbrahim Ethem Akyıldız^a

Abstract

Introduction: This article explores the role of trade openness, foreign direct investment, human capital, and R&D in shaping total factor productivity (TFP) in Türkiye. TFP is used as an indicator of how effectively an economy transforms its inputs into output, reflecting efficiency improvements, technological capability, and resource-use performance.

Method: The analysis relies on annual time-series observations for Türkiye. The TFP series is drawn from the Penn World Table, whereas trade openness and foreign direct investment are sourced from the World Bank database. Human capital is proxied by the ratio of university graduates to total population, calculated using data from the Turkish Statistical Institute (TurkStat) and the Council of Higher Education. The R&D series is obtained from TurkStat. The empirical strategy combines Fourier ADF unit root testing, RALS Fourier ADL cointegration analysis, DOLS estimation, and Toda–Yamamoto and Fourier Toda–Yamamoto causality procedures.

Results or Findings: The results provide evidence that the variables are connected over the long run. The DOLS estimates indicate positive productivity effects for human capital, trade openness, and foreign direct investment. R&D has a positive estimated coefficient, but the effect remains statistically insignificant. The causality findings reveal a one-directional link from trade openness to TFP.

Discussion or Conclusion: The results suggest that Türkiye's productivity performance is closely linked to external integration, foreign investment, and human capital accumulation. However, innovation efforts should be transformed more effectively into productivity gains through stronger absorptive capacity, university–industry cooperation, and technology-oriented policy design.

Keywords: total factor productivity, trade openness, Türkiye, foreign direct investment.

JEL Codes: O47, F43, F21, O32, J24

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Araştırma Makalesi

**Ticari Açıklık, Doğrudan Yabancı Yatırımlar ve Beşeri Sermayenin Toplam
Faktör Verimliliğinin Belirleyicileri Olarak Rolü: Türkiye'den Kanıtlar**

İbrahim Ethem Akyıldız^a

Öz

Giriş: Bu çalışma, Türkiye’de toplam faktör verimliliğinin belirleyicilerini ticari açıklık, doğrudan yabancı yatırımlar, beşeri sermaye ve araştırma-geliştirme değişkenleri çerçevesinde incelemektedir. Toplam faktör verimliliği, uzun dönemli ekonomik performansın temel göstergelerinden biri olarak, ekonominin kaynakları ne ölçüde etkin kullandığını, teknolojik kapasitesini ve üretim sürecindeki verimlilik kazanımlarını yansıtmaktadır.

Yöntem: Çalışmada Türkiye’ye ait yıllık zaman serisi verileri kullanılmıştır. Toplam faktör verimliliği Penn World Table veri tabanından, ticari açıklık ve doğrudan yabancı yatırımlar Dünya Bankası’ndan, beşeri sermaye TÜİK ve YÖK verilerinden, Ar-Ge değişkeni ise TÜİK’ten elde edilmiştir. Ampirik analizde Fourier ADF birim kök testi, RALS Fourier ADL eşbütünleşme testi, DOLS tahmincisi ile Toda–Yamamoto ve Fourier Toda–Yamamoto nedensellik testleri uygulanmıştır.

Sonuçlar ya da Bulgular: Analiz sonuçları, değişkenlerin uzun dönemde birlikte hareket ettiğini ortaya koymaktadır. DOLS sonuçları, ticari açıklık, beşeri sermaye ve doğrudan yabancı yatırımların toplam faktör verimliliğini pozitif etkilediğini; Ar-Ge değişkeninin ise pozitif ancak istatistiksel olarak anlamsız bir katsayıya sahip olduğunu ortaya koymaktadır. Nedensellik analizi, ticari açıklıktan toplam faktör verimliliğine doğru nedensellik ilişkisi bulunduğunu göstermektedir.

Tartışma ya da Yapılan Çıkarımlar: Sonuçlar, Türkiye’nin verimlilik performansının dışa açıklık, yabancı yatırım ve beşeri sermaye birikimiyle yakından ilişkili olduğunu göstermektedir. Bununla birlikte, Ar-Ge faaliyetlerinin verimlilik kazanımlarına dönüşebilmesi için beşeri sermaye niteliğinin, üniversite-sanayi iş birliğinin ve teknoloji odaklı politika tasarısının güçlendirilmesi gerekmektedir.

Anahtar Kelimeler: toplam faktör verimliliği, ticari açıklık, Türkiye, doğrudan yabancı yatırımlar.

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Introduction

Total factor productivity (TFP) helps explain long-run economic performance by showing the growth component that cannot be explained by labour and capital accumulation alone. In this respect, TFP reflects how efficiently economies combine inputs, organise production, adopt new technologies, and transform knowledge into output. Rather than being treated as a narrow indicator of technological change, TFP should be understood as a broader measure of productivity performance that may reflect efficiency gains, technological progress, organisational improvements, resource allocation, and other factors shaping production outcomes (Haider et al., 2021; Radlo & Tomeczek, 2022). Historical studies further indicate that TFP growth has been an important driver of labour productivity and long-term economic development, especially during periods of technological, organizational, and infrastructural change. For this reason, identifying the factors that shape TFP is important for understanding how economies can maintain growth beyond the accumulation of labour and capital. These determinants include knowledge creation, technology transfer, human capital formation, trade openness, imports of advanced goods, institutional quality, financial development, infrastructure, competition, and absorptive capacity, all of which may influence the extent to which economies convert resources and knowledge into productivity-based development (Isaksson, 2007).

Within this context, the four variables considered in the study—trade openness, foreign direct investment, human capital, and R&D—are treated as factors that may support improvements in total factor productivity. Trade openness may enhance productivity by increasing exposure to foreign competition, imported intermediate goods, capital equipment, and external knowledge flows, while FDI may contribute to productivity through technology transfer, managerial know-how, and spillover effects. Evidence from Pakistan shows that patents, imported machinery, trade openness, education, and financial development support TFP growth, indicating that external integration and domestic capability may jointly shape productivity performance (Saleem et al., 2019). Similarly, evidence from Asian economies suggests that ICT, governance, investment, and technological capability are important for TFP, although R&D does not always produce statistically significant productivity gains when domestic absorptive capacity remains limited (Afzal & Ahmad, 2018). Recent studies suggest that R&D is closely linked to technological progress, whereas external channels such as imports, ICT investment, and foreign technology linkages may contribute to productivity through efficiency improvements and diffusion effects (Haider et al., 2021; Santos, 2023). Overall, these studies suggest that openness, FDI, human capital, and R&D do not affect productivity in isolation; rather, their contribution to TFP depends on the extent to which economies can absorb external knowledge, strengthen domestic innovation capacity, and transform technological interaction into sustained efficiency and productivity gains.

Türkiye provides a relevant case for examining these channels because its recent growth experience combines increasing external integration, foreign capital inflows, expanding higher education, and efforts to strengthen domestic R&D capacity. Despite these developments, transforming openness, FDI, human capital, and innovation efforts into sustained productivity gains remains a central challenge for the Turkish economy. This makes Türkiye a suitable case for analysing whether external knowledge channels and domestic absorptive capacity jointly contribute to total factor productivity. In this respect, the Turkish case allows the study to evaluate how an emerging economy seeking productivity-based growth converts trade integration, foreign investment, human capital formation, and R&D efforts into efficiency and technological upgrading. Previous studies on Türkiye provide important evidence on different dimensions of productivity. FDI is found to support both TFP and economic growth in the long

run, while financial openness, innovation, FDI, financial development, macroeconomic stability, and institutional quality are identified as important determinants of productivity performance (Arisoy, 2012; Serdaroğlu, 2015). The role of human capital, however, appears more nuanced. Although cross-country evidence suggests that education contributes to productivity growth, this effect does not clearly materialize in Türkiye, while more recent regional evidence shows that human capital is an important factor behind output growth but that scale inefficiencies may limit overall TFP performance (Saygılı et al., 2005; Yiğiteli & Şanlı, 2024). Sectoral and firm-level studies also indicate that Türkiye's productivity performance differs across banking, agriculture, energy, manufacturing, and regions. In the banking sector, productivity gains are mainly linked to efficiency improvements rather than technological progress; in agriculture, some studies report weak technological change, while others find productivity gains driven mostly by efficiency improvements; and at the firm level, productivity dispersion remains high across manufacturing firms (Isik & Hassan, 2003; Ozden, 2014; Sözen & Alp, 2013). However, the existing Turkish literature generally examines these channels separately or focuses on specific sectors, regions, or institutional dimensions. Therefore, there is a need for a more integrated empirical framework that evaluates how trade openness, FDI, human capital, and R&D jointly affect TFP in Türkiye. Such a framework is particularly important because the productivity effects of external openness and foreign investment depend on domestic absorptive capacity and innovation capability.

This study contributes to the literature by examining Türkiye's productivity dynamics through an empirical model that combines external integration variables with domestic capability indicators. In this framework, trade openness and foreign direct investment capture external channels, while human capital and R&D represent the domestic capacity to absorb and generate knowledge. By doing so, it evaluates both external knowledge channels and domestic absorptive and innovation capacities in explaining Türkiye's productivity performance. From a methodological perspective, the analysis is designed as a time-series investigation that allows for possible structural changes. To this end, the Fourier ADF test is employed to assess unit-root properties, followed by the RALS Fourier ADL approach for the cointegration analysis. DOLS is then used to obtain the long-run coefficients, whereas the direction of causality is evaluated through the Toda–Yamamoto and Fourier Toda–Yamamoto tests. This empirical design allows the study to capture the long-run and causal dynamics among productivity, external openness, foreign investment, human capital, and innovation capacity more comprehensively. Beyond its empirical contribution, the study is also expected to provide policy-relevant insights for Türkiye by clarifying how productivity-enhancing channels can be strengthened in an economy characterized by external integration, technological upgrading needs, and the challenge of transforming human capital and innovation efforts into sustained efficiency gains. In this respect, the findings may also be relevant for emerging economies with comparable structural features, particularly those seeking to convert openness, investment, and domestic capabilities into long-term productivity growth.

Theoretical Framework and Related Literature

Theoretical Framework and Research Question

The study's theoretical argument is developed from growth theory and the growth-accounting tradition. In this tradition, Tinbergen (1942), Abramovitz (1956), and Solow (1957) show that output growth is not driven only by labour and capital accumulation. The remaining part of growth is therefore associated with technological progress, efficiency improvements, and the way inputs are used over time. The human capital approach developed by Schultz (1961) further emphasizes that education, skills, and knowledge improve the productive

capacity of labour. Endogenous growth theory, particularly Romer's (1990) contribution, extends this view by treating knowledge creation, innovation, and R&D as internal sources of technological progress.

Building on this theoretical background, total factor productivity in this study is explained through the interaction between external knowledge channels and domestic absorptive capacity. Trade openness and foreign direct investment represent external mechanisms through which economies may access foreign technologies, imported intermediate goods, capital equipment, managerial knowledge, competitive pressure, and international production networks. However, these external channels do not automatically generate productivity gains. Their impact depends on the ability of the domestic economy to absorb, adapt, and use external knowledge effectively. Human capital strengthens this absorptive capacity by improving workers' skills, learning capacity, and ability to adopt new technologies. R&D, in turn, represents the domestic innovation effort required to transform knowledge into new production processes, efficiency improvements, and technological upgrading. In this sense, trade openness, FDI, human capital, and R&D function as interrelated determinants of TFP. While openness and FDI create channels for accessing foreign knowledge and technology, human capital and R&D shape the economy's ability to transform this knowledge into lasting productivity gains.

Within this theoretical framework, the research is guided by the following question:

RQ: How do foreign investment, trade openness, human capital formation, and R&D activity influence Türkiye's total factor productivity?

This research question is designed to examine whether Türkiye's productivity performance is shaped mainly by external integration channels, domestic capability-building mechanisms, or the interaction between the two. Trade openness and FDI are expected to capture the role of external knowledge diffusion, international competition, and technology transfer, while human capital and R&D represent the domestic capacity to absorb, adapt, and generate knowledge. In this respect, the study does not treat these variables as isolated determinants, but as interconnected channels through which external openness and domestic innovation capacity may jointly influence total factor productivity in Türkiye. This objective is particularly relevant for Türkiye, where the coexistence of external integration, human capital expansion, and R&D efforts raises the question of whether these channels can be transformed into sustained productivity gains.

Literature Studies

In the Turkish context, the literature on TFP has developed around the broader question of whether productivity gains are mainly driven by external openness, foreign direct investment, human capital accumulation, technological capability, sectoral efficiency, or regional development dynamics. Earlier evidence highlights foreign direct investment as an important mechanism through which capital accumulation and technology spillovers may strengthen productivity and growth, as shown by Arisoy (2012), who reports a positive long-run relationship between FDI, TFP, and economic growth in Türkiye. This external-openness perspective is complemented by studies focusing on financial liberalization and financial openness. Isik and Hassan (2003) report that productivity improvements in Turkish commercial banking after deregulation were driven mainly by efficiency gains rather than advances in technology, while Serdaroğlu (2015) provides broader macroeconomic evidence that financial openness, together with human capital, innovation, FDI, financial development, macroeconomic stability, and institutional quality, contributes positively to TFP. However, the

role of human capital appears more complex in the Turkish case. Although Saygılı et al. (2005) find that education generally supports productivity growth across countries, they report that this effect does not clearly materialize for Türkiye, suggesting that increases in educational attainment do not automatically translate into productivity gains unless they are supported by quality improvements and a suitable technological and institutional environment. More recent regional evidence by Yiğiteli and Şanlı (2024) reinforces the importance of human capital for output growth, but also shows that scale inefficiencies may limit overall TFP performance across Turkish regions. Sectoral studies further indicate that Türkiye's productivity problem is not uniform across the economy. In agriculture, Ozden (2014) reports a decline in TFP mainly due to weak technological change. Energy-related studies also point to an efficiency challenge: Sözen and Alp (2013) and İskender and Sözen (2016) show that although Türkiye has achieved some improvements in energy performance, it still lags behind European benchmarks in the effective use of energy inputs. In addition, Ursavaş (2020) shows that demographic indicators such as income, urbanization, life expectancy, and population density are associated with a higher probability of TFP growth, whereas dependency ratios and fertility may weaken this probability. Finally, Olomola and Osinubi (2018), by placing Türkiye within the MINT country group, report that human capital and government stability contribute to long-run TFP performance, whereas FDI and corruption are found to have negative effects in their panel framework. The literature suggests that TFP is closely associated with external openness, FDI, human capital formation, and technological capability. Trade openness and FDI may affect productivity through competition, technology transfer, imported inputs, and knowledge spillovers, while human capital determines the economy's capacity to absorb and effectively use these external gains. R&D, in turn, represents the domestic innovation capacity required to transform knowledge, skills, and external linkages into sustained productivity improvements. However, the Turkish evidence also indicates that these channels do not operate automatically. The effects of openness, foreign investment, human capital, and R&D on productivity depend on human capital quality, technological capacity within the economy, and the ability to turn external integration and innovation efforts into efficiency gains and technological progress.

International evidence on total factor productivity shows that productivity dynamics are shaped by a wide set of factors, including technological capability, R&D, human capital, trade openness, imported technology, digital transformation, environmental regulation, energy efficiency, and regional heterogeneity. In this literature, technological progress and innovation appear as central channels through which economies improve productivity. Haider et al. (2021) find that R&D supports technological progress in advanced manufacturing sectors, whereas imports and ICT investment contribute to productivity mainly through efficiency gains and delayed technology diffusion. In emerging economies, Saleem et al. (2019) provide evidence from Pakistan that patents, imported machinery, trade openness, education, and financial development support TFP growth, while inflation weakens productivity performance. Recent evidence further strengthens the view that trade openness is one of the key channels through which productivity gains may emerge. Wu and Han (2022) show that economic openness enhances city-level TFP in China through trade facilitation, infrastructure connectivity, technical efficiency, and technological progress. de Almeida et al. (2024) reach a comparable conclusion for Brazil, showing that trade openness is positively associated with TFP over both short- and long-term horizons, whereas absorptive capacity does not have a statistically significant direct effect. In their analysis of BRICS and D-8 economies, Iftikhar et al. (2025) report an overall positive link between openness and TFP and further suggest that innovation reinforces this productivity channel, although the size and direction of the estimates vary across country groups. Dai et al. (2025) add evidence from China by showing that digital trade raises green TFP, with trade openness and FDI further supporting this improvement. These findings

suggest that openness can enhance productivity when it facilitates access to foreign technology, imported machinery, knowledge spillovers, infrastructure connectivity, and broader market integration. However, the effect of external integration depends on domestic absorptive capacity, especially human capital and innovation capability. Afzal and Ahmad (2018), focusing on Asian economies including Türkiye, also report that ICT, governance, and investment are positively linked to TFP, whereas R&D has a positive but statistically insignificant coefficient, indicating that innovation inputs may not automatically generate productivity gains unless they are supported by institutional and technological capacity.

Recent studies also emphasize that the productivity effects of FDI are not automatic and depend on spillover mechanisms, firm linkages, ownership structure, institutional conditions, and absorptive capacity. Bournakis et al. (2022) examine how multinational enterprises shape domestic firms' TFP and show that productivity gains mainly arise through backward vertical spillovers, while horizontal spillovers are weaker and depend on foreign ownership structure and domestic firms' ability to absorb external knowledge. Santos (2023), reviewing macroeconomic and microeconomic models on the FDI–productivity nexus, concludes that empirical evidence remains mixed and that forward linkages, absorptive capacity, institutional quality, human capital, and technology transfer mechanisms should be more explicitly incorporated into empirical models. Makiela and Ouattara (2026) provide additional evidence that FDI contributes to TFP growth in developing countries only when it exceeds a certain threshold and follows a sustained upward trajectory. Malik and Sah (2026), in contrast, find that FDI inflows are positively associated with GDP and trade openness but negatively associated with TFP in expanded BRICS economies, indicating that the FDI–productivity link may vary across country samples and periods. Evidence from middle-income and emerging economies further links FDI, openness, and productivity to growth performance. Duong et al. (2022) report growth-enhancing effects of FDI and trade openness in middle-income economies, while Le et al. (2024) show that FDI and TFP jointly support growth performance in the same country group. Hao (2023) also reports that FDI supports China's industrial growth, whereas the long-run role of trade openness remains statistically limited. Taken together, this literature suggests that FDI can support productivity when it generates technology transfer, vertical linkages, knowledge spillovers, and learning effects, but its impact may remain limited or even ambiguous when domestic absorptive capacity, institutional quality, or productive linkages are weak.

More recent studies broaden the productivity discussion by incorporating digitalization, environmental quality, and energy efficiency. Pan et al. (2022) report a positive and nonlinear association between the digital economy and TFP in China, especially in more developed eastern regions, while Zhang et al. (2023) find that digitalization improves agricultural green TFP through agricultural technological innovation. Environmental and energy-related studies also indicate that productivity gains increasingly depend on sustainable production capacity. Fan et al. (2022) show that environmental technological progress and environmental regulation can improve green TFP, while Liang and Wang (2023) find that TFP growth contributes to better environmental quality through innovation input. Santos et al. (2021) add another perspective by showing that energy efficiency is strongly linked to TFP in Portugal and may act as an important driver of technical change. Finally, Zhang et al. (2024), using data from 171 economies, show that both TFP and green TFP support clean energy transition, although the effect of green TFP is stronger, particularly through green efficiency improvements. A broader review-based literature also supports this multidimensional view of productivity. Radlo and Tomeczek (2022) identify FDI, globalization and international trade, human capital, ICT, R&D and innovation, global value chains, labor allocation, and regional differences as major

productivity-related factors. Zhang et al. (2021) group the drivers of green total factor productivity under technical, economic, and government-related dimensions and show that technological progress and technological efficiency play a decisive role. Sharma et al. (2025), based on a review of 425 green total factor productivity studies, identify environmental regulation, green financing, industrial structure, digital technologies, technological innovation, and energy transition as major themes in this literature. Çetin et al. (2025) find that green growth and higher energy productivity are associated with lower CO₂ emissions in G7 economies, whereas Yaqoob et al. (2022) provide sectoral evidence from Pakistan that climate variation and changing consumption patterns have important implications for agricultural TFP.

Data and Model

The empirical model focuses on Türkiye's total factor productivity and four potential drivers: trade openness, foreign direct investment, human capital, and R&D. The dataset consists of annual observations for the period 1990–2023, with the sample range limited by the joint availability of the variables. The specification follows the productivity-oriented studies of Saleem et al. (2019) and Olomola and Osinubi (2018), which relate productivity outcomes to external integration, innovation capacity, human capital formation, and macroeconomic conditions. TFP is taken from the Penn World Table. Trade openness is defined as exports plus imports relative to GDP. FDI corresponds to net inflows as a share of GDP, whereas R&D is represented by R&D expenditures relative to GDP. The human capital proxy is constructed as the number of higher education graduates divided by total population, using data from TurkStat and the Council of Higher Education. Before estimation, all variables are transformed into logarithmic form.

Table 1

Description of Variables

Symbol	Variable	Definition	Source
TFP	Total factor productivity	Total factor productivity index	Penn World Table
TRADE	Trade openness	Sum of exports and imports as a percentage of GDP	World Bank
FDI	Foreign direct investment	Foreign direct investment, net inflows (% of GDP)	World Bank
HC	Human capital	Ratio of higher education graduates to total population	TurkStat and Council of Higher Education
RD	Research and development	R&D expenditures as a percentage of GDP	TurkStat

Note. Created by the author.

Following the theoretical framework and the empirical literature, the model is specified as follows:

$$\ln TFP_t = \alpha_0 + \alpha_1 \ln TRADE_t + \alpha_2 \ln FDI_t + \alpha_3 \ln HC_t + \alpha_4 \ln RD_t + \varepsilon_t$$

where TFP_t denotes total factor productivity, $TRADE_t$ represents trade openness, FDI_t refers to foreign direct investment, HC_t denotes human capital, and RD_t represents

research and development. The subscript t indicates time, α_0 is the constant term, and ε_t is the error term. The coefficients α_1 , α_2 , α_3 , and α_4 capture the long-run elasticities of total factor productivity with respect to trade openness, FDI, human capital, and R&D, respectively.

The model assumes that trade openness may affect TFP through international competition, access to imported intermediate and capital goods, and technology diffusion. FDI is expected to influence productivity through capital accumulation, managerial knowledge, production technologies, and spillover effects. Human capital reflects the economy's absorptive capacity and its ability to use and adapt external knowledge. R&D represents domestic innovation capacity and the potential to generate technological improvements. Therefore, the model evaluates both external knowledge channels and domestic capability-building mechanisms as factors that shape productivity performance in Türkiye.

Econometric Methodology

The empirical strategy proceeds in two stages: first, it examines whether a long-run relationship exists among the variables; second, it investigates the direction of causal interactions. Total factor productivity is specified as the outcome variable, while trade openness, foreign direct investment, human capital, and R&D are included as explanatory factors. All series are log-transformed before the estimation stage to limit scale-related variation and to express the coefficients in elasticity terms.

The analysis first determines whether the series contain unit roots. To do so, the study applies the standard Augmented Dickey–Fuller test together with the Fourier ADF test introduced by Enders and Lee (2012). After the integration structure of the variables is clarified, the study turns to the RALS Fourier ADL test to evaluate cointegration. The advantage of this approach is that it combines the Fourier ADL framework of Banerjee et al. (2017) with a structure that can account for gradual breaks in the long-run relationship. The use of Fourier-based techniques is also consistent with Ilkay et al. (2021), who emphasize the usefulness of Fourier terms in modelling smooth structural shifts in macroeconomic time series. When the cointegration relationship is verified, the long-run parameters are estimated with the Dynamic Ordinary Least Squares approach of Stock and Watson (1993). In the final stage, causal interactions are tested through the Toda–Yamamoto (1995) procedure and its Fourier-augmented version developed by Nazlioglu et al. (2016).

Fourier ADF Unit Root Test

The integration properties of the variables are evaluated before the cointegration stage. For this purpose, the study uses the conventional ADF test together with the Fourier ADF procedure developed by Enders and Lee (2012). The Fourier-based test is appropriate for macroeconomic series because such variables may be affected by gradual shifts, nonlinear movements, or regime changes over time. Its main advantage is that it can account for smooth structural changes endogenously, without imposing a predetermined break date or break form. The Fourier ADF specification can be written as follows:

$$\Delta y_t = \alpha_0 + \gamma y_{t-1} + \alpha_1 \sin\left(\frac{2\pi kt}{T}\right) + \alpha_2 \cos\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^p \delta_i \Delta y_{t-i} + \varepsilon_t$$

where y_t denotes the variable being tested, k is the Fourier frequency, T is the number of observations, p is the optimal lag length, and ε_t is the error term. The unit root null hypothesis is tested against the alternative of stationarity. The relevance of the Fourier components is assessed through the F-statistic. When these components are significant, the Fourier ADF

findings are used; when they are not significant, the results of the standard ADF test are taken as the basis for interpretation.

RALS Fourier ADL Cointegration Test

Once the integration order of the series is identified, the study tests whether total factor productivity, foreign direct investment, human capital, trade openness, and R&D share a stable long-run association by using the RALS Fourier ADL cointegration procedure. The Fourier ADL framework of Banerjee et al. (2017) is suitable for this purpose because it permits the cointegration relationship to be analysed in the presence of smooth and gradual structural changes. This feature is important for Türkiye, where productivity dynamics may be affected by trade liberalisation, financial integration, economic crises, policy changes, and transformations in the innovation environment.

The RALS Fourier ADL approach extends the Fourier ADL framework by incorporating the residual augmented least squares procedure. This extension improves the power of the test by using additional information from non-normally distributed residuals. Therefore, the RALS Fourier ADL test provides a more flexible and robust framework for testing cointegration under possible nonlinearities and structural changes.

The general Fourier ADL specification can be written as follows:

$$\Delta y_t = \alpha_0 + \phi y_{t-1} + \theta' x_{t-1} + \sum_{i=1}^p \beta_i \Delta y_{t-i} + \sum_{j=0}^q \lambda_j \Delta x_{t-j} + \alpha_1 \sin\left(\frac{2\pi kt}{T}\right) + \alpha_2 \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t$$

where y_t represents total factor productivity, x_t denotes the vector of explanatory variables including trade openness, FDI, human capital, and R&D, and the sine and cosine terms capture smooth structural changes. The test is conducted under the null hypothesis of no cointegration. If this null hypothesis is rejected, it indicates that the variables are linked by a stable long-run equilibrium relationship.

Dynamic Ordinary Least Squares Estimator

After the presence of cointegration is established, the study estimates the long-run coefficients by applying the Dynamic Ordinary Least Squares estimator of Stock and Watson (1993). DOLS is used because it addresses potential endogeneity and serial correlation problems through the inclusion of leads and lags of the first-differenced explanatory variables. This makes the estimator suitable for long-run parameter estimation in cointegrated systems.

The DOLS specification used in this study can be expressed as follows:

$$\ln TFP_t = \alpha_0 + \alpha_1 \ln TRADE_t + \alpha_2 \ln FDI_t + \alpha_3 \ln HC_t + \alpha_4 \ln RD_t + \sum_{j=-q}^q \delta_j \Delta X_{t-j} + \varepsilon_t$$

where TFP_t denotes total factor productivity, $TRADE_t$ represents trade openness, FDI_t refers to foreign direct investment, HC_t denotes human capital, and RD_t represents research and development. Because the variables are transformed into logarithms, the estimated parameters can be interpreted as long-run elasticities. In this context, α_1 , α_2 , α_3 , and α_4 represent the long-run effects of trade openness, FDI, human capital, and R&D on total factor

productivity, respectively. The long-run specification also includes a linear trend and its squared term to account for possible nonlinear deterministic movements in TFP over time.

Toda–Yamamoto and Fourier Toda–Yamamoto Causality Tests

The final stage investigates causal directions among the variables by applying the Toda–Yamamoto and Fourier Toda–Yamamoto approaches. The Toda–Yamamoto approach conducts causality analysis within an augmented VAR structure. This procedure is suitable when the variables are either stationary at level or integrated of order one, provided that the maximum order of integration is properly determined.

The augmented VAR model can be written as follows:

$$Y_t = \alpha + \sum_{i=1}^{k+d_{max}} A_i Y_{t-i} + \varepsilon_t$$

where Y_t is the vector of variables, k is the optimal lag length, d_{max} is the maximum integration order, and ε_t is the error term. The causality relationship is tested through Wald restrictions imposed on the first k lagged coefficients.

The optimal lag length of the VAR model is determined using the Schwarz Information Criterion (SIC). The Toda–Yamamoto causality procedure is then implemented by augmenting the selected VAR lag order (p) with the maximum order of integration (d_{max}). The standard Toda–Yamamoto test, however, does not directly consider structural changes. Therefore, the Fourier Toda–Yamamoto causality test proposed by Nazlioglu et al. (2016) is also applied. This approach adds Fourier sine and cosine terms to the causality model, enabling the analysis to account for gradual shifts in the causal relationships among the variables. Thus, the Fourier Toda–Yamamoto test provides a more flexible approach for analysing whether trade openness, FDI, human capital, and R&D have predictive power for total factor productivity in Türkiye, and whether feedback effects exist from productivity to these explanatory variables.

Results

Unit Root Test Results

Before testing for cointegration, the integration order of each variable is assessed with the conventional ADF and Fourier ADF unit root tests. The choice between the two test results is based on the statistical significance of the Fourier terms. Specifically, the F-statistic is first used to test whether the Fourier components are statistically significant. When the Fourier terms are significant, indicating the presence of smooth structural changes, the Fourier ADF statistic is used to determine stationarity. When the Fourier terms are not significant, the conventional ADF statistic is used instead. For example, for LNTTP, the Fourier terms are significant at the level ($F = 19.697$); therefore, the Fourier ADF statistic (-1.399) is used, which fails to reject the unit root null hypothesis. At the first difference, the Fourier terms are not significant ($F = 2.321$), so the conventional ADF statistic (-6.705) is used, indicating stationarity. Hence, LNTTP is classified as $I(1)$. The same decision rule is applied consistently to all variables. Table 2 summarizes the unit root test findings.

Table 2*ADF and Fourier ADF Unit Root Test Results*

Variable	Form	Frequency	Fourier ADF F-stat.	ADF	Decision
LNTPP	Level	1	-1.399	19.697*	-2.576 I(1)
LNTPP	First difference	4	0.410	2.321	-6.705*
LNTRADE	Level	4	-0.164	4.758	-3.065 I(1)
LNTRADE	First difference	4	-4.493	5.126	-5.043*
LNFDI	Level	1	-3.630	4.314	-1.264 I(1)
LNFDI	First difference	5	-6.470	1.015	-6.391*
LNHC	Level	1	-3.420	8.919***	-0.608 I(1)
LNHC	First difference	4	-4.555	0.400	-6.110*
LNRD	Level	4	0.016	2.304	-0.486 I(1)
LNRD	First difference	4	-4.517	2.505	-7.244*

Note. Created by the author using data obtained from the Penn World Table, World Bank, TurkStat, the Council of Higher Education, and EViews statistical software. The symbols *, **, and *** refer to significance at the 1%, 5%, and 10% levels, respectively.

Applying the decision rule described above, none of the variables is found to be stationary at the level based on the appropriate unit root test selected according to the significance of the Fourier terms. After first differencing, however, the unit root null hypothesis is rejected for all variables. The results indicate that all variables are non-stationary in their level forms. However, after taking first differences, all variables become stationary. Therefore, LNTPP, LNTRADE, LNFDI, LNHC, and LNRD are integrated of order one, I(1). This finding provides the necessary basis for proceeding with the cointegration analysis.

Cointegration Test Results

After all variables are found to be integrated of order one, I(1), the study proceeds to examine whether total factor productivity, trade openness, FDI, human capital, and R&D are connected through a long-run relationship. For this purpose, the RALS Fourier ADL cointegration test is applied. The appropriate test specification is determined on the basis of the minimum AIC value, and the results are presented in Table 3.

Table 3*RALS Fourier ADL Cointegration Test Results*

Test specification	Value
Lag length of LNTPP	3
Lag length of LNTRADE	3
Lag length of LNFDI	3
Lag length of LNHC	3
Lag length of LNRD	2
Frequency	2
Minimum AIC	-5.015
Rho	0.420

Test	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value	Decision
Fourier ADL	-5.913	-5.645	-4.934	-4.593	Cointegration
RALS Fourier ADL	-12.484	-4.182	-3.495	-3.123	Cointegration

Note. Created by the author using data obtained from the Penn World Table, World Bank, TurkStat, the Council of Higher Education, and EViews statistical software.

The Fourier ADL statistic is calculated as -5.913, and its absolute value is greater than the critical values at the 1%, 5%, and 10% significance levels. The RALS Fourier ADL statistic, reported as -12.484, also exceeds all corresponding critical values in absolute terms. These findings lead to the rejection of the null hypothesis of no cointegration. Therefore, the results provide evidence of a stable long-run equilibrium relationship among total factor productivity, trade openness, FDI, human capital, and R&D in Türkiye.

Long-Run Coefficient Estimates

Since the cointegration tests indicate a long-run association among the variables, the next step is to estimate the long-run coefficients by using the DOLS estimator. This estimator is employed because it reduces possible endogeneity and serial correlation problems by incorporating leads and lags of the first-differenced explanatory variables. To assess the sensitivity of the long-run findings to the choice of estimator, the Canonical Cointegrating Regression (CCR) estimator is additionally employed as an alternative cointegration estimator. Table 4 presents the DOLS estimates.

Table 4*DOLS Long-Run Estimation Results*

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNTRADE	0.549643	0.094810	5.797339	0.0000
LNHC	0.439569	0.222322	1.977172	0.0667
LNFDI	0.059999	0.023531	2.549811	0.0222
LNRD	0.008327	0.095252	0.087420	0.9315
C	-0.873441	0.520206	-1.679028	0.1139
Trend	-0.072675	0.025004	-2.906535	0.0108
Trend²	0.000800	0.000251	3.182182	0.0062
Fourier sine term	-0.009079	0.009023	-1.006216	0.3303
Fourier cosine term	0.004285	0.011231	0.381570	0.7081

Note. Created by the author using data obtained from the Penn World Table, World Bank, TurkStat, the Council of Higher Education, and EViews statistical software. The dependent variable is LNTPP. Fixed leads and lags are set to 1.

The DOLS results show that trade openness, human capital, and FDI have positive long-run effects on total factor productivity. The coefficient of trade openness is positive and statistically significant, indicating that a 1% increase in trade openness increases TFP by approximately 0.550%. This result suggests that trade openness is the strongest long-run determinant of total factor productivity in the model.

The coefficient of human capital is also positive, showing that a 1% increase in human capital raises TFP by approximately 0.440%. However, the statistical significance of this coefficient is weaker than that of trade openness and FDI. This indicates that human capital contributes positively to productivity, but its effect may be more dependent on structural conditions such as education quality, skill formation, and the effective use of knowledge in production.

The coefficient of FDI is positive and statistically significant. A 1% increase in FDI increases TFP by nearly 0.060%. Although this effect is smaller than the effects of trade openness and human capital, it shows that foreign investment contributes to Türkiye's long-run productivity performance.

In contrast, the coefficient of R&D is positive but statistically insignificant. This indicates that R&D does not have a statistically meaningful direct effect on TFP over the examined period. Therefore, the results suggest that R&D expenditures may require stronger commercialization channels, production linkages, and innovation capacity before generating measurable productivity gains.

As a sensitivity analysis, the long-run coefficients were also estimated using the CCR estimator, and the results are reported in Appendix 1. The CCR estimates provide support for the main DOLS findings regarding trade openness and FDI, as both coefficients remain positive and statistically significant. R&D remains statistically insignificant under both estimators.

However, the human capital coefficient becomes statistically insignificant in the CCR estimation, indicating that the long-run evidence for human capital is sensitive to the choice of estimator.

To further examine the adjustment toward the long-run equilibrium, an error correction model (ECM) is estimated. The ECM results are presented in Table 5.

Table 5

Error Correction Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LNTRADE)	0.149352	0.087269	1.711400	0.0985
D(LNHC)	-0.076463	0.084334	-0.906663	0.3726
D(LNFDI)	-0.023913	0.019447	-1.229682	0.2294
D(LNRD)	0.038243	0.090281	0.423601	0.6752
ECT(-1)	-1.057711	0.363999	-2.905805	0.0072

To further examine the adjustment toward the long-run equilibrium, an error correction model (ECM) is estimated. The coefficient of the lagged error correction term, ECT(-1), is negative and statistically significant ($\beta = -1.058$, $p = 0.007$), confirming the presence of a long-run adjustment mechanism. Its magnitude slightly above unity indicates a relatively rapid adjustment process with some overshooting around the long-run equilibrium. Among the short-run coefficients, only trade openness is statistically significant at the 10% level ($\beta = 0.149$, $p = 0.099$), while human capital, FDI, and R&D are statistically insignificant.

Causality Test Results

In the final stage, the causal relationships among the variables are examined using both the Toda–Yamamoto and Fourier Toda–Yamamoto causality tests. The Fourier Toda–Yamamoto approach is useful because it allows for gradual structural shifts in causal dynamics. The results are presented in Table 5.

Table 5

Toda–Yamamoto and Fourier Toda–Yamamoto Causality Test Results

Causality Direction	Toda–Yamamoto Wald Stat.	Bootstrap p-value	Fourier TY Frequency	Fourier TY Wald Stat.	Bootstrap p-value
LNTRADE→LNTTP	10.356**	0.013	1	10.363*	0.004
LNHC → LNTTP	1.085	0.309	1	0.284	0.592
LNFDI → LNTTP	0.504	0.485	1	2.492	0.130
LNRD → LNTTP	0.391	0.824	1	0.580	0.747
LNTTP→ LNTRADE	1.476	0.485	1	0.023	0.877

Causality Direction	Toda– Yamamoto Wald Stat.	Bootstrap p- value	Fourier TY Frequency	Fourier TY Wald Stat.	Bootstrap p- value
LNTTP → LNHC	0.951	0.341	1	1.728	0.196
LNTTP → LNFDI	0.234	0.636	1	0.208	0.648
LNTTP → LNRD	3.360	0.212	1	1.852	0.414

Note. Created by the author using data obtained from the Penn World Table, World Bank, TurkStat, and the Council of Higher Education, and EViews statistical software. Bootstrap p-values are reported.

Both causality tests point to the same result: changes in trade openness help explain subsequent movements in total factor productivity. This outcome indicates that openness plays a predictive role in Türkiye’s productivity dynamics. However, no statistically significant causal relationship is found from human capital, FDI, or R&D to total factor productivity. Similarly, there is no evidence of reverse causality from total factor productivity to trade openness, human capital, FDI, or R&D. Overall, the causality evidence highlights trade openness as the most dynamic channel among the explanatory variables in explaining changes in total factor productivity.

Conclusion

This study examined how foreign direct investment, trade openness, human capital, and R&D influence Türkiye’s total factor productivity. The empirical findings provide a clear answer to the main research question: Türkiye’s total factor productivity is shaped mainly by external integration and domestic absorptive capacity, while innovation-related inputs require stronger institutional and productive linkages to generate statistically significant productivity gains. The cointegration evidence shows that the variables move together in the long run, suggesting that productivity dynamics in Türkiye reflect structural interactions rather than only short-term fluctuations. Instead, they reflect deeper structural relationships between openness, foreign investment, human capital formation, and innovation capacity.

The strongest long-run effect is found for trade openness. This result suggests that external integration is a central productivity-enhancing channel for Türkiye. In economic terms, trade openness may improve TFP by increasing access to imported intermediate and capital goods, exposing domestic firms to international competition, expanding market opportunities, and facilitating knowledge diffusion. The causality findings reinforce this interpretation by indicating that changes in trade openness help explain subsequent movements in TFP. This means that trade openness is not merely associated with productivity in the long run, but also has predictive power for productivity dynamics. This finding is supported by the results of Saleem et al. (2019), Wu and Han (2022), de Almeida et al. (2024), and Iftikhar et al. (2025), where openness is linked to productivity gains through trade, imported technology, infrastructure connectivity, market access, and innovation channels. Therefore, the Turkish evidence supports the broader view that openness contributes to productivity when it strengthens technology diffusion and efficiency-enhancing competition. The DOLS estimates indicate a positive long-run association between human capital and TFP; however, this finding should be interpreted cautiously, as the human capital coefficient is not statistically significant in the alternative CCR estimation. This finding is theoretically important because human capital

reflects how effectively an economy can absorb and apply knowledge from external sources. The result is consistent with studies emphasizing the role of education, skills, and absorptive capacity in productivity performance, such as Serdaroğlu (2015), Olomola and Osinubi (2018), Yiğiteli and Şanlı (2024), and Radlo and Tomeczek (2022). However, the relatively weaker statistical significance of human capital suggests that education and skill accumulation may not automatically generate productivity gains. For Türkiye, this implies that the quality of human capital, vocational skills, university–industry cooperation, and compatibility between education and technological transformation are crucial for converting human capital accumulation into productivity growth.

The FDI estimate is positive and statistically significant, showing that foreign investment contributes to Türkiye’s productivity performance, although its magnitude remains modest relative to the effects associated with openness and human-capital accumulation. Thus, FDI supports TFP but does not appear to be the dominant productivity channel. The result is consistent with Arısoy (2012) and Serdaroğlu (2015), who report positive productivity effects of FDI in Türkiye. It also aligns with Bournakis et al. (2022) and Santos (2023), who emphasize that the productivity impact of FDI depends on technology transfer, vertical linkages, spillover mechanisms, institutional quality, and absorptive capacity. However, recent evidence also shows that FDI does not always generate productivity gains automatically. For example, Makiela and Ouattara (2026) show that FDI contributes to TFP growth in developing countries only under certain threshold and trajectory conditions, while Malik and Sah (2026) report a negative association between TFP and FDI inflows in expanded BRICS economies. In this respect, the Turkish evidence suggests that FDI can support productivity more effectively when it is technology-intensive, connected with domestic firms, and embedded in stronger local production networks. In contrast, R&D has a positive estimate that is not statistically significant. This result should not be interpreted as evidence that R&D is unimportant for productivity. Rather, it indicates that R&D expenditures may not directly translate into measurable TFP gains unless they are effectively commercialized and linked to production processes. This finding is consistent with Afzal and Ahmad (2018), who report that R&D is positively related to TFP but lacks statistical significance in Asian economies. It also corresponds to the broader literature emphasizing that innovation-related productivity gains depend on absorptive capacity, institutional quality, technology-transfer channels, and well-functioning innovation systems. For Türkiye, the weak statistical role of R&D may reflect weaknesses in commercialization, private-sector R&D capacity, university–industry cooperation, and the time lag between innovation investment and productivity outcomes. The absence of statistically significant causality linking FDI, human capital, and R&D with TFP does not contradict their positive long-run coefficients. Instead, it suggests that these variables may influence productivity through slower and more structural mechanisms. Human capital accumulation, FDI spillovers, and R&D activities generally require time, institutional support, sectoral transformation, and firm-level linkages before they produce measurable productivity effects. Therefore, the causality findings identify trade openness as the most immediate and dynamic productivity channel, while FDI, human capital, and R&D appear to operate through long-run structural conditions.

The policy implications of the study follow directly from these findings. First, trade openness should be supported by policies that increase the technological content of exports, improve access to high-quality imported intermediate and capital goods, and help domestic firms integrate into global value chains. Second, FDI policies should go beyond attracting capital inflows and prioritize technology-intensive investments, stronger linkages between foreign and domestic firms, and greater spillover effects. Third, human capital policies should

give priority to raising education quality, strengthening vocational training, developing digital skills, and expanding university–industry cooperation. Finally, R&D policies should aim to improve the effectiveness of innovation expenditures by supporting commercialization, private-sector innovation, research infrastructure, and cooperation between firms, universities, and public institutions. This study has some limitations that may guide future research. First, the empirical analysis relies on aggregate Turkish time-series data, which does not allow sectoral or firm-level heterogeneity to be examined. Second, the study focuses on selected determinants of TFP, whereas additional factors, including institutional quality, the development of financial systems, and green transformation, may also shape productivity dynamics. Third, the R&D variable captures innovation input, but it may not adequately represent the quality, efficiency, or commercialization capacity of innovative activities. Future studies may therefore examine sectoral differences, firm-level spillovers, regional productivity gaps, and the role of digital and green transformation in Türkiye’s productivity performance. Overall, the findings suggest that Türkiye’s productivity challenge should be understood as a structural issue that requires stronger connections between openness, foreign investment, human capital formation, and innovation capacity.

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Appendix

Appendix 1: CCR Long-Run Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNTRADE	0.362501	0.021438	16.908950	0.0000
LNHC	-0.022196	0.027053	-0.820455	0.4200
LNFDI	0.012192	0.005755	2.118540	0.0447
LNRD	-0.018891	0.027639	-0.683509	0.5008
C	-1.232859	0.065933	-18.698550	0.0000
Trend	-0.017267	0.004017	-4.298082	0.0002
Trend²	0.000263	0.000044	6.016116	0.0000
Fourier sine term	-0.003724	0.003337	-1.116096	0.2754
Fourier cosine term	0.015423	0.003262	4.728199	0.0001

Note. Created by the author using data obtained from the Penn World Table, World Bank, TurkStat, the Council of Higher Education, and EViews statistical software. The dependent variable is LNTPP

Information About the Article/Makale Hakkında Bilgiler

The Ethical Rules for Research and Publication / Araştırma ve Yayın Etiği

The author declared that the ethical rules for research and publication were followed while preparing the article.

Yazar makale hazırlanırken araştırma ve yayın etiğine uyulduğunu beyan etmiştir.

Conflict of Interests/ Çıkar Çatışması

The author has no conflict of interest to declare.

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The draft process of the manuscript/ Taslağın Hazırlanma Süreci İ.E.A., Data Collection/Verilerin Toplanması İ.E.A., Writing the Manuscript/ Makalenin Yazılması İ.E.A., Submit, Revision and Resubmit Process/ Başvuru, Düzeltme ve Yeniden Başvuru Süreci İ.E.A.

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