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Determinants of Economic Growth in Türkiye: A Dynamic ARDL Simulation Analysis of External Debt, Government Size, and Energy Use

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Abstract

This study investigates the determinants of economic growth in Türkiye by examining the roles of external debt, government size and energy consumption over the period 1970–2019. Using the novel Dynamic Autoregressive Distributed Lag (DYNARDL) simulation approach, this study captures both short- and long-run effects and generates counterfactual simulations that visualize how GDP responds to shocks in each variable. The results reveal three consistent patterns. First, external debt exerts a significant drag on growth in both the short and long run, supporting the debt overhang hypothesis and underscoring the risks of persistent borrowing. Second, government size constrains growth in the short term, likely due to crowding-out and inefficiencies, but its long-run effect appears neutral, reflecting structural fiscal reforms implemented in the aftermath of major crises, notably the 2001 financial crisis. Third, energy consumption emerges as a strong driver of output, emphasizing the critical role of energy security and efficiency in sustaining industrial expansion. Human capital, included as a control variable, also contributes positively in both horizons, reinforcing productivity gains through education and workforce quality. These findings highlight the need to redirect public expenditures toward efficiency-enhancing uses, strengthen debt sustainability frameworks, and expand investments in renewable energy and technological upgrades to reduce import dependency. Continued progress in education and skills development will further support long-term growth. By integrating dynamic simulations and counterfactual analysis with structural growth drivers, this study provides new evidence for Türkiye and demonstrates how simulation-based approaches can enrich growth diagnostics in other emerging economies.

Keywords:* *Economic Growth, Debt, Government Size, Energy Consumption, Dynamic ARDL Simulation.

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1. INTRODUCTION

Understanding the drivers of economic growth remains a central concern in development economics, particularly for emerging economies like Türkiye, which has experienced persistent macroeconomic volatility, recurrent debt episodes, and energy dependency. Since the 1980s, Türkiye's economic landscape has been shaped by structural reforms, including trade liberalization, privatization, and fiscal consolidation efforts—most notably after the 2001 financial crisis (Uygur, 2010). Despite periods of rapid growth, Türkiye's economy still faces external imbalances, public spending inefficiencies, and costly energy imports. These vulnerabilities were further exposed during the COVID-19 pandemic, with sharp sectoral contractions and uneven recoveries (Ozcan, 2025).

In this context, evaluating how external debt, energy consumption, and government size influence growth is essential. Each variable represents a distinct channel: external debt can finance capital formation but may deter investment if excessive (Krugman, 1988; Pattillo & Ricci, 2011); energy consumption promotes industrial and infrastructure growth (Stern, 2011) but is constrained by Türkiye's reliance on imported fuels; government size can stimulate demand but also risk crowding out private activity when inefficient (Barro, 1990). Human capital is included in this study as a control variable to isolate the effects of these policy-relevant factors. Although not the primary focus, its contribution to labor productivity and long-term growth is well established in the literature (Hanushek & Woessmann, 2023).

Türkiye's external debt has played a major role in shaping its economy, rising from 15.4% of GNI in 1970 to 55.4% in 2019 (World Bank, 2024). It spiked during key crises—reaching 52% in 1994 during a currency crisis, 57.4% in 2001 amid financial turmoil, and 60.4% in 2020 due to pandemic-related borrowing. By 2022, debt was 58% of GDP, with 53% held by the private sector and about a third classified as short-term—making the economy more vulnerable to rising global interest rates and exchange rate swings (International Monetary Fund [IMF], 2023). In 2018, a mix of global tightening, high foreign currency debt, and a widening current account deficit triggered a sharp lira crash—losing 40% of its value in two weeks—and inflation surged to 25% (Organisation for Economic Co-operation and Development [OECD], 2023). To contain the fallout, the Central Bank raised interest rates to 24% and pursued debt restructuring. This revaluation of foreign-currency liabilities amplified corporate debt burdens, as non-financial firms struggled to service USD-denominated loans, deepening the recession with GDP contracting in the second half of 2018 (Akcay & Güngen, 2019).

Beyond its immediate macroeconomic costs, the crisis illustrated the fragility of a growth model reliant on capital inflows and short-term borrowing. As Akcay and Güngen (2019) argue, Türkiye's experience is best understood as a case of "*dependent financialization*", where credit-driven expansion is sustained by external liquidity but leaves the economy vulnerable to sudden stops. The episode thus revealed not only cyclical volatility but also structural limits: high dollarization, a persistent current account deficit, and policy frameworks that prioritized financial deepening without addressing underlying imbalances. In this light, the 2018–2019 turmoil highlights the long-term need for policies that reduce foreign-currency debt, strengthen risk management frameworks, and deepen domestic capital markets to enhance resilience against future global shocks.

Compounding these challenges, Türkiye's dependence on imported energy amplifies macroeconomic fragility. In 2022, the country's energy trade deficit surged to a record USD 81.1 billion, up from USD 42.4 billion in 2021, driven largely by a 310% spike in natural gas prices amid geopolitical tensions. Energy imports soared to 11% of GDP—double the previous decade's average—causing the current account deficit to widen sharply (Central Bank of the Republic of Türkiye [CBRT], 2023). A recent paper using time-varying Granger-causality shows that the link between crude-oil price volatility and Türkiye's industrial production is dynamic and fluctuates over time with effects intensifying during external economic and geopolitical crises (Oztutus, 2025). While energy consumption remains a crucial driver of growth, especially for Türkiye's industrial base, this vulnerability highlights the need for a dual strategy: increasing energy efficiency and diversifying energy sources through renewables (Altun & İşleyen, 2018).

Government size can support growth through investment and services, but excessive government size may hinder it by crowding out private activity (Afonso & Furceri, 2010). Since 1980, Türkiye's transition from state-led import substitution to market-oriented liberalization has been shaped by crises that reconfigured the state's role and scale: the 24 January 1980 program—marked by a major devaluation, price and trade liberalization, subsidy cuts, and progressive relaxation of foreign exchange and capital controls—explicitly aimed to reduce state intervention and shrink the public sector, while subsequent stabilization efforts (notably in 1988 and the 5 April 1994 package) reinforced fiscal restraint, privatization, and market discipline (Ridvan & Sevilay, 2016); the 2001 financial crisis, while collapsing output and employment, marked a turning point in Türkiye's neoliberal trajectory, ushering in a regulatory state where IMF–World Bank programs and EU conditionality anchored fiscal discipline, prudential regulation, and foreign investment liberalization (Öniş, 2009); and the 2008–09 global crisis, unlike earlier downturns, allowed Türkiye to adopt counter-cyclical policies, with significant interest-rate cuts and fiscal stimulus supported by a more robust macroeconomic framework and resilient financial markets (Rawdanowicz, 2010).

Recent evidence on Türkiye's government size and growth reveals consistent non-linearities supporting the Armey curve. Iyidoğan and Turan (2017) identify thresholds of 16.5% of GDP for total expenditures, 12.6% for consumption, and 3.9% for investment. Şen et al. (2023) similarly find growth-maximizing levels in the range of 4–15% depending on the measure. In practice, considering the general government final consumption expenditure as a share of GDP—a widely used indicator—Türkiye has maintained a moderate government size (World Bank, 2024); policy should aim to keep aggregate size near the growth-maximizing range while tilting composition toward high-return investment and efficiency-enhancing services.

Although each of these growth determinants has been widely studied, there remains a lack of empirical frameworks that examine how they interact dynamically within Türkiye's evolving macroeconomic environment. Most existing studies rely on single-equation or static models—such as VAR (Rezitis & Ahammad, 2015), traditional ARDL (Gövdeli, 2019; Uslu, 2021), or newer extensions like NARDL (Göksu, 2024)—that capture important relationships but fall short in simulating how the economy adjusts to shocks over time. This is a significant limitation for Türkiye, where repeated episodes of macroeconomic instability and structural reform have shaped the trajectory of growth. To address this gap, the present study applies the Dynamic ARDL (DYNARDL) simulation method developed by Jordan and Philips (2018), which extends traditional ARDL by enabling scenario-based simulations of both short-run and long-run effects. Unlike conventional approaches, DYNARDL offers an intuitive and visual interpretation of how GDP responds over time to changes in each variable while controlling for the influence of others (Sarkodie & Owusu, 2020). This makes it particularly well suited for analyzing policy-relevant shocks in economies with complex adjustment dynamics—such as Türkiye.

This study focuses on four interrelated questions: whether external debt generates debt overhang effects; how energy consumption influences growth under high import dependency; whether moderate government size contributes to or constrains output; and how human capital affects long-term productivity. By modeling these factors jointly within a dynamic framework, the study provides a more realistic view of how Türkiye's economy responds to structural shocks and policy shifts. The findings contribute to the growth literature by capturing time-sensitive dynamics and offer practical insights for improving fiscal efficiency, managing external vulnerabilities, and supporting sustainable growth in Türkiye.

The rest of the paper is organized as follows: Section 2 reviews the theoretical and empirical literature. Section 3 outlines the data and model specification. Section 4 presents the results of the DYNARDL simulations and discusses the findings and their implications. Section 5 concludes with policy recommendations and directions for future research.

2. LITERATURE REVIEW

The determinants of economic growth, particularly in emerging economies like Türkiye, have been extensively studied, with external debt, government size, human capital, and energy consumption emerging as critical factors. Türkiye's economic history, shaped by debt crises, fiscal consolidation post-2001, and structural transitions toward liberalization in the 1980s, provides a unique context for examining these variables. Its reliance on energy imports and recurring macroeconomic volatility further emphasize the relevance of these factors. Theoretical frameworks suggest that external debt can finance productive investments but may hinder growth through debt overhang effects, while government size, human capital, and energy consumption influence output via fiscal policy, productivity, and infrastructure. However, empirical findings are mixed, particularly regarding external debt's impact on growth, necessitating a comprehensive review to contextualize our study. This literature review synthesizes theoretical and empirical research on these determinants, focusing on Türkiye and comparable emerging economies. It is structured as follows: first, we discuss the theoretical foundations of growth determinants; second, we examine external debt's role; third, we review government size, energy consumption and human capital; and finally, we identify gaps that our study addresses using DYNARDL simulations over the period 1970–2019.

2.1. Theoretical Foundations

A wide range of theoretical frameworks have been developed to explain the determinants of economic growth, emphasizing different roles for capital, labor, human capital, government size, external debt, and energy. Neoclassical growth models, such as Solow's (1956), emphasize capital accumulation, labor, and technological progress as drivers of output, with external debt potentially addressing capital shortages in economies like Türkiye, as seen in the post-1980s liberalization period when borrowing was used to finance infrastructure. The debt overhang hypothesis (Krugman, 1988) posits that high external debt levels deter investment by increasing uncertainty and reducing returns—a mechanism particularly relevant to Türkiye's debt crises in the 1980s and early 2000s. Kraay and Nehru (2006) further argues that the effectiveness of external debt in promoting growth depends on institutional quality and efficient financial intermediation, which influence whether borrowed funds are used productively.

Barro (1990) and Afonso and Furceri (2010) highlight that government size, measured by public consumption relative to GDP, can influence growth, with excessive size potentially crowding out private investment—a dynamic relevant to Türkiye's fiscal expansions in the 1990s. In contrast to these capital-focused models, Stern (2011) challenges the traditional exclusion of energy from growth theory and argues that energy is central to sustaining long-term economic growth, particularly in industrializing economies where it underpins productivity and technological advancement. Endogenous growth theory, advanced by Barro (1991), Lucas (1988) and Romer (1990), centers on human capital as a driver of long-term growth through productivity and innovation. This framework aligns with Türkiye's post-2001 period, during which productivity improvements were driven largely by education and health sector reforms. In empirical models, human capital is often included as a control variable to isolate the effects of other growth drivers, such as external debt or energy consumption. These theories provide a foundation for examining how external debt, government size, energy consumption and human capital shape economic growth in Türkiye, with empirical outcomes varying depending on policy regimes and methodological approaches.

2.2. External Debt and Economic Growth

The relationship between external debt and economic growth has been a focal point in the literature, with conflicting findings in Türkiye and other emerging economies. Several studies report positive effects of external debt on Türkiye's growth. Gövdeli (2019) and Uslu (2021), using ARDL analysis for 1970–2016, find that external debt positively impacts Türkiye's economic growth, with Uslu estimating a 0.13% increase in national income per 1% rise in debt stock. Akduğan and Yıldız (2020), using VAR analysis and impulse-response functions, find a unidirectional causal relationship from external debt to GDP in Türkiye and South Africa, indicating that external borrowing positively contributes to economic growth in these two Fragile Five economies. These findings align with studies suggesting that debt can enhance growth in capital-scarce economies (Kasidi & Said, 2013; Ndubuisi, 2017).

Conversely, other studies emphasize negative effects, often tied to debt overhang. In Türkiye, Çelik and Başkonuş Direkci (2013) and Çöğürcü and Çoban (2011) find that external debt constrains growth, consistent with Karagol's (2012) evidence of negative short-run impacts from debt servicing. Roy (2023), employing DARDL simulations, demonstrates that external debt reduces India's growth in both short and long run, stressing debt overhang effects in emerging economies. In cross-country analyses of developing economies, Pattillo and Ricci (2011) show that the relationship between external debt and growth is nonlinear, with growth turning negative as debt rises beyond certain thresholds—particularly 35–40% of GDP. They find that high debt reduces growth mainly by lowering the efficiency of investment. In a follow-up study, Pattillo et al. (2004) suggest that debt negatively affects both physical capital accumulation and total factor productivity, with the majority of the impact occurring through the latter. They caution that economic growth is not always positively correlated with rising external debt, especially when countries struggle to manage the composition of their debt or meet their repayment obligations. Reinhart and Rogoff (2010) find that economic growth slows sharply when government debt exceeds 90 percent of GDP in both advanced and emerging economies, and that external debt above 60 percent of GDP is associated with significantly lower growth in emerging markets. Despite these broader patterns, some empirical findings from Türkiye diverge. Doruk (2018), for instance, finds no significant long-term relationship between external debt and economic growth.

Methodological differences contribute to these variations. ARDL models (Dey & Tareque, 2020; Gövdeli, 2019; Uslu, 2021) capture short- and long-run relationships, while Generalized Method of Moments (GMM) approaches (Pattillo & Ricci, 2011) address endogeneity. Quantile regression results in (Mohsin et al., 2021) indicate that the negative impact of external debt on growth intensifies at higher growth levels, reflecting a nonlinear and asymmetric relationship. Taken together, these mixed findings suggest that the growth effects of external debt in Türkiye depend not only on debt levels and macroeconomic shocks (Calvo, 1998; Özatay & Sak, 2002; Uygur, 2010), but also on the methodological approaches employed.

2.3. Government Size and Economic Growth

The debate on the relationship between government size and economic growth is deeply rooted in competing theoretical frameworks. Keynesians advocate for a larger government role via expansionary fiscal policies, particularly during recessions, arguing that increased public spending stimulates economic activity when market mechanisms fail (Keynes, 1937). New growth theories also support this view, highlighting both short- and long-term effects of fiscal policy (Lucas, 1988; Romer, 1986). In contrast, Classical and Neoclassical theorists highlight a crowding-out effect, where public spending substitutes private goods, raises interest rates by pressuring credit markets, or distorts resource allocation through higher taxes, ultimately hampering growth (Barro, 1990; Kneller et al., 1999). These contrasting perspectives frame the empirical analysis of government size's impact in Türkiye, where fiscal policies have evolved through deficits and reforms.

Empirical studies reveal varied impacts, driven by country context and methodology. Ghali (1999) finds positive long-run effects in OECD countries using cointegration, supporting Keynesian views. However, Heitger (2001) reports negative effects from consumption spending, and Afonso and Furceri (2010) suggest that the size and volatility of several government components—especially consumption, indirect taxes, and subsidies—significantly hamper growth in OECD and EU countries. Afonso and Jalles (2011) find that government consumption negatively affects growth for a panel of 108 countries from 1970–2008, with stronger negative effects when institutional quality is lower. In emerging economies, Landau (1986) finds that government consumption expenditure negatively affects growth in less developed countries, with private investment being crucial, while Ghosh and Gregoriou (2008), using panel data for 15 developing countries, find that current spending boosts growth, whereas capital spending has a negative impact. Sabra (2016), analyzing eight MENA countries from 1977–2013, finds that government size exceeds optimal levels, undermining private sector activity and investment, and suggests shifting spending toward infrastructure and reducing market intervention.

For Türkiye, Altunc and Aydın (2013) apply the ARDL bounds approach and suggest that public expenditure exceeds the growth-maximizing level, recommending more efficient spending. Similarly, Iyidoğan and Turan (2017) identify a nonlinear relationship, with consumption above 12.6% of GDP reducing growth—consistent with the Armey Curve. Taban (2010) finds that total government spending and public investment have negative long-run effects on per capita GDP growth in Türkiye, using ARDL analysis for the 1987–2006 periods. Celik and Köstekçi (2024) use the A-ARDL bounds testing approach for Türkiye (1980–2021), finding that current and investment expenditures positively affect growth in both the short and long run, while transfer spending negatively affects growth in the short term. These findings highlight the importance of context-specific analysis, reinforcing the need for updated empirical work on Türkiye's government size–growth dynamics using recent data and a more targeted approach.

2.4. Energy Consumption and Economic Growth

Traditional growth models often exclude energy, focusing on capital, labor, and technology. Yet, Stern (2011) critiques this omission, emphasizing that energy is a fundamental input to all economic production due to thermodynamic constraints. While neoclassical models underemphasize energy, ecological economists overstate its role, often treating it as the central driver of growth (Hall et al., 1986). Stern argues that energy is necessary—but not sufficient—for long-run growth, as institutions, knowledge, and technology also matter (Howitt, 2010). He highlights that output ultimately depends on the availability and quality of energy resources. Concepts like energy return on investment (EROI) show that lower-quality energy yields less surplus, potentially constraining both growth and sustainability (Murphy & Hall, 2010). Though substitution and efficiency gains help, Stern cautions against assuming they always offset depletion. His synthesis challenges energy-neutral assumptions in growth theory and supports including energy explicitly—especially for energy-dependent economies like Türkiye.

Empirical research has explored the energy–growth nexus using diverse methods and country samples—critical for Türkiye's energy-dependent economy. Across emerging economies, Ozturk et al. (2010), studying 51 countries from 1971 to 2005, find energy and GDP cointegrated, with middle-income countries like Türkiye showing robust ties. Shahbaz et al. (2018), applying a quantile-on-quantile approach to top energy-consuming countries, find a generally positive but state-dependent relationship between energy and growth. Rezitis and Ahammad (2015), using panel VAR for South and Southeast Asia, detect bidirectional causality, suggesting strong interdependence between energy consumption and output. Herrerias et al. (2013) highlight energy intensity's role in Chinese provinces. The energy–growth nexus is not only about the overall level of consumption but also about the composition of energy sources. Demir and Görür (2020), examining 36 OECD countries, show that hydroelectric and renewable energy consumption have long-run growth-enhancing effects, whereas thermal energy consumption exerts a negative impact.

In Türkiye, Ozturk and Acaravci (2010), using ARDL for 1968–2005, find energy consumption and GDP cointegrated, with a 1.375 income elasticity—highlighting energy's role in growth. Balat (2008) links rising energy demand since the 1980s to industrialization and urbanization, noting import dependency and post-2001 reforms. Erdal et al. (2008), applying Pair-wise Granger causality tests for 1970–2006, find bidirectional causality between energy consumption and GNP, highlighting energy's critical role in driving Türkiye's economy. Göksu (2024), applying the NARDL method for 1972–2020, reveals asymmetric cointegration, with reductions in fossil energy consumption exerting a stronger negative impact on growth than increases, and finds causality varying by energy type—neutral for coal, feedback for natural gas, and growth-driven for oil—underscoring the non-linear dynamics of Türkiye's energy–growth nexus. The energy–growth link is context-specific, shaped by development stage, energy efficiency, and method—supporting a tailored model for Türkiye's energy-dependent economy.

2.5. Research Gap and Contribution

Despite the extensive research conducted on Türkiye's economic growth, there is no unified framework that addresses how external debt, energy consumption, government size, and human capital interact over time. Most available studies focus on one or two of these variables, using methods like VAR, traditional ARDL, or recent innovations such as NARDL to capture asymmetric effects, but fail to model how an economy adjusts to shocks in both the short and long run. This is a major limitation, particularly for an economy like Türkiye's, which has repeatedly experienced episodes of macroeconomic instability, financial crises, and structural change.

This study fills that gap by being the first to jointly analyze these four critical growth determinants using the DYNARDL simulation method , applied to a long-term dataset covering Türkiye's full post-1970 macroeconomic trajectory, including major crises, liberalization, and structural reforms. The extended time span allows us to capture not just short-term fluctuations but also persistent patterns and regime-specific dynamics in the relationship between these variables and economic growth. Different from standard ARDL approaches, DYNARDL allows for the estimation of both short- and long-run effects while also generating scenario-based simulations. These simulations make it possible to visualize how GDP responds over time to changes in each variable, holding others constant—capturing dynamic adjustment paths rather than just equilibrium outcomes.

The main contribution of this paper lies in integrating methodological innovation with empirical relevance. By combining external debt, energy consumption, government size, and human capital into a single dynamic model, this study provides a more comprehensive and realistic view of Türkiye's growth drivers. The use of DYNARDL simulations enhances interpretability and policy relevance, particularly in a context where the timing and sequencing of economic shocks and policy responses matter. In doing so, this research not only improves upon previous empirical approaches but also offers practical insights for managing debt risks, optimizing fiscal policy, and reducing energy dependency—challenges that are central not only to Türkiye, but to many emerging economies.

3. DATA, MODEL AND METHODOLOGY

3.1. Data and Model

This study uses annual data for Türkiye covering the period from 1970 to 2019 to investigate the key determinants of economic growth. The dependent variable is GDP per capita (constant 2015 US dollars), a standard measure of economic performance. The independent variables capture structural, fiscal, and productivity-related influences on Türkiye's economic output. External debt stock (debt), measured as a percentage of GNI reflects macroeconomic debt burden. Government final consumption, expressed as a percentage of GDP, represents fiscal policy and aggregate demand. Human capital is included as a control variable to isolate the effects of debt, fiscal policy, and energy use on growth, consistent with endogenous growth models. HCI captures the quality and productivity of labor, while energy consumption per capita signals infrastructure capacity and economic modernization. Both variables are retained in the model as they represent theoretically distinct dimensions of development.To account for scale differences, potential non-linearity, and heteroskedasticity, all variables are log-transformed—except human capital, which is kept in levels due to its narrow range and better model fit. All data are sourced from the World Bank's World Development Indicators (WDI), the Penn World Table (PWT) and Energy Institute. Table 1 summarizes the variables and their definitions.

Table 1. Summary of Variables Used in the Model

Variable	Description	Source
GDP per capita	GDP per capita, constant 2015 US dollars	World Development Indicators (WDI)
External debt	External debt stock (% of GNI)	WDI
Government size	General government final consumption expenditure (% of GDP)	WDI
Energy consumption	Primary energy use per capita (Gigajoules per person)	Energy Institute
Human capital index	Index based on years of schooling and returns to education	Penn World Table (PWT)

Source: Author's computation

Table 2 presents the descriptive statistics for the variables over the 1970–2019 period. The natural logarithm of GDP per capita (lnGDP) has a mean of 8.67 with a relatively low standard deviation, indicating moderate variation in income levels across the period. External debt (lnDEBT) and energy consumption per capita (lnEC) both exhibit a wider range, suggesting fluctuations in Türkiye's external financing and energy use. Government size (lnGOV) shows limited dispersion, which reflects the relatively stable role of the public sector in aggregate demand. The human capital index (HC), reported in level form, has a mean of 1.87 and ranges from 1.31 to 2.51, indicating gradual improvement in educational and skill development over time.

Table 2. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lnGDP	50	8.671	.391	8.063	9.405
lnDEBT	50	3.539	.426	2.4	4.05
lnGOV	50	2.459	.185	2.017	2.751
lnEC	50	3.667	.462	2.699	4.379
HC	50	1.868	.356	1.311	2.514

Source: Author's computation

This study examines the long-run and short-run determinants of economic growth in Türkiye by modeling the relationship between GDP per capita and a set of structural and policy-related variables.

The goal is to assess how external debt, government size, energy consumption, and human capital have influenced economic performance over the period 1970–2019.

The functional relationship is specified as:

$$GDP=f(DEBT,GOV,EC,HC) \quad (1)$$

In this formulation, GDP represents gross domestic product per capita and serves as the dependent variable. DEBT denotes external debt stock as a percentage of GNI, capturing the macroeconomic burden of foreign borrowing. GOV refers to government final consumption expenditure as a share of GDP, used as a proxy for the scale of public sector activity. EC stands for per capita energy consumption, reflecting infrastructure intensity and economic modernization. HC is the human capital index, which represents the quality and productivity of labor based on education and experience. This selection captures Türkiye's key macroeconomic dynamics: debt cycles, public spending patterns and energy dependency. Including human capital as a control helps isolate the effects of the three main policy levers.

This framework is well-suited to the case of Türkiye, an economy shaped by structural changes, recurring policy shifts, and external shocks over the past five decades. From debt crises and IMF interventions in the 1980s and 2000s to major fiscal adjustments and shifts in energy policy, these developments have had lasting effects on economic performance. The selected variables capture the main channels through which these macroeconomic and institutional dynamics have influenced growth.

To allow for elasticity interpretation and address potential non-linearity and heteroskedasticity, Equation (1) is transformed into a semi-logarithmic form. All variables are expressed in natural logs except the human capital index, which is kept in levels due to its measurement scale and distributional properties. The log-linear model is presented below:

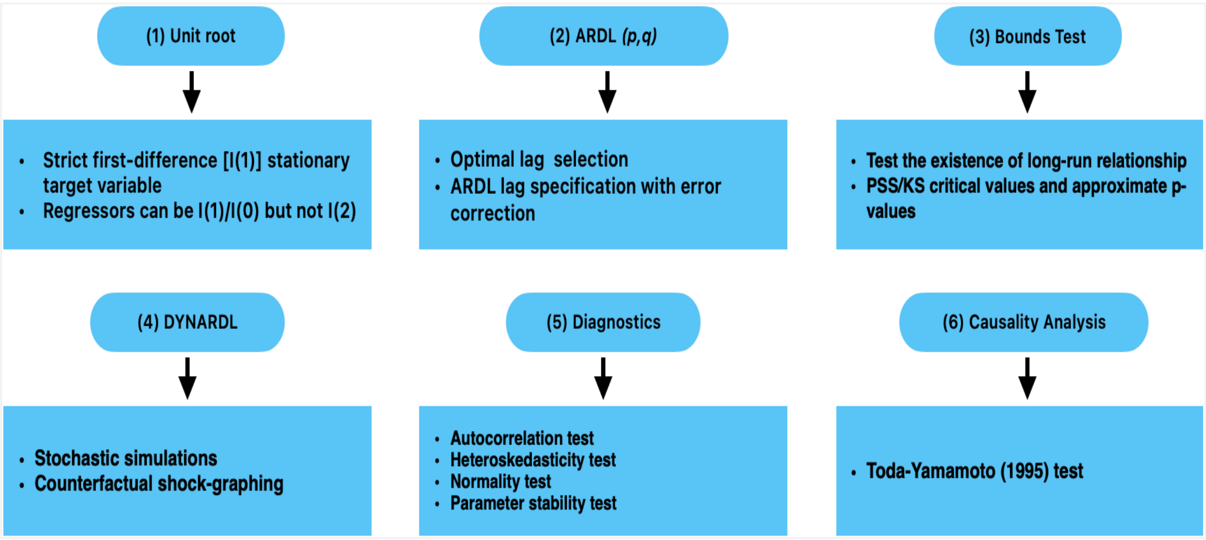
$$\Delta lnGDP = \alpha_0 + \alpha_1 lnGDP_t + \alpha_2 lnDEBT_t + \alpha_3 lnGOV_t + \alpha_4 lnEC_t + \alpha_5 HC_t + \mu_t \quad (2)$$

In Equation (2), t denotes the time period, α_0 is the constant term, α_1 to α_5 are the estimated coefficients, and μ_t represents the error term. The expected signs of the coefficients in this study are guided by theoretical and empirical literature on economic growth. The relationship between external debt (DEBT) and growth is complex: moderate debt can finance productive investments, fostering growth, but excessive debt may lead to a debt overhang or macroeconomic instability, thereby constraining growth (Krugman, 1988; Pattillo & Ricci, 2011). Government consumption (GOV) is typically expected to have a neutral or negative impact, especially if spending is inefficient or crowds out private investment, as shown in endogenous growth models and empirical studies (Barro, 1990; Kneller et al., 1999). Energy consumption (EC) is expected to contribute positively to growth, particularly in developing economies, where it supports industrial activity, infrastructure, and productivity—a view supported by studies emphasizing energy's role as a critical input in production (Azam et al., 2015; Stern, 2011). Human capital (HC), proxied by education or health metrics, consistently drives growth by enhancing labor productivity and innovation, a finding central to endogenous growth theory (Barro & Lee, 2013; Hanushek & Woessmann, 2023; Lucas, 1988).

3.2. Methodology

This study utilizes the DYNARDL simulation method introduced by Jordan and Philips (2018) to to explore how economic growth responds to its key drivers over both short and long time horizons. Unlike the standard ARDL model, the dynamic version allows for counterfactual simulations, making it possible to trace the trajectory of the dependent variable in response to a one-time change in a given explanatory variable, holding other variables constant (Sarkodie & Owusu, 2020). These simulations generate dynamic visualizations of both the short-run and long-run effects, capturing adjustment periods and magnitudes more clearly than standard error correction models. For reference, Figure 1 provides a schematic outline of the modeling and testing procedure used in this study.

Figure 1. Flowchart of the Empirical Strategy



Before estimating the model, the time series properties of all variables are examined to determine their order of integration. As noted by Jordan and Philips (2018), the DYNARDL framework requires the dependent variable to be integrated of order one I(1), while explanatory variables may be either level stationary [I(0)] or first-difference stationary, but not I(2). To assess this, we employ a combination of conventional and break-sensitive unit root tests.

Specifically, the Augmented Dickey–Fuller (ADF), Phillips–Perron (PP), and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests are first applied. The ADF and PP tests evaluate the null hypothesis of a unit root, while the KPSS test evaluates the null of stationarity, thereby providing a complementary perspective. However, conventional tests may be biased when structural breaks are present. To address this, we also apply the Zivot–Andrews (ZA) (1992) test, which endogenously identifies a single structural break, and the Clemente–Montañés–Reyes (CMR) (1998) test, which allows for two mean shifts under the innovational outlier (IO) specification. This helps reduce the risk of spurious results and ensures more reliable inference, particularly in an economy like Türkiye's, where major policy shifts and external shocks are common (Ventosa-Santaulària & Vera-Valdés, 2008).

Having verified the stationarity conditions, we then proceed to test for cointegration using the bounds testing procedure in the ARDL framework developed by Pesaran et al. (2001). We apply the updated critical values and p-values of Kripfganz and Schneider (2020), which provide better inference especially in small samples.

The ARDL bounds model is specified as follows:

$$\begin{aligned}\Delta lnGDP_t = {} & \alpha_0 + \alpha_1 lnGDP_{t-i} + \alpha_2 lnDEBT_{t-i} + \alpha_3 lnGOV_{t-i} + \alpha_4 lnEC_{t-i} \\ & + \alpha_5 HC_{t-i} + \sum_{i=1}^{m} \beta_1 \Delta lnGDP_{t-i} + \sum_{i=1}^{m} \beta_2 \Delta lnDEBT_{t-i} \\ & + \sum_{i=1}^{m} \beta_3 \Delta lnGOV_{t-i} + \sum_{i=1}^{m} \beta_4 \Delta lnEC_{t-i} + \sum_{i=1}^{m} \beta_5 \Delta HC_{t-i} + \mu_t\end{aligned} \tag{3}$$

Where Δ denotes the first-difference operator, and is μ_t the white noise error term. The lag lengths are indicated by $t - i$, selected based on information criteria. The α coefficients capture the long-run relationships between the dependent variable and its regressors, while the β coefficients reflect the short-run dynamics. The model includes both lagged level and differenced terms to capture the adjustment process toward long-run equilibrium. The long-run cointegration is assessed through two hypotheses, which test the joint significance of the lagged level terms in the ARDL model.

$(H_0 = \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0)$ and

$(H_1 \neq \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq 0)$

To determine whether a stable long-run relationship exists, we compare the computed F-statistic and t-statistic against the critical bounds provided in Kripfganz and Schneider (2020). A result above the upper bound supports the presence of cointegration, while values below the lower bound suggest no such relationship. Intermediate values indicate inconclusive evidence.

As an additional robustness check, we also apply the Gregory–Hansen (1996) cointegration test, which explicitly allows for a single structural break in the long-run relationship. This test is estimated under three alternative specifications—level shift, level shift with trend, and regime shift—and evaluates the null hypothesis of no cointegration against the alternative of cointegration with a structural break. By incorporating this approach alongside ARDL bounds testing, we ensure that the long-run dynamics are robust to potential regime shifts in Türkiye's economy.

After verifying that lnGDP is stationary in first differences and confirming cointegration through the bounds test, complemented by the Gregory–Hansen (1996) test to account for potential structural breaks, we selected the model's optimal lag structure based on AIC, HQC, SBIC, and other standard criteria. With these prerequisites met, the ARDL model was estimated to examine both the short-run dynamics and the long-run relationship between the variables. The full model specification follows.

$$lnGDP_{t-1} = \rho_0 + \sum_{i=1}^{m} \theta_1 \, lnGDP_{t-i} + \sum_{i=1}^{m} \theta_2 \, lnDEBT_{t-i} + \sum_{i=1}^{m} \theta_3 \, lnGOV_{t-i} + \sum_{i=1}^{m} \theta_4 \, lnEC_{t-i} + \sum_{i=1}^{m} \theta_5 \, HC_{t-i} + \sum_{i=1}^{m} \vartheta_1 \, \Delta lnGDP_{t-i} + \sum_{i=1}^{m} \vartheta_2 \, \Delta lnDEBT_{t-i} + \sum_{i=1}^{m} \vartheta_3 \, \Delta lnGOV + \sum_{i=1}^{m} \vartheta_4 \, \Delta lnEC_{t-i} + \sum_{i=1}^{m} \vartheta_5 \, \Delta HC_{t-i} + \emptyset ECT_{t-1} + \mu_t \quad (4)$$

In this specification θ represents the long-run variation, while ϑ reflects the short-run dynamics. The error correction term $\emptyset ECT_{t-1}$ captures the speed at which deviations from the long-run equilibrium are corrected. We validated the model through several diagnostic checks: serial correlation (Breusch-Godfrey), heteroscedasticity (ARCH and Breusch–Pagan–Godfrey), model specification (Ramsey RESET), and residual normality (Jarque-Bera). Structural stability was evaluated using the CUSUMSQ test as proposed by Brown et al. (1975).

To capture dynamic effects and run counterfactual simulations, this study employs the innovative Dynamic ARDL simulation model introduced by Jordan and Philips (2018). This method extends the traditional ARDL framework by simulating the impact of a change in one independent variable over time while holding others constant. Following Sarkodie et al. (2019) and Sarkodie & Owusu (2020), the model generates both short- and long-run estimates and forecasts responses to positive and negative shocks. The baseline specification of the simulation model is outlined below:

$$\Delta lnGDP_t = \alpha_0 + \vartheta_0 lnGDP_{t-1} + \varphi_1 \Delta lnDEBT_t + \vartheta_1 lnDEBT_{t-1} + \varphi \Delta lnGOV_t + \vartheta_2 lnGOV_{t-1} + \varphi_3 \Delta lnEC_t + \vartheta_3 lnEC_{t-1} + \varphi_4 \Delta lnHC_t + \vartheta_4 lnHC_{t-2} + \emptyset ECT_{t-1} + \mu_t \quad (5)$$

In Equation (5), the difference operator Δ captures the short-run dynamics, while the intercept term α_0 represents the constant. The long-run coefficients are denoted by $\vartheta_1, \vartheta_2, \vartheta_2, \vartheta_4$, and the short-run coefficients by $\varphi_1, \varphi_2, \varphi_3, \varphi_4$. The error term μ_t accounts for random disturbances in the model.

Finally, to test for Granger causality we applied the Toda–Yamamoto (1995) procedure, which is robust to different orders of integration and the presence of cointegration among variables. The optimal lag length of the VAR (p) was first selected using the Akaike Information Criterion (AIC), and the system was then augmented by the maximum order of integration (m) to estimate a VAR (p+m). Wald tests were conducted on the first p lags to test the null of non-causality, with the statistics asymptotically chi-square distributed.

4. EMPIRICAL RESULTS AND DISCUSSION

To ensure the robustness of the time-series properties, we employed a set of complementary unit root tests under the assumption of both a constant and a trend. Conventional approaches (ADF, PP, and KPSS) were first applied, followed by structural break–sensitive methods: Zivot–Andrews (ZA), which allows for a single endogenous break, and Clemente–Montañés–Reyes (CMR), which incorporates two breaks under the innovational outlier specification. The detailed results are reported in Tables 3 and 4.

Conventional tests (Table 3) indicate that lnGDP, lnDEBT, lnGOV, lnEC, and HC are non-stationary in levels: ADF and PP fail to reject the unit root, while KPSS rejects the null of trend-stationarity for lnGDP, lnDEBT, and lnEC. After first differencing, all variables become stationary: ADF and PP reject the unit root at the 1% level (except for ΔHC, which is only significant at the 10% level in PP), and KPSS no longer rejects trend-stationarity. This suggests that all series are integrated of order one, I(1), with ΔHC showing somewhat weaker support in the PP test.

Table 3. Stationarity Tests Using ADF, KPSS and PP Methods

Variables	ADF	KPSS	PP
Level		Test Stats values	
lnGDP	-0.996	0.255***	–1.474
lnDEBT	-2.065	0.200**	–2.118
lnGOV	-2.856	0.107	–2.457
lnEC	-2.830	0.201**	–3.175*
HC	-1.750	0.083	–1.998
First Difference			
ΔlnGDP	-3.957***	0.048	–7.100***
ΔlnDEBT	-4.206***	0.048	–7.161***
ΔlnGOV	-3.927***	0.056	–6.518***
ΔlnEC	-3.045***	0.057	–7.844***
ΔHC	-3.203**	0.081	–2.483*

Note(s): For the ADF and PP tests, ***p < 0.01, **p < 0.05, *p < 0.10 indicate rejection of the unit root null hypothesis, implying stationarity of the series. For the KPSS test, ***p < 0.01, **p < 0.05, *p < 0.10 indicate rejection of the null of stationarity, suggesting non-stationarity. All tests are conducted with a constant and a linear trend.

Structural break tests (Table 4) offer further nuance. The ZA test suggests weak evidence of level stationarity for lnDEBT, lnGOV, and lnEC at the 10% level. The more stringent CMR test confirms non-stationarity in levels, with only lnGOV showing marginal significance. After first differencing, all series—lnGDP, lnDEBT, lnGOV, lnEC, and HC—are found stationary (ZA at 1% for all; CMR at 1% for ΔlnGDP, ΔlnDEBT, ΔlnGOV, and ΔlnEC). The CMR statistic for ΔHC (–4.355) does not exceed the 5% critical value (–5.49). This borderline result likely reflects the smoother trajectory of human capital accumulation, which is less sensitive to abrupt regime shifts than more volatile macroeconomic variables like debt or government size. HC evolves gradually, making break-based tests more conservative in identifying stationarity.

Importantly, the timing of the structural breaks adds credibility to the test results. The break dates identified by ZA and CMR align with major episodes in Türkiye's economic history—including the 1978–79 oil shock, the 1980 stabilization program, the 1994 currency crisis, the 2001 banking crisis, and the 2008 global financial crisis—reinforcing the plausibility of the statistical findings.

Overall, the convergence of results across both conventional and structural break–adjusted tests confirms that all variables are integrated of order one, I(1), with no evidence of integration at order two, I(2). This supports the validity of using the ARDL bounds testing approach for subsequent cointegration and long-run dynamics analysis.

Table 4. Stationarity Tests Using ZA and CMR

Variables	ZA		CMR	
Level		Breaking Year		Breaking Years
lnGDP	-4.075	1999	–1.644	1982, 2002
lnDEBT	-4.994*	1977	–4.783	1978, 2000
lnGOV	-4.526*	1989	–5.334*	1979, 1987
lnEC	-4.215*	1987	–4.017	1984, 2001
HC	-3.890	1990	-1.468	1979, 1994
First Difference				
ΔlnGDP	-7.374***	1981	–8.330***	2000, 2008
ΔlnDEBT	-8.192***	1979	–5.767***	1986, 1993
ΔlnGOV	-7.452***	1986	–8.265***	1987, 1992
ΔlnEC	-8.651***	1982	–7.642***	1981, 2000
ΔHC	-6.574***	1986	–4.355	1979, 1984

Note(s): ***, **, * indicate significance at 1%, 5%, and 10%, respectively.

To determine the optimal lag length for the ARDL model, we apply several lag selection criteria, including Log-Likelihood (LL), Likelihood Ratio (LR), Final Prediction Error (FPE), Akaike Information Criterion (AIC), Hannan-Quinn Information Criterion (HQIC), and Schwarz Information Criterion (SIC). The results are presented in Table 5. The LR test, FPE, and AIC suggest a lag length of 3, indicated by their lowest values. However, HQIC and SIC favor lag 2. Given that AIC and FPE balance model fit and complexity effectively, we select a lag length of 3 for the ARDL model to ensure the best fit for long-run analysis.

Table 5. Lag length selection results

Lags	LL	LR	FPE	AIC	HQIC	SIC
0	90.641		2.7e-07	-3.767	-3.707	-3.608
1	331.216	481.150	1.6e-11	-13.5311	-13.2333	-12.7361
2	367.857	73.281	6.5e-12	-14.4285	-13.8924*	-12.9974*
3	388.202	40.69*	5.6e-12*	-14.6175*	-13.8431	-12.5503
4	397.972	19.54	8.0e-12	-14.3466	-13.334	-11.6434

Note: * indicates lag order selected by the criterion.

After establishing the optimal lag length, we apply the bounds testing method developed by Pesaran et al. (2001). As reported in Table 6, the F-statistic (7.904) exceeds the I(1) critical value at the

1% level (5.943), and the t-statistic (–4.582) surpasses the I(1) 5% threshold (–4.045). The p-values, based on Kripfganz and Schneider (F: 0.001, t: 0.017), confirm statistical significance at the 5% level. These results provide strong evidence to reject the null hypothesis of no cointegration and confirm the existence of a long-run relationship among the variables.

Table 6. Table PSS Bounds Testing in ARDL with Novel p-values by Kripfganz & Schneider (2020)

Log-linear model	F-statistic	t-statistic	k	H_0	$H_{alternative}$	
GDP=f(DEBT,GOV,EC,HC)	7.904	-4.582	4	No-cointegration	Cointegration	
Kripfganz & Schneider(2020)'s Tests Significance	Critical values				p-values	
	F-statistic		t-statistic		I(0)	I(1)
	I(0)	I(1)	I(0)	I(1)	For F-test	
10%	2.603	3.783	-2.550	-3.658	0.000	0.001
5%	3.126	4.440	-2.888	-4.045	For t-test	
1%	4.341	5.943	-3.567	-4.812	0.001	0.017

Note(s): I(0) and I(1) represent the lower and upper critical values at the 10%, 5%, and 1% significance levels of the Pesaran et al. (2001) bounds test. The p-values are based on the critical values and approximate p-values from Kripfganz & Schneider (2020).

To further verify the long-run equilibrium in the presence of potential structural breaks, we applied the Gregory–Hansen (1996) cointegration test under three specifications (level shift, level shift with trend, and regime shift). The results (Table 7) show that both the level shift (–5.55) and level shift with trend (–5.91) models reject the null of no cointegration at the 10% and 5% levels, respectively, with a break date in 2012, broadly reflecting post-crisis global and domestic adjustments. This confirms that the long-run relationship among the variables remains valid despite structural breaks.

Table 7. Gregory-Hansen Test Results for Cointegration with Structural Break

Test Statistic	**ADF***	**T_b**	**1% CV**	**5% CV**	**10% CV**	**Decision**
GH (level)	-5.55*	2012	–6.36	–5.83	–5.59	Reject null hypothesis
GH (level shift with trend)	–5.91**	2012	–6.36	–5.83	–5.59	Reject null hypothesis
GH (regime)	-5.69	2006	-6.92	-6.41	-6.17	Accept null hypothesis

Note(s): T_b denotes the estimated break date. ***, **, * indicate significance at 1%, 5%, and 10%, respectively. Critical values (CV) are from Gregory–Hansen (1996) for m=4.

Table 8 presents the estimation results from the dynamic ARDL model, highlighting the short-run and long-run effects of the explanatory variables on Türkiye's economic growth. A 1% increase in external debt is associated with a 0.10% decline in growth in the short run and a 0.09% decline in the long run, both statistically significant at the 1% level. These findings support the debt overhang hypothesis proposed by Krugman (1988), which suggests that high debt levels discourage investment by creating uncertainty over future policy and debt servicing. Türkiye's long-standing reliance on external borrowing, especially during the 1990s and early 2000s, contributed to recurrent balance-of-payments crises and macroeconomic instability (Özatay & Sak, 2002). These debt episodes often triggered in IMF stabilization programs, which although aimed at structural reforms, were sometimes criticized for their deflationary impact and growth slowdowns (Dreher, 2006). The growth-constraining effects of debt are not unique to Türkiye. Reinhart and Rogoff (2010), analyzing data from 44 countries over two centuries, argue that once debt surpasses critical thresholds, it tends to suppress growth by raising risk premia, tightening fiscal space, and increasing exposure to financial shocks.

Calvo (1998) explains that economies heavily reliant on external debt are vulnerable to sudden stops in capital flows, which can trigger financial crises even without major fiscal problems. In Türkiye's case, this risk is heightened by its reliance on short-term and foreign-denominated debt, making the economy prone to sharp contractions when global financing conditions tighten. This dynamic supports the finding that external debt constrains growth by increasing financial fragility. While external borrowing can finance productive investments, over-dependence risks cumulative growth losses. In the post-COVID-19 era —characterized by global debt surges—Türkiye must prioritize fiscal discipline and strategic investment to safeguard long-term economic resilience.

The results show that a 1% increase in government size reduces Türkiye's economic growth by 0.128% in the short run, significant at the 5% level. In the long run, a 1% increase decreases growth by 0.030%, but this effect remains statistically insignificant. Keynesian theory suggests that government expenditure can stimulate aggregate demand during downturns, thereby supporting economic growth (Keynes, 1937). However, neoclassical perspectives, as discussed by Barro (1990), argue that inefficiencies or persistent fiscal deficits can reduce the effectiveness of government spending, crowd out private investment, and ultimately hinder long-term growth. These theoretical perspectives help contextualize Türkiye's experience from 1970 to 2019, when expansionary fiscal policies in the 1970s and 1990s, marked by deficits and inefficiencies, led to short-term instability, notably culminating in the 2000–2001 crisis (Ozkan, 2005). Over the long term, Türkiye's moderate government size and post-2001 fiscal reforms likely minimized distortions, aligning more closely with fiscal neutrality principles (Afonso & Furceri, 2010). The results reflect a pattern where temporary fiscal imbalances slow growth in the short run without altering the long-term trajectory. Policymakers should focus on enhancing the efficiency of public spending to mitigate short-term disruptions and support stable, sustainable growth in Türkiye.

Energy consumption remains a critical driver of Türkiye's economic growth. In the short run, a 1% increase in energy consumption raises GDP by 0.536%, significant at the 1% level, highlighting its essential role in powering industrial production and broader economic activity. In the long run, a 1% increase raises GDP by 0.123%, significant at the 5% level, suggesting that energy consumption maintains a positive, though relatively smaller, impact over time. This pattern aligns with Türkiye's energy-intensive economy, where energy supports key sectors like manufacturing and exports (Kaplan et al., 2011). Over the long run, improvements in energy efficiency or sectoral diversification may explain the more moderate effect. This moderation is consistent with Türkiye's gradual, though slower-than-OECD, transition toward renewable energy (Altun & İşleyen, 2018). Given Türkiye's rising energy demand and heavy reliance on imports, strengthening energy security through renewable sources and efficiency measures is critical to sustaining stable, long-term growth (Erdal et al., 2008), especially in the post-COVID-19 context of global energy volatility.

The results further indicate that human capital, measured by the PWT index reflecting education levels and returns to schooling, positively influences Türkiye's GDP growth. Human capital drives a rise in GDP in the short run by 0.921 percent at the 5% significance level and provides a smaller but highly reliable contribution in the long run by 0.293 percent at the %1 significance level. Overall, the findings indicate that human capital has a meaningful but varying impact over time, with a larger short-term effect and a more stable long-term contribution, consistent with the theoretical expectations (Barro, 1991; Mankiw et. al, 1992). The results align with Demir (2021), who shows that fiscal inputs such as education, health, and R&D expenditures foster growth, yet they contrast with Altun et al. (2018), who report insignificant effects of education spending despite positive contributions from health.

The error correction term (ECT) indicates the speed of adjustment toward long-run equilibrium. A coefficient of –0.30 implies that 30% of the disequilibrium from the previous period is corrected each year. While this speed of adjustment may appear rapid in light of Türkiye's history of macroeconomic volatility and frequent external shocks, it should be interpreted as a property of the estimated ARDL model rather than as a direct measure of macroeconomic stability. The adjusted R-squared value indicates that the explanatory variables in this model explain 68% of the variation in GDP. The F-statistic's p-value confirms that the model is a good fit for the data, and the included regressors significantly explain the fluctuations in the dependent variable.

Table 8. Short and Long-run DYNARDL Simulations Results

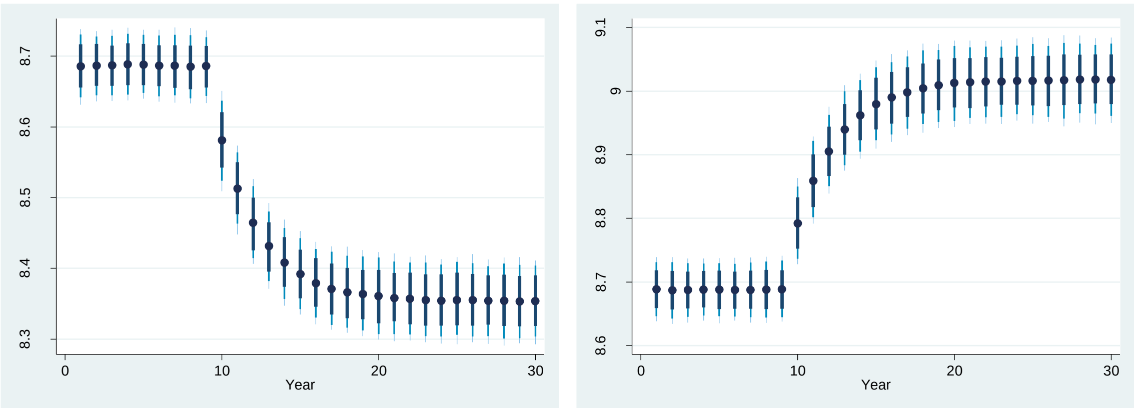
Variables	Coefficient	Std. errors	t-values	Min 95%	Max 95%
ECT (-1)	-0.300***	0.078	-3.820	-0.458	-0.141
Short run					
lnDEBT	-0.105***	0.023	-4.490	-0.152	-0.057
lnGOV	-0.128**	0.059	-2.180	-0.247	-0.008
lnEC	0.536***	0.084	6.410	0.366	0.706
HC	0.921**	0.403	2.280	0.104	1.737
Long run					
lnDEBT	-0.099***	0.028	-3.610	-0.155	-0.043
lnGOV	-0.030	0.037	-0.810	-0.106	0.045
lnEC	0.123**	0.057	2.170	0.008	0.237
HC	0.293***	0.108	2.710	0.073	0.512
_cons	2.028***	0.553	3.670	0.908	3.146
R^2=0.74	Adj R^2=0.68	Prob > F =0.00	Obs=48	Simulations =5000	

Note(s): ***, **, * indicate significance at 1%, 5 and 10% respectively.

The dynamic ARDL framework allows us to simulate how shocks to the explanatory variables affect real GDP while holding other factors constant. This approach traces the adjustment path of lnGDP in response to a permanent ±1% change in a regressor, thereby illustrating both short-run dynamics and long-run equilibrium effects. In line with Jordan and Philips (2018), shocks are introduced at period 10 by construction, which ensures that the model first establishes a stable baseline before the shock occurs. The graphs obtained by running 5,000 simulations for the parameter vector in the dynamic ARDL model are presented in Figures 2–5.

As Figure 2 shows, a +1% shock in predicted external debt is followed by a gradual, roughly 10-period decline in lnGDP that eventually levels off at a persistently lower plateau. This delayed yet lasting effect indicates that higher external debt amplifies financial vulnerabilities that compound over time, constraining long-term growth through debt servicing burdens. In contrast, a -1% shock may affect economic growth initially, but growth subsequently accelerates, eventually stabilizing above baseline. The adjustment pattern spanning 15–20 periods indicates that debt sustainability policies require sustained commitment before benefits materialize. These results highlight the importance of proactive debt reduction and restructuring, as the permanent nature of GDP improvements contrasts sharply with temporary policy effects, making debt management a critical tool for achieving sustained macroeconomic growth and financial stability.

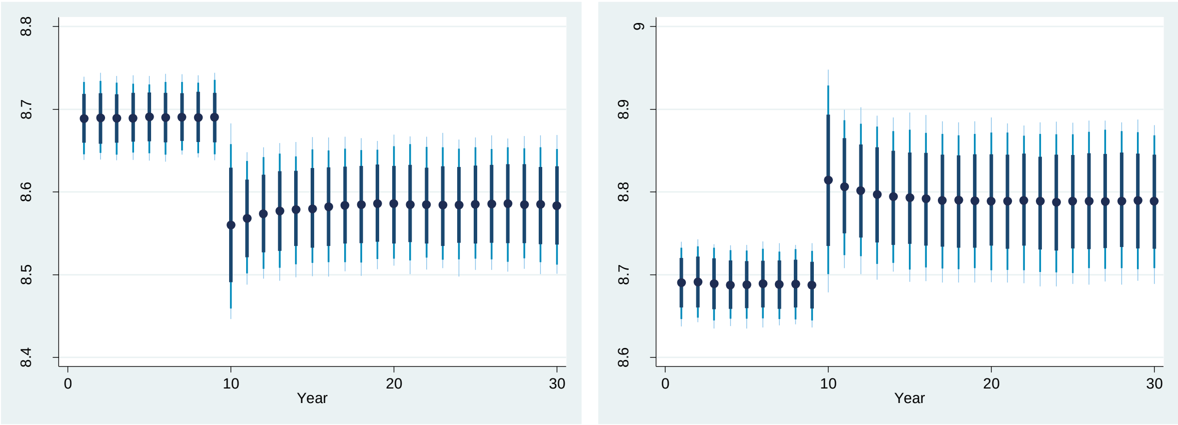
Figure 2. Dynamic Response of lnGDP to ±1 Shocks in lnDEBT



Note(s): Dynamic simulation of the impact of a ±1% change in external debt stock (lnDEBT) on real GDP (lnGDP). The plot shows the average predicted response of lnGDP following a shock to lnDEBT, based on the DYNARDL model. Dots represent the predicted values, while the shaded bands indicate the 75%, 90%, and 95% confidence intervals, from darkest to lightest.

Figure 3 captures the effects of a +1% shock in predicted government size, revealing an initial GDP decline followed by a modest recovery. This indicates that increased government spending may disrupt economic activity in the short run, potentially due to inefficiencies or crowding out of private investment. Conversely, a −1% shock produces an initial rise in GDP, which gradually diminishes, implying that reduced government size can provide a temporary boost before output converges very close to its long-run path. This suggests that while fiscal expansions or contractions can influence short-term dynamics, they do not produce lasting significant growth shifts in this setting. At the policy level, the results highlight the importance of structural reforms for sustaining any growth benefits beyond the short-run adjustment horizon.

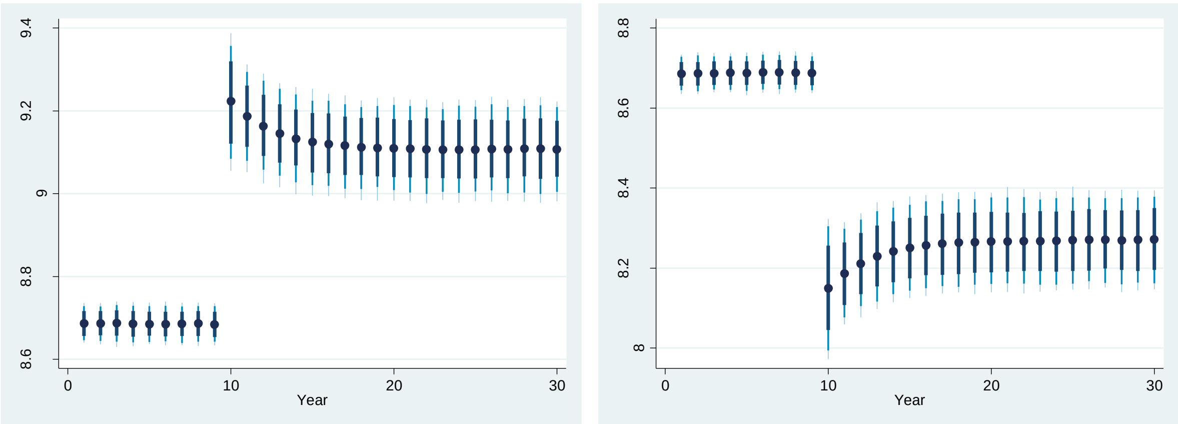
Figure 3. Dynamic Response of lnGDP to ±1 Shocks in lnGOV



Note(s): Dynamic simulation of the impact of a ±1% change in government size (lnGOV) on real GDP (lnGDP), based on the DYNARDL model. The plot shows the predicted response of lnGDP to the shock, with dots representing mean estimates and shaded areas indicating the 75%, 90%, and 95% confidence intervals from darkest to lightest.

The plots in Figure 4 expose that a 1% increase in predicted energy consumption leads to an immediate and sustained rise in GDP. The output remains elevated throughout the simulation period, indicating strong and lasting productivity gains from improved energy access. Following a −1% shock, GDP experiences an immediate and persistent contraction, highlighting the critical role of energy availability in maintaining economic output. The immediate adjustment pattern (occurring within 1-2 periods post-shock) suggests that energy policies deliver rapid economic returns, contrasting with the gradual effects observed for debt management. These dynamics strongly support energy sector investments and infrastructure development as high-impact growth strategies, particularly renewable energy transitions that can simultaneously increase consumption capacity while ensuring long-term sustainability.

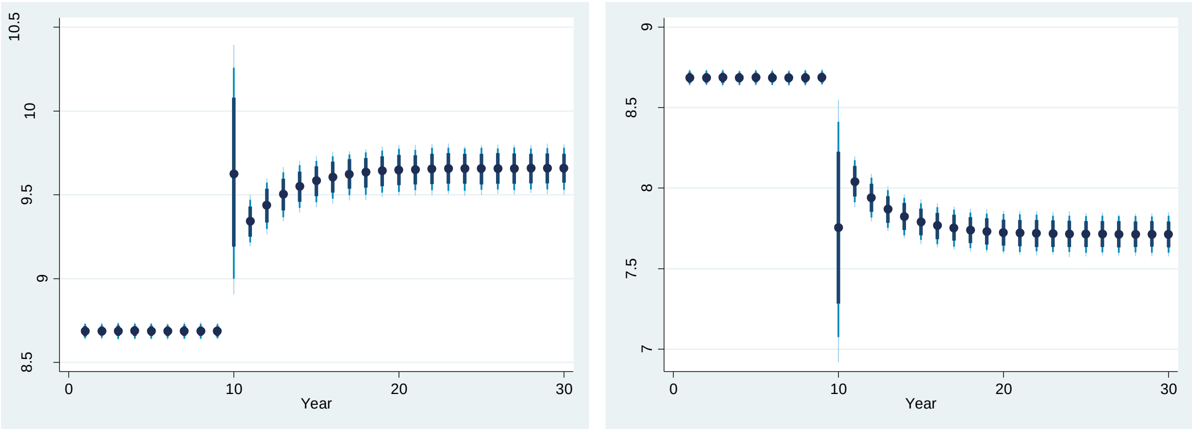
Figure 4. Dynamic Response of lnGDP to ±1 Shocks in lnEC



Note(s): Dynamic simulation of the impact of a ±1% change in energy consumption (lnEC) on real GDP (lnGDP), based on the DYNARDL model. The plot illustrates the predicted trajectory of lnGDP following the shock, with dots indicating mean responses and shaded bands representing the 75%, 90%, and 95% confidence intervals from darkest to lightest.

Figure 5 illustrates that a +1 unit shock in predicted human capital boosts GDP immediately, remaining stable at this elevated level throughout the simulation period, demonstrating that enhancements in education, skills, and workforce quality yield sustained productivity gains. Following a -1 unit shock, GDP contracts immediately and persistently, emphasizing the crucial role of sustained investments in education and skill development programs. The rapid adjustment within only a few periods implies that human capital policies deliver rapid economic returns, similar to energy consumption. The permanent nature of human capital-GDP linkages indicates that educational policies should be prioritized in short and long-term development planning.

Figure 5. Dynamic Response of lnGDP to ±1 Shocks in lnHC



Note(s): Dynamic simulation of the impact of a ±1 unit change in human capital index (HC) on real GDP (lnGDP), based on the DYNARDL model. The plot illustrates the predicted response of lnGDP following the shock, with dots showing the mean estimates and shaded areas indicating the 75%, 90%, and 95% confidence intervals from darkest to lightest.

Table 9 presents the results of several diagnostic tests conducted to assess the robustness and adequacy of the estimated model. The Breusch-Godfrey LM test indicates no evidence of serial correlation, while the Breusch-Pagan-Godfrey test suggests homoskedastic residuals, confirming the absence of heteroskedasticity. The Jarque-Bera test fails to reject the null hypothesis of normally distributed residuals. Lastly, the Ramsey RESET test supports the proper functional specification of the model. Overall, these results validate the reliability of the model for inference.

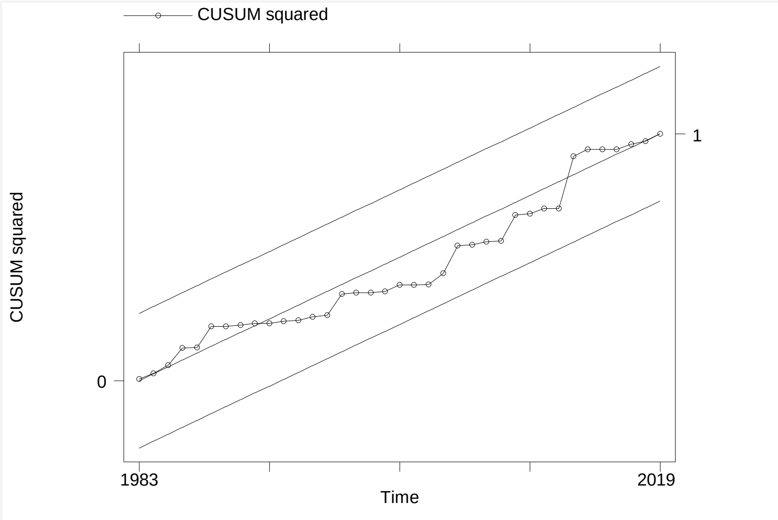
Table 9. Diagnostic tests

Diagnostic test	X^2 (p-value)	Results
Breusch-Godfrey LM	0.60(0.44)	No evidence of serial correlation
Breusch-Pagan-Godfrey	4.71(0.585)	No evidence of heteroscedasticity
Jarque Bera test	1.64(0.44)	Residuals are normally estimated
Ramsey reset test	0.92(0.44)	Proper specification of the model

Source: Authors' computations

The CUSUM of Squares test was conducted to examine the stability of the regression parameters over the sample period. As shown in Figure 6**,** the CUSUMSQ line remains within the 95% confidence bounds, indicating that there are no structural breaks and the model parameters are stable over time.

Figure 6. CUSUM of Squares Test for Parameter Stability



Note(s): The CUSUM of Squares test assesses the stability of the model's parameters over time. The plot displays the cumulative sum of squared recursive residuals along with 5% significance bounds.

Table 10 reports the Toda–Yamamoto Granger causality results. The test indicates several significant linkages: bidirectional causality between lnGDP and lnGOV, suggesting strong feedback between fiscal policy and economic activity; unidirectional causality from lnDEBT to lnGDP at the 10% level, implying that debt dynamics influence growth but not vice versa; and unidirectional causality from lnGDP to lnEC at the 10% level, reflecting the growth-driven nature of energy demand in the short run. By contrast, no causal relationship is observed between HC and lnGDP, indicating that its effects may manifest through longer-term channels not captured in this framework. Taken together, these results complement the dynamic simulation evidence by illustrating the distinction between short-run feedbacks and long-run structural effects.

Table 10. Causality test results (Toda–Yamamoto)

Causality direction	χ^2	p-value	Causality direction	χ^2	p-value	Decision
lnGDP→lnDEBT	0.758	0.685	lnDEBT→lnGDP	4.672	0.097*	Unidirectional causality from lnDEBT to lnGDP (10% level)
lnGDP→lnGOV	6.995	0.030**	lnGOV→lnGDP	12.504	0.002***	Bidirectional causality between lnGDP and lnGOV
lnGDP→lnEC	4.820	0.090*	lnEC→lnGDP	1.907	0.385	Unidirectional causality from lnGDP to lnEC (10% level)
lnGDP→HC	4.300	0.116	HC→lnGDP	0.222	0.895	No causality between lnGDP and HC

Note(s): ***, **, * indicate significance at 1%, 5 and 10% respectively.

5. CONCLUSION

This study examined the determinants of economic growth in Türkiye, focusing on external debt, government size, energy consumption, and human capital. Employing a dynamic ARDL simulation approach over the period 1970–2019, it aimed to capture both the short-run fluctuations and long-run relationships that shape Türkiye's growth dynamics through counterfactual scenarios that visualize the impact of policy shifts.

The empirical results reveal critical insights. First, external debt has a statistically significant negative effect on GDP in both the short and long run, confirming the debt overhang hypothesis and highlighting the growth risks of excessive foreign borrowing. Second, government size is found to reduce growth in the short term, while its long-run effect is statistically insignificant, suggesting fiscal neutrality post-2001 reforms. Third, energy consumption strongly drives growth across both time horizons, underscoring its central role in supporting industrial output and overall economic activity. Finally, human capital significantly boosts growth, particularly in the long run, reaffirming the importance of education and labor quality in Türkiye's development trajectory.

These findings, visualized through DYNARDL simulations (Figures 2–5), offer clear policy guidance. The negative growth effects of external debt calls for disciplined borrowing strategies and stronger debt management to reduce financial fragility. This entails closer coordination between the Central Bank and the Treasury to improve the maturity structure and composition of external debt, with priority given to longer-term and less volatile financing instruments. The short-term fiscal drag highlights the need to improve public spending efficiency through structural reforms. At the same time, prioritizing high-impact infrastructure and innovation projects is crucial to mitigate the risk of crowding out private investment. Given energy's pivotal role, Türkiye must address its energy dependency by promoting renewable energy investments, such as solar and wind projects, through tax incentives and public-private partnerships, alongside improving energy efficiency via smart grid technologies and nuclear power development to reduce import reliance and safeguard economic stability. In parallel, continued investment in education and workforce development is essential to sustain long-term productivity and inclusive growth.

This study has certain limitations. The data cover up to 2019, missing recent economic disruptions like the COVID-19 pandemic and subsequent monetary and policy changes. Additionally, while the model effectively captures major macroeconomic dynamics, it excludes factors such as geopolitical uncertainties or nonlinear effects that could shape growth patterns. Future research could incorporate post-2020 data, explore asymmetric or threshold effects, or include variables related to institutional strength, financial development, or global spillovers to deepen understanding of Türkiye's growth dynamics and inform strategies for similar emerging economies.

Ethics Committee approval was not required for this study.

The author declares that the study was conducted in accordance with research and publication ethics.

The author affirms that artificial intelligence (AI) tools were employed exclusively to enhance the clarity and readability of the manuscript. The author declares that their use was conducted in strict accordance with the ethical standards of the journal.

The author declares that there are no financial conflicts of interest involving any institution, organization, or individual associated with this article.

The author affirms that the entire research process was performed by the sole declared author of the study.

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