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Relationship between trade openness, innovation, and total factor productivity in BRICS and D-8 countries

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Abstract

Research Background: Understanding how trade openness (TO) and innovation interact to drive total factor productivity (TFP) growth is a critical debate. Policymakers in BRICS and D-8 countries require evidence-based insights to formulate strategies that effectively integrate trade and innovation policies.
Purpose of the article: The purpose is to assess whether and how TO contributes to TFP growth, emphasizing interaction with innovation, and to provide insights to policymakers in BRICS and D-8 countries in formulating strategies that integrate trade and innovation policies.
Methods: The study employs robust econometric techniques to address panel data challenges and ensure reliable results. These techniques help to accurately capture the effects of TO on TFP while considering the moderating role of innovation. The study also includes a heterogeneous analysis to account for differences in the developmental contexts between BRICS and D-8 countries.
Findings & value added: The findings reveal that TO positively and significantly impacts TFP, driven by improved resource allocation and access to new markets. Innovation significantly enhances the productivity benefits of TO, particularly in BRICS. The heterogeneous analysis indicates consistent TFP improvements across both groups, although the impact of innovation varies, reflecting different developmental stages. The positive impact of TO on TFP in both groups highlights the importance of integrating trade and innovation policies. The study underscores the importance of reducing trade barriers and investing in research and development and patent protection to maximize productivity. These insights offer valuable guidance for policymakers in tailoring trade and innovation strategies for BRICS and D-8 countries.

Introduction

The recent debate on international trade policy highlights the significant challenges that countries face in liberalizing their economies. Wealthy nations advocate for less restrictive trade policies in poorer nations while strategically safeguarding their markets. Moreover, trade openness (TO) is a metric for assessing a country's level of engagement in the global trade network. Since Adam Smith and David Ricardo, two of the founders of modern economics, saw the benefits of specialization and trade as the foundation for national prosperity, productivity has emerged as a significant concern. In economic theory, productivity[1] is viewed as the "ultimate

[1] During the 1950s, Solow and Swan created a growth model that considered changes in an economy's physical capital, labor, and total factor productivity (TFP). Theoretical econo-

driver of growth and development in the world economy" and corresponds to the "two truly big riddles of economics" (Krugman, 1994). The emphasis on productivity originated when Hicks (1939) and Schumpeter (1942) stressed the importance of productivity advances in the early half of the 20th century as Western countries began to improve after the Great Depression[2]. Resources moving from less to more productive sectors was necessary for economic growth (Ben-David & Loewy, 1998; Easterly & Levine, 2001; Jorgenson *et al*., 2008).

Historically, economic theory has acknowledged productivity as an important factor in boosting economic growth[3]. Endogenous growth models emphasize the importance of human capital, human resources, and knowledge capital in technology innovation, adoption, and absorption in driving productivity (Sohag *et al*., 2015). Empirical studies have supported this view, demonstrating that investing in research and development (R&D) yields strong returns through technological innovation and adoption, especially when combined with trade liberalization. These insights underscore why productivity has become a contentious topic in industrialized and emerging countries (Chand & Sen, 2002). Intense debates regarding trade liberalization and its influence on various economic variables have been provoked by recent technological advancements, unprecedented innovations, and the evolution of trade policies and their modifications.

Trade theory posits that expanding trade will increase labor and TFP because of the benefits derived from economies of scale (Grossman & Helpman, 1991b). Raghutla (2020) revealed that trade liberalization influences various macroeconomic variables and economic growth while generating new economic activities and altering the sectoral composition of output in the long run. However, the long-term productivity gains from TO remain contested, with evidence suggesting heterogeneity in the outcomes across different economies. While most past empirical debates and research

mists have been addressing this issue at least since the 1980s. Past studies included technical advancement as a driver of long-term growth through R&D.

[2] Since the decline of communist regimes in Eastern Europe and East Asia during the early 1990s and the subsequent decrease in productivity growth in developed countries during the 1970s and 1980s, there has been a notable surge in the interest in understanding the factors that drive growth and productivity.

[3] Neoclassical growth accounting considers productivity and input accumulation as two separate but intertwined factors that determine output growth. Exogenous processes are considered as such in the neoclassical paradigm optimal growth models and the Solow's growth model.

have focused on the impact of TO on aggregate economic growth and development (Asghar *et al*., 2024), Miller and Upadhyay (2000) argued that most studies have suggested that increasing trade improves TFP, although there is no unanimous agreement. This study contributes to the literature by challenging the consensus and exploring how variations in gains from trade, economies of scale, and innovation shape the trade and TFP relationship over time and across economies.

Several studies have examined the effect of trade liberalization on various domains of the economy, including economic growth (Raghutla, 2020), foreign direct investment (Rehman & Islam, 2023), knowledge spillover (Gonçalves *et al*., 2021), capital accumulation (Damasceno & Guedes, 2024), technological breakthroughs, and changes in trade policy (Shabbir *et al*., 2023), examining the impact of trade on specialization and its overall benefits. Sakyi *et al*. (2015) found that trade substantially and consistently influences labor productivity. Further, Banday *et al*. (2021) proposed that trade liberalization impacts various macroeconomic factors, affecting economic growth and altering the sectoral distribution of output over time. Similarly, another study highlighted that extensive trade liberalization can modify the composition of production, which is crucial for understanding productivity dynamics (Barros & Martínez-Zarzoso, 2022). While numerous studies have explored that trade liberalization enhances GDP growth through efficient resource allocation and economies of scale (Asghar *et al*., 2024; Obstfeld & Rogoff, 2000), there is limited empirical evidence addressing how these mechanisms influence TFP in distinct economic blocs, such as BRICS and D-8 countries. This study fills this gap, offering a deeper understanding of the trade–TFP relationship in these contexts.

Economic theory suggests several pathways through which TO can influence TFP. First, TO encourages competition, which can lead to more efficient resource allocation and productivity improvements (Melitz & Trefler, 2012). Second, it allows countries to specialize in industries with a comparative advantage, leading to gains from trade (Krugman, 1994; Trejos & Barboza, 2015). Third, TO facilitates the diffusion of technology and knowledge across borders, enhancing innovation and productivity (Grossman & Helpman, 1991b). Recent studies on innovation energy consumption, TO, and how financial openness promotes completeness, such as Asghar *et al*. (2024) and (Aman *et al*., 2024), highlight the need to examine the moderating role of innovation in amplifying these benefits. This study builds on such insights, emphasizing how technological advancements and

R&D strengthen the productivity gains from trade liberalization, particularly in emerging economies. Therefore, investigating the moderating role of innovation is particularly noteworthy and provides a deeper understanding of how TO translates into productivity gains.

Our study focuses on the impact of TO on TFP while considering the moderating role of innovation in BRICS and D-8 countries from 1990 to 2023. Using robust econometric techniques, including generalized method of moments (GMM) estimators, we address the endogeneity and cross-sectional dependence (CD) issues in the panel data. First, the findings reveal that TO positively and significantly impacts TFP, indicating that reducing trade barriers enhances productivity by enabling efficient resource allocation and access to new markets. Second, innovation, used as a moderating factor, significantly amplifies TFP, particularly in BRICS, highlighting the role of technological advancement in shaping the TO and TFP relationship. Finally, group analysis reveals that heterogeneity with TO consistently improves TFP across both groups, while innovation's impact varies due to differing developmental and structural contexts. While TO consistently improves TFP across both groups, the effect of innovation varies, indicating different developmental and structural contexts in these regions.

TFP has long been a central economic focus due to its critical role in explaining economic growth and development. Traditional studies, rooted in neoclassical growth theories, emphasize the role of capital and labor accumulation in driving growth, with TFP capturing the residual impact of technological progress and efficiency improvements . Recent literature has expanded this foundation by examining how innovation enhances productivity, enabling economies to shift their production possibility frontiers and enhance TFP. Countries with higher levels of innovation are better positioned to capitalize on the opportunities provided by trade, such as access to new technologies and markets (Impullitti & Licandro, 2018). By focusing on BRICS and D-8 countries, the study captures these regions' economic diversity and significance. As major emerging economies, BRICS represent substantial global trade involvement, while D-8 countries have varied trade and innovation profiles.

This study contributes to the existing literature by extending the analysis to a more diverse group of countries, including both emerging and developing economies. Unlike prior studies, which often assumed uniform effects of innovation on productivity, our study explicitly investigates the heterogeneous impacts of innovation on TFP growth across these econo-

mies. This approach fills a significant gap in the literature and has practical implications for policymakers aiming to foster sustainable growth through innovation-led strategies in economies at varying stages of development. It provides a comprehensive analysis that sheds light on the key mechanisms driving productivity growth in emerging economies.

Second, it explores the moderating role of innovation, demonstrating how technological advancements amplify the benefits of TO. Third, by focusing on emerging economies, the study bridges a critical gap in the literature, offering unique insights into how TO and innovation interact within the distinctive institutional, structural, and economic contexts of BRICS and D8 countries. The heterogeneous group analysis further enriches the findings, enabling the formulation of tailored policies that address the varied development stages of these countries. This approach highlights the differential pathways through which TO and innovation can drive TFP growth across diverse economic landscapes. Then, the study ensures that the findings are robust in different settings to provide better policy insights. Lastly, the study advocates customized strategies that align with the unique needs and growth trajectories of BRICS and D8 economies, equipping governments with evidence-based tools to enhance productivity and sustain long-term economic growth.

The rest of this paper is structured as follows: Section 2 provides a literature review; Section 3 presents the data and method; Section 4 discusses the findings; and the last section closes with the conclusion and policy recommendations.

Literature review

Theoretical literature

TFP[4] is a crucial measure of economic development, capturing the income level from a productivity perspective and incorporating data comparable to human capital from a technological perspective. Contemporary endogenous growth theories, such as those by Lucas (1988) and provide theoretical

[4] In 1947, George J. Stigler came up with the phrase "total factor productivity" or TFP for short. Since then, the concept of TFP has been utilized in the field of economics for more than half a century. In 1950, Solow and Swan created a growth model that considers changes in an economy's physical capital, labor, and TFP.

support for a positive relationship between trade liberalization and economic growth. According to Solow (1957), differences in this exogenous residual between countries can lead to substantial variations in output per capita, highlighting TFP's significance.

The new growth theories offer alternative explanations for why TFP can endogenously explain GDP growth through mechanisms such as foreign technology spillovers (Grossman & Helpman, 1991b). According to the endogenous growth model, two major components may ultimately determine TFP — human capital and R&D activities. Some other schools of thought on the growth theory emphasize the contribution of human capital in promoting productivity and efficiency (Ibrahim, 2023; Kalapouti *et al*., 2020; Rehman & Islam, 2023)[5].

Empirical literature

Our study aligns with previous literature's scope, theoretical framework, and empirical method. Previous literature offers a strong foundation for our study, but there are still gaps in our understanding of the impact of TO on TFP when trade barriers are reduced. While numerous studies provide evidence of the impact of trade on improving TFP in terms of labor productivity (Grossman & Helpman, 1991b), there is a lack of systematic and empirical evidence. TO facilitates trade, promotes competition, spreads technology, and opens up new international interactions and learning opportunities because goods often contain technology (Gonçalves *et al*., 2021; Mohamed Sghaier, 2023; Raghutla, 2020).

There are many ways through which trade activities can influence productivity. International trade can encourage domestic firms to improve their inputs and machinery due to imported goods. Increased output results from this capital inflow outside the receiving country (Becker & Muendler, 2015; Grossman & Helpman, 1991b). In the second channel, increased competition redistributes resources in the importing country. According to the theory, less efficient firms are eliminated, helping more efficient ones and thus increasing economic productivity (Dobson & Ramlogan, 2009; Gonçalves *et al*., 2021). The third channel arises from the exchange of information and technological knowledge between users and producers of goods (Cerulli & Poti, 2009). Herzer (2022) and Miller and

[5] More exactly, qualified human capital contains the requisite capabilities for becoming acquainted with and efficiently utilizing current innovations.

Upadhyay (2000) established significant correlations between TO, trade orientation, and FDI as a way to improve productivity, whereas FDI has a significant and negative relationship with TFP (Rehman & Islam, 2023). However, it is widely thought that FDI may boost productivity at the macro level (Ayhan Kose *et al*., 2009; Elfaki & Ahmed, 2024; Islam *et al*., 2020).

Several studies have explored the mechanisms through which TO influences TFP. For instance, Grossman and Helpman (1991b) and Romer (1990) emphasized the role of foreign technology spillovers and innovation driven by trade (Kijek & Matras-Bolibok, 2019). Moreover, TO can encourage firms to upgrade their inputs and machinery, increasing productivity (Becker & Muendler, 2015). However, previous findings on the impact of assistance on development in developing countries have asserted that TFP growth accelerated after the 1991 economic reforms in far less developing countries, contradicting the findings from several earlier studies (Ayhan Kose *et al*., 2009; Mastromarco & Zago, 2012). Although empirical evidence favours a positive relationship between TO and TFP, we cannot disregard the fact that TO has no impact in some cases (Ottaviano *et al*., 2018; Wu & Han, 2022).

Given these mixed results, it is essential to investigate the specific impact of TO on TFP in different economic contexts. Our study focuses on BRICS and D-8 countries, representing a diverse group of emerging economies with varying levels of TO and economic development. By examining these countries, we aim to better understand how trade policies affect productivity in different settings. Thus, our first hypothesis is as follows:

Hypothesis 1 (H1): *TO has a significant impact on TFP*.

This hypothesis is supported by the theoretical framework of endogenous growth models, which proposes that trade liberalization can enhance productivity through mechanisms such as technology transfer, competition, and access to larger markets. The empirical investigation of BRICS and D-8 countries will help validate this hypothesis and contribute to the broader trade and economic development literature.

Innovation is a critical factor that can moderate the relationship between TO and TFP. Innovation encompasses new ideas, technologies, and processes that drive productivity and economic growth. The ability to innovate can enhance the benefits of TO by enabling countries to better absorb and utilize foreign technologies and knowledge. Theoretical and empirical lit-

erature supports the notion that innovation significantly enhances productivity and imports (Kijek & Matras-Bolibok, 2019). Innovation can amplify the positive effects of TO by fostering technological advancements and improving production efficiency (Elfaki & Ahmed, 2024; Kijek & Matras-Bolibok, 2019; Rehman & Islam, 2023).

Innovation can act as a moderator by influencing how effectively countries leverage TO to enhance TFP. Countries with higher levels of innovation are better positioned to capitalize on the opportunities provided by trade, such as access to new technologies and markets (Impullitti & Licandro, 2018). Conversely, countries with lower innovation levels may struggle to fully benefit from TO, resulting in weaker TFP growth. The spread of innovation from outside can be defined explicitly in terms of technology transfer, setting a standard for TFP (Arshad *et al*., 2023; Coe *et al*., 1997). Asghar *et al*. (2024), Griffith *et al*. (2006), Shabbir (2016) have all demonstrated that innovation in the form of patents and R&D investment has a positive relationship with TFP.

Empirical studies have demonstrated that the interaction between TO and innovation can lead to varying outcomes. Ayhan Kose *et al*. (2009) revealed that trade and productivity development are mutually reinforcing, particularly in East Asian nations with high innovation levels. In developed economies, the moderating role of innovation in the relationship between TO and TFP is crucial. Rapid innovation allows firms to adapt quickly to market opportunities, maximizing the benefits of TO on TFP (Gonçalves *et al*., 2024). Past studies consistently support innovation's role in amplifying TO's positive effects on TFP and economic growth (Hong *et al*., 2010; Ibrahim, 2023). Further, several studies have demonstrated a continuous cycle in which innovation, TFP, and income per capita all work hand in hand to propel nations to long-term sustainable growth levels (Godil *et al*., 2021; Rouvinen, 2002).

While much of the literature highlights the positive effect of innovation on TFP growth in emerging economies, other studies suggest that this relationship is context-dependent. For instance, Kraus *et al*. (2021) found that weak institutional frameworks in some developing countries diminish the impact of innovation, while Gupta *et al*. (2020) highlighted the role of government subsidies in amplifying this effect. These conflicting findings point to the need for a more nuanced approach, which our study addresses by analyzing the heterogeneous impacts of innovation in emerging and developing economies, accounting for institutional and policy differences. In the

context of BRICS and D-8 countries, examining the moderating role of innovation can provide valuable insights into how TO interacts with innovation to influence TFP. Therefore, our second hypothesis is proposed as follows:

Hypothesis 2 (H2): *Innovation positively moderates the relationship between TO and TFP.*

This hypothesis is grounded in the endogenous growth models' theoretical framework, which highlights innovation's importance in driving productivity and economic growth. By investigating the moderating role of innovation, our study contributes to the broader literature on trade, innovation, and economic development, particularly in the context of BRICS and D-8 countries.

The theoretical framework for this study integrates growth theories to explore the dynamic relationship between TO, TFP, and innovation. The Solow model emphasizes the role of TFP in driving variations in output per capita, while the endogenous growth theories by Grossman and Helpman (1991b) and highlight the significance of foreign technology spillovers, human capital, and R&D as determinants of productivity growth. Lucas (1988) examined the positive relationship between trade liberalization and economic growth, further emphasizing the importance of innovation in driving productivity. The current study aims to build on these theoretical foundations by examining how innovation moderates the relationship between TO. As depicted in Figure 1, it seeks to understand the extent to which innovation amplifies the productivity gains from TO, particularly in emerging economies.

However, empirical studies in this domain face several challenges that must be addressed. The key issue is endogeneity, particularly the reverse causality between TFP and innovation, which complicates identifying the true impact of TO. Moreover, cross-country studies often grapple with heterogeneity in institutional and structural factors, which can obscure the distinctions of the innovation–TFP relationship (Kijek & Matras-Bolibok, 2019). Additionally, the dynamic nature of TFP growth necessitates models capable of addressing short- and long-term effects and potential biases from CD in panel data. Building on these theoretical and empirical insights, this study employs advanced econometric techniques to overcome these challenges and provide robust evidence on the moderating role of innova-

tion in the relationship between TO and TFP. By focusing on BRICS and D-8 countries, the study bridges gaps in the literature by addressing heterogeneity in institutional contexts and offering tailored policy recommendations. Integrating theoretical foundations with empirical rigor sets the stage for the methodological approach detailed in the next section.

Research design

Data and sample

This study examines how TO directly affects TFP while considering the moderating role of innovation in this relationship. The study focuses on BRICS and D-8 countries from 1990 to 2023. These groups represent significant emerging and developing economies with considerable variation in innovation and productivity trends. This selection enables a comparative analysis of the heterogeneous effects of innovation on TFP growth in countries with similar economic classifications but differing institutional and policy environments. The control variables employed include the following: the financial development index (*FDI*), human capital index (*HCI*), tariff rate (*Tariff*), terms of trade (*TOT*), unemployment (*UNEMP*), inflation (*INF*), and gross domestic product growth (*GDPG*). The data are collected from Penn World 10.0, Federal Reserve Economic Data (FRED), World Development Indicators (WDI), and the International Monetary Fund (IMF). A detailed description of the variables is presented in Table 1. Moreover, the list of BRICS and D8 countries sampled is provided in Table A1 in the Appendix.

Variable description

TFP

TFP measures the efficiency of all factor inputs in production based on an aggregate production function that links total output to individual factor inputs. It is the total output divided by the weighted average of inputs. Government policies can influence technical processes, which in turn affect TFP. Applying insights from the growth accounting framework, as capital and labor efficiency impact production, various factors might influence

output indirectly. TFP, also known as the Solow residual, refers to the portion of output that remains unexplained after considering the direct contributions of inputs. To keep the analysis straightforward, we adopt the Cobb–Douglas production function as follows:

$$Y = A\,(L)^{\alpha}\,(K)^{\beta} \tag{1}$$

In the above equation[6], Y measures real GDP; L is the labor force; K is the physical capital stock that makes up the productivity index; and are the weights; and A is an index of TFP. Thus, the standard form of the total productivity index is as follows:

$$\mathrm{A} = \frac{\mathrm{Y}}{\mathrm{L}^{\alpha}\ \mathrm{K}^{\beta}} \tag{2}$$

Dividing Equations (1) and (2) by labor force L expresses output and the physical capital stock on a per-worker basis as follows:

$$\frac{\mathrm{Y}}{\mathrm{L}} = \mathrm{A}\left(\frac{L}{L}\right)^{\alpha}\left(\frac{K}{L}\right)^{\beta} \tag{3}$$

The equation is further simplified to the following:

$$\mathrm{y} = \mathrm{A}k^{\beta}L^{\alpha-1} \tag{4}$$

In Equation 4[7], y represents real GDP per worker, and k denotes the per-worker stock of capital.

By taking logarithms on both sides, the following is derived:

$$lny = lnA + \beta lnk + (\alpha - 1)lnL \tag{5}$$

Constant returns to scale imply that the coefficient of equals zero. Neoclassical growth accounting considers productivity and input accumulation as separate but intertwined factors determining output growth. Therefore,

[6] $0 \leq \alpha \leq 1 \text{and} 0 \leq \beta \leq 1(1)$ allow for the possibility of nonconstant returns to scale by not restricting $\alpha + \beta$ to one.

[7] The production function displays increasing, constant, or decreasing returns to scale when $\alpha + \beta$ is greater than, equal to, or less than one, respectively.

increases in efficiency or productivity cause movements in the production possibility frontier for a given mix of input factors.

In our study, we used data from the Penn World Table 10.0, as described by Feenstra *et al*. (2015). This dataset offers a comprehensive and updated measurement method for TFP, encompassing GDP, capital stock, labor force, and human capital measures. TFP values are presented at constant price levels, with 2017 as the base year (2017 = 1). This ensures comparability across time and countries, aligning with standardized practices for macroeconomic analyses.

TO

TO is quantified using three commonly employed measures in the empirical literature, total trade flow as a share of GDP, exports as a share of GDP, and imports as a share of GDP. These measures reflect the degree to which a country engages in international trade relative to its economic size. The total trade flow as a share of GDP captures the combined value of exports and imports, offering a comprehensive view of a nation's trade activity. Numerous researchers have employed different indices to evaluate TO (Aggarwal & Karwasra, 2024; Dollar & Kraay, 2004; Kong *et al*., 2021; Shabbir *et al*., 2023). The metrics illustrate various understandings of openness, ranging from trade strategy to global policy direction. These metrics provide a robust assessment of TO and its impact on economic variables.

Innovation

Innovation is a moderator that is measured with patent application data, comprising resident and non-resident patent filings. Patent applications serve as a proxy for inventive activity and the generation of new technologies in a country (Anakpo & Oyenubi, 2022; Raghupathi & Raghupathi, 2017; Shabbir *et al*., 2023). By analyzing resident and non-resident patent applications, we comprehensively understand the innovative environment and its contributions to TFP. This dual approach helps to differentiate between domestic innovation capacity and the influence of international technological inflows. Patent application is a well-recognized proxy for innovation in macroeconomic studies, reflecting the creation of new technologies and the formalization and protection of intellectual property at the

national level[8]. This proxy is particularly relevant for analyzing trends in BRICS and D-8 countries, as it provides a consistent measure across diverse economic contexts.

Empirical model

To empirically test the impact of TO and the moderating effect of innovation on TFP, we employ a rigorous baseline econometric model as follows:

$$TFP_{it} = \alpha_0 + \beta_1 TO_{it} + \delta_i Control_{it} + \partial CountryFE + \mu TimeFE + \varepsilon_{it} \quad (6)$$

$$TFP_{it} = \alpha_0 + \beta_1 EXP_{it} + \beta_2 IMP_{it} + \delta_i Control_{it} + \\ + \partial CountryFE + \mu TimeFE + \varepsilon_{it} \quad (7)$$

$$TFP_{it} = \alpha_0 + \beta_1 TO_{it} + \beta_2 PAT_{it} + \beta_3 TO_{it} * PAT_{it} + \\ + \delta_i Control_{it} + \partial CountryFE + \mu TimeFE + \varepsilon_{it} \quad (8)$$

$$TFP_{it} = \alpha_0 + \beta_1 EXP_{it} + \beta_2 IMP_{it} + \beta_3 PAT_{it} + \beta_4 EXP_{it} * PAT_{it} + \\ + \beta_5 IMP_{it} * PAT_{it} + \delta_i Control_{it} + \partial CountryFE + \\ + \mu TimeFE + \varepsilon_{it} \quad (9)$$

TFP is the dependent variable; *TO* is the independent variable; *PAT* stands for innovation and is the moderating variable; and *EXP* and *IMP* denote exports and imports, respectively. Equations 6 and 7 examine the effect of trade and the segregated factors of exports and imports on TFP. In Equations 8 and 9, innovation is included to analyze its direct impact and interaction with TO, exports, and imports to determine its moderating influence in the TO–TFP relationship, recognizing each component's unique effect on the explanatory variable. In the above model, the controls include country-specific factors — *FDI*, *HCI*, *Tariff*, *TOT*, *UNEMP*, *INF*, and *GDPG*. The models incorporate country and time fixed effects.

[8] While patent data may not fully capture process innovations or technology adoption, it is one of the few standardized indicators available for emerging and developing economies, ensuring comparability and robustness of results. Moreover, patent data capture key innovation activities that are closely tied to economic growth and productivity improvements, making it a suitable proxy for the scope of our study.

Method

In the empirical analysis, we started with descriptive statistics and correlation and then moved to the CD mean difference test to find potential heterogeneity between the two groups (Bagh *et al*., 2024). We conducted stationarity and cointegration tests to establish statistical support and ensure the robustness of the baseline model, thereby enhancing the reliability of subsequent empirical findings. A recent empirical study by Zhao *et al*. (2023) challenged the assumption of independence, implying that economic policy changes in one nation can affect global economies. Therefore, scaled Lagrange multiplier (LM) and CD tests (Breusch & Pagan, 1980), LM tests, and bias-corrected scaled LM tests (Baltagi *et al*., 2012) were employed to address CD. To address stationarity, we used second-generation panel unit root tests and CIPS tests for reliability (Zhao *et al*., 2023). The CIPS unit root test is crucial for assessing stationarity[9], and its determination involves averaging the cumulative augmented Dickey–Fuller.

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1} + \delta_i \bar{y}_{t-j} + \sum_{j=0}^{\rho} \theta_{ij} \Delta y_{i,t} + \sum_{j=1}^{\rho} \mu_{ij} \Delta y_{i,t-j} + \varepsilon_{ij} \quad (10)$$

$$CIPS = \frac{1}{N} \sum_{t=1}^{n} CADF_i \quad (11)$$

Additionally, our study incorporated integrated variables to conduct a thorough co-integration analysis. This strategic approach involves leveraging second-generation tests (Kao, 1999; Pedroni, 2004; Westerlund, 2008) to ensure a comprehensive understanding of the persistence of long-term relationships despite CD. We further applied the feasible generalized least squares (FGLS) (Bagh *et al*., 2024; Iftikhar *et al*., 2024). Endogeneity is a common problem in economics research. Asymptotically, the most reliable econometrics tool for addressing endogeneity is the GMM, which generates instrumental variables and eliminates endogeneity and reverse causation[10] (Arellano & Bond, 1991; Arellano & Bover, 1995). The study employed alternative techniques in robustness tests to enhance the results' authenticity and efficiency. First, we applied another estimating method called panel-corrected standard error (PCSE) (Arshad, 2021). A similar

[9] The long-term analysis should use the mixed integrated orders of I(1) and I(2).

[10] GMM models are advantageous because they automatically generate instrumental variables and address the issues of endogeneity and reverse causation, whereas ordinary least square and fixed effect models do not.

analysis was performed for the heterogeneous results with the two groups of countries. While GMM primarily captures long-run dynamics, robustness checks were conducted using complementary techniques, including panel quantile regression, PCSE, and FGLS, to validate the results and explore heterogeneity across BRICS and D-8 countries. We employed panel quantile analysis to determine the relationships between the variables. These analyses are essential for validating the integrity and reliability of our findings.

Results and discussion

Descriptive statistics and correlations

The economic characteristics of BRICS, D-8, and full sample countries are summarized in Panels A, B, and C of Table 2, respectively, presenting a descriptive summary of the variables. TFP has a mean value of 0.5 and a moderate variability of 0.151, as presented in the table. It appears that the productivity levels of BRICS are evenly distributed. There is a wide range of trade engagement, from 2.718 to 4.706, as indicated by the variation of 0.388 in TO, which averages 3.648. A mean value of 10.266 and an SD of 1.422 for patents indicate that BRICS are substantially distinct in innovation and technical progress. The average TFP for D-8 countries is 0.687, with a high variation of 0.406 when compared with that of BRICS, indicating a more widespread distribution of productivity levels. The mean patent value of D-8 countries is 7.406, indicating a generally lower, but diverse, level of patenting activity when compared with BRICS. D-8 countries exhibited a higher degree of TO variability, with a variation of 0.55 and an average TO of 3.868. The data reveal that patents are 8.491 and TO is 3.783, with a mean TFP of 0.615 in the complete sample. Other economic indicators, including *GDP* and *INF*, are well distributed, as presented in the table. Overall, the descriptive statistics indicate that BRICS and D-8 countries are somehow similar and different in innovation, TO, and TFP, providing a basis for further analysis of the impact of TO on TFP.

Table 3 presents the correlation matrix and means VIF, which provides insights into the relationships among the key variables and potential multicollinearity issues. The table indicates that TFP is positively correlated with

TO and patents, while a negative correlation is observed for tariffs[11]. Tariffs also misallocate resources by protecting less efficient domestic industries from more competitive and productive ones, lowering TFP. The sample includes emerging countries with considerable tariff barriers and low productivity development; thus, the negative relationship may represent structural inefficiencies. The VIF values are all below 5, with an average of 2.354, indicating that multicollinearity is not a significant concern in this analysis.

Preliminary Testing

Mean difference and CD Tests

Table 4 presents the differences in the means to compare the key economic variables between BRICS and D-8 countries, revealing several key differences. TFP is notably higher in D-8 countries (mean = 0.686) compared with BRICS (mean = 0.501), with a significant difference of -0.185 ($t = -5.713$, $p < 0.01$). TO is significantly higher in D-8 countries (mean = 3.868) than in BRICS (mean = 3.647), with a difference of -0.221. Conversely, BRICS exhibit significantly higher levels of innovation, as evidenced by patents, with a mean of 10.225 compared with 7.405 in D-8 countries. This difference of 2.819 is significant. These differences highlight the distinct economic characteristics and degrees of development between BRICS and D-8 countries. Table 5 reports the results of the Cd test, revealing significant dependence among all variables for BRICS and D-8 countries from 1990 to 2023, as indicated by significant Breusch–Pagan LM, Pesaran scaled LM, bias-corrected scaled LM, and Pesaran CD statistics ($p < 0.01$).

Stationarity and co-integration Test

Table 6 variables are stationary at levels (I(0)), and others become stationary after first differencing (I(1)). Further, Table 7 presents mixed co-

[11] The negative correlation between tariffs and TFP can be explained by the fact that higher tariffs hinder TO, restricting access to foreign markets, advanced technologies, and competitive inputs. This limitation reduces firms' ability to innovate and efficiently allocate resources, which are critical for boosting productivity. In contrast, lower tariffs foster a more competitive and dynamic environment, encouraging innovation and technology transfer, which positively influence TFP. Hence, the observed negative relationship aligns with the economic theory linking trade barriers to reduced productivity growth.

integration test results, with the Westerlund and Pedroni tests indicating significant co-integration between TO and TFP in the full sample and BRICS but not in D-8 countries. The moderating effect of patents on this relationship is also significant, particularly in the full sample and BRICS. The Kao test provides further evidence of cointegration, especially for BRICS, reinforcing the long-term relationship between these variables.

Baseline regression

Table 8 reports the benchmark regression analysis to explore TO's impact on TFP and innovation's moderating role in BRICS and D-8 countries. Columns (1) to (3) report the direct effects of the full sample and group analysis of BRICS and D-8 countries, respectively. For the combined sample, TO boosts TFP, implying that exposure to the international market fosters efficiency and innovation. In BRICS, the positive relationship implies that TO facilitates access to advanced technologies, promotes competitive markets, and encourages efficient resource allocation. The results reveal that TO has a positive and significant impact on TFP, indicating that increased trade integration can enhance productivity. Moreover, for D-8 countries, it is negative, indicating structural problems their economies[12], such as poorer institutional frameworks, inadequate technical readiness, or reliance on low-value-added sectors, which might prevent them from enjoying TO.

Furthermore, the study incorporates innovation as a significant moderator in Columns (4)–(6). The interaction term (*PAT*TO*) represents how the relationship between TO and TFP changes depending on the level of innovation (*PAT*). The coefficient of the interaction term (*PAT*TO*) is positive, indicating that trade's positive impact on TFP becomes stronger as innovation increases. The findings reveal that innovation significantly enhances TFP, and the interaction term highlights the significant moderating role of innovation in the relationship between TFP and TO. In BRICS and D-8 countries, this positive moderating effect is even more pronounced, implying that when these countries enhance their innovation capabilities, the gains from TO can be substantial. This emphasizes innovation's critical role

[12] In essence, the diversity in the results for D-8 countries emphasizes the need to examine country-specific issues even if the general results demonstrate a beneficial influence of TO on productivity. D-8 countries may need policies targeted at enhancing institutional quality, innovation capability, and industrial structures if they are to fully enjoy trade integration.

in maximizing TO's productivity benefits. Thus, our results support our hypotheses.

Panel data challenges

Table 9 summarizes the FGLS analysis, which addresses panel data issues, such as heteroskedasticity. Column (1) presents the overall effect of TO on TFP, revealing a positive and significant impact. This indicates that TO generally enhances productivity. Columns (2) and (3) break down these effects for BRICS and D-8 countries. For BRICS, the effect is notably higher, implying a more substantial productivity gain from TO in these emerging economies.

In contrast, D-8 countries exhibit a significant, minor, and negative effect[13]. The moderating effect of patent activity (*PAT*) on the relationship between TO and TFP is analyzed in Columns (4)–(6). Column (4) demonstrates a substantial positive moderating effect, indicating that increased patent activity significantly enhances the productivity benefits of TO. The group analysis is provided in Columns 5 and 6. A higher coefficient for the interaction term (*PAT*×*TO*) implies that an increase in patent activity (innovation) substantially amplifies the productivity benefits of TO in D-8 countries compared with BRICS. The higher coefficient for D-8 countries implies a greater sensitivity of productivity to the combined effect of TO and innovation. This can be attributed to their reliance on innovation to overcome structural and developmental challenges. In contrast, being more advanced economically, BRICS might experience diminishing marginal returns from innovation-driven productivity growth, which explains the relatively lower coefficient. Further, the findings may reflect the differing stages of development or industrial focus between BRICS and D-8 countries.

TO segregation analysis

Table 10 examines the effects of segregating TO into exports and imports on TFP in Columns (1)–(3) and the moderating role of innovation in

[13] In D-8 countries, TO can negatively impact TFP if increased import competition hampers local industries, leading them to reduce investments in technology and innovation. Additionally, reliance on low-value-added exports can stifle the development of higher productivity sectors. The economic volatility from global market fluctuations might also discourage long-term productivity-enhancing investments in these countries.

Columns (4)–(6) across the full sample, BRICS, and D-8 countries, respectively. For the full sample and D-8 countries, exports significantly and negatively impact TFP, implying that merely increasing exports does not enhance productivity without concurrent quality improvements or innovation. Conversely, imports positively affect TFP in these groups, indicating that foreign technologies and high-quality inputs contribute to productivity gains, aligning with the endogenous growth theory, which emphasizes technology transfer. However, in BRICS, imports negatively impact TFP, highlighting that the benefits of TO are context specific. The moderating role of innovation is evident as patent activity positively influences TFP across all samples, with the most significant impact on D-8 countries. Further, the interaction between patent activity and imports dramatically enhances productivity in D-8 countries, emphasizing that combining innovation with technology absorption from imports can maximize productivity benefits. This analysis reveals that robust innovation policies should complement effective trade policies to fully leverage globalization for productivity improvements. The FGLS method ensures robust and reliable results, accounting for potential biases in the panel data.

Bias-corrected method of the moment estimator

Table 11 presents the results of the bias-corrected method of moments estimator to address endogeneity in analyzing the impact of TO on TFP in Columns (1)–(3) and the moderating role of innovation in Columns (4)–(6) across the full sample, BRICS, and D-8 countries, respectively. The results are based on a dynamic model estimation, which accounts for the lagged effects of TFP (L.TFP and L2.TFP) and mitigates endogeneity concerns. This dynamic approach provides a more refined understanding of how innovation moderates the relationship between TO and productivity over time. For the full sample, TO positively and significantly affects TFP, implying that increased TO generally enhances productivity.

In BRICS, TO positively and significantly impacts TFP, indicating more substantial productivity gains from TO in these emerging economies. Conversely, in D-8 countries, TO has a negative and significant effect on TFP, implying that the benefits of TO are context-specific and may not uniformly translate to productivity gains. Column (4) reveals a significant positive impact of *PAT* on TFP, indicating that increased innovation enhances the productivity benefits from TO across the full sample. This positive moder-

ating effect is more pronounced in BRICS, as presented in Column (5), highlighting that innovation amplifies the gains from TO in these economies. In D-8 countries, the interaction term remains positive and significant, emphasizing the importance of innovation in maximizing the benefits of TO.

Robustness check

Table 12 presents a robust analysis using PCSE[14] to examine the impact of TO on TFP and the moderating role of innovation (*PAT*). For the full sample, TO positively and significantly impacts TFP, implying that increased trade can enhance productivity. This effect is notably stronger in BRICS, where TO substantially boosts productivity. In D-8 countries, there is a negative impact. When considering the moderating role of innovation, the results align with the baseline regression, although the magnitude of this effect is less straightforward. Table 13 provides quantile regression estimates to explore the impact of TO on TFP across different distributions, along with a visual analysis of the results in Figure 2. The findings reveal consistent results and support the basic hypotheses of the study. Overall, while TO benefits productivity, the impact of innovation as a moderating factor varies by region, with more pronounced benefits in less developed economies.

Economic impact

TO facilitates the efficient allocation of resources, access to larger markets, and the transfer of technology and knowledge. Countries can specialize in industries with a comparative advantage by reducing trade barriers, leading to productivity gains (Ramzan *et al*., 2019). These findings highlight the importance of TO policies in driving economic growth and improving productivity by enabling countries to benefit from global knowledge transfers, economies of scale, and increased competition . The positive impact of TO on TFP is underpinned by several economic theories. The endogenous growth theory reveals that TO enhances productivity by providing access to new technologies and ideas, which are crucial for innovation and effi-

[14] Using the PCSE method helps account for potential panel data issues such as heteroskedasticity and autocorrelation to provide more reliable results.

ciency (Grossman & Helpman, 1994). The technology transfer theory supports this by highlighting how trade facilitates the adoption of advanced technologies, boosting productivity (Widman *et al*., 1988). The comparative advantage and competitive advantage theories also explain how specialization and global trade can improve productivity.

The substantial moderating effect of patent activity indicates that innovation is critical in realizing productivity gains (Qiao *et al*., 2023). In less developed D-8 countries, the interaction between TO and patent activity is even more pronounced, emphasizing the need for strong innovation policies to fully leverage the benefits of TO (Herzer, 2022). The negative impact of exports on TFP in these regions might indicate that without concurrent innovation or quality improvements, exporting alone does not lead to significant productivity gains (Kim *et al*., 2009). The findings of this study are context-specific, focusing on BRICS and D-8 countries, and may not be fully generalizable to other emerging or developed economies. These results reflect the unique characteristics of these countries, such as their economic structures, institutional quality, and innovation capabilities. Although institutional factors are not directly analyzed in this study, they are likely to influence the relationship between TO, innovation, and TFP. Strong institutions can enhance technology transfer, support innovation, and amplify the productivity gains from trade, while weaker institutions may limit these benefits. Future research can investigate how institutional quality interacts with trade and innovation policies in BRICS and D-8 countries.

While our analysis controls for potential endogeneity using a GMM bias-corrected model to mitigate reverse causality concerns, future research can further explore this relationship in other regional or income-based contexts to validate and extend these findings. This study advances the literature by providing an integrative framework that highlights the relationship between TO, innovation, and productivity while accounting for developmental heterogeneity across emerging economies. These comparisons emphasize the contribution of integrating TO, innovation, and productivity dynamics while offering actionable insights into emerging economies to the literature. By linking these findings to prior research, we highlight the policy relevance of fostering innovation ecosystems with TO efforts to achieve sustained productivity gains in diverse economic contexts.

Conclusions

In our study, we explore the impact of TO on TFP with the moderating role of innovation, focusing on BRICS and D-8 countries from 1990 to 2023. Using robust econometric techniques to address panel data issues, we find that TO positively and significantly impacts TFP, highlighting the importance of reducing trade barriers to enhance productivity through efficient resource allocation and access to new markets. Our analysis reveals that innovation, particularly in BRICS, significantly moderates the relationship between TO and TFP, underscoring the critical role of technological advancement and R&D in amplifying productivity gains from TO. Our choice of BRICS and D-8 countries stems from their economic significance and diversity, offering a rich context for analyzing the interplay between TO, innovation, and productivity.

This study contributes to the understanding of economic dynamics by exploring the moderating role of innovation in shaping the relationship between TO and TFP. It also demonstrates how technological advancements amplify the benefits of TO, offering valuable insights into the rapidly evolving global commerce landscape. The group analysis provides heterogeneous evidence, indicating consistent improvements in TFP from TO in both BRICS and D-8 countries but with varying impacts of innovation, reflecting different developmental and structural contexts in these regions. Furthermore, it provides tailored policy recommendations, emphasizing the need for policies that reduce trade barriers, invest in innovation, and address the unique needs of BRICS and D-8 countries.

In conclusion, the positive impact of TO on TFP in BRICS and D-8 countries highlights the importance of integrating trade and innovation policies. Based on our findings, BRICS and D-8 countries can take several measures to maximize their potential for TFP growth. These include strengthening their innovation ecosystems through increased R&D investments, improving institutional frameworks to ensure intellectual property protection and regulatory quality, and focusing on human capital development through education and training. Therefore, policymakers should focus on reducing trade barriers while investing in R&D and patent protection and fostering a culture of innovation. This dual approach can maximize the productivity benefits of TO by ensuring that countries participate in global markets and enhance their technological capabilities. Promoting TO and attracting foreign direct investment can also facilitate technology transfer and produc-

tivity gains. Finally, leveraging digital and green technologies offers sustainable and inclusive growth pathways. These measures, tailored to the unique challenges of BRICS and D-8 countries, can help unlock their productivity potential. Furthermore, tailored policies for D-8 countries should address the need for quality improvements and innovation in exports to realize significant productivity gains.

Despite the significant findings, our study has limitations. This study focuses on BRICS and D-8 countries due to their unique institutional and economic characteristics as rapidly industrializing economies. Although these findings may not be fully generalizable to other emerging or developed economies, they provide valuable insights into the innovation–TFP relationship in countries with similar developmental trajectories. Future research can explore the impact of TO on TFP in other regions and incorporate additional variables such as institutional quality and infrastructure development. Institutional and structural factors play a pivotal role in shaping the innovation–TFP relationship, particularly in the context of emerging and developing economies. Our analysis employed proxies such as TO and R&D intensity to capture the key structural dynamics influencing productivity. However, institutional quality, governance, and economic structures are additional factors that can significantly impact the innovation–TFP relationship. Although not explicitly analyzed in this study, these elements are critical avenues for future research. By addressing these limitations and expanding the scope of the analysis, future research can provide a more comprehensive understanding of the complex relationships between TO, innovation, and productivity.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the authors. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

All data generated or analyzed are included in the published article. The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation. The raw anonymized data can be provided by emailing the primary author.

Author contributions

All listed authors have made a substantial, direct and intellectual contribution to the work, and approved it for publication. The authors take full responsibility for the accuracy and the integrity of the source analysis.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Annex

Table 1. Variable description

Variables	Code	Description
Dependent Variable		
Total factor Productivity	TFP	The TFP data used in this study are sourced from the Penn World Tables (Version 10.0), where the price level is fixed at 2017 as the base year (2017 = 1).
Independent Variables		
TO	TO	Trade is the sum of the total value of products and services a country exports and imports expressed as a percentage of its GDP.
Export	EXP	The total value of products and services that a country exports expressed as a percentage of its GDP
Import	IMP	The total value of products and services that a country imports expressed as a percentage of its GDP
Moderator		
Innovation	PAT	Intellectual property right application/registration by residents and noncountry residents
Economic Characteristics		
Financial Development Index	FDI	The elements that facilitate the growth of financial systems across various economies
Human capital index	HCI	Index of human capital per person based on years of schooling and returns to education.
Tariff	Tariff	Tariff rate, applied, weighted mean, all products (%)
Terms of Trade	TOT	Terms of trade using export and import price indices
Unemployment	UNEM	Total number of unemployed as a percentage of the labor force
Inflation	INF	Annual percentage change in the cost to the average consumer for acquiring a basket of goods and services
GDP Growth	GDPG	Growth in the real market value of goods and services in an economy

Note: Table 1 presents the description of the variables. The data are collected from PWT10.0, WDI, IMF, and FRED statistics.

Table 2. Descriptive statistics

BRICS	Mean	SD	Min	Median	Max	N
TFP	0.501	0.151	0.221	0.461	0.884	170
PAT	10.226	1.442	8.052	10.117	14.382	170
TO	3.648	0.388	2.718	3.740	4.706	170
FDI	0.468	0.104	0.205	0.469	0.674	170
HCI	2.460	0.535	1.487	2.382	3.497	170
Tariff	2.030	0.767	-1.347	1.986	4.032	170
TOT	4.566	0.178	4.125	4.557	5.121	170
UNE	2.114	0.608	0.863	2.055	3.429	170
INF	2.085	1.531	-1.056	1.884	7.988	170
GDPG	3.822	4.835	-14.53	4.211	14.23	170

Table 2. Continued

D-8 Countries	**Mean**	**SD**	**Min**	**Median**	**Max**	**N**
TFP	0.687	0.406	-0.313	0.647	1.457	272
PAT	7.406	1.222	4.673	7.265	9.696	272
TO	3.868	0.550	2.794	3.778	5.395	272
FDI	0.321	0.141	0.121	0.289	0.732	272
HCI	2.060	0.437	1.223	2.004	3.168	272
Tariff	2.240	0.921	0.247	2.301	4.514	272
TOT	4.633	0.315	3.462	4.611	5.610	272
UNE	1.574	0.786	-0.916	1.514	2.616	272
INF	2.192	0.954	-0.539	2.175	4.828	272
GDPG	4.640	3.441	-13.126	5.017	15.329	272
Full Sample	Mean	SD	Min	Median	Max	N
TFP	0.615	0.344	-0.313	0.572	1.457	442
PAT	8.491	1.898	4.673	8.640	14.382	442
TO	3.783	0.505	2.718	3.756	5.395	442
FDI	0.378	0.147	0.121	0.364	0.732	442
HCI	2.214	0.515	0.000	2.147	3.497	442
Tariff	2.159	0.870	-1.347	2.192	4.514	442
TOT	4.607	0.273	3.462	4.605	5.610	442
UNE	1.782	0.768	-0.916	1.873	3.429	442
INF	2.151	1.208	-1.056	2.040	7.988	442
GDPG	4.325	4.049	-14.53	4.844	15.329	442

Note: The table provides descriptive statistics of the economic characteristics of BRICS and D-8 countries from 1990 to 2023.

Table 3. Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	VIF	1/VIF
(1) TFP	1.000											
(2) PAT	-0.076	1.000									2.76	0.362
(3) TO	0.034	0.152***	1.000								1.79	0.558
(4) FDI	-0.025	0.734***	0.457***	1.000							3.95	0.253
(5) HCI	-0.017	0.631***	0.464***	0.779***	1.000						3.34	0.299
(6) Tariff	-0.097**	-0.466***	-0.437***	-0.585***	-0.619***	1.000					1.83	0.547
(7) TOT	0.146***	-0.104**	-0.141***	-0.015	0.029	0.099**	1.000				1.32	0.760
(8) UNE	0.082*	0.228***	0.038	0.254***	0.273***	-0.251***	-0.349***	1.000			1.36	0.734
(9) INF	-0.052	0.087*	-0.128***	-0.038	-0.002	-0.062	-0.086*	-0.007	1.000		1.13	0.883
(10) GDPG	-0.079*	-0.012	0.082*	-0.044	-0.171***	0.108**	0.021	-0.192***	-0.243***	1.000	1.20	0.831
Mean VIF											2.08	

Note: ***, **, and * indicate significance at p<0.01, p<0.05, and p<0.1, respectively

Table 4. Difference in the mean between BRICS and D-8 countries

Variables	BRICS		D8 Countries		T-test of Difference
	Obs.	Mean	Obs.	Mean	Difference
TFP	170	0.501	272	0.686	-0.185***
PAT	170	10.225	272	7.405	2.819***
TO	170	3.647	272	3.868	-0.221***
FDI	170	0.468	272	0.321	0.146***
HCI	170	2.460	272	2.060	0.400***
Tariff	170	2.029	272	2.240	-0.211***
TOT	170	4.565	272	4.633	-0.067***
UNE	170	2.114	272	1.574	0.540***
INF	170	2.085	272	2.192	-0.107
GDPG	170	3.822	272	4.640	-0.818**

Note: Table 4 provides the difference in mean between the two groups—BRICS and D-8 countries—and their respective t-test difference findings.

Table 5. CD test

Variable	Breusch-Pagan LM	Pesaran-scaled LM	Bias-corrected scaled LM	Pesaran CD
(1) TFP	814.8***	59.0***	58.8***	5.0***
(2) PAT	1085.8***	80.7***	80.5***	27.5***
(3) TO	495.8***	33.5***	33.3***	6.8***
(4) FDI	1233.5***	92.5***	92.3***	33.0***
(5) HCI	2317.1***	179.3***	179.1***	47.9***
(6) Tariff	1285.1***	96.6***	96.4***	32.8***
(7) TOT	1623.4***	123.7***	123.5***	-3.8***
(8) UNE	463.6***	30.9***	30.7***	8.0***
(9) INF	356.5***	22.2***	22.1***	14.3***
(10) GDPG	209.1***	10.4***	10.2***	9.8***

Note: Table 5 provides the results of the diagnostic tests for the CD among all variables for BRICS and D8 countries from 1990 to 2023, based on a total of 1,070 observations. *** denote significance at *** p<.01.

Table 6. Sample stationarity test

Variable	I(0)	I(1)
(1) TFP	-1.097	-4.760***
(2) PAT	-2.459***	
(3) TO	-1.742	-5.279***
(4) FDI	-2.341***	
(5) HCI	-2.506***	
(6) Tariff	-1.793	-4.920***
(7) TOT	-1.595	-4.445***
(8) UNE	-1.773	-4.870***
(9) INF	-2.809***	
(10) GDPG	-3.546***	

Table 7. Co-integration test

Test	Effect of TO on TFP			Moderating effect of the PAT	
	Full	BRICS	D8	Full	BRICS
Westerlund Test					
Variance Ratio	-0.254	-0.816	0.321	2.446***	2.528***
Pedroni Test					
Modified Phillips-Perron t	3.405***	2.421***	2.765***	3.545***	2.892***
Phillips-Perron t	-0.012	-8.761***	0.217	-0.208	0.495
Augmented Dickey-Fuller t	0.294	-0.257	0.578	-0.232	0.274
Kao Test					
Modified Dickey-Fuller t	0.292	-1.571*	0.081	-0.490	-1.802**
Dickey-Fuller t	-0.123	-2.640***	0.162	-0.565	-1.435*
Augmented Dickey-Fuller t	0.208	-2.182**	-0.290	-0.140	-2.105**
Unadjusted Modified Dickey-Fuller t	-0.050	-1.455*	-0.312	-0.333	-1.291*
Unadjusted Dickey-Fuller t	-0.137	-2.596***	-0.123	-0.464	-1.231

Note: The null hypothesis (H0) for all tests is that there is no cointegration between TO and TFP and between TO and the moderating effect of patent (*PAT*).

Table 8. Baseline model

Variables	Direct Effect			Moderating effect	
	(1) Full	(2) BRICS	(3) D-8	(4) Full	(5) BRICS
TO	0.070***	0.022*	-0.060*	0.096***	0.604*
	(0.024)	(0.012)	(0.035)	(0.036)	(0.332)
PAT				0.028*	0.303**
				(0.016)	(0.140)
PAT*TO				0.009**	2.441*
				(0.004)	(1.269)
FDI	-0.619***	-0.157**	-0.640***	-0.059*	-0.081
	(0.113)	(0.067)	(0.169)	(0.034)	(0.105)
HCI	0.123***	-0.012*	0.271***	-0.296*	-0.143***
	(0.036)	(0.006)	(0.048)	(0.172)	(0.034)
Tariff	-0.051***	0.015**	0.024	-0.014***	-0.053***
	(0.013)	(0.006)	(0.018)	(0.005)	(0.011)
TOT	0.042*	0.082***	0.057**	0.034*	-0.058
	(0.025)	(0.022)	(0.028)	(0.018)	(0.039)
UNE	0.035*	0.000	0.081***	0.007	-0.186***
	(0.019)	(0.009)	(0.023)	(0.006)	(0.028)
INF	-0.000	0.000**	-0.000	-0.000**	-0.000***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
GDPG	0.004**	0.002***	0.001	0.004***	0.003**
	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)
Constant	0.684***	-0.116	0.123	-0.274*	-1.538*
	(0.171)	(0.112)	(0.229)	(0.141)	(0.927)
Observations	442	170	272	429	170
R-squared	0.164	0.297	0.256	0.210	0.497
Number of IDs	13	5	8	13	5
Hausman test statistics	$\chi2 = 0.11$	$\chi2 = 182.86$***	$\chi2 = 81.49$***	$\chi2 = 54.52$***	$\chi2 = 285.98$***
Wooldridge test	F(1, 12)= 106.067***	F(1, 4)= 186.035***	F(1, 7)= 88.239***	F(1, 12)= 106.887***	F(1, 4)= 112.817***
The Breusch–Pagan test for heteroskedasticity	Chi2 (1) = 13.80***	Chi2 (1) = 16.55***	Chi2 (1) = 7.57***	chi2 (1) = 0.06	Chi2 (1) = 16.01***

Note: The table provides the empirical results of exploring the direct impact of TO on TFP and further analyzes the moderation impact of innovation in BRICS and D-8 countries from 1990 to 2023. The estimation results based on the fixed effects model reveal a positive impact of TO on TFP, with a significant moderating impact of innovation. Further country control variables with time and country fixed effects are included. The results are reported with the significance level at p-value and SE at *** p<0.01, ** p<0.05, and * p<0.1.

Table 9. FGLS analysis

Variables	(1) Full	(2) BRICS	(3) D8	(4) Full	(5) BRICS	(6) D8
TO	0.001*	0.006***	-0.002***	0.007***	0.281***	-0.008**
	(0.000)	(0.001)	(0.001)	(0.002)	(0.101)	(0.004)
PAT				0.221***	0.109**	0.826***
				(0.083)	(0.047)	(0.188)
PAT*TO				-0.051**	0.040***	0.113**
				(0.020)	(0.009)	(0.045)
FDI	-0.333*	-0.539***	-0.938**	-0.800*	-1.158***	-1.111*
	(0.178)	(0.112)	(0.368)	(0.431)	(0.272)	(0.647)
HCI	-0.114**	0.040	-0.060	-0.814	0.222***	-0.689***
	(0.052)	(0.025)	(0.114)	(2.356)	(0.048)	(0.205)
Tariff	-0.009***	-0.011***	-0.005**	-0.210***	-0.334***	-0.009***
	(0.001)	(0.001)	(0.002)	(0.050)	(0.041)	(0.003)
TOT	0.003***	0.000	0.003***	0.005***	0.047	0.579***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.126)	(0.146)
UNE	0.017***	0.013***	0.059	0.042***	0.302***	0.142**
	(0.003)	(0.001)	(0.037)	(0.007)	(0.053)	(0.062)
INF	-0.000	-0.000	0.003*	-0.000	-0.000**	0.003
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.002)
GDPG	-0.005	0.003	-0.007	-0.001	0.027***	-0.004
	(0.004)	(0.002)	(0.007)	(0.008)	(0.005)	(0.012)
Constant	0.615***	0.856***	0.343*	-1.321***	0.461	-5.609***
	(0.115)	(0.081)	(0.193)	(0.277)	(0.940)	(0.752)
Observations	442	170	272	442	160	272
Number of IDs	13	5	8	13	5	8

Note: The table provides the empirical results of exploring the direct impact of TO on TFP and further analyzes the moderation impact of innovation in BRICS and D-8 countries from 1990 to 2023. The estimation results are based on the FGLS model to address the data issue of heteroscedasticity, auto-correlation, and CD. The findings reveal a positive impact of TO on TFP, with a significant moderating impact of innovation. Further country control variables with time and country fixed effects are included. The results are reported with the significance level at p-value and SE at *** p<0.01, ** p<0.05, and * p<0.1.

Table 10. FGLS with Segregation of TO into export and import

Variables	(1) Full	(2) BRICS	(3) D-8	(4) Full	(5) BRICS	(6) D-8
EXP	-0.317***	-0.085	-0.408***	0.800***	0.365*	6.146***
	(0.057)	(0.064)	(0.075)	(0.196)	(0.197)	(0.753)
IMP	0.416***	-0.147**	0.364***	0.454***	-0.432**	-5.407***
	(0.062)	(0.063)	(0.100)	(0.093)	(0.217)	(1.029)
PAT				0.417***	0.101***	0.635**
				(0.074)	(0.039)	(0.252)
PAT*EXP				-0.149***	-0.069***	-1.008***
				(0.024)	(0.019)	(0.110)
PAT*IMP				0.018*	0.015	0.934***
				(0.010)	(0.019)	(0.150)
FDI	-0.139	-0.416***	0.989***	-0.578***	-0.844***	1.472**
	(0.170)	(0.130)	(0.373)	(0.205)	(0.296)	(0.579)
HCI	-0.078	0.063*	-0.134	0.011	0.172**	-0.953***
	(0.052)	(0.034)	(0.116)	(0.054)	(0.068)	(0.182)
Tariff	-0.069***	-0.087***	-0.032	-0.045*	-0.325***	0.035
	(0.023)	(0.016)	(0.035)	(0.023)	(0.041)	(0.053)
TOT	0.219***	0.001	0.195**	0.270***	-0.149	0.749***
	(0.063)	(0.059)	(0.081)	(0.063)	(0.138)	(0.121)
UNE	0.066***	0.170***	0.081**	0.043*	0.201***	0.184***
	(0.023)	(0.017)	(0.034)	(0.023)	(0.057)	(0.052)
INF	-0.000	-0.000*	0.003**	-0.000	-0.000***	-0.002
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.002)
GDPG	-0.010**	0.006**	-0.011	-0.010**	0.016***	-0.018*
	(0.004)	(0.002)	(0.007)	(0.004)	(0.005)	(0.010)
Constant	-0.408	1.020***	-0.202	-4.328***	0.943	-8.105***
	(0.341)	(0.303)	(0.463)	(0.744)	(0.883)	(2.103)
Observations	442	170	272	442	160	272
Number of IDs	13	5	8	13	5	8

Note: The table provides the empirical results for exploring the direct impact of TO on TFP by classifying trade into exports and imports individually and further analyzes the moderation impact of innovation in BRICS and D-8 countries from 1990 to 2023. The estimation results are based on the FGLS model to address the data issue of heteroscedasticity, auto-correlation, and CD. The findings reveal a significant and negative impact of exports and a positive impact of imports on TFP, with a significant negative and positive moderating impact of innovation with exports and imports, respectively. Further country control variables with time and country fixed effects are included. The results are reported with the significance level at p-value and SE at *** p<0.01, ** p<0.05, and * p<0.1.

Table 11. GMM estimation results

Variables	(1) Full	(2) BRICS	(3) D-8	(4) Full	(5) BRICS	(6) D-8
L.TFP	0.333***	0.254***	1.133***	-0.494***	0.272**	0.346***
	(0.057)	(0.084)	(0.022)	(0.122)	(0.134)	(0.060)
L2.TFP	-0.203**		-0.332***	0.137**	-0.025***	-0.197***
	(0.085)		(0.068)	(0.056)	(0.009)	(0.076)
TO	0.088*	0.001**	-0.044**	0.078*	0.075***	-0.002*
	(0.048)	(0.000)	(0.018)	(0.046)	(0.018)	(0.001)
PAT				0.033***	0.021*	0.027**
				(0.011)	(0.011)	(0.014)
PAT*TO				0.194***	0.159*	0.140**
				(0.056)	(0.093)	(0.057)
FDI	-0.070**	-0.282***	-0.191***	-0.078	-0.012	0.316
	(0.033)	(0.094)	(0.071)	(0.100)	(0.054)	(0.258)
HCI	-0.367*	-0.022	-0.473	-0.055***	-0.031	-1.139***
	(0.213)	(0.014)	(0.502)	(0.019)	(0.039)	(0.230)
Tariff	-0.002***	-0.003	-0.003***	-0.043***	0.007	0.000
	(0.000)	(0.003)	(0.001)	(0.016)	(0.019)	(0.001)
TOT	0.025	0.015	0.090**	0.038	0.023	0.043
	(0.029)	(0.019)	(0.043)	(0.039)	(0.044)	(0.029)
UNE	0.007	0.009	0.008	0.028	-0.024	0.008
	(0.014)	(0.010)	(0.006)	(0.023)	(0.021)	(0.006)
INF	0.000**	0.000**	-0.001***	0.000***	0.000***	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GDPG	0.006***	0.004***	0.006***	0.002	0.003***	0.008***
	(0.001)	(0.000)	(0.001)	(0.002)	(0.001)	(0.001)
Constant	-0.092	-0.040	-0.483*	-0.216	0.069	-0.517***
	(0.160)	(0.059)	(0.283)	(0.137)	(0.504)	(0.190)
Country effect	Yes	Yes	Yes	Yes	Yes	Yes
Year effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	416	165	256	416	160	256

Note: The table provides the empirical results of exploring the direct impact of TO on TFP by classifying trade into exports and imports individually and further analyzes the moderation impact of innovation in BRICS and D-8 countries from 1990 to 2023. The estimation results were obtained using the GMM-bias corrected model to address endogeneity issues. The findings reveal a positive impact of TO on TFP, with a significant moderating impact of innovation. Further country control variables with time and country fixed effects are included. The results are reported with the significance level at p-value and SE at *** p<0.01, ** p<0.05, and * p<0.1.

Table 12. Robustness check

Variables	(1) Full	(2) BRICS	(3) D-8	(4) Full	(5) BRICS	(6) D-8
TO	0.001***	0.298***	-0.002***	0.008***	0.878**	-2.413**
	(0.000)	(0.029)	(0.001)	(0.002)	(0.349)	(0.986)
PAT				0.321***	0.295***	1.958***
				(0.063)	(0.104)	(0.326)
PAT*TO				2.825***	4.786***	0.443***
				(0.551)	(1.211)	(0.092)
FDI	-0.285**	-0.573***	-0.960**	-0.672*	-0.453*	-1.930***
	(0.130)	(0.104)	(0.400)	(0.388)	(0.238)	(0.711)
HCI	-0.117***	0.057**	-0.068	-0.461***	0.124**	-0.548***
	(0.036)	(0.024)	(0.081)	(0.088)	(0.052)	(0.130)
Tariff	-0.008***	-0.013***	-0.004*	-0.014***	-0.038***	-0.009**
	(0.002)	(0.001)	(0.002)	(0.003)	(0.004)	(0.004)
TOT	0.003***	0.000	0.266***	0.769***	-0.138	0.006***
	(0.001)	(0.000)	(0.083)	(0.123)	(0.113)	(0.001)
UNE	0.016***	0.013***	0.048	0.076*	-0.023	0.106*
	(0.002)	(0.001)	(0.032)	(0.042)	(0.059)	(0.060)
INF	-0.000**	-0.000***	0.003***	0.000	-0.000***	0.002*
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
GDPG	-0.005*	0.004**	-0.007*	-0.017***	0.014***	-0.008
	(0.003)	(0.002)	(0.004)	(0.006)	(0.005)	(0.008)
Constant	0.621***	1.690***	-0.599*	-9.878***	11.226***	-11.651***
	(0.080)	(0.123)	(0.345)	(1.517)	(2.127)	(3.701)
Observations	442	170	272	442	160	272
R-squared	0.146	0.617	0.153	0.250	0.651	0.385
Number of IDs	13	5	8	13	5	8

Note: The table provides a robust estimation to analyze the impact of TO on TFP and further analyzes the moderation impact of innovation in BRICS and D-8 countries from 1990 to 2023. The findings are consistent with the baseline regression using the alternative estimator PCSE and alternative proxies. Further country control variables with time and country fixed effects are included. The results are reported with the significance level at p-value and SE at *** p<0.01, ** p<0.05, and * p<0.1

Table 13. Quantile regression

VARIABLES	Panel A: Full Sample				Panel B: BRICS				Panel C: D-8		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	q25	q50	q75	q90	q25	q50	q75	q90	q25	q50	q75
TO	-2.051***	-1.899***	-1.129**	-1.057***	-0.350	1.418***	1.214***	0.947***	-3.544***	-3.765***	-3.345***
	(0.310)	(0.516)	(0.456)	(0.191)	(1.694)	(0.383)	(0.361)	(0.253)	(1.304)	(0.543)	(0.329)
PAT	-1.049***	-0.916***	-0.535**	-0.459***	-0.137	0.426***	0.322***	0.212**	-1.581**	-1.867***	-1.630***
	(0.145)	(0.265)	(0.218)	(0.067)	(0.459)	(0.120)	(0.100)	(0.086)	(0.730)	(0.304)	(0.179)
PAT*TO	9.211***	7.489***	3.737**	3.120***	1.583	-5.611***	-4.726***	-3.636***	14.366***	15.014***	12.812***
	(1.241)	(2.137)	(1.882)	(0.673)	(5.477)	(1.370)	(1.175)	(0.982)	(5.432)	(2.312)	(1.380)
Constant	-15.973***	-11.303***	-4.204	-2.874***	-4.012	10.033***	8.795***	7.026***	-23.317***	-22.028***	-17.812***
	(1.899)	(3.229)	(2.939)	(1.025)	(8.948)	(2.383)	(1.943)	(1.744)	(7.707)	(3.494)	(2.050)
Observations	442	442	442	442	170	170	170	170	272	272	272

Note: The table provides robust estimates using quantile regression to analyze the impact of TO on TFP in BRICS and D-8 countries from 1990 to 2023.

Figure 1. Conceptual framework

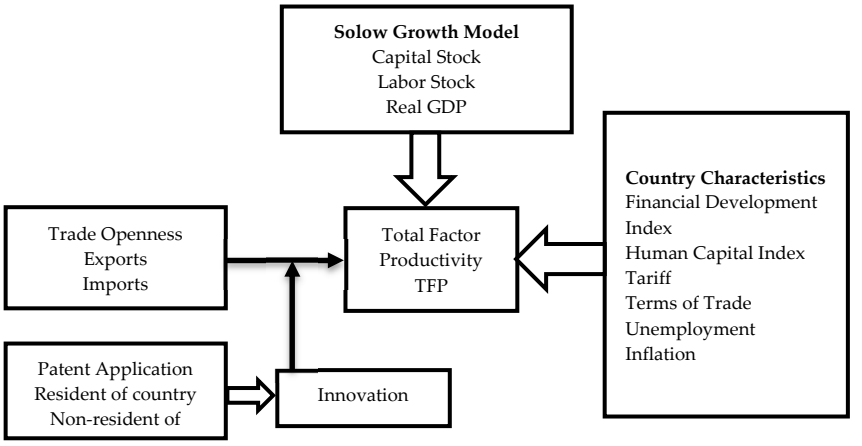


Figure 2. Quantile regression

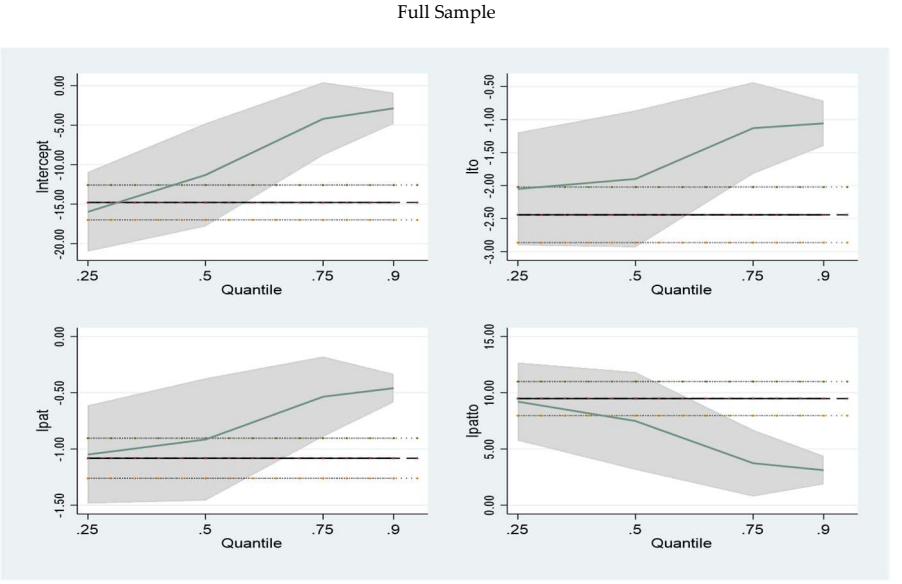
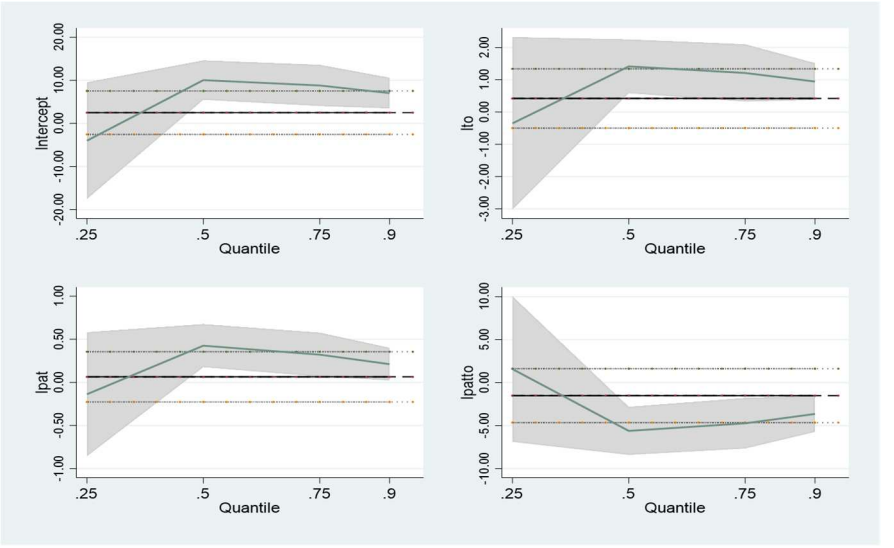
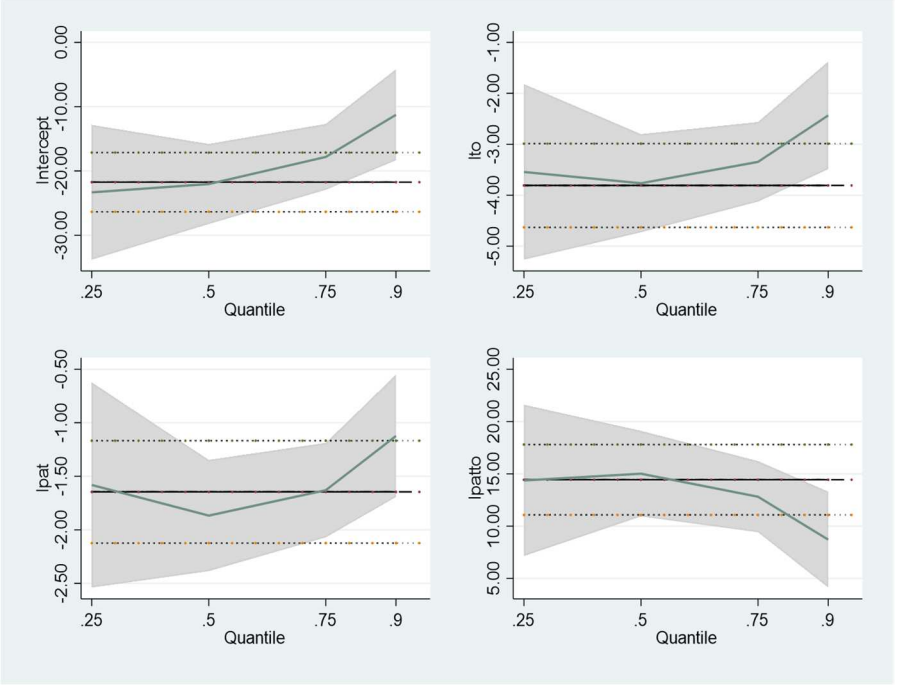


Figure 2. Continued

BRICS



D8



Appendix

Table A1. Countries

BRICS	D8
Brazil	Bangladesh
Russia	Egypt
India	Indonesia
China	Iran
South Africa	Malaysia
	Nigeria
	Pakistan
	Turkey