



Modeling and Forecasting the Dynamics of BRICS Socioeconomic Integration in Context of Global Economic Fragmentation

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Abstract

This research aims to model and forecast the trajectory of socioeconomic integration between the BRICS countries and Turkey in the context of deglobalization and escalating geoeconomic fragmentation. The study evaluates the impact of external shocks, including the updated US tariff regime, trade conflicts, global downturns, sanctions pressure, and institutional limitations, on the sustainability and intensity of intra-bloc engagement. Employing a comparable panel time series from 2000 to 2023 for a selected set of countries, we apply several econometric methods for the first time in a unified framework: panel ARDL, Dumitrescu-Hurlin panel Granger causality tests, impulse response functions, variance decomposition, and ARIMA forecasting up to 2030. The empirical analysis results show that regional financial integration, infrastructure development, and R&D have a statistically significant and persistently positive impact on intra-bloc trade volumes and socioeconomic cooperation between BRICS countries and Turkey. Simultaneously, digital connectivity shows a short-term stimulating effect followed by phase saturation, indicating the need for the structural modernization of the digital environment. Institutional attributes exhibit heterogeneous effects, underscoring the necessity of harmonizing regulatory frameworks and aligning them with international sustainable development standards. The scientific novelty of this study resides in the design and empirical validation of an advanced forecasting model that incorporates institutional, infrastructural, innovation-related, and digital dimensions. This study delineates integration scenarios for BRICS and Turkey intended to inform strategies for regional macroeconomic coordination, establish transaction mechanisms based on national currencies, and define balanced investment priorities within the transition toward a multipolar global governance architecture.

Keywords:

BRICS; Turkey;
Socioeconomic Integration;
Regional Financial Integration;
Trade Shocks; Panel ARDL Model;
Impulse Response Functions (IRF);
ARIMA; Forecasting; R&D Investment;
Digital Connectivity; Institutional Quality;
Renewable Energy Consumption;
Geopolitical Turbulence;
Scenario Modelling.

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1- Introduction

The contemporary global economy is undergoing a period of intensified socio-economic fragmentation, driven by the resurgence of protectionist policies, escalating trade disputes, and the imposition of sanctions. These developments have

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exerted complex and multifaceted effects on global supply chains, prompting a strategic reassessment of international economic cooperation frameworks, particularly among the BRICS nations: Brazil, Russia, India, China, and South Africa. As a geopolitical coalition, BRICS has emerged as a pivotal actor in shaping an alternative architecture of global economic governance. Collectively, the bloc accounts for over 35% of global GDP and represents more than 40% of the world's population [1]. With the expansion of the format to BRICS, the importance of countries that are not part of the core membership but actively cooperate with the alliance, such as Turkey, is increasing. Turkey, with its strategic position among Europe, Asia, and the Middle East, is strengthening ties with key BRICS members by promoting projects in infrastructure, energy, digital transformation, and alternative financial mechanisms. This makes it a significant partner in the development of multilevel socioeconomic integration [2]. The BRICS countries are constantly striving for institutional, socio-economic and structural convergence, expanding by adding new members to the alliance, despite the presence of asymmetries in the levels of economic development, institutional models and modernization strategies.

China, the largest exporter to the U.S. market, particularly in the electronics, textiles, and machinery sectors, faces the risk that its products will be less competitive due to higher U.S. tariffs. In response, China is stepping up efforts to strengthen intra-bloc trade by investing in joint digital, logistics, and technology projects with BRICS partners and neighboring countries [3-5]. India, though less dependent on exports to the US, is vulnerable in pharmacy, textiles, and electronics. Considering its growing manufacturing base and strong position in information technology, India is increasing cooperation with BRICS as a strategic tool to reduce dependence on Western markets [6].

Under large-scale sanctions and economic isolation by the West, Russia is strengthening ties with China, India, Central Asia, and the Middle East, promoting initiatives on alternative financial and payment mechanisms (the system for transfer of financial messages SPFS, the cross-border interbank payment system CIPS), technological integration, and energy security [7, 8]. Due to its geopolitical and resource potential, Russia plays a coordinating role in institutionalizing BRICS [9].

Brazil, as the largest economy in Latin America and one of the founders of BRICS, occupies a specific position in the BRICS cooperation architecture. On the one hand, the country maintains close ties with Western markets, and on the other hand, it seeks active participation in forming alternative global orders. The main vectors of Brazil's inclusion in BRICS integration processes are agrarian exports, energy, environmental agenda, and digital technologies. In the face of growing pressure from the US and the EU in climate policy and trade standards, Brazil is intensifying cooperation with China, India, and Russia to build a balanced and sustainable growth model [10, 11].

South Africa, representing the African continent in BRICS, plays a critical role in forming a bridge between the countries of the Global South. With its well-developed financial infrastructure, logistical capabilities, and strategic location at the crossroads of southern maritime routes, South Africa actively participates in BRICS initiatives, creating a new architecture for South-South cooperation [12]. South Africa pays particular attention to projects in energy, green transformation, telecommunications, and educational exchanges. South Africa is also contributing to the institutionalization of BRICS on the African track by strengthening coordination with regional organizations (e.g., the African Union and Southern African Development Community SADC) and developing instruments of multi-level economic interaction [13].

Thus, the socioeconomic integration between China, Russia, India, Turkey, Brazil, and South Africa is becoming a strategic direction in forming an alternative model of global development and the core of a new economic balance capable of withstanding the challenges of global turbulence through institutional synergy, resource complementarity, technological cooperation, and sustainable macroeconomic policies [14].

2- Research Background

Several studies highlight the importance of BRICS as an alternative center of power in the emerging polycentric world order [15, 16]. Contemporary studies increasingly perceive BRICS rather as a potential polycentric center of power capable of influencing the formation of an alternative world order than as an informal forum. In particular, it is emphasized that the bloc can become the basis for the creation of new mechanisms for economic coordination based on strategic autonomy and complementarity. Thus, it is noted that BRICS strives to form "global rules" that reflect the interests of the global South, rather than Western institutions [17]. At the same time, to achieve these goals, it is necessary to synchronize the national strategies of the participants, which requires a balance between maintaining their sovereign independence and strengthening coalition cohesion. However, most existing publications are limited to either descriptive analysis or forecasting of individual parameters, such as demography, energy engineering, and investment, without constructing an integrated model of socio-economic integration in the context of global instability [18-21].

Research conducted within the framework of the forecast models of the Russian Academy of Sciences and IMEMO [22] points to a growing stratification between the BRICS countries in terms of the pace of digitalization, institutional sustainability, and resource endowment. In particular, integration effects are often offset by differences in political and economic regimes and institutional instability [18]. The problem of the "middle income trap", examined in detail using the example of China [23], actualizes the issue of the adaptive capacity of the BRICS countries to new challenges, including digital inequality, environmental transformations, and the loss of global markets [24].

The development of socioeconomic integration between China, Russia, India, Turkey, Brazil, and South Africa remains the subject of close academic attention, especially in the context of global instability, protectionism, and sanctions policies [25, 26]. However, despite the abundance of scientific publications, significant research gaps remain, hindering the formation of a holistic, scientifically based conceptual model.

Some studies [27, 28] suggest scenario analysis and ARIMA models to predict the direction of cooperation, linking technological trends to digital connectivity, green energy, and cross-border trade. Abbas et al. [29] and Shah & Ximei [30] emphasize the importance of institutions, infrastructure, and technology levels in determining the volume and direction of trade flows. However, most studies are limited to descriptive analysis and do not reveal complex inter-factor relationships.

Financial integration is significant for coherent macroeconomic policies. Taghizadeh-Hesary et al. [31] point to lower transaction costs and increased resilience to shocks. The New BRICS Development Bank and currency swap arrangements are institutional instruments for deepening financial linkages. Simultaneously, Orłowski [32] criticizes the lack of coordination of exchange rate policies and fragmented capital markets, which reduces the effectiveness of integration.

Infrastructure, including transportation and digital infrastructure, determines the potential for trade interaction. China shows superiority in logistics, while Brazil and South Africa face high costs. Ali et al. [33] and Sadiq et al. [34] document significant differences in digital infrastructure, which inhibits e-commerce development and reinforces trade asymmetries. Qualitative differences in infrastructure remain the least explored topic. Institutional regulation directly affects the reduction of non-tariff barriers, transparency of procedures, and investor confidence. Sadiq et al. [34] and Alariqi et al. [35] emphasize the importance of harmonizing standards and legal regimes. However, the BRICS countries still have different administrative systems, which hinder the formation of a common legal space.

R&D investment and the level of technological development play a key role in innovation competitiveness. China, dominating in R&D investment, sets a high standard for other alliance members [36, 37]. However, the relationship between R&D and digital connectivity in the BRICS context remains poorly understood despite the obvious dependence of technological exchange efficiency on institutional and infrastructural factors. Digital integration facilitates the acceleration of cross-border trade and the formation of an electronic interaction environment. Despite active investments in digital transformation, BRICS countries demonstrate a high level of unevenness in digitalization, which limits intra-bloc trade and supply chain synergies [38, 39].

Gold and foreign exchange reserves are traditionally considered a factor of macroeconomic sustainability, but their strategic use for intra-alliance trade purposes remains understudied. Several studies [40, 41] suggest the possibility of using reserves as a tool for increasing liquidity and confidence between countries. However, in actual BRICS practice, there is no coordinated policy on reserve allocation, which limits the adaptive capacity of the bloc.

The inclusion of Turkey in our study within the BRICS analytical framework seems to be scientifically and strategically justified. First, Turkey occupies a key socioeconomic position at the intersection of Europe, Asia, and the Middle East [2]. Second, the country is actively developing trade and investment ties with Russia, India, and South Africa, participating in multilateral initiatives (G20), and demonstrating digital and environmental infrastructure growth [42, 43]. Third, Turkey actively develops alternative financial mechanisms, including currency swaps and settlements in national currencies, which coincide with the BRICS course of de-dollarization [44-46]. Fourth, Turkey's investments in renewable energy, the digital economy, and transportation infrastructure provide the basis for sustainable cooperation [47]. These factors make Turkey an essential component of the BRICS model in the face of global instability. Turkey emphasizes energy, infrastructure, digital projects, and participation in alternative regional coordination mechanisms. The pursuit of a multi-vector foreign economic policy brings Turkey institutionally closer to BRICS initiatives.

Despite the significant expansion of scientific research on BRICS integration, including recent empirical assessments of the impact of energy prices on the bloc's stock markets [16], analyses of sustainable development amid global turbulence [3, 48], scenario modeling of long-term trajectories for BRICS and G7 [49], and evaluations of BRICS's sustainable development policies [50], notable gaps remain in the literature. First, the mechanisms linking institutional regulation and financial integration under sanctions and new US tariff policies are insufficiently understood, limiting the predictive capacity of existing models [6, 9]. Second, empirical studies examining how digital connectivity and R&D investments influence trade flows within BRICS are fragmented and fail to account for the full spectrum of country asymmetries [51, 52]. Third, the importance of international reserves in creating a clear and consistent monetary strategy is rarely discussed, which makes it harder to build a unified macroeconomic plan [14, 53]. Finally, there is a lack of theoretical and quantitative research on Turkey's active role in promoting sustainable and flexible cooperation within the expanded BRICS, which is especially important during a time of increasing economic division around the world. Filling these scientific gaps requires an interdisciplinary approach that combines panel and non-linear modelling techniques while also accounting for political and institutional factors; such an approach is essential to enhance the accuracy of forecasts and to increase the practical relevance of the resulting integration scenarios. In response to this need, the present study proposes a comprehensive predictive model of socioeconomic cooperation, incorporating institutional, digital, infrastructural, and macroeconomic variables. This approach enables the development of plausible scenarios for regional cooperation under conditions of global economic deglobalization, geopolitical polarization, intensifying sanctions regimes, and escalating trade tensions.

2-1- Research Gap

Thus, there remains a significant gap in the research on the long-term integration dynamics of the BRICS-T context, regarding macroeconomic, institutional, infrastructural and technological factors, and exogenous shocks. Also, the issue of quantitative assessment of the mutual influence of these factors and scenario modelling of sustainable convergence paths remains not fully resolved. Our study aims to form a multilayered structure describing which economic, institutional and digital factors can ensure sustainable integration of BRICS and Turkey in the context of global shocks and fragmentation of the world economy. Against this backdrop, we articulate the purpose of the study, formulate specific research questions, and present the conceptual framework guiding our analysis. The study seeks to construct scientifically verifiable scenarios for future regional cooperation using panel econometric procedures.

2-2- Research Questions

Given the multilevel interdependence among trade, finance, and technology in the BRICS-T context, we have organized our investigation through a set of bloc-grouped research questions (RQs). These RQs reflect both theoretical considerations and applied dimensions of the integration process (see Table 1). By aligning our research questions with the interdisciplinary model outlined above, we ensure coherence between the identified research gaps, the methodological strategy, and the objectives of the study.

Table 1. Research questions and their theoretical rationale for analyzing BRICS-T integration under socioeconomic instability

No. and block of question	Research question	Key idea
RQ1. Infrastructure and finance	How does the combined improvement in transport and logistics infrastructure quality (INFQ) and growth in regional financial integration (RFI) affect the increase in domestic trade among BRICS-T during sanctions?	High-quality transport and logistics infrastructure reduces unit delivery costs, while deep financial integration minimizes currency and regulatory risks, thereby increasing the economic attractiveness of intra-bloc trade.
RQ2. Institutions and innovation	Do the sustainability and volume of mutual trade increase when institutional quality (IQ) and R&D investment (RDI) improve?	Efficient legal institutions reduce contractual costs, and increased investment in R&D accelerates technology diffusion; their combined effect synergizes deepening economic linkages.
RQ3. The synergy effect of digitalization and green energy	How much does the expansion of digital infrastructure (digital connectivity DC), the share of renewables (RENEW), and international reserves (FXR) stimulate trade and investment within the bloc?	Developed digital infrastructure reduces information and transaction costs, an increased share of renewable energy sources diversifies the resource base, and adequate international reserves ensure the economy against currency shocks, thereby increasing the investment attractiveness of the domestic market.
RQ4. Trade protectionism	Does the strengthening of tariff restrictions by the United States lead to a redistribution of export and investment flows of the BRICS-T in favor of intra-bloc partners?	Tightening foreign trade barriers from the U.S. raises bilateral trade costs, prompting states to reorient trade activity toward the domestic regional space.
RQ5. Recessions and cooperation	Do global recessions (RECESS) enhance cooperation within a bloc?	With the overall decline in the global economy, the bloc's countries can integrate more actively to cushion the fall in demand.
RQ6. Sanctions and development of financial technologies	Do sanctions accelerate the development of own payment systems and settlements in national currencies?	Restricted access to global payment infrastructures stimulates states to deploy autonomous settlement mechanisms.
RQ7. Single payment platform	Does the launch of a single common payment system (PAYSYS) reduce transfer costs and make intra-bloc trade more sustainable?	Economies of scale and competition between domestic currencies lead to lower transaction fees and reduced exchange rate volatility.
RQ8. Cumulative stress test	Does the combination of tariffs, sanctions, and global recession lead the bloc to shift to a strategy of internal diversification and its own financial institutions?	The cumulative impact of multifactor shocks may contribute to the transformation of intra-bloc cooperation relying predominantly on domestic resources.

Figure 1 presents a multi-tiered conceptual configuration illustrating how the long-term trajectory of BRICS-Turkey integration is shaped by the interdependent processes: the mobilization of domestic and intra-bloc financial and investment resources; their strategic allocation toward critical technological innovation and infrastructure; and the development of robust, autonomous institutional and financial architectures.

Figure 1 illustrates the multilayered structure of the drivers and mechanisms underpinning BRICS-Turkey socio-economic integration in the context of global fragmentation. The model distinguishes three key categories of integration determinants. First, structural resilience is reinforced by infrastructure quality (INFQ), regional financial integration (RFI), institutional quality (IQ), and investment in research and development (RDI). Second, technological and resource-based resilience is shaped by digital connectivity (DC), the share of renewable energy in the energy mix (RENEW), and the accumulation of foreign reserves (FXR). Third, adaptation mechanisms, including trade diversion, investment and supply chain re-routing, and the development of a BRICS payment system (PAYSYS), serve to mitigate external vulnerabilities. These interacting components collectively enhance resilience to exogenous shocks and contribute to stable integration outcomes, such as increased intra-bloc trade shares, deeper financial co-movements, and strengthened institutional coordination. Over time, such dynamics foster greater economic resilience, reduce dependency on global economic nodes, and support the emergence of a more balanced and polycentric global order.

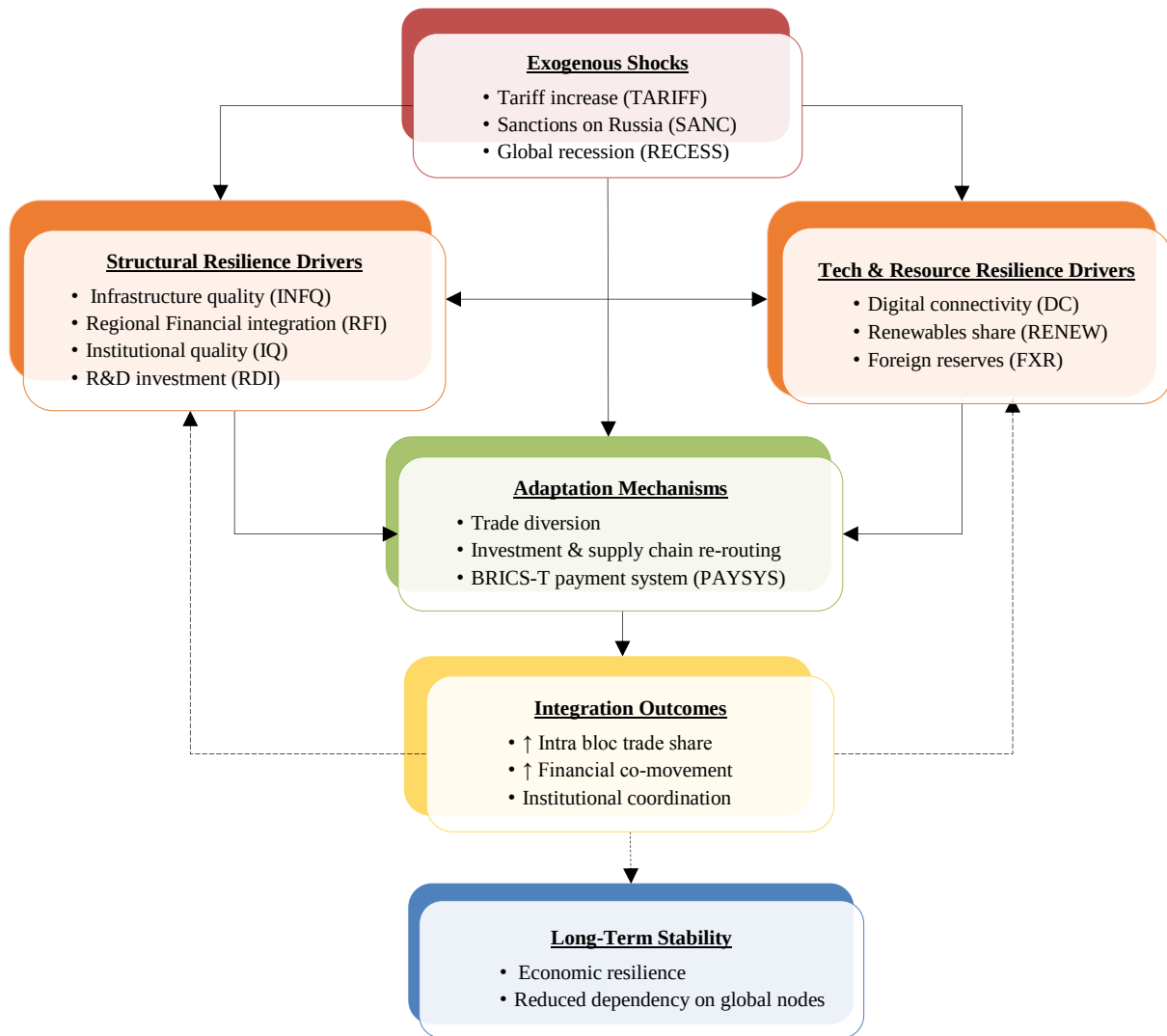


Figure 1. Multilayer configuration of shocks, drivers, and mechanisms governing BRICS-Turkey socioeconomic integration amid global economic fragmentation

3- Methodology

3-1-Methodological Scheme

The methodological foundation of this study lies in the empirical investigation of the key determinants shaping socioeconomic integration between BRICS and Turkey, particularly within the context of global uncertainty and increasing systemic fragmentation of the world economy.

To achieve this, the study adopts a comprehensive panel-based econometric approach that integrates both short-run and long-run dynamic analyses. The methodological architecture comprises the Panel Autoregressive Distributed Lag (ARDL) estimator for assessing cointegration relationships, Dumitrescu-Hurlin panel Granger causality tests to evaluate directional linkages between variables, and the computation of Impulse Response Functions (IRF) and Variance Decomposition Analysis (VDA) to assess the magnitude and temporal propagation of structural shocks within the system. Additionally, the Autoregressive Integrated Moving Average (ARIMA) model is employed to project future trends up to 2030 under multiple policy scenarios.

The integration of these econometric methods ensures both methodological rigor and analytical depth by capturing lag structures, interdependencies, and dynamic feedback mechanisms. This approach allows for the identification of key integration drivers and the construction of policy-relevant forecasts that are grounded in statistically validated patterns, offering insights for strategic planning and resilience-building in BRICS-Turkey cooperation.

Figure 2 illustrates the generalized methodological scheme of the study, reflecting the successive stages of data processing from identifying key socioeconomic indicators and assessing the stationarity of time series to applying the panel ARDL model to identify short- and long-term relationships, performing causality tests, analyzing impulse responses, and forecasting using ARIMA. Each block of the framework reflects the retrospective and forecasting components of the study, ensuring its reproducibility and transparency.

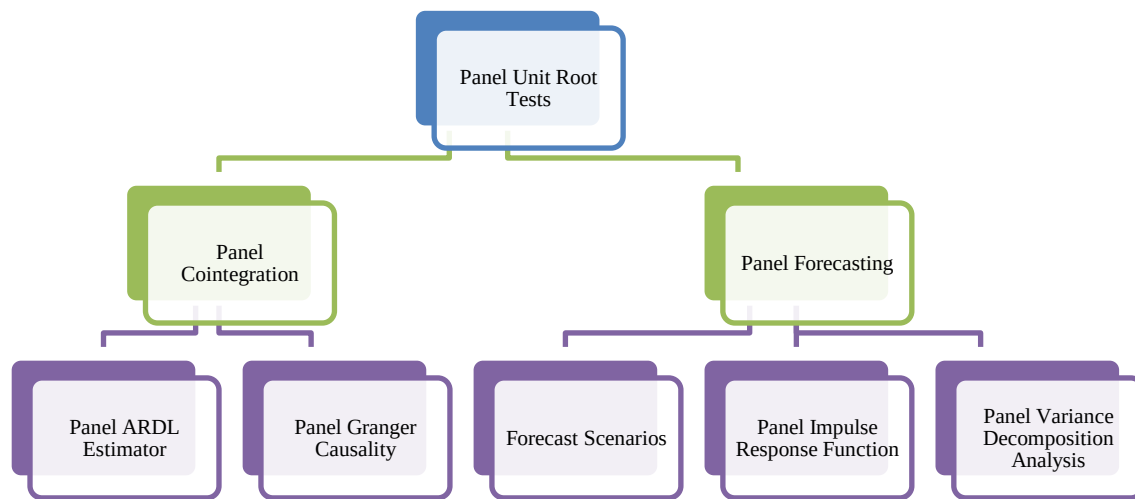


Figure 2. Methodological Framework for Panel Analysis and Forecasting of BRICS-Turkey Socioeconomic Integration

EViews 12 software was used for statistical processing and implementing econometric models, providing panel ARDL estimates, causality tests, impulse response analysis, variance decomposition, and ARIMA forecasting. This enables reliable quantitative estimates and scenario forecasts based on representative data and robust analysis tools with aggregated annual frequency at the country level, covering the period from 2000 to 2023.

3-2- Data Sources and Description of Variables

A data panel with aggregated annual frequency at the country level, covering the period from 2000 to 2023, was used for the empirical analysis. The primary source of information was the World Development Indicators (WDI) database of the World Bank [54], which provides verified macroeconomic, financial, and institutional indicators. This database allows for comprehensive modeling of cross-country socioeconomic integration under conditions of global instability, including the impact of trade conflicts, sanctions, recessions, and transformation of financial architecture. The applied methods (panel ARDL, Granger causality test, Dumitrescu-Hurlin tests, IRF, VDA, and ARIMA) provide the identification of stable relationships between variables and the construction of forecast scenarios under exogenous shocks.

The empirical foundation of our analysis was based on comprehensive data collected from multiple authoritative sources. For China, we sourced macroeconomic and sectoral data from the National Bureau of Statistics of China [55], which offers comprehensive annual series on GDP components, trade flows, and energy balances. Turkey's dataset was drawn primarily from the Turkish Statistical Institute (TurkStat) [56] and the Central Bank of the Republic of Turkey [57], providing time-series on national accounts, reserve holdings, and payment system transactions. India's variables were obtained from the Ministry of Statistics and Program Implementation (MOSPI) [58] and supplemented with monetary and external sector aggregates from the Reserve Bank of India [59]. South African indicators derive from Statistics South Africa [60] and the South African Reserve Bank [61], covering trade openness, foreign reserves, and energy consumption. For Brazil, we draw on comprehensive economic statistics from the Brazilian Institute of Geography and Statistics (IBGE) [62] via its SIDRA interactive platform, complemented by macroeconomic time series from the Central Bank of Brazil's Open Data portal [63], sectoral and financial data from <https://www.statista.com>, and harmonized indicators, such as GDP, trade, and R&D expenditure, sourced from the World Bank's World Development Indicators [54]. The Russian dataset follows a parallel structure, with national accounts, sectoral output, and innovation metrics obtained from the Federal State Statistics Service (Rosstat) [64]; monetary and external sector series are derived from the Bank of Russia's statistics portal [65]. We further incorporate standardized R&D and researcher headcount figures from UNESCO's Institute for Statistics [66] and the OECD's Main Science and Technology Indicators [67], as well as World Bank WDI series for consistency. Environmental performance indicators are drawn from the Ministry of Natural Resources and Environment of the Russian Federation [68], while energy balances and sectoral production statistics are provided by the Ministry of Energy of the Russian Federation [69].

To enhance cross-country comparability, we supplemented these national sources with harmonized series from UN Comtrade [70] (for bilateral trade), the International Energy Agency [71] (for renewable energy shares), and the IMF's International Financial Statistics [72] (for foreign exchange reserves). Despite these efforts, we encountered gaps and occasional inconsistencies in certain series, particularly digital connectivity metrics and detailed R&D expenditure breakdowns, in some countries. Where high-frequency data were unavailable or exhibited structural breaks, we employed linear interpolation or, in cases of severe discontinuity, omitted the affected variable from the country-specific analysis. Consequently, while our panel spans 2000-2023, a small number of country-variable pairs are based on interpolated values or have been excluded to preserve overall data integrity.

The selection of variables for the ARDL and ARIMA models was guided by theoretical relevance to socioeconomic integration, empirical evidence from prior literature on BRICS and Turkey, data availability and quality for the period 2000-2023, and statistical requirements (e.g., stationarity conditions for ARIMA and I(0)/I(1) properties for ARDL).

Our study covers a broad set of indicators reflecting the key dimensions of socioeconomic cooperation between BRICS and Turkey. All variables are grouped into the following thematic clusters. Prior to estimation, each candidate variable was tested for unit roots (ADF, PP tests) to ensure compatibility with ARDL bounds testing (i.e., integration of order I(0) or I(1) but not I(2)), and their time series properties were assessed for ARIMA modelling (stationarity or appropriate differencing).

Dependent variable: trade openness is the ratio of exports and imports to GDP (%). It reflects the level of integration of countries in international trade and sensitivity to global flows of goods and services.

Independent Variables:

1) Financial integration:

- FDI to GDP Ratio is the share of foreign direct investment in GDP, characterizing involvement in cross-border financial flows.
- Foreign exchange reserves (FXR) are expressed in months of import coverage, reflecting the ability of countries to withstand external shocks and maintain macro-financial stability.

2) Energy and infrastructure:

- Energy production volume includes coal, oil, and gas production and reflects industrial capacity and sustainability of supply chains.
- Infrastructure quality (IQ) is a composite index of transport and digital infrastructure development (railroads, highways, and internet) that determines the efficiency of trade and cooperation.

3) Institutional and regulatory environment:

- The regulatory quality (RQ) index assesses the degree of transparency and efficiency of legislation in the economic sphere.
- Institutional regulatory governance (IRG) describes the ability of institutions to enforce norms and standardize the business environment.

4) Trade resilience and macroeconomic indicators:

- Economic stability (ES) assesses the ability to maintain macroeconomic equilibrium in crises.
- Trade balance (TB) is the ratio of exports and imports, reflecting the structure of foreign economic activity.

5) Socioeconomic indicators:

- The unemployment rate (UR) reflects internal economic stability.
- The poverty rate/level (PL) and social protection system are indicators that characterize the quality of life and institutional sustainability.
- Income inequality (II) includes the Gini coefficient and per capita income distribution.

6) Innovation and digitalization:

- R&D investments are expenditures on research and technological development that affect competitiveness.
- Digital connectivity (DC) covers the level of internet penetration, the density of broadband connections, and the degree of digital integration in commerce.
- Green transformation: Renewable energy consumption (REC) is the share of renewable sources in energy consumption, reflecting environmental sustainability and adaptation to global requirements.

Dummy Variables:

- Sanctions {it} reflect the impact of sanctions on the economies of countries and their foreign trade, including changes in trade routes and partners.
- Payment system {it} is the development of alternative payment mechanisms (e.g., BRICS Pay) that reduce dependence on Western systems.
- US tariff shock {t} is the impact of abrupt changes in US tariff policy on foreign trade strategy.
- Global recession {t} is the impact of global recessions on macroeconomic stability.
- Combined shock {t} is an aggregate variable that accounts for the simultaneous impact of tariffs, sanctions, and recessions.

These variables reflect the multilevel structure of factors that determine the nature and sustainability of socioeconomic integration within the BRICS-Turkey framework. It covers financial, institutional, infrastructural, digital, and environmental dimensions and provides a basis for building verifiable interaction and forecasting models.

Variables were included if they (1) have documented theoretical or empirical linkage to trade openness and socioeconomic integration in the context of emerging and developing economies; (2) exhibit sufficient data coverage and reliability in WDI (or equivalent sources) for all countries in the sample over 2000-2023; (3) satisfy statistical requirements for ARDL (I(0) or I(1) integration) or ARIMA (stationarity after differencing if necessary); and (4) capture distinct dimensions, avoiding redundant measures when high overlap exists.

To mitigate multicollinearity among regressors in the ARDL panel, we performed correlation analysis and computed variance inflation factors (VIF) for initial sets of continuous variables. Variables with high pairwise correlations (e.g., Pearson's $|r| > 0.8$) or VIF exceeding a threshold (commonly $VIF > 10$) were examined: when they measured closely related concepts, they were combined into composite indices (e.g., composite Infrastructure Quality), or one was excluded based on theoretical priority and statistical diagnostics. In some cases, principal component analysis (PCA) was applied to underlying indicators to construct orthogonal factors representing latent dimensions (e.g., digital connectivity components). All variables were standardized before PCA and VIF computation to ensure comparability. For ARIMA models (univariate forecasting of individual series), multicollinearity is not directly relevant; however, when including exogenous regressors (ARIMAX), similar pre-tests for collinearity among exogenous inputs were conducted, and highly collinear predictors were excluded or aggregated.

After estimation, residual diagnostics (serial correlation, heteroskedasticity) and robustness checks (alternative variable definitions, lag specifications) were employed to confirm that remaining regressors did not unduly affect coefficient estimates due to collinearity. Sensitivity analyses included re-estimating models with and without borderline variables to assess stability of key coefficients.

For clarity, a list of all variables used, their labels, units of measurement, and sources are presented in Table A1.

3-3- Methods

3-3-1- Panel Unit Root Tests

The investigation starts with panel unit root tests to see if the variables series are stable over time. Panel unit root tests, such as the Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS), and Fisher-type tests, determine if variables are integrated in the same order. Variables are rationalized to avoid drawing inaccurate conclusions from non-stationary data. Panel unit root tests evaluate whether variables should be converted or differencing to allow for additional investigation. If the variables are integrated into mixed orders, the panel autoregressive distributed lag (ARDL) model investigates the variables' short- and long-term relationships. Equations 1 to 8 show the panel unit roots illustrations for ready reference:

$$\Delta IBT_{i,t} = \alpha + \beta TIME + \gamma IBT_{i,t-1} + \delta_1 \Delta IBT_{i,t-1} + \dots + \delta_{p-1} \Delta IBT_{i,t-p-1} + \varepsilon_{i,t} \quad (1)$$

$$\Delta RFI_{i,t} = \alpha + \beta TIME + \gamma RFI_{i,t-1} + \delta_1 \Delta RFI_{i,t-1} + \dots + \delta_{p-1} \Delta RFI_{i,t-p-1} + \varepsilon_{i,t} \quad (2)$$

$$\Delta IQ_{i,t} = \alpha + \beta TIME + \gamma IQ_{i,t-1} + \delta_1 \Delta IQ_{i,t-1} + \dots + \delta_{p-1} \Delta IQ_{i,t-p-1} + \varepsilon_{i,t} \quad (3)$$

$$\Delta IRG_{i,t} = \alpha + \beta TIME + \gamma IRG_{i,t-1} + \delta_1 \Delta IRG_{i,t-1} + \dots + \delta_{p-1} \Delta IRG_{i,t-p-1} + \varepsilon_{i,t} \quad (4)$$

$$\Delta R\&D_{i,t} = \alpha + \beta TIME + \gamma R\&D_{i,t-1} + \delta_1 \Delta R\&D_{i,t-1} + \dots + \delta_{p-1} \Delta R\&D_{i,t-p-1} + \varepsilon_{i,t} \quad (5)$$

$$\Delta DC_{i,t} = \alpha + \beta TIME + \gamma DC_{i,t-1} + \delta_1 \Delta DC_{i,t-1} + \dots + \delta_{p-1} \Delta DC_{i,t-p-1} + \varepsilon_{i,t} \quad (6)$$

$$\Delta ES_{i,t} = \alpha + \beta TIME + \gamma ES_{i,t-1} + \delta_1 \Delta ES_{i,t-1} + \dots + \delta_{p-1} \Delta ES_{i,t-p-1} + \varepsilon_{i,t} \quad (7)$$

$$\Delta REC_{i,t} = \alpha + \beta TIME + \gamma REC_{i,t-1} + \delta_1 \Delta REC_{i,t-1} + \dots + \delta_{p-1} \Delta REC_{i,t-p-1} + \varepsilon_{i,t} \quad (8)$$

where *IBT* is the intra-BRICS-Turkey (intra-block) trade, reflecting the volume and direction of trade flows within the BRICS-Turkey framework, *RFI* is regional financial integration, measuring the degree of financial interconnectedness among member countries, *IQ* is infrastructure quality, representing the transport and digital infrastructure development level, *IRG* is institutional regulatory governance, capturing the effectiveness and coherence of regulatory frameworks, *R&D* is research and development expenditures, indicating innovation capacity and long-term competitiveness, *DC* is digital connectivity, assessing internet penetration, broadband infrastructure, and digital readiness, *ES* is economic stability, reflecting macroeconomic resilience to external shocks, *REC* is renewable energy consumption, measuring the share of renewables in the national energy mix, *I* is the cross-sectional unit (country index), *T* is the time index (year), ε is the error term, capturing stochastic disturbances not explained by the model.

3-3-2- Lag Length Selection Criteria

Choosing the appropriate lag length is critical for panel data modeling. The lag length is calculated using the Akaike information criterion (AIC), the Schwarz-Bayesian criterion (SBC), and the Hannan-Quinn information criterion (HQIC). Using these criteria, one may calculate a lag length that captures dynamic variable connections while minimizing information loss. The selected lag duration has an impact on short- and long-term coefficient estimates, as well as causal relationship interpretation. Other methods for assessing the model's robustness include comparing outcomes across specifications and accounting for lag lengths.

3-3-3- Panel ARDL Estimator

This study used panel ARDL to examine the correlations between the two datasets. This model is helpful since it estimates both short and long-term impacts in a single model and allows for different integration orders (I(0) and I(1)) [73]. The panel ARDL technique examines long-term and short-term intra-BRICS-T trade dynamics as a function of explanatory variable changes, assuming a stable long-run equilibrium connection across the panel of states. The ARDL model uses error correction to account for long-run equilibrium adjustment. The coefficients of the model are calculated using a dynamic specification, considering short-term dynamics and long-run equilibrium connections. This approach illustrates the long- and short-term effects of regional financial integration, infrastructure quality, and institutional governance on BRICS-T trade flows. Equations 9 and 10 show panel ARDL illustrations for capturing the short- and long-term effects and error correction term to confirm the cointegration process:

$$\ln(IFT)_{it} = \alpha_0 + \sum_{i=1}^p \alpha_1 \Delta(IFT)_{i,t-i} + \sum_{i=0}^q \alpha_2 \Delta(RFI)_{i,t-i} + \sum_{i=0}^r \alpha_3 \Delta(IQ)_{i,t-i} + \sum_{i=0}^t \alpha_4 \Delta(IRG)_{i,t-i} + \sum_{i=0}^u \alpha_5 \Delta(R\&D)_{i,t-i} + \sum_{i=0}^w \alpha_6 \Delta(DC)_{i,t-i} + \sum_{i=0}^x \alpha_7 \Delta(ES)_{i,t-i} + \sum_{i=0}^y \alpha_8 (REC)_{i,t-i} + \sum_{i=0}^z \alpha_9 (DUMMY)_{i,t-i} + \beta_1 \ln(RFI)_{it} + \beta_2 (IQ)_{it} + \beta_3 (IRG)_{it} + \beta_4 (R\&D)_{it} + \beta_5 (DC)_{it} + \beta_6 (ES)_{it} + \beta_7 (REC)_{it} + \beta_8 (DUMMY)_{it} + \varepsilon_{it} \quad (9)$$

$$\ln(IFT)_{it} = \alpha_0 + \rho(ECT)_{i,t-1} + \sum_{i=1}^p \alpha_1 \Delta(IFT)_{i,t-i} + \sum_{i=0}^q \alpha_2 \Delta(RFI)_{i,t-i} + \sum_{i=0}^r \alpha_3 \Delta(IQ)_{i,t-i} + \sum_{i=0}^t \alpha_4 \Delta(IRG)_{i,t-i} + \sum_{i=0}^u \alpha_5 \Delta(R\&D)_{i,t-i} + \sum_{i=0}^w \alpha_6 \Delta(DC)_{i,t-i} + \sum_{i=0}^x \alpha_7 \Delta(ES)_{i,t-i} + \sum_{i=0}^y \alpha_8 (REC)_{i,t-i} + \sum_{i=0}^z \alpha_9 (DUMMY)_{i,t-i} + \beta_1 \ln(RFI)_{it} + \beta_2 (IQ)_{it} + \beta_3 (IRG)_{it} + \beta_4 (R\&D)_{it} + \beta_5 (DC)_{it} + \beta_6 (ES)_{it} + \beta_7 (REC)_{it} + \beta_8 (DUMMY)_{it} + \varepsilon_{it} \quad (10)$$

where ρ shows the convergence coefficient, DUMMY shows five different dummies, including sanctions dummy, payment system dummy, US tariff shock dummy, global recession dummy, and combined shock dummy, ECT shows the error correction term, and Δ shows the differenced operator.

3-3-4- Panel Granger Casualty

To analyze the factors determining the dynamics of intra-bloc trade between BRICS countries and Turkey, this study applies the panel Granger causality test and the panel autoregressive distributed lag (ARDL) model. Combining these methods makes it possible to establish the existence of short- and long-term relationships between variables and identify the directionality of causal relationships. The Granger causality test in panel form is used to assess the extent to which the values of one variable in previous periods statistically significantly predict the values of another variable. This methodology makes it possible to reconstruct the structure of inter-factor relationships and identify the key determinants of BRICS-T intra-bloc trade. It is essential to establish whether improvements in institutional governance, increased financial integration, or infrastructure development lead to deeper trade cooperation or whether, on the contrary, trade growth stimulates the modernization of these components.

The causality test results are of applied significance for government agencies and international institutions because they make it possible to identify unidirectional or bilateral causal relationships between strategically essential variables. This, in turn, makes it possible to prioritize trade and institutional policies based on empirically confirmed regularities.

Equations 11 to 18 are the formalized multivariate panel Granger model used for statistical inference of causality between variables.

$$IFT_{it} = \alpha_0 + \sum_{i=1}^2 \alpha_1 IFT_{i,t-i} + \sum_{i=1}^2 \alpha_2 RFI_{i,t-i} + \sum_{i=1}^2 \alpha_3 IQ_{i,t-i} + \sum_{i=1}^2 \alpha_4 IRG_{i,t-i} + \sum_{i=1}^2 \alpha_5 R\&D_{i,t-i} + \sum_{i=1}^2 \alpha_6 DC_{i,t-i} + \sum_{i=1}^2 \alpha_7 ES_{i,t-i} + \sum_{i=1}^2 \alpha_8 REC_{i,t-i} + \varepsilon_{it} \quad (11)$$

$$RFI_{it} = \alpha_0 + \sum_{i=1}^2 \alpha_1 RFI_{i,t-i} + \sum_{i=1}^2 \alpha_2 IFT_{i,t-i} + \sum_{i=1}^2 \alpha_3 IQ_{i,t-i} + \sum_{i=1}^2 \alpha_4 IRG_{i,t-i} + \sum_{i=1}^2 \alpha_5 R\&D_{i,t-i} + \sum_{i=1}^2 \alpha_6 DC_{i,t-i} + \sum_{i=1}^2 \alpha_7 ES_{i,t-i} + \sum_{i=1}^2 \alpha_8 REC_{i,t-i} + \varepsilon_{it} \quad (12)$$

$$IQ_{it} = \alpha_0 + \sum_{i=1}^2 \alpha_1 IQ_{i,t-i} + \sum_{i=1}^2 \alpha_2 RFI_{i,t-i} + \sum_{i=1}^2 \alpha_3 IFT_{i,t-i} + \sum_{i=1}^2 \alpha_4 IRG_{i,t-i} + \sum_{i=1}^2 \alpha_5 R\&D_{i,t-i} + \sum_{i=1}^2 \alpha_6 DC_{i,t-i} + \sum_{i=1}^2 \alpha_7 ES_{i,t-i} + \sum_{i=1}^2 \alpha_8 REC_{i,t-i} + \varepsilon_{it} \quad (13)$$

$$IRG_{i,t} = \alpha_0 + \sum_{i=1}^2 \alpha_1 IRG_{i,t-i} + \sum_{i=1}^2 \alpha_2 RFI_{i,t-i} + \sum_{i=1}^2 \alpha_3 IQ_{i,t-i} + \sum_{i=1}^2 \alpha_4 IBT_{i,t-i} + \sum_{i=1}^2 \alpha_5 R\&D_{i,t-i} + \sum_{i=1}^2 \alpha_6 DC_{i,t-i} + \sum_{i=1}^2 \alpha_7 DC_{i,t-i} + \sum_{i=1}^2 \alpha_8 ES_{i,t-i} + \sum_{i=1}^2 \alpha_9 REC_{i,t-i} + \varepsilon_{i,t} \quad (14)$$

$$R\&D_{i,t} = \alpha_0 + \sum_{i=1}^2 \alpha_1 R\&D_{i,t-i} + \sum_{i=1}^2 \alpha_2 RFI_{i,t-i} + \sum_{i=1}^2 \alpha_3 IQ_{i,t-i} + \sum_{i=1}^2 \alpha_4 IRG_{i,t-i} + \sum_{i=1}^2 \alpha_5 IBT_{i,t-i} + \sum_{i=1}^2 \alpha_6 DC_{i,t-i} + \sum_{i=1}^2 \alpha_7 DC_{i,t-i} + \sum_{i=1}^2 \alpha_8 ES_{i,t-i} + \sum_{i=1}^2 \alpha_9 REC_{i,t-i} + \varepsilon_{i,t} \quad (15)$$

$$DC_{i,t} = \alpha_0 + \sum_{i=1}^2 \alpha_1 DC_{i,t-i} + \sum_{i=1}^2 \alpha_2 RFI_{i,t-i} + \sum_{i=1}^2 \alpha_3 IQ_{i,t-i} + \sum_{i=1}^2 \alpha_4 IRG_{i,t-i} + \sum_{i=1}^2 \alpha_5 R\&D_{i,t-i} + \sum_{i=1}^2 \alpha_6 IBT_{i,t-i} + \sum_{i=1}^2 \alpha_7 DC_{i,t-i} + \sum_{i=1}^2 \alpha_8 ES_{i,t-i} + \sum_{i=1}^2 \alpha_9 REC_{i,t-i} + \varepsilon_{i,t} \quad (16)$$

$$ES_{i,t} = \alpha_0 + \sum_{i=1}^2 \alpha_1 ES_{i,t-i} + \sum_{i=1}^2 \alpha_2 RFI_{i,t-i} + \sum_{i=1}^2 \alpha_3 IQ_{i,t-i} + \sum_{i=1}^2 \alpha_4 IRG_{i,t-i} + \sum_{i=1}^2 \alpha_5 R\&D_{i,t-i} + \sum_{i=1}^2 \alpha_6 DC_{i,t-i} + \sum_{i=1}^2 \alpha_7 DC_{i,t-i} + \sum_{i=1}^2 \alpha_8 IBT_{i,t-i} + \sum_{i=1}^2 \alpha_9 REC_{i,t-i} + \varepsilon_{i,t} \quad (17)$$

$$REC_{i,t} = \alpha_0 + \sum_{i=1}^2 \alpha_1 REC_{i,t-i} + \sum_{i=1}^2 \alpha_2 RFI_{i,t-i} + \sum_{i=1}^2 \alpha_3 IQ_{i,t-i} + \sum_{i=1}^2 \alpha_4 IRG_{i,t-i} + \sum_{i=1}^2 \alpha_5 R\&D_{i,t-i} + \sum_{i=1}^2 \alpha_6 DC_{i,t-i} + \sum_{i=1}^2 \alpha_7 DC_{i,t-i} + \sum_{i=1}^2 \alpha_8 ES_{i,t-i} + \sum_{i=1}^2 \alpha_9 IBT_{i,t-i} + \varepsilon_{i,t} \quad (18)$$

3-3-5- Intertemporal Forecasting Using Impulse Response Function and Variance Decomposition Analysis (IRF and VDA)

This study uses panel impulse response function (IRF) and variance decomposition analysis (VDA) to analyze the dynamics of interactions between variables and estimate the effects of exogenous shocks on BRICS-T intra-bloc trade volume. These tools make it possible to establish how fluctuations in independent variables, such as the level of financial integration, the quality of infrastructure, or R&D investment, affect intra-bloc trade in the short and long run. The impulse response function tracks the time profile of trade response to external political economy shocks, modeling the behavior of the system in response to a single perturbation of one of the variables, all other things being equal. This makes it possible to identify the sensitivity of BRICS-T trade to changes in the institutional environment, subsidy policies, changes in the payment system, and other key determinants.

Variance decomposition analysis quantifies the contribution of each independent variable to the overall variability (variation) of intra-block trade. It identifies which factors most explain the predicted variation in trade flows. Such assessments are of high value for decision-makers in BRICS-T countries because they enable targeted prioritization of integration policy directions and more precise adjustment of trade support measures.

3-3-6- ARIMA-Based Forecasting

The autoregressive integrated moving average (ARIMA) model was used to build a medium-term forecast of intra-bloc trade and obtain key macroeconomic indicators. At the preliminary stage, the plots of the autocorrelation function (ACF) and partial autocorrelation function (PACF) were analyzed to determine the correct order of autoregressive (AR) and moving average (MA) components of the model.

ACF plots revealed significant autocorrelation lags to determine the optimal number of MA components, while the PACF identified the required number of AR components reflecting stable dependencies between time lags. The parameters obtained made it possible to construct several ARIMA model specifications, among which the best approximation quality was selected using the Akaike information criterion (AIC) and Schwarz-Bayesian information criterion (SBC). The correctness of the constructed model was confirmed using the Ljung-Box Q-test, which demonstrated the absence of autocorrelation of the residuals, indicating the high accuracy of the model and its suitability for forecasting. Thus, the ARIMA model with the panel instruments IRF and VDA provides a robust framework for analyzing future trade and economic integration trajectories within BRICS-T, considering the cyclical and structural components of the macroeconomic dynamics.

4- Results

This section interprets the empirical results obtained and analyzes the nature of intra-bloc trade and integration in BRICS-T. Special attention is paid to descriptive statistics of key variables reflecting institutional, infrastructural, and macroeconomic characteristics of the countries involved in the study. Analysis at this stage is necessary to verify data quality, identify heterogeneity within the bloc, and for a preliminary understanding of structural differences affecting the intensity of trade and economic interaction.

Table 2 shows descriptive statistics for the main variables of the model, reflecting the dynamics of trade within the BRICS-T, the level of financial and institutional integration, and infrastructural and digital development.

Table 2. Descriptive statistics

Methods	IBT	RFI	IQ	IRG	R&D	DC	ES	REC
Mean	46.034	2.130	68.018	-0.086	1.044	8.305	9.2221	21.160
Maximum	81.170	9.677	95.212	0.819	2.432	44.728	25.389	50
Minimum	22.105	-1.756	8.099	-1.141	0.465	0.001	1.927	3.200
Std. deviation	11.875	1.395	24.985	0.351	0.439	9.697	4.899	15.707
Skewness	-0.172	1.198	-1.332	0.336	1.461	1.355	0.698	0.565
Kurtosis	2.729	7.782	3.603	3.326	4.965	4.492	2.778	1.739
Observations	144	144	144	144	144	144	144	144
Countries	6	6	6	6	6	6	6	6

Note: IBT shows intra-BRICS-T trade, RFI shows regional financial integration, IQ shows infrastructure quality, IRG shows institutional regulatory quality, R&D shows research and development expenditures, DC shows digital connectivity, ES shows economic stability, and REC shows renewable energy consumption.

The mean value of the intra-bloc trade (IBT) indicator is 46.034, which indicates an average level of economic connectivity between BRICS-Turkey during the study period. The minimum value (22.105) can be associated with economic shocks, trade conflicts, or institutional barriers, while the maximum value (81.170) indicates periods of intense trade growth or enhanced cooperation between individual countries. The standard deviation of IBT (11.875) indicates significant variability of trading activity within the block, while the near-zero value of distribution skewness (-0.172) demonstrates the absence of pronounced skewness, which evidences balanced trade flows without extremes.

The average value of regional financial integration (RFI) is 2.130, reflecting a moderate but positive level of cross-border capital flows between the block countries. A significant range of values (from -1.756 to 9.677) indicates asymmetry in financial flows – from intensive capital inflows in some countries to its outflow or absence in others. Positive asymmetry and the value of kurtosis confirm the influence of exogenous factors, including changes in global liquidity and domestic institutional reforms.

Infrastructure quality (IQ) is 68.018 on average, confirming base transport and digital connectivity. However, the range from 8,099 to 95,212 shows a high heterogeneity within the block, reflecting institutional and technological differences between countries. The data indicate the presence of both leaders and laggards in infrastructure development.

The index of regulatory quality/governance (IRG) has a mean value of -0.086 on a scale of -2.5 to +2.5, reflecting a significant institutional deficit, evidencing the need for institutional modernization and improved regulatory efficiency, especially in countries with low scores.

The average level of investment in R&D is 1.044% of GDP, indicating moderate attention to innovative development in BRICS-T countries. The dispersion of values demonstrates a significant difference in the scientific and technological potential of the countries, with some states actively increasing investment in innovation and others lagging. The digital connectivity (DC) indicator of 8.305 internet users per 100 people reflects progress in digitalization. The positive skewness of the distribution indicates accelerated development of digital platforms in some countries during the study period. The average level of foreign exchange reserves (FXR) that characterizes ES is 9 months of import cover, indicating that most countries in the bloc have significant resources to ensure macroeconomic stability. However, the range of values (from 1.927 to 25.389) indicates significant differences in resilience to external shocks across countries.

Finally, the share of renewable energy consumption (REC) averages 21.160%, confirming the moderately growing role of renewable energy sources (RES) in the energy balance of BRICS-T countries, also evidencing a move towards sustainable development, although growth rates remain heterogeneous. Thus, the results of the descriptive analysis confirm the presence of high cross-country heterogeneity within BRICS-T by most key indicators. These differences should be considered when interpreting the regression analysis results and developing differentiated policies to deepen regional integration. The descriptive statistics show that there are 6 countries in the panel with 144 observations (total number), hence, the study safely proceed for empirical estimation of the studied variables.

Table 3 presents the results of the Im-Pesaran-Shin (IPS) panel unit-root tests, confirming the integration orders of the series and thereby validating the suitability of our econometric framework.

Table 3. IPS-panel unit root estimates

Variables	Level		First difference		Decision
	Constant	Constant and trend	Constant	Constant and trend	
IBT	-0.274 (0.392)	-1.015 (0.154)	-6.134 (0.000)	-5.015 (0.000)	I(1)
RFI	-1.415 (0.078)	-1.371 (0.085)	-5.524 (0.000)	-5.560 (0.000)	I(1)
IQ	0.722 (0.765)	0.245 (0.596)	-4.541 (0.000)	-3.135 (0.000)	I(1)
IRG	1.504 (0.933)	-1.376 (0.084)	-4.556 (0.000)	-3.567 (0.000)	I(1)
R&D	0.286 (0.612)	-1.222 (0.110)	-5.147 (0.000)	-3.792 (0.000)	I(1)
DC	4.795 (1.000)	-0.0003 (0.499)	-2.233 (0.012)	-1.134 (0.128)	I(1)
ES	-1.652 (0.049)	-0.726 (0.233)	-8.635 (0.000)	-7.216 (0.000)	I(0)
REC	-3.576 (0.000)	-0.438 (0.330)	-3.876 (0.000)	-3.388 (0.000)	I(0)

Note: IBT shows intra-BRICS-T trade, RFI shows regional financial integration, IQ shows infrastructure quality, IRG shows institutional regulatory quality, R&D shows research and development expenditures, DC shows digital connectivity, ES shows economic stability, and REC shows renewable energy consumption. Small bracket shows probability value.

The findings demonstrate that most variables have a unit root and only become stationary after first differencing, except for economic stability (ES) and renewable energy consumption (REC), which are stable. Due to mixed integration, advanced econometric approaches like the panel ARDL methodology used in this study are necessary to handle variables with different integration qualities. R&D, DC, IBT, RFI, IQ, and IRG were non-stationary at such levels. It shows that these variables' initial shapes have constant shocks or patterns. Their first-differenced stationarity shows an I(1) process after differencing the unit root, stabilizing their time series properties characteristic of macroeconomic and trade-related statistics since structural changes, external shocks, and policy changes may affect long-term trends.

However, the stationary level defines economic stability (ES) and renewable energy consumption (REC), staying essentially constant or exhibiting mean reversion over time without differencing. The stationarity of ES reflects that import coverage shows mostly consistent BRICS-T reserves despite economic fluctuations. This conclusion supports the assumption that governments hold reserves to manage their economies during external shocks. The stationarity of REC may reflect policies aimed at a sustainable energy transition and climate change mitigation that seek to integrate renewable energy into the energy mix. Given the presence of I(0) and I(1) variables, the panel ARDL model can efficiently and consistently estimate parameter values for mixed integration orders.

The lag length selection criteria in Table 4 are vital to the accuracy and stability of the panel ARDL model. The right lag length captures dynamic variable interactions and prevents model overfitting or underfitting. Results show some variation in criterion. The final prediction error (FPE), Schwarz information criterion (SC), and Hannan and Quinn information criterion (HQIC) recommend two lag durations for parameter estimation in the panel ARDL model. A two-lag time is a suitable center since model complexity and explanatory power conform to it. AIC predicts greater lag duration of eight, whereas the likelihood ratio (LR) criteria predict six. In time-limited models, LR and AIC may overfit due to their tendency to capture all dynamic interactions, resulting in more lag choices and overfitting. This study used a two-lag panel ARDL computation using the SC criteria considering these discrepancies.

SC for simpler models supports this choice. A higher risk for incorporating more lags reduces overfitting while keeping the model's ability to capture essential dynamics. This work estimates short- and long-term associations without complexity, and SC is suitable for the dataset. The model captures the independent variables' immediate and somewhat delayed impacts on intra-BRICS-T trade with a two-lag length. Statistics is more practical when examined via trade flows, financial integration, institutional governance, and this lag structure. The study indicates that this model can handle variables with varying integration orders, making parameter prediction straightforward and reliable. A detailed method improves the study's analytical framework and ensures an optimum panel ARDL model. This method improves econometric results and illuminates how important factors interact over time, improving intra-BRICS-T trade understanding.

Table 4. Lag length selection criteria estimates

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1884.472	NA	1.8319639	39.426	39.640	39.512
1	-783.905	1994.776	0.007695*	17.831	19.754*	18.608*
2	-744.218	65.317	0.013103	18.337	21.970	19.806
3	-697.426	69.213	0.020072	18.696	24.038	20.855
4	-647.215	65.901	0.030625	18.983	26.035	21.834
5	-580.705	76.209	0.036743	18.931	27.692	22.472
6	-493.379	85.506*	0.032989	18.445	28.916	22.678
7	-395.963	79.151	0.029636	17.749	29.929	22.672
8	-271.758	80.215	0.021025	16.494*	30.385	22.109

* shows a lag order selected by the criterion.

In Table 5, panel ARDL estimates demonstrate complex intra-BRICS-T trade and factor interactions, exhibiting short- and long-term dynamics. Regional financial integration boosts BRICS-T commerce in the short and long term. Local financing and overseas portfolio purchase lower transaction costs and improve trade flows temporarily. This shows how integrated financial systems may reduce economic barriers and boost regional commerce. The positive impact shows how crucial financial connection is for helping businesses and reducing liquidity restrictions [74]. In the long run, commerce drives infrastructure and industrial capacity investment. The gravity model of trade emphasizes financial closeness for bilateral and international trade network improvement [75]. Better financial links across sectors enhanced economic resilience and trade growth [76, 77]. These findings show that BRICS-T governments must coordinate financial policies to strengthen trade. According to the endogenous growth paradigm, merely having capital promotes economic growth and commerce. Regional financial integration facilitates capital movement, which improves innovation, manufacturing efficiency, and cross-regional trade [78]. With this knowledge, BRICS-T officials may improve trade by implementing targeted financial efforts, including harmonized regulatory frameworks and investment incentives.

Table 5. Panel ARDL estimates

Dependent variable: D(IBT)				
Selected model: ARDL (2, 2, 2, 2, 2, 2, 2)				
Variables	Coefficient	Std. error	t-Statistic	Prob. value
Long run equation				
RFI	8.741	0.972	8.997	0
IQ	0.366	0.03	12.179	0
IRG	-27.324	9.037	-3.022	0.003
R&D	17.592	2.87	6.136	0
DC	-0.542	0.086	-6.297	0
ES	-0.423	0.215	-1.967	0.049
REC	-0.086	0.06	-1.431	0.154
Dummy variables				
US tariff shock t (2018)	-0.476	0.21	-2.268	0.024
Global recession t (2008-09, 2020)	-0.312	0.148	-2.107	0.036
Sanctions i,t (Russia: 2014, China: 2018)	-1.087	0.472	-2.303	0.022
Payment system i,t (CIPS, SPFS)	0.679	0.327	2.078	0.038
Combined shock t (Total pressure index)	-0.544	0.37	-1.47	0.142
Short run equation				
COINTEQ01	-0.295	0.124	-2.376	0.018
D(IBT(-1))	0.421	0.144	2.929	0.004
D(RFI)	0.253	0.906	0.279	0.781
D(RFI(-1))	-1.032	0.537	-1.922	0.057
D(IQ)	0.514	0.695	0.74	0.46
D(IQ(-1))	1.289	1.709	0.754	0.451
D(IRG)	-10.218	4.628	-2.206	0.028
D(IRG(-1))	6.021	15.015	0.401	0.688
D(R&D)	-15.361	14.857	-1.034	0.302
D(R&D(-1))	-15.522	10.244	-1.515	0.131
D(DC)	1.417	0.667	2.127	0.034
D(DC(-1))	2.291	1.269	1.806	0.071
D(ES)	-1.329	0.632	-2.103	0.035
D(ES(-1))	-0.521	0.752	-0.694	0.489
D(REC)	-0.899	0.487	-1.847	0.068
D(REC(-1))	1.476	2.536	0.582	0.56

<i>Dummy variables</i>				
US tariff shock t (2018)	-0.341	0.2	-1.705	0.089
Global recession t (2008-09, 2020)	-0.225	0.152	-1.484	0.137
Sanctions i,t (Russia: 2014, China: 2018)	-0.782	0.456	-1.717	0.087
Payment system i,t (CIPS, SPFS)	0.533	0.295	1.804	0.072
Combined shock t (Total pressure index)	-0.491	0.308	-1.597	0.111

Note: IBT shows intra-BRICS-T trade, RFI shows regional financial integration, IQ shows infrastructure quality, IRG shows institutional regulatory quality, R&D shows research and development expenditures, DC shows digital connectivity, ES shows economic stability, and REC shows renewable energy consumption.

Institutional governance plays a pivotal role in shaping trade trajectories, with empirical evidence indicating that improvements in institutional quality substantially enhance intra-BRICS-T trade over time. Robust institutional arrangements, marked by the effective enforcement of trade agreements, the minimization of transaction costs, and the strengthening of investor confidence, serve as critical enablers of regional trade integration. These findings align with the central tenets of institutional economics, which underscore the function of governance structures in mitigating market failures and reducing uncertainty, thereby promoting long-term economic performance [79]. Nevertheless, the gains from institutional reform are often deferred, as transitional frictions, implementation delays, and structural adjustments within financial systems tend to impede the timely realization of trade-related benefits. While high-quality institutions are instrumental in attracting foreign direct investment and enhancing export competitiveness, their positive externalities accrue incrementally [80].

Given the heterogeneity in institutional capacities across the BRICS-T, structural transformation aimed at strengthening regulatory oversight, customs efficiency, and dispute resolution mechanisms is essential. According to transaction cost theory, well-functioning institutions lower coordination frictions, mitigate enforcement asymmetries, and reduce information gaps that inhibit trade expansion [81]. Conversely, institutional weaknesses, particularly inconsistent or overly complex regulations, may generate both short- and long-term inefficiencies, impeding intra-bloc commerce. While regulatory coherence is fundamental to market stability and investor trust, excessive compliance costs and procedural delays can discourage entrepreneurial activity. From the perspective of institutional theory, rigid or fragmented regulatory regimes constrain market entry and distort competitive dynamics [82]. Promoting an integrated regional trade environment within the BRICS-T initiative requires the harmonization of legal norms and the mitigation of policy fragmentation, especially in federated or multi-jurisdictional settings where divergent regulations exacerbate trade distortions [83, 84].

The findings further emphasize the strategic relevance of endogenous growth mechanisms, particularly the role of research and development (R&D) investment in fostering sustainable economic advancement. Rooted in endogenous growth theory, innovation and technological progress are viewed as principal drivers of long-run economic performance and cross-border trade expansion [85]. For BRICS-T economies, intensified R&D investment facilitates the production of high-value, technologically advanced goods capable of securing durable positions in international markets. Given the structural asymmetries in scientific and industrial capacity across member states, R&D serves as a levelling force, enhancing export diversification and elevating the bloc's collective technological profile [86]. Empirical evidence confirms that such investments reduce marginal production costs, improve product quality, and expand the high-tech content of exports, particularly in sectors characterized by elevated value-added components.

Moreover, digital connectivity emerges as a significant short-term enabler of trade, reducing transaction costs, increasing transparency, and accelerating the flow of goods and information across digital platforms. This supports the logic of network theory, which highlights the critical role of digital linkages in optimizing supply chains and market access [87]. However, the over-reliance on digital infrastructure introduces vulnerabilities in the long term, including exposure to cybersecurity risks, growing digital divides, and systemic fragility in cross-border trade routes [88]. Therefore, alongside infrastructure development, there is a pressing need for coherent regulatory and legal frameworks to govern digital commerce. Such frameworks must ensure that trade acceleration does not come at the expense of socioeconomic resilience or inclusivity. Strengthening the institutional and technological underpinnings of digital trade is particularly vital for fostering sustainable integration among BRICS-T economies amidst escalating global fragmentation and developmental divergence.

Macroeconomic stability exerts both short- and long-term effects on intra-BRICS-T trade flows, suggesting that the structural configuration of the bloc's macroeconomic governance may account for these dynamics. While large foreign exchange reserves are conventionally interpreted as indicators of stability, they may paradoxically curtail trade-enhancing investments if held as precautionary buffers rather than mobilized through productive channels. This interpretation aligns with the precautionary savings hypothesis, which posits that economic resilience, if not strategically leveraged, can suppress trade expansion by crowding out growth-oriented expenditures [89, 90]. Our empirical findings further indicate that trade-stimulating policies must strike a balance between dynamism and macroeconomic restraint to sustain intra-bloc cooperation. In the short run, renewable energy consumption exerts a negative impact on intra-BRICS-

T trade, with its influence diminishing to statistical insignificance over the long term. This short-term drag may stem from high upfront capital costs and transitional inefficiencies associated with large-scale shifts toward renewables. Over time, as these economies adapt to cleaner energy systems, the trade-disruptive effects appear to taper off [91]. These observations are consistent with the Environmental Kuznets Curve hypothesis, which anticipates an initial slowdown in economic performance due to green regulatory pressures, followed by neutrality or recovery as technological advancements offset early-stage constraints [92].

ARDL panel findings illuminate the complex dynamics of intra-BRICS-T trade, highlighting financial, institutional, technological, and environmental aspects. These results affect legislators seeking to optimize trade strategy in a fast-changing market. Table 6 shows the panel Granger causality estimates for ready reference.

Table 6. Dumitrescu-Hurlin panel Granger causality tests estimates

Null hypothesis	W-Stat.	Zbar-Stat.	Prob.
IQ → IBT	6.182	3.700	0.000
IBT → IQ	3.988	1.626	0.103
IRG → IBT	4.064	1.698	0.089
IBT → IRG	2.608	0.322	0.746
R&D → IBT	9.273	6.621	4.E-11
IBT → R&D	3.430	1.100	0.271
DC → IBT	5.600	3.150	0.001
IBT → DC	1.743	-0.494	0.621
ES → IBT	6.323	3.833	0.000
IBT → ES	7.830	5.257	1.E-07
REC → IBT	4.609	2.213	0.026
IBT → REC	1.712	-0.523	0.600
IQ → RFI	4.286	1.908	0.056
RFI → IQ	3.394	1.066	0.286
R&D → RFI	6.807	4.290	2.E-05
RFI → R&D	2.061	-0.194	0.846
DC → RFI	3.984	1.623	0.104
RFI → DC	6.511	4.011	6.E-05
ES → RFI	5.973	3.503	0.000
RFI → ES	4.044	1.680	0.092
IRG → IQ	2.723	0.431	0.665
IQ → IRG	4.968	2.553	0.010
DC → IQ	5.834	3.372	0.000
IQ → DC	3.081	0.769	0.441
R&D → IRG	5.094	2.672	0.007
IRG → R&D	2.087	-0.169	0.865
DC → IRG	4.187	1.814	0.069
IRG → DC	2.623	0.337	0.736
ES → IRG	4.096	1.728	0.083
IRG → ES	3.765	1.416	0.156
REC → IRG	5.939	3.470	0.000
IRG → REC	3.328	1.003	0.315
ES → R&D	5.661	3.207	0.001
R&D → ES	3.882	1.527	0.126
REC → ES	5.584	3.135	0.001
ES → REC	2.461	0.184	0.853

Note: IBT shows intra-BRICS-T trade, RFI shows regional financial integration, IQ shows infrastructure quality, IRG shows institutional regulatory quality, R&D shows research and development expenditures, DC shows digital connectivity, ES shows economic stability, and REC shows renewable energy consumption.

In Table 7, the impulse response function (IRF) estimates show how intra-BRICS-T trade (IBT) would respond to significant driving shocks in the coming decade.

Table 7. Impulse response function (IRF) estimates of intra-BRICS-T trade (IBT)

Period	IBT (95% CI)	RFI (95% CI)	IQ (95% CI)	IRG (95% CI)	R&D (95% CI)	DC (95% CI)	ES (95% CI)	REC (95% CI)
2024	4.126 (3.85, 4.40)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
2025	3.711 (3.45, 3.97)	0.429 (0.32, 0.54)	0.024 (0.01, 0.04)	0.021 (0.00, 0.04)	0.717 (0.58, 0.86)	0.432 (0.30, 0.56)	0.612 (0.49, 0.73)	-0.783 (-0.94, -0.62)
2026	3.108 (2.87, 3.35)	0.313 (0.22, 0.41)	0.136 (0.10, 0.17)	0.037 (0.01, 0.06)	0.713 (0.59, 0.83)	0.627 (0.52, 0.73)	0.273 (0.15, 0.40)	-1.028 (-1.19, -0.87)
2027	2.497 (2.31, 2.68)	0.198 (0.10, 0.30)	0.173 (0.14, 0.21)	0.016 (-0.01, 0.04)	0.519 (0.39, 0.65)	0.672 (0.55, 0.79)	0.106 (-0.01, 0.22)	-0.951 (-1.09, -0.81)
2028	1.967 (1.81, 2.12)	0.122 (0.03, 0.22)	0.250 (0.21, 0.29)	-0.004 (-0.03, 0.02)	0.289 (0.16, 0.42)	0.619 (0.51, 0.73)	-0.004 (-0.12, 0.11)	-0.787 (-0.91, -0.66)
2029	1.538 (1.40, 1.68)	0.084 (0.00, 0.17)	0.305 (0.26, 0.35)	-0.028 (-0.06, 0.00)	0.080 (-0.03, 0.19)	0.550 (0.44, 0.66)	-0.062 (-0.17, 0.04)	-0.629 (-0.74, -0.52)
2030	1.202 (1.09, 1.31)	0.067 (0.00, 0.14)	0.356 (0.31, 0.40)	-0.047 (-0.08, -0.01)	-0.093 (-0.19, 0.00)	0.486 (0.38, 0.59)	-0.097 (-0.21, 0.02)	-0.496 (-0.61, -0.38)
2031	0.943 (0.85, 1.04)	0.059 (0.00, 0.13)	0.393 (0.35, 0.44)	-0.063 (-0.09, -0.03)	-0.231 (-0.34, -0.12)	0.436 (0.34, 0.53)	-0.116 (-0.23, -0.01)	-0.391 (-0.49, -0.29)
2032	0.743 (0.67, 0.82)	0.056 (0.00, 0.12)	0.422 (0.38, 0.46)	-0.076 (-0.10, -0.05)	-0.340 (-0.45, -0.23)	0.399 (0.31, 0.49)	-0.128 (-0.25, -0.01)	-0.310 (-0.40, -0.22)
2033	0.589 (0.52, 0.66)	0.056 (0.00, 0.12)	0.442 (0.40, 0.48)	-0.087 (-0.11, -0.06)	-0.425 (-0.54, -0.30)	0.372 (0.29, 0.45)	-0.135 (-0.25, -0.02)	-0.247 (-0.33, -0.17)

Note: IBT shows intra-BRICS-T trade, RFI shows regional financial integration, IQ shows infrastructure quality, IRG shows institutional regulatory quality, R&D shows research and development expenditures, DC shows digital connectivity, ES shows economic stability, REC shows renewable energy consumption, and CI is a confidence interval.

The empirical findings indicate that regional financial integration (RFI), infrastructure quality (IQ), and digital connectivity (DC) are expected to exert a positive and sustained influence on intra-BRICS-Turkey trade (IBT) throughout the projection horizon. This persistent effect underscores the critical role of financial integration in facilitating cross-border capital flows, reducing transaction costs, and enhancing the efficiency of trade mechanisms. Moreover, improvements in infrastructure and digital networks contribute to lowering logistical frictions and enabling more resilient supply chains, thereby strengthening the structural foundation for regional integration.

High-quality institutions boost commerce by improving openness, cutting transaction costs, and strengthening governance, supporting institutional theories that emphasize the need for strong institutions in economic development. Digital connectivity is transforming the BRICS-T, improving communication, simplifying supply chains, and enabling e-commerce, which boosts trade volumes. The expected consequences of institutional regulatory governance (IRG), R&D investment, and economic stability have a more complicated temporal structure. IRG is expected to impact IBT positively from 2025 to 2028, reflecting regulatory improvements' immediate trade-promoting benefits. As trade systems stabilize, IRG's decline after 2028 may indicate regulatory consistency concerns or regulatory modification's diminishing benefits. IBT will benefit from R&D expenditure from 2025 to 2029. This early impact supports the assumption that innovation boosts competitiveness and trade diversification. However, declining influence of R&D beyond 2029 emphasizes the need for continued investment and legislative support to sustain innovation-driven trade development. This motivates BRICS-T leaders to prioritize long-term research and innovation. IBT promotes dependable commerce, reduces uncertainty, and boosts investor confidence, which should boost economic stability from 2025 to 2027. The following deterioration threatens long-term macroeconomic stability. Unexpected occurrences or underlying issues might reverse brief advances in economic stability due to cycles. Policy must be proactive to ensure stability and trade gains. The projected decline in the contribution of renewable energy consumption (REC) to intra-BRICS-T trade (IBT) between 2025 and 2033 may reflect temporary integration challenges such as high initial costs, infrastructural bottlenecks, and potential disruptions to existing trade flows. These findings underscore the need for comprehensive policy frameworks that reconcile environmental objectives with trade efficiency. In particular, renewable energy initiatives should be aligned with trade policy to mitigate any adverse long-term impacts on IBT.

These dynamics are further examined through impulse response analysis. Figure 3 presents the overall impulse response functions over a ten-period horizon, based on Cholesky decomposition. Each subplot corresponds to a one-standard-deviation shock in a given variable and traces the responses of all variables in the system. On each panel, the horizontal axis denotes periods after the shock (e.g., years), and the vertical axis measures the magnitude of the response relative to baseline. Colored lines show the estimated point responses for intra-BRICS-T trade (IBT), regional financial integration (RFI), infrastructure quality (IQ), institutional regulatory governance (IRG), R&D investment, digital connectivity (DC), economic stability (ES), and REC. Shaded bands (or dashed lines) around these lines indicate ± 2 standard errors (approximately the 95% confidence interval). Together, the panels illustrate the direction, magnitude, and persistence of shocks: for example, a positive shock to institutional regulatory quality may boost IBT in the short run before effects dissipate, whereas a disturbance in REC could initially depress trade before stabilizing. By showing how each variable dynamically affects and is affected by others, Figure 3 highlights the temporal patterns and relative strengths of interactions among the key determinants of socioeconomic integration.

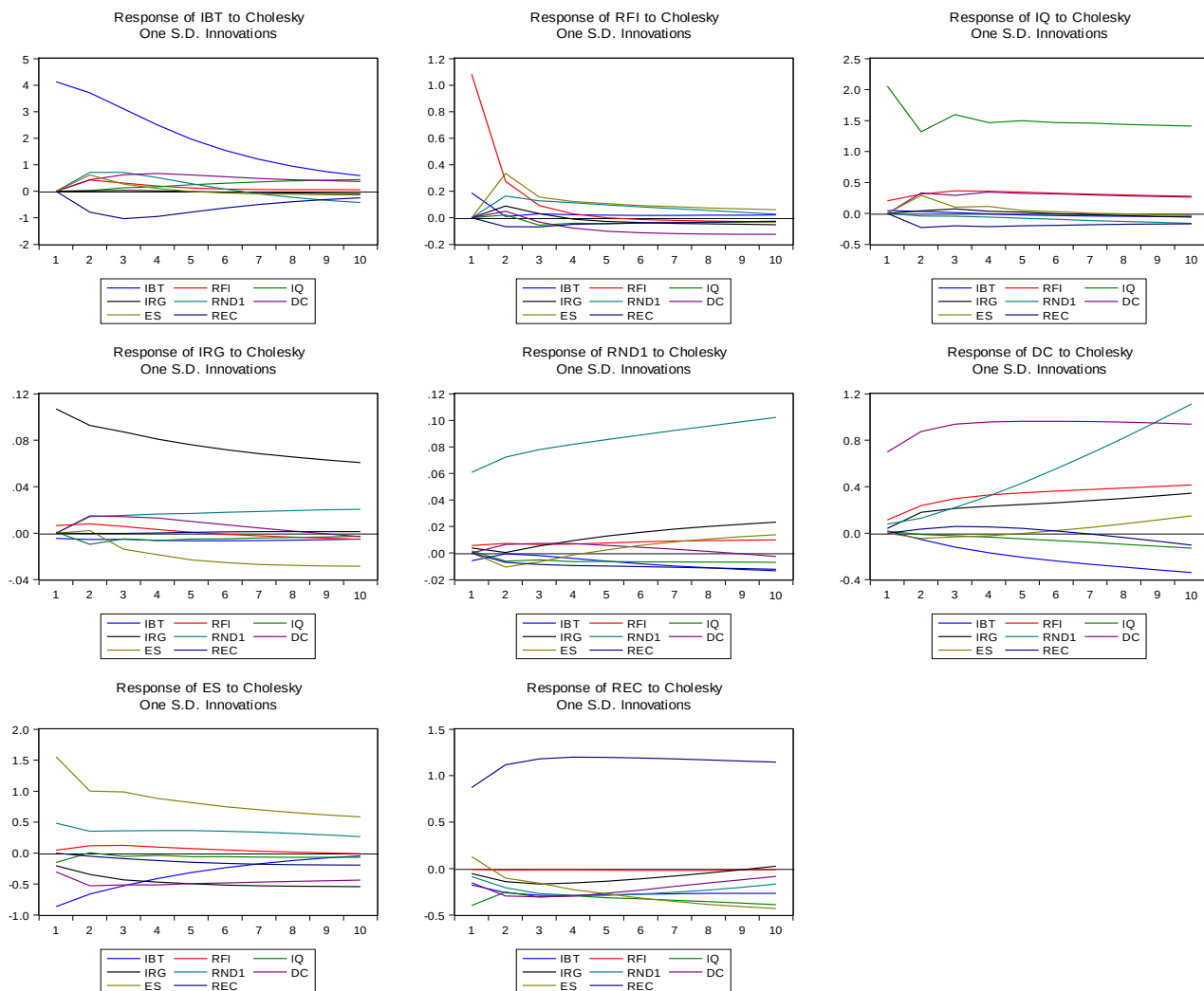


Figure 3. Impulse response functions of intra-BRICS-Turkey trade and key determinants to one-standard-deviation shocks over a ten-period horizon, estimated from a panel VAR model

The impulse response function (IRF) gives economic understanding by tracking the dynamic effects of a one-time shock on its current and future values. Direction, magnitude, and persistence may help explain energy security, research and development, and infrastructure quality shocks. However, statistical limitations may alter IRF results. Since confidence ranges around answers may be high, estimates may be problematic over extended periods. The choice of model specification that affects IRF, such as the order of variables and the selection of lags, can also affect economic robustness. Even though the IRF provides insights into dynamic interactions, these statistical constraints need careful consideration when interpreting data.

Table 8 provides a panel variance decomposition analysis (VDA) that illustrates the factors influencing future intra-BRICS-T trade (IBT) volatility. The IBT variance shock is expected to be primarily affected by renewable energy consumption (REC), which accounts for 6.257% of the variation. This significant impact shows how renewable energy is shaping BRICS-T trade trends. Changes in member countries' cost structures, energy reliance, and competitive advantages from renewable energy affect trade patterns.

The second most significant component, digital connectivity (DC), explains 3.684% of IBT variance, demonstrating that BRICS nations prioritize digital transformation to boost trade efficiency and connectivity. Digital connectivity improves supply chain management, e-commerce, and information flow, increasing trade volumes. DC's relatively big variance shock seems realistic as the digital economy emphasizes the exponential consequences of connection on economic activity. R&D spending affects IBT, with a variance shock of 2.627%. R&D highlights how innovation boosts trade competitiveness and diversity. Nations may enhance manufacturing and trade commodity quality by investing in R&D. They gain credibility in regional and worldwide markets. Infrastructure quality (IQ) explains 1.298% of IBT variance due to its influence on trade-supporting legislation and governance. Strong institutions that improve openness, lower transaction costs, and build trade partner trust boost commerce. Institutional reforms are needed to sustain trade-enhancing effects. RFI contributes the least to the variance in IBT, with a shock of 0.540%. Financial integration lowers

transaction costs and increases capital availability, but its indirect influence on IBT needs to be more visible. Trade may be affected by various factors, like the BRICS-T financial market growth. The analysis suggests that RFI is still significant for economic integration, but enhanced cross-border investment frameworks and uniform banking norms may be needed to benefit from trade. Figure 4 presents the results of the forecast error variance decomposition (VDA) for each key variable in the system over a horizon ranging from 1 to 10 periods. In each subplot, the horizontal axis represents the number of periods ahead in the forecast horizon (e.g., years following an initial shock), while the vertical axis shows the percentage of the forecast error variance of the given variable explained by shocks across all included factors. The legend specifies the correspondence between colored lines: the own shock of the analyzed variable and shocks from other factors (e.g., IBT, RFI, IQ, IRG, R&D, DC, ES, REC).

Table 8. Panel variance decomposition analysis of intra-BRICS-T trade

Period	S.E.	IBT (%)	RFI (%)	IQ (%)	IRG (%)	R&D (%)	DC (%)	ES (%)	REC (%)
		(CI 95%)	(CI 95%)	(CI 95%)	(CI 95%)	(CI 95%)	(CI 95%)	(CI 95%)	(CI 95%)
2024	4.126	100 (100-100)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
2025	5.716	94.26 (92-96)	0.56 (0.3-0.9)	0.002 (0-0.005)	0.001 (0-0.003)	1.58 (1-2.5)	0.57 (0.3-0.8)	1.15 (0.8-1.7)	1.88 (1.2-2.6)
2026	6.669	90.95 (89-93)	0.64 (0.4-1)	0.04 (0.02-0.07)	0.004 (0-0.01)	2.30 (1.6-3)	1.30 (0.8-1.9)	1.01 (0.7-1.4)	3.75 (2.8-4.7)
2027	7.24	89.07 (87-91)	0.61 (0.4-0.9)	0.09 (0.06-0.13)	0.004 (0-0.01)	2.47 (1.7-3.2)	1.97 (1.2-2.6)	0.88 (0.5-1.3)	4.91 (3.8-6)
2028	7.58	88.00 (86-90)	0.59 (0.3-0.8)	0.19 (0.12-0.26)	0.004 (0-0.01)	2.39 (1.8-3)	2.46 (1.8-3.1)	0.80 (0.5-1.1)	5.56 (4.4-6.8)
2029	7.787	87.29 (85-89)	0.57 (0.3-0.8)	0.34 (0.24-0.44)	0.005 (0-0.01)	2.28 (1.7-2.9)	2.83 (2.1-3.6)	0.77 (0.5-1)	5.92 (4.8-7)
2030	7.919	86.70 (84-89)	0.56 (0.3-0.8)	0.53 (0.42-0.65)	0.008 (0-0.02)	2.22 (1.6-2.9)	3.11 (2.4-3.8)	0.76 (0.5-1)	6.12 (5-7.2)
2031	8.011	86.12 (84-88)	0.55 (0.3-0.8)	0.76 (0.60-0.92)	0.014 (0-0.03)	2.25 (1.7-2.9)	3.34 (2.6-4)	0.76 (0.5-1)	6.22 (5-7.3)
2032	8.081	85.48 (83-88)	0.54 (0.3-0.8)	1.02 (0.82-1.2)	0.023 (0-0.04)	2.39 (1.8-3)	3.53 (2.8-4.2)	0.77 (0.5-1)	6.26 (5-7.4)
2033	8.139	84.77 (82-87)	0.54 (0.3-0.8)	1.30 (1-1.6)	0.034 (0-0.05)	2.63 (2-3.3)	3.68 (2.9-4.4)	0.79 (0.5-1.1)	6.26 (5-7.5)

Note: S.E. is standard error, IBT shows intra-BRICS-T trade, RFI shows regional financial integration, IQ shows infrastructure quality, IRG shows institutional regulatory quality, R&D shows research and development expenditures, DC shows digital connectivity, ES shows economic stability, REC shows renewable energy consumption, and CI is a confidence interval.

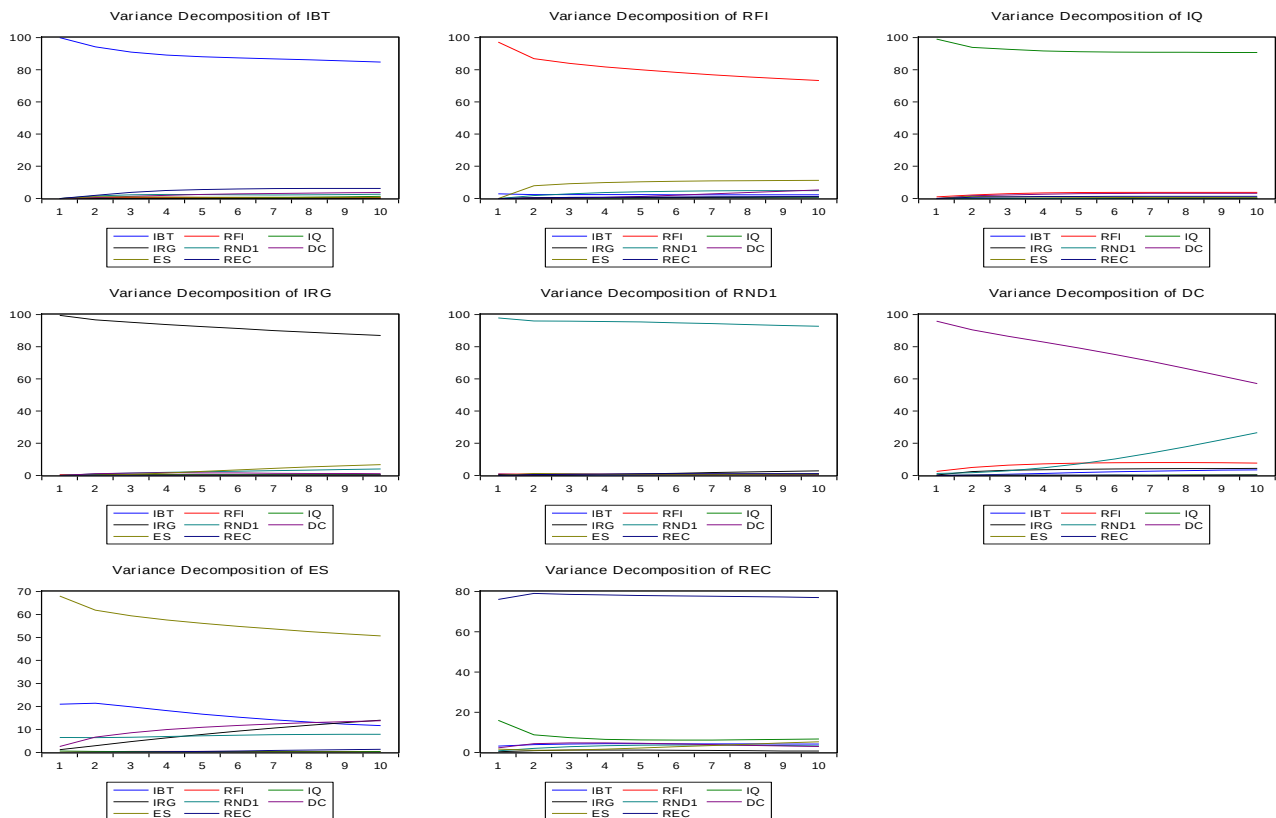


Figure 4. Overall VDA estimates

In the panel for intra-BRICS-Turkey (IBT), it is evident that at initial horizons, model uncertainty is primarily driven by the own shock of IBT (accounting for more than 90% of the variance). However, as the forecast horizon extends, the

contributions of factors such as renewable energy consumption (REC) and regional financial integration (RFI) gradually increase. This suggests that structural determinants begin to play a more prominent role in trade fluctuations over the medium term.

For regional financial integration (RFI) panel, the own shock dominates initially, although its share declines over time, while the contributions of other variables, particularly REC and ES, rise. This indicates growing interdependence between financial integration, energy-related, and macroeconomic shocks. In the panels for infrastructure quality (IQ) and institutional regulation governance (IRG), high persistence is observed: the own shock remains the primary source of forecast error across all horizons, with minimal contributions from other factors, indicating the relatively autonomous dynamics of these determinants.

The panel for R&D investments also shows dominance of the own shock, suggesting sustained internal dynamics in innovation activity. For digital connectivity (DC), while the majority of variance is initially explained by its own shock, the contribution of other factors, notably IBT, increases gradually with the forecast horizon. This variation highlights strengthening interlinkages between trade and the digital sector in the long run. Economic stability (ES) exhibits a declining share of the own shock as the horizon lengthens, accompanied by a rising influence of shocks from IBT, RFI, and REC. This finding underscores the interdependence of economic stability with developments in trade, finance, and energy engineering.

Finally, in the panel for renewable energy consumption (REC), the own shock remains the main driver of forecast error variance, with external shocks having only a minor impact, reflecting a relatively predictable trend in the development of the “green” sector over the analytical horizon. Overall, Figure 4 illustrates that for most variables, own dynamic effects are dominant. However, for certain indicators, particularly IBT, RFI, DC, and ES, the influence of external factors intensifies over time. These findings highlight the importance of considering interactions between trade, financial integration, digitalization, energy transitions, and macroeconomic determinants when formulating medium- and long-term strategies for regional cooperation.

Variance decomposition analysis (VDA) makes it possible to assess the contribution of various macroeconomic and institutional variables to the variation of the forecast error of the intra-bloc trade (IBT) model between BRICS countries and Turkey in dynamics. At the initial forecast horizons, a significant part of the variation is explained by IBT autogeneration – more than 90% of the variance is accounted for by the trade indicator itself, indicating that trade flows are highly inertial. However, as the time horizon increases, the contribution of factors such as investment in R&D, domestic consumption, and the share of renewable energy sources (RES) in the energy balance increases. This means that in the medium and long term, structural reforms and public policy measures aimed at supporting domestic demand, promoting innovation, and green transformation become key drivers of sustainable trade within the bloc.

The validity of the conclusions is strengthened by constructing confidence intervals around variable contributions to the variation, which makes it possible to account for uncertainty and fluctuations in the estimates. This is essential for the practical application of the results in strategic planning because it enables the formulation of risk-tolerant and empirically based recommendations for public policy agencies. Nevertheless, interpreting the results of variance decomposition analysis should consider a range of methodological limitations. First, the sensitivity of VDA to the ordering of variables in the vector autoregression (VAR) model can distort quantitative estimates, especially when factors are highly interdependent. Changing the order of the variables may lead to a redistribution of the shares of explained variance among the factors, which requires robust sensitivity tests. Second, confidence intervals obtained using bootstrapping or the Monte Carlo method, are approximations that do not always reflect structural or nonlinear dependencies characteristic of real economic systems. This limits the possibility of interpreting the obtained contributions in terms of causality and requires combining VDA with other methods, such as causality tests or impulse response, to build a comprehensive picture of interactions.

Thus, the variance decomposition analysis (VDA) enables the quantification of the relative contribution of specific structural shocks to the forecast error variance of BRICS-Turkey trade indicators. This method allows for the identification of the most influential sources of variability within the system. When combined with complementary econometric techniques, such as impulse response functions and panel autoregressive models, VDA supports evidence-based calibration of trade, infrastructure, and innovation policies under conditions of global economic volatility.

Table 9 presents medium- and long-term forecast scenarios assessing BRICS-Turkey cooperation across key domains, including trade, regional financial integration, infrastructure development, renewable energy, and institutional quality.

Table 9. Scenario-based forecasts of BRICS-Turkey socioeconomic integration

Scenario type	Description	Key variables and rationalization
Optimistic scenario	Trade, financial integration, infrastructure development, technological innovation, and digital connectivity boost BRICS-T socioeconomic cooperation to new heights.	IBT (Intra-BRIC-T trade): Reduced trade barriers, uniform tariffs, and enhanced logistical networks drive rapid growth.
		RFI (Regional financial integration): Common financial institutions and currency exchanges strengthen regional economic integration.
		IQ (Infrastructure quality): Belt and Road and other investment plans have accelerated financing, increasing regional links.
		REC (Renewable energy consumption): Rapid implementation of sustainable technology propelled by legislative incentives.
Neutral scenario	BRICS-T's progress is steady but unspectacular. Trade and financial integration deepen with moderate digital infrastructure and renewable energy developments.	IBT: Selected trade agreements enable steady growth, but non-tariff barriers persist.
		RFI: Regional integration persists consistently despite intermittent setbacks caused by local economic volatility.
		R&D (Research and development expenditures): Engaging in more measured investment in innovation, driven by intense global competition.
		DC (Digital connectivity): Consistent employment of digital technologies enhances productivity but lacks a transformational effect.
Pessimistic scenario	Policy contradictions and geopolitical issues slow economic integration and collaboration. Inadequate infrastructure and institutions hinder growth and sustainability.	IRG (Institutional regulatory quality): Inadequate regulatory frameworks hinder policy execution and economic collaboration.
		ES (Economic stability): Significant exposure to global economic disruptions compromises long-term strategizing.
		REC: Reliance on fossil fuels is perpetuated by the minimal progress in adopting renewable energy.
		IQ: Infrastructure projects encounter delays and budget overruns, hindering improvements in connection.

In the optimistic scenario, the model assumes strategic investments in research and development (R&D), enhanced digital connectivity, and deepening intra-regional trade and financial ties – conditions conducive to strong regional collaboration. The neutral scenario reflects moderate progress in economic stability and infrastructure, tempered by institutional and policy misalignments that slow convergence. The pessimistic scenario emphasizes how inadequate institutional capacity, geopolitical disruptions, and low commitment to renewable energy transition can lead to stagnation, highlighting the critical need for coordinated and resilient regional strategies.

Figure 5 presents impulse and accumulated responses with ± 2 standard error bounds, reflecting the 95% confidence interval for the estimated dynamic effects of a one-standard-deviation innovation.

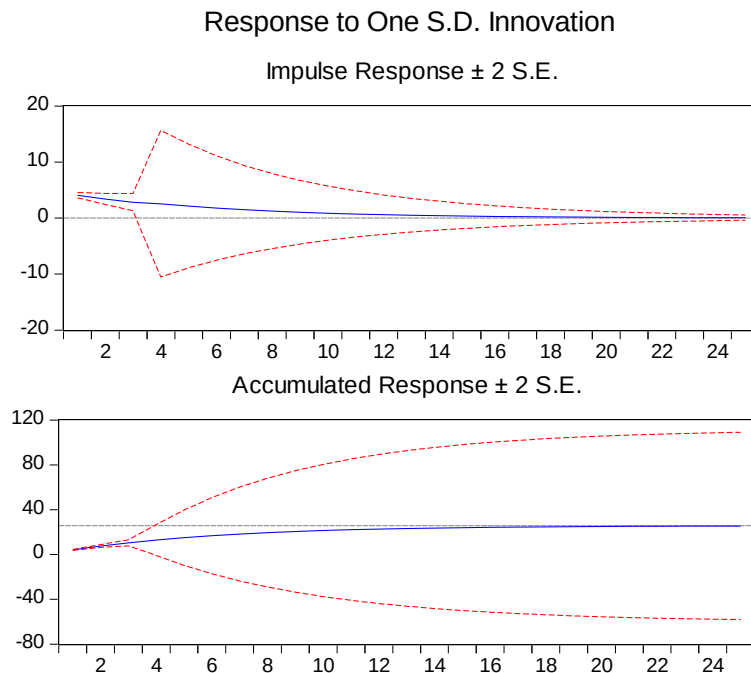


Figure 5. Dynamic responses to a one-standard-deviation innovation: impulse and accumulated impulse response functions “ $\pm 95\%$ confidence interval”: (Source: Author's estimation in EViews based on World Development Indicators [54])

Figure 5 presents the impulse response function (IRF) to a one-standard-deviation shock applied to the system, with the horizontal axis representing time periods (e.g., years) and the vertical axis showing the magnitude of the immediate

response. The blue line indicates the estimated response, while the red dashed lines represent the ± 2 standard error bounds, corresponding to an approximate 95% confidence interval.

The bottom panel illustrates the accumulated response function, which captures the cumulative effect of the same shock over the forecast horizon. This provides insight into the long-run dynamic impact of the innovation. Similar to the IRF, the dashed lines denote the uncertainty range (± 2 S.E.), which widens with time, reflecting the increasing prediction uncertainty. These results are derived from a panel vector autoregressive (PVAR) model using macroeconomic indicators from the World Bank. The findings help assess both the short-term and long-term transmission mechanisms within the system, though real-world deviations may occur due to structural changes or exogenous shocks.

The forecast scenarios are constructed based on structured assumptions regarding macroeconomic trends, trade and investment policies, regulatory and institutional reforms, technological diffusion, and global economic volatility. Nevertheless, exogenous shocks, particularly geopolitical conflicts or financial crises, may lead to substantial deviations from these simulated trajectories.

In order to select the most appropriate ARIMA specifications for each country's series, we evaluated both the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). Table 10 summarizes these model-selection metrics alongside the chosen ARIMA(p,d,q) orders. Specifically, the lowest AIC and BIC for each country guided the selection: for Brazil, an ARIMA(1,1,2) model was preferred; the Russian Federation's series fit best with ARIMA(2,1,2); India with ARIMA(1,1,1); China with ARIMA(1,1,2); South Africa with ARIMA(2,1,2); and Turkey with ARIMA(1,0,2), indicating that Turkey's series appeared stationary in levels. These results ensure that the forecasting models are tailored to the underlying data characteristics in each country.

Table 10. AIC, BIC, and ARIMA (p, d, q) specification by countries

Country	AIC	BIC	ARIMA (p, d, q)
Brazil	1.384	1.416	(1,1,2)
Russian Federation	1.412	1.624	(2,1,2)
India	1.298	1.354	(1,1,1)
China	1.389	1.485	(1,1,2)
South Africa	1.221	1.301	(2,1,2)
Turkey	1.301	1.398	(1,0,2)

Table 10 confirms that model orders vary across countries, reflecting differences in data stationarity and autocorrelation patterns, and underpins the country-specific forecasts presented above. Table 11 shows the forecasted economic indicators for BRICS-T from 2025 to 2030 using ARIMA modelling.

Table 11. Projected economic indicators for the BRICS-Turkey (2025-2030) based on ARIMA modelling technique

Country	Years	IBT	IQ	IRG	RND	DC	ES	REC	RFI
Brazil	2025	32.106	27.608	-0.260	1.248	22.946	14.838	47.140	3.413
	2026	32.443	28.443	-0.280	1.257	23.954	15.196	47.265	3.426
	2027	32.780	29.279	-0.300	1.266	24.962	15.554	47.390	3.440
	2028	33.117	30.114	-0.320	1.275	25.970	15.912	47.515	3.453
	2029	33.455	30.949	-0.340	1.284	26.978	16.270	47.640	3.467
	2030	33.792	31.785	-0.360	1.293	27.986	16.628	47.765	3.480
Russian Federation	2025	41.221	65.738	-0.763	0.968	29.935	17.147	3.349	0.714
	2026	40.466	65.722	-0.787	0.959	31.248	17.525	3.343	0.629
	2027	39.711	65.705	-0.811	0.951	32.561	17.903	3.338	0.544
	2028	38.956	65.689	-0.835	0.942	33.873	18.281	3.333	0.458
	2029	38.201	65.673	-0.859	0.934	35.186	18.659	3.327	0.373
	2030	37.446	65.656	-0.883	0.925	36.499	19.037	3.322	0.288
India	2025	50.421	81.030	-0.201	0.636	2.306	7.991	29.538	1.891
	2026	50.969	80.972	-0.194	0.629	2.409	7.955	28.896	1.911
	2027	51.518	80.915	-0.187	0.622	2.512	7.918	28.254	1.932
	2028	52.067	80.858	-0.180	0.615	2.614	7.882	27.612	1.952
	2029	52.616	80.800	-0.173	0.609	2.717	7.845	26.970	1.973
	2030	53.165	80.743	-0.165	0.602	2.819	7.809	26.328	1.993

China	2025	35.362	70.572	-0.282	2.713	42.314	15.324	9.178	0.821
	2026	34.586	70.053	-0.280	2.784	44.278	15.285	8.655	0.676
	2027	33.809	69.534	-0.279	2.855	46.242	15.247	8.131	0.532
	2028	33.033	69.015	-0.277	2.925	48.207	15.209	7.607	0.387
	2029	32.257	68.495	-0.275	2.996	50.171	15.171	7.083	0.243
	2030	31.480	67.976	-0.273	3.067	52.135	15.133	6.559	0.098
South Africa	2025	61.010	92.651	-0.225	0.644	3.494	6.387	7.020	2.288
	2026	61.501	92.582	-0.268	0.641	3.640	6.549	6.815	2.327
	2027	61.992	92.512	-0.310	0.637	3.785	6.712	6.610	2.366
	2028	62.483	92.442	-0.352	0.634	3.930	6.874	6.405	2.405
	2029	62.974	92.373	-0.395	0.630	4.076	7.037	6.200	2.444
	2030	63.465	92.303	-0.437	0.627	4.221	7.199	5.995	2.483
Turkey	2025	68.592	66.493	-0.019	1.507	23.682	4.607	10.838	1.556
	2026	69.672	66.022	-0.032	1.553	24.693	4.595	10.615	1.557
	2027	70.753	65.551	-0.046	1.600	25.704	4.584	10.392	1.559
	2028	71.834	65.081	-0.060	1.646	26.715	4.572	10.169	1.560
	2029	72.915	64.610	-0.074	1.692	27.726	4.560	9.946	1.561
	2030	73.996	64.139	-0.087	1.738	28.737	4.548	9.724	1.562

5- Discussion

5-1- Summary of Results by Country

Intra-BRICS trade (IBT) forecasts for Brazil range from 32.11% of GDP to 33.79% of GDP. This suggests that Brazil will continue actively participating in regional economic exchanges, notwithstanding global trade trends. However, the country's institutional regulatory quality (IRG) is between -0.26 and -0.36, suggesting that regulatory organizations may struggle to maintain investor confidence amid political and economic uncertainties. Brazil is expected to increase its infrastructure quality (IQ) by using electricity from oil, gas, and coal sources (% of total) from 1.25% to 1.29% due to investments in energy production. R&D investment in Brazil is predicted to remain between 1.25% of GDP and 1.29% of GDP, suggesting a reasonable commitment to technological innovation and advancement. Brazilian energy sector predictions show digital connectivity (DC) growth measured by fixed broadband subscriptions (per 100 people) from 22.95 to 27.99, signifying better digital infrastructure to boost economic development and integration. Renewable energy consumption (REC) in Brazil is expected to remain between 47.14% and 47.77%, demonstrating its commitment to renewable energy despite moderate development. Regional financial integration (RFI) measured by FDI inflows in Brazil is predicted to fluctuate between 3.41% of GDP and 3.48% of GDP, indicating significant foreign investment in the renewable energy sector.

Russia demonstrates an expected decline in the intra-bloc trade indicator from 41.22 to 37.45 owing to increased sanctions pressure, lower international investment confidence, and restrictions on cross-border flows. Meanwhile, infrastructure quality (IQ) remains stable (65.74-65.66), which supports the country's industrial and logistics potential. However, the decline in institutional regulatory quality (IRG) from -0.76 to -0.88 indicates increased administrative instability and reduced transparency of economic policies. The decrease in R&D investment (from 0.97 to 0.93) is associated with limited resources and anti-crisis policy priorities. Digital connectivity (DC) rises from 29.93 to 36.50, reflecting the modernization of digital infrastructure. However, extremely low REC from 3.35 to 3.32 and declining regional financial integration (RFI) from 0.71 to 0.29 confirm geopolitical isolation and limited access to cross-border capital.

India, by contrast, demonstrates a positive trajectory, with IBT rising from 50.42 to 53.16, reflecting its strengthening role in global and regional trade. High values of infrastructure quality IQ (81.03-80.74) are maintained through prioritized public investment. A slight improvement in IRG from -0.20 to -0.17 reflects the progress in the institutional environment. The slight decline in R&D investment from 0.64 to 0.60 is due to a reorientation toward the manufacturing sector. The DC forecast from 2.31 to 2.82 demonstrates the progressive expansion of digital services, while the relatively stable REC from 29.54 to 26.33 confirms the steady integration of renewable energy sources. The increase in RFI from 1.89 to 1.99 is caused by the growing interest of foreign investors in the country's energy sector.

Despite its strong economic growth, China demonstrates a decline in IBT from 35.36 to 31.48 due to a reorientation of export strategies or a weakening of intra-risk trade amid global trade conflicts. IQ remains high (70.57-67.98), reflecting sustained infrastructure investment. The improvement in IRG from -0.28 to -0.27 indicates growing institutional resilience. A significant increase in R&D expenditure from 2.71 to 3.07 demonstrates technological

leadership. The significant expansion of DC from 42.31 to 52.14 confirms the prioritization of digital transformation. However, the decrease in REC from 9.18 to 6.56 indicates the challenges in scaling RES with high energy consumption. RFI remains low (0.82-0.10), indicating continued investment restraint due to foreign policy tensions.

South Africa demonstrates stable dynamics: IBT remains high (61.01-62.48), reflecting a strong position in regional trade. IQ (92.65-92.44) confirms advanced logistics and digital infrastructure. The improvement in IRG (from -0.35 to -0.23) indicates the effectiveness of institutional reforms. R&D investment is maintained at 0.63-0.64, supporting innovation activity. The growth of DC from 3.49 to 3.93 demonstrates progressive digital development. REC is stable (7.02-6.41), and high investor interest contributes to maintaining RFI in the range of 2.29-2.40.

Turkey demonstrates mixed dynamics. The increase in IBT from 32.11 to 33.79 indicates the intensification of regional trade, including with BRICS members. IQ growth from 27.61 to 31.78 reflects the potential for an infrastructure push. IRG remains low (-0.36 to -0.26), restraining investment inflows. Nevertheless, rising R&D investment from 1.25 to 1.29 and active expansion of digital infrastructure (DC raised from 22.95 to 27.99) indicate a strategic focus on modernization. The high REC (47.14-47.77) confirms the prioritization of green energy, while the stable RFI (3.41-3.48) indicates the continued international interest in the Turkish energy sector. Thus, the analysis of forecast indicators indicates the divergent trajectories of BRICS-Turkey under conditions of global fragmentation. While India and South Africa show signs of cautious development and institutional strengthening, Russia face the challenges of socioeconomic isolation by a number of European countries and the US.

6- Conclusion

The aim of this study, to model and forecast the dynamics of BRICS-Turkey socio-economic integration amid global economic fragmentation, was realized through a multi-stage econometric approach incorporating panel Autoregressive Distributed Lag (ARDL) modelling, Dumitrescu-Hurlin panel causality tests, impulse response functions (IRF), variance decomposition analysis (VDA), and medium-term forecasting using ARIMA. This integrated methodological framework enabled the joint estimation of inertial and structural effects across a heterogeneous panel of six countries, thereby capturing both short-run dynamics and long-term adjustment processes.

The key result is the verification of a robust and statistically significant long-run impulse from regional financial integration, infrastructure quality and R&D spending to intra-bloc trade (coefficients 8.74; 0.366; 17.59 at $p < 0.01$). At the same time, digital connectivity shows a 'peak' pattern, with short-term improvements followed by saturation, indicating the need to upgrade the digital infrastructure of the bloc. The increasing share of renewables has so far had a negative impact on trade, supporting the idea that green transitions involve transit costs. An additional contribution of the study was the empirical identification of high intra-group asymmetry in most indicators, from financial flows to institutional quality, which requires differentiated rather than unified integration strategies.

From an academic perspective, this paper advances current research in three key ways. Firstly, it incorporates Turkey into the model for the first time, transforming the analysis of BRICS from a closed group of five to an open, polycentric growth ecosystem. Secondly, it demonstrates the effectiveness of the combined 'global shocks, panel ARDL, scenario ARIMA' approach, which is suitable for estimating the effect of sanctions, tariff wars and recessions in a single framework. Thirdly, the study shows that impulse response functions (IRF) and variance decomposition analysis (VDA) enable the quantitative prioritization of integration policies, shifting the focus from descriptive statistics to evidence-based decision-making.

The obtained results are generally consistent with the findings of most empirical studies conducted in 2020-2023, emphasizing the importance of infrastructure modernization, financial integration, and institutional convergence for deepening trade and economic cooperation among the BRICS countries [31, 33]. However, unlike these studies, which are limited to descriptive or sectoral analysis, the present study proposes an integrated model that considers political and economic shocks and institutional asymmetries. In particular, unlike [29], which focuses on the impact of digitalization and R&D, our study reveals a short-term saturation effect from digital infrastructure, and a delayed positive impact of R&D on trade. These findings are particularly relevant against the backdrop of forecasting and analytical reports of recent years [18, 22], which emphasize the need for strategic autonomy and institutional coordination within BRICS+. Thus, this study clarifies and complements the existing scientific agenda, forming empirically substantiated scenarios for sustainable macroeconomic convergence.

6-1-Limitations of the Study and Directions for Future Work

The limitations of this study come primarily from the use of secondary data, mainly from the World Development Indicators, which may introduce measurement errors and restrict the precision of some findings. However, the econometric methods employed, including ARDL panel models and causality tests, enable us to draw valid conclusions regarding the socio-economic integration of BRICS-Turkey within the context of global economic fragmentation. The study does not fully capture political reforms and external shocks, which are areas for future research, where additional variables reflecting policy changes and exogenous shocks will be incorporated. Moreover, more advanced econometric

techniques, such as structural VAR models, are planned to better analyze dynamics and causality. A key limitation is the insufficient representation of institutional asymmetry and governance diversity within BRICS and Turkey; thus, future studies should include more detailed, disaggregated indicators of institutional development and governance, potentially considering interaction effects, to enhance understanding of cross-country differences and their influence on integration processes. Further, qualitative methods such as expert interviews and case studies should be integrated for a more in-depth assessment of integration processes.

The linear nature of the ARDL method may limit the detection of non-linear relationships, making it advisable to apply more advanced techniques such as the QARDL panel model or machine learning algorithms capable of capturing complex dynamics more accurately. Additionally, predicting the effectiveness of digital initiatives like the Digital Connectivity Index (DCI) and the BRICS trade facilitation mechanism presents a promising direction for future research. The political dimensions of integration were not addressed in this study but represent a significant area for further exploration, as political dynamics and inter-state relations can greatly influence the sustainability and depth of economic and institutional integration. Future work should also focus on examining in detail the impact of emerging technologies, such as artificial intelligence, blockchain platforms, and decentralized financial systems, on cooperation within BRICS and Turkey.

This study relies on secondary sources for contextualization without employing primary qualitative methods. This approach limits our ability to capture stakeholders' direct perspectives on implementation barriers and policy dynamics. Future research would benefit substantially from targeted qualitative investigations in each country to validate the mechanisms identified econometrically and to refine recommendations in light of local institutional and sociopolitical nuances. Future research should prioritize the collection and use of more granular and harmonized institutional datasets, including subnational and sector-specific indicators, to capture heterogeneity in governance quality and regulatory environments. Efforts to develop or adopt internationally standardized methodologies for assessing digital infrastructure, encompassing metrics such as connection speeds, rural and remote area coverage, and levels of digital literacy, are also essential to ensure comparability across contexts. Moreover, incorporating primary qualitative investigations with policymakers, industry representatives, and relevant organizations will help elucidate the mechanisms underlying econometric findings, particularly with respect to institutional obstacles and digital constraints, thereby enhancing the validity and policy relevance of future analyses.

Our analysis of institutional quality relies primarily on composite indices provided by sources such as the World Governance Indicators (WGI) and similar databases. These indices are subject to methodological revisions over time, involve expert-based or survey-based components, and may exhibit variability in coverage and frequency across countries, particularly in the early years of the 2000-2023 period. As a result, some countries or years may have missing observations or differences in indicator definitions, which could affect cross-country comparability. To mitigate these issues, we employed alternative proxies where available (e.g., components from the Global Competitiveness Report or country-specific governance assessments) and, in cases of isolated missing years without evidence of structural breaks, applied cautious linear interpolation. Nevertheless, interpolation and proxy substitution may introduce measurement error and partial bias in coefficient estimates.

Digital connectivity metrics were obtained from international databases (e.g., ITU, World Bank) and include variables such as internet penetration rates, fixed broadband subscriptions per capita, and mobile broadband subscriptions. However, differences in data collection methodologies, reporting standards, and temporal availability across BRICS countries and Turkey can affect consistency. Moreover, these proxies capture the quantity of connections but may not fully reflect service quality, geographic coverage (e.g., urban vs rural disparities), or user skills and usage patterns important for trade facilitation. To address this, we conducted robustness checks using alternative definitions (e.g., distinguishing fixed versus mobile broadband) and, where data permitted, constructed composite digital connectivity indices via principal component analysis. Despite these efforts, we acknowledge that remaining heterogeneity in definitions and possible gaps may influence the interpretation of relationships between digital connectivity and trade openness.

Overall, while we have taken steps to minimize biases through alternative data sources, interpolation, and robustness analyses, the inherent limitations of institutional and digital connectivity measures should be borne in mind when interpreting the estimated long-run associations and forecasting scenarios. Future research would benefit from more granular, harmonized time-series data on governance and digital infrastructure quality, potentially supplemented by primary data collection or stakeholder consultations to validate and enrich the quantitative findings.

6-2- Practical Implications

The empirical findings of the study form a coherent set of practical recommendations for BRICS-Turkey integration policies in the context of increasing geo-economic fragmentation. First, the confirmed long-term positive impact of regional financial integration on intra-bloc trade (coefficient 8.74; $p < 0.01$) underscores the critical importance of accelerating the development of a multilevel payment and settlement ecosystem, ranging from bilateral swap lines to a supranational BRICS Pay platform with mutual clearing in national currencies. The implementation of such a system will reduce transaction costs and increase resilience to sanctions risks, which is especially important for Russia and China.

Second, the synergy between investments in transport, logistics, and digital infrastructure (+0.366) and the short-term momentum of +0.627 for digital connectivity acts as a catalyst for enhancing trade flows. A practical measure would be the creation of green multimodal corridors, such as port, rail, and data center links, that integrate initiatives like the Belt & Road, North-South, and Trans-Anatolian routes. Joint infrastructure funds should include 'hard' (rails, terminals) and 'soft' (API protocols, cybersecurity) components to address the observed technological asymmetry between China, Brazil and South Africa.

Third, the statistically significant impact of R&D expenditures (+17.6 in the long run) underlines the need to establish a joint innovation fund of at least 0.1% of the bloc's total GDP. The fund should prioritize areas such as payment technologies, smart logistics, and renewable energy. Additionally, a mechanism for an 'R&D export voucher' is proposed, enabling participating companies to reimburse up to 30% of the costs associated with localizing high-tech products in their partner markets. This will directly support export diversification predicted by the ARIMA scenario of IBT growth in the optimistic trajectory.

Fourth, the negative response of trade flows to renewable energy growth (-0.54) underscores the need for a gradual, phased green transition. It is recommended to harmonize a unified carbon technical regulation and introduce the 'BRICS-T-Renew Credit,' a platform for the circulation of renewable certificates linked to export consignments. This will reduce carbon barriers in third-country markets and help accelerate the monetization of green investments.

Finally, the significant trade inertia (accounting for over 90 % of IBT's variance in the first year) necessitates the establishment of a permanent 'Macro Stress Test Board' under the New Development Bank. The Board will recalculate VAR and IRF models quarterly in order to adjust tariff and exchange rate policies in advance in response to combined shocks such as tariff wars, sanctions, and global recessions. Therefore, a comprehensive set of measures, from payment architecture and infrastructure synergies to the coordination of stress tests, will translate these statistical dependencies into a strategic roadmap to strengthen BRICS-T intra-regional integration and resilience.

Although BRICS-T is analyzed as a collective grouping, it does not constitute a formalized bloc in the institutional sense. Accordingly, this study puts forward country-specific and context-sensitive strategies for each member state, along with Turkey, to strengthen regional integration and resilience in the face of deepening geopolitical fragmentation.

For Russia, participation in the BRICS alliance means a strategic opportunity to deepen an open dialogue with key countries of the Global South, form new sustainable foreign economic ties and strengthen its position in the international arena. Against the backdrop of sanctions pressure and the global order transformation, BRICS is becoming a platform where Russia retains its subjectivity, promotes initiatives for settlements in national currencies, the development of transport and logistics infrastructure and technological cooperation. Integration within BRICS meets Russia's short-term objectives of stabilizing foreign economic activity and long-term interests in creating alternative centers of power in a multipolar world. The creation of the BRICS grain exchange provides Russia with significant strategic opportunities. First, the exchange will allow the formation of transparent price indicators, getting rid of the dominance of Western platforms and intermediaries, which is especially important for the largest wheat exporter (55.3 million tons in 2023/24). Second, the new infrastructure, logistics hubs, ports, elevators and financial instruments, will strengthen Russia's food security and tighten control over exports.

Precisely China generates a multiplier effect, strengthening integration even in the face of global shocks (as confirmed by the IRF and VDA analysis). For China, key priorities should include expanding investments in joint digital infrastructure projects and logistics systems, which will help improve the competitiveness of goods and services amid US tariff restrictions. It is also important to continue leading in R&D by actively involving other BRICS countries in technological collaboration.

India should focus more on joint innovation projects, especially in information technology and pharmaceuticals, to diversify exports and reduce dependence on Western markets. Additionally, mechanisms to support small and medium-sized enterprises should be developed to encourage their integration into the trade and investment flows of BRICS-Turkey.

Brazil needs to deepen cooperation in sustainable agriculture, environmental, and climate projects, considering the increasing pressure from the US and the EU regarding climate standards. Supporting technology exchange programs in agriculture and energy sectors is also crucial to enhance the resilience of the national economy.

For South Africa, the key task is to develop financial infrastructure and logistics corridors to strengthen its role as a logistics and financial hub for Africa. Policymakers are advised to focus on attracting investments in green energy and infrastructure projects, as well as enhancing collaboration with regional organizations such as the African Union and SADC.

Turkey should focus on multilateral projects in the fields of energy, infrastructure, and digitalization, serving as a link between Europe, Asia, and the Middle East. Priority should be given to developing regional mechanisms for cross-border settlements in national currencies, as well as promoting renewable energy projects and environmentally friendly transportation solutions that strengthen regional cooperation.

Therefore, each member of the BRICS-T, drawing on its unique strengths and specific geopolitical and economic circumstances, will be able to ensure sustainable development and effective integration in the face of increasing global instability and a worldwide economic recession.

6-3-Importance for Managers and Education Systems

The recommendations of this study can apply to developing regional settlement mechanisms in national currencies, harmonizing regulatory standards, and stimulating cross-border innovation projects. In addition, the proposed scenarios can be used in the framework of strategic planning and trade and investment forecasting at the intergovernmental level and within the framework of economic unions and central banks.

For educational and research purposes, this article paves the way for interdisciplinary analyses at the intersection of international economics, digital technologies, institutional design, and predictive analytics. University programs focused on the economics of sustainable development, digital transformation, and international cooperation within political, economic, and regional blocs can use this research to develop case studies, teaching modules, and comparative courses. Our findings highlight the importance of shifting from purely descriptive approaches to quantitatively verifiable models that are applicable both in management and education.

6-4-Novelty and Scientific Contribution

This study goes beyond the traditional trade volume analysis by considering institutional, digital, financial, and technological determinants and generates realistic scenarios with high practical applicability. This study fills a significant empirical and conceptual gap in understanding the scalability of country cooperation in the face of global instability.

From an academic and practical point of view, this study proposes structured development scenarios (optimistic, pessimistic, and neutral) to formulate macroeconomic strategies, align trade and investment priorities, and design regional payment and digital infrastructures. In addition, this study identifies research gaps and formulates directions for future empirical and institutional developments in the context of a multipolar world and the transformation of the global economic order.

7- Nomenclature

ACF	Autocorrelation function	AIC	Akaike information criterion
ARDL	Autoregressive distributed lag	ARIMA	Autoregressive integrated moving average
BIC	Bayesian information criterion	BRICS	Brazil, Russia, India, China, South Africa
BRICS-T	BRICS-Turkey	CI	Confidence interval
CIPS	Cross-border interbank payment system	DCI	Digital Connectivity Index
FPE	Final prediction error	IRF	Impulse response function
IPS	Im-Pesaran-Shin test	IBT	Intra-BRICS trade
HQIC	Hannan-Quinn information criterion	LR	Likelihood ratio
MA	Moving average	R&D	Research and Development
PACF	Partial autocorrelation function	SBC	Schwarz-Bayesian criterion
SC	Schwarz information criteria	SPFS	System for transfer of financial messages
VAR	Vector autoregression	VDA	Variance decomposition analysis
WDI	World Development Indicators		

8- Declarations

8-1-Author Contributions

Conceptualization, G.P. and Y.V.; methodology, G.P. and V.P.; software, A.S.; validation, A.S., E.K., and E.R.; formal analysis, N.K., T.B., and E.K.; investigation, all the authors; resources, I.E., E.K., and E.R.; data curation, G.P., N.K., and V.P.; writing—original draft preparation, all the authors; writing—review and editing, all the authors; visualization, V.P., N.K., and T.B.; supervision, Y.V. and A.S.; project administration, G.P. and V.P. All authors have read and agreed to the published version of the manuscript.

8-2-Data Availability Statement

The data presented in this study are available in this paper.

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8-4-Institutional Review Board Statement

Not applicable.

8-5- Informed Consent Statement

Not applicable.

8-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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Appendix I

Table A1. List of variables used in this study

Variable name	Symbol	Unit	Source
Trade openness	TO	% of GDP	WDI
FDI to GDP ratio	FDI	% of GDP	WDI
Foreign exchange reserves	FXR	Months of import	WDI
Energy production volume	EP	Million tons of oil equivalent	WDI
Infrastructure quality	IQ	Index (0-100)	WDI
Regulatory quality	RQ	Index (0-100)	WDI
Institutional governance	IRG	Index (0-100)	WDI
Economic stability	ES	Score	WDI
Trade balance	TB	% of exports to imports	WDI
Unemployment rate	UR	%	WDI
Poverty level	PL	% of population	WDI
Income inequality	II	Gini coefficient	WDI
R&D expenditures	R&D	% of GDP	WDI
Digital connectivity	DC	per 100 people	WDI
Renewable energy consumption	REC	% of the total energy consumption	WDI
Intra-BRICS-Turkey trade	IBT	Index (0-100)	Authors' estimate
Regional financial integration	RFI	Index (0-100)	Authors' estimate
Sanctions {it}	SANC	Dummy	Authors' estimate
Payment system {it}	PAYSYS	Dummy	Authors' estimate
US tariff shock {t}	Tariff shock	Dummy	Authors' estimate
Global recession {t}	RECESS	Dummy	Authors' estimate
Combined shock {t}	Combined shock	Composite dummy	Authors' estimate