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Geopolitical Risk, The Real Effective Exchange Rate and Industrial Production in Türkiye: Evidence From a Fourier ARDL Approach

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Abstract

This study examines the short- and long-run relationships between geopolitical risk, the real effective exchange rate, and industrial production in Türkiye using monthly data from January 2014 to December 2024. A Fourier autoregressive distributed lag (FARDL) model is employed to accommodate smooth structural changes during a period marked by currency shocks, the COVID-19 pandemic, and heightened geopolitical tensions. The series are seasonally adjusted and logarithmically transformed, and unit root tests establish their suitability for bounds testing. The results provide evidence of cointegration among the variables. Long-run estimates indicate that a 1% increase in geopolitical risk and the real effective exchange rate is associated with approximately 0.15% and 0.57% lower industrial production, respectively. Since an increase in the exchange rate index denotes real appreciation, the latter finding suggests that appreciation weakens industrial output. Both variables exhibit negative contemporaneous short-run effects, followed by positive lagged responses. The error-correction coefficient indicates that approximately 19.2% of disequilibrium is corrected each month. Fourier dynamic ordinary least squares estimates corroborate the negative long-run relationships. These findings highlight the importance of supply-chain diversification, energy security, real exchange-rate stability, and stronger corporate risk management for industrial resilience.

JEL Codes: E23, F31, F51

1. Introduction

Industrial production is among the most important real economic indicators shaping structural transformation, foreign trade performance, and employment dynamics. Through its direct influence on productive capacity, exports, investment trends, and economic growth, the industrial sector-particularly in developing economies-is highly sensitive to cyclical fluctuations and external shocks. A systematic analysis of the global and domestic risk factors affecting industrial production is therefore crucial for macroeconomic policy design and sustainable growth strategies (Caldara & Iacoviello, 2022; Ortega-Ruiz et al., 2022).

Over the past decade, global geopolitical realignments, intensifying regional conflicts, trade wars, energy crises, and pandemic-related supply-chain disruptions have increased the sensitivity of industrial production to geopolitical risk (Asadollah et al., 2024; Caldara & Iacoviello, 2022). At the same time, exchange-rate volatility and fluctuations in real effective exchange rates have raised concerns about the extent to which import-dependent production structures in developing economies are constrained through cost and competitiveness channels (Amiti et al., 2014; Bahmani-Oskooee & Hegerty, 2007). How these two channels jointly shape industrial production remains a pertinent research question, especially for developing economies with substantial exposure to geopolitical risk and external financing conditions (NguyenHuu & Örsal, 2023; Soybilgen et al., 2019).

The Turkish economy exhibits structural vulnerabilities through which both dependence on imported inputs and exchange-rate pass-through may affect industrial production. Intermediate goods account for approximately 73% of total imports, whereas consumer goods account for about 12%, indicating that production relies heavily on imported inputs (Bari & Şıklar, 2021). This feature allows exchange-rate movements to affect industrial production directly through production costs (Feng et al., 2016; López & Nguyen, 2015). Several studies show that exchange-rate pass-through in Türkiye is stronger for producer prices than for consumer prices. Using an SVAR model, Özdoğan (2022) estimates aggregate pass-through at approximately 18% and finds a more pronounced effect on producer prices. Based on ARDL bounds-test results, Ömer Fazıl Emek et al. (2021) report that a 1% increase in the industrial production index raises the CPI by approximately 0.37%, whereas a 1% increase in the nominal exchange rate raises the PPI by about 0.82%.

The Turkish economy is also highly sensitive to geopolitical risk. Türkiye's proximity to regional flashpoints—including the Syrian civil war, the Russia–Ukraine war, and rising geopolitical uncertainty in the Middle East—is among the principal factors elevating the country's geopolitical risk. The geopolitical risk index developed by Caldara and Iacoviello (2022) records pronounced increases for Türkiye in October 2012, May 2013, November 2015, July 2016, February 2018, and during the Russia-Ukraine war (Caldara & Iacoviello, 2022; Demir et al., 2020). Moreover, Türkiye's energy-import-dependent production structure amplifies the effect of geopolitical-risk-induced energy price shocks on industrial output (Bredin et al., 2010; Meng, 2026; Zhu et al., 2025).

During the sample period, the Turkish economy experienced major structural changes induced by both global and country-specific shocks. The 2016 coup attempt, the 2018 currency crisis and subsequent rise in exchange-rate volatility, the COVID-19 pandemic in 2020, the high-inflation episode that became particularly pronounced during 2021–2023 and the monetary tightening implemented in 2024 had substantial effects on Türkiye's macroeconomic balances (Aytekin, 2020; Yıldırım, 2020). These developments suggest that the relationship among industrial production, the real effective exchange rate, and geopolitical risk has not remained constant over time but has been sensitive to gradual and transitional structural changes. Conventional ARDL models that do not accommodate such changes flexibly may therefore fail to capture the full dynamics of this relationship.

Fourier-based methods offer an important methodological advantage when the dates, number, and forms of structural changes are unknown. Enders and Lee (2012) show that smooth and gradual structural shifts can be modelled flexibly by incorporating trigonometric Fourier terms into the deterministic component. Including Fourier terms does not imply that all forms of nonlinearity are captured; rather, it allows smooth transitions in the deterministic structure to be accommodated. Accordingly, the Fourier ARDL approach is well suited to account for the structural changes affecting the relationship among geopolitical risk, the real effective exchange rate, and industrial production in Türkiye after 2014.

This study aims to analyse the short- and long-run effects of geopolitical risk and the real effective exchange rate on industrial production in Türkiye using the Fourier ARDL approach. Monthly data covering 2014M01–2024M12 are employed. The industrial production index is the dependent variable, while the geopolitical risk index and real effective exchange rate are the explanatory variables.

The study seeks to make three contributions to the literature. First, it jointly examines industrial production, geopolitical risk, and the real effective exchange rate in Türkiye, thereby placing risk, competitiveness, and production within a unified empirical framework. Second, it augments the conventional ARDL model

with Fourier terms to accommodate smooth structural changes. Third, by covering the post-2014 period, it analyses an era marked by multiple structural transformations in the Turkish economy, including currency shocks, the pandemic, geopolitical tensions, and policy shifts.

The remainder of the article is organised as follows. Section 2 develops the conceptual framework, and Section 3 reviews the international and Türkiye-specific literature. Section 4 presents the data and methodology, while Section 5 reports and discusses the empirical findings. The final section offers conclusions and policy implications.

2. Conceptual Framework

This section discusses the theoretical channels through which geopolitical risk and the real effective exchange rate may affect industrial production in Türkiye. The framework has two main dimensions. The first concerns the direct and indirect effects of geopolitical risk on industrial production; the second explains how the real effective exchange rate may influence production through competitiveness, imported-input costs, substitution toward domestic production, and cost–price dynamics. These dimensions are evaluated jointly in light of Türkiye's dependence on imported intermediate goods and energy, need for external financing, and proximity to regional geopolitical tensions.

Geopolitical risk refers to the possibility or actual occurrence of war, terrorism, international tension, coup attempts, and large-scale political conflict. The news-based index developed by Caldara and Iacoviello (2022) measures such risk through textual analysis of leading international newspapers and enables its effects on real investment, employment, and economic activity to be examined. Geopolitical risk is therefore not merely a political or security indicator; it is a multidimensional macroeconomic risk factor capable of affecting the real economy through production, investment, finance, foreign trade, and expectations.

The first channel operates through the postponement of investment decisions. Greater risk and uncertainty may worsen firms' expectations and make them more cautious about investment and capacity expansion. In sectors where investment entails irreversible costs, heightened uncertainty can induce a wait-and-see response. Bloom (2009) shows that uncertainty shocks may temporarily suspend firms' investment and hiring decisions, with contractionary consequences for output. This channel may be particularly pronounced in economies such as Türkiye that depend on imported inputs, external finance, and imported energy.

The second channel is general uncertainty. Rising geopolitical tensions may increase firm-level forecast errors and prompt economic agents to reassess long-term production, investment, inventory, and financing plans. Using a news-based economic policy uncertainty index, Baker et al. (2016) show that greater uncertainty may adversely affect investment, employment, and economic activity. Geopolitical risk may consequently slow industrial production by disrupting production planning, inventory management, procurement decisions, and investment timing.

The third channel operates through financing costs and the sovereign risk premium. Higher geopolitical risk can worsen international investors' perceptions, slowing capital inflows, reducing portfolio investment, and increasing the country risk premium. Geopolitical risk has been shown to raise financial stress in emerging economies, particularly in foreign-exchange, banking, and debt markets (NguyenHuu & Örsal, 2023). In Türkiye, this mechanism can restrict credit access for industrial firms reliant on external financing, raise borrowing costs, and limit investment capacity. Higher geopolitical risk may therefore exert a strong indirect drag on industrial production by tightening financial conditions.

The fourth channel involves supply-chain disruption. Geopolitical tensions, wars, sanctions, insecure trade routes, and cross-border logistics bottlenecks can interrupt global supply chains. Such disruptions may undermine production continuity, particularly in industries that use imported intermediate goods intensively. Asadollah et al. (2024) show that geopolitical risk and global supply-chain pressures can have pronounced effects on inflation dynamics. Because industrial production in Türkiye relies heavily on imported intermediate inputs, supply-chain shocks may directly affect both production costs and output volumes.

The fifth channel operates through energy costs. Geopolitical risk can increase volatility in fossil-fuel prices, particularly those of oil and natural gas, and thereby raise energy costs. In energy-import-dependent economies, geopolitical-risk-induced energy price shocks increase production costs and may constrain industrial output. Bredin et al. (2010) document a negative effect of oil-price uncertainty on industrial production. For Türkiye, Karakoyun and Özenç (2023) use an ARDL model to show that energy prices constitute an important cost channel for industrial production. The energy-price channel is therefore a potentially powerful transmission mechanism in the Turkish economy.

The sixth channel concerns export-market risk. Geopolitical tensions may weaken external demand, reduce trading partners' import demand, and restrict access to export markets. Regional conflicts, sanctions, insecurity along trade routes, and contractions in global demand can limit manufacturing exports and the associated production volume. Türkiye's strong trade links with Europe, the Middle East, the Black Sea region, and Asia make export-market risk particularly relevant to industrial production. Higher geopolitical risk may thus affect production not only through costs but also through external demand and market access.

Alongside these multiple geopolitical-risk channels, the real effective exchange rate is a key macroeconomic determinant of industrial production in Türkiye. It measures the real value of a country's currency relative to those of its trading partners. An increase generally denotes a real appreciation of the domestic currency, whereas a decrease indicates real depreciation. Its effect on industrial production is theoretically ambiguous because export competitiveness, imported-input costs, substitution toward domestic production, and cost–price pass-through may work in different directions. Bahmani-Oskooee and Hegerty (2007) provide extensive evidence that the relationship between exchange-rate volatility and trade flows varies with country- and sector-specific structural characteristics.

The first real-exchange-rate channel is export competitiveness. A real appreciation raises the foreign-currency relative price of exports and may weaken exporters' price competitiveness in international markets. This can reduce external demand and constrain output, especially in manufacturing subsectors where price competition is decisive. Conversely, real depreciation may make export prices more attractive to foreign buyers and support export demand and industrial production. The real effective exchange rate is therefore a central competitiveness indicator for export-oriented industries.

The second channel operates through imported intermediate-input and energy costs. Real appreciation reduces the domestic-currency cost of imported inputs and may lower production costs, whereas real depreciation raises the costs of imported intermediate and capital goods and energy. The large share of intermediate goods in Türkiye's total imports increases the relevance of this mechanism (Bari & Şıklar, 2021). Hence, real exchange-rate movements affect industrial production not only through external competitiveness but also through production costs and profitability.

The third channel concerns substitution between domestic and imported goods. Real appreciation makes imports relatively cheaper and may weaken domestic producers' competitiveness in the home market, allowing imports to displace domestic production, particularly in consumer goods and some intermediate goods. Real depreciation, by contrast, raises import prices and may encourage substitution toward domestic output. Whether this supports industrial production depends on the degree of imported-input dependence; when such dependence is high, cost increases may offset the favourable substitution effect.

The fourth channel operates through cost–price pass-through and producer prices. Exchange-rate movements may directly affect producer prices, cost structures, and industry's international competitive position. Evidence that exchange-rate pass-through in Türkiye is stronger for producer prices than for consumer prices reinforces the cost channel linking the real exchange rate to industrial production (Ö.F. Emek et al., 2021; Özdoğan, 2022; Tekin & Yazgan, 2008). Real exchange-rate fluctuations may accordingly influence output through production costs, pricing behaviour, and capacity-utilisation decisions.

Considered jointly, geopolitical risk and the real effective exchange rate create a three-layer transmission mechanism for industrial production in Türkiye. First, geopolitical risk may directly affect output through delayed investment, uncertainty, financing costs, supply-chain disruption, energy costs, and export-market risk. Second, the real effective exchange rate may operate through export competitiveness, imported-input costs, substitution toward domestic production, and cost–price competitiveness. Third, geopolitical risk may influence industrial production indirectly through the exchange rate and financial conditions. In an economy such as Türkiye-highly dependent on imported inputs and energy and sensitive to external financing-these channels are interdependent rather than isolated.

This integrated framework yields three principal empirical hypotheses. First, higher geopolitical risk is expected to reduce industrial production in Türkiye in both the short and long run through the combined effects of delayed investment, uncertainty, financing costs, supply-chain disruption, energy costs, and export-market risk. Second, an increase in the real effective exchange rate is expected to have a negative long-run effect through the combined influence of export competitiveness, imported-input costs, substitution toward domestic production, and cost-price competitiveness. Third, geopolitical risk and the real effective exchange rate are treated as two major external-vulnerability channels that jointly affect industrial production in Türkiye within the same model.

3. Literature Review

Academic interest in the macroeconomic effects of geopolitical risk increased markedly after Caldara and Iacoviello (2022) developed their news-based Geopolitical Risk Index. The index is constructed from newspaper coverage of war, terrorism, international tensions, and coup attempts. High index values are associated with lower real investment and employment, a greater perceived probability of disaster, and larger downside risks.

Seminal studies in the uncertainty literature show that uncertainty affects economic activity primarily through investment and waiting channels. Bloom (2009) demonstrates that uncertainty shocks induce firms to postpone investment and hiring, potentially reducing output and employment in the short run. Baker et al. (2016), using a news-based economic policy uncertainty index, likewise show that increases in uncertainty can adversely affect investment, employment, and economic activity.

Evidence for emerging economies also points to contractionary real effects. Soybilgen et al. (2019) find a negative and statistically significant effect of geopolitical risk on growth in a sample of 18 emerging economies. NguyenHuu and Örsal (2023) show that geopolitical risk increases financial stress in emerging markets, with particularly pronounced effects through foreign-exchange, banking, and debt-market channels.

Research on Türkiye has examined several transmission channels. Demir et al. (2020) identify asymmetric effects of pronounced increases in Türkiye's geopolitical risk index on tourist arrivals. Tuna and Çalışkan (2022) report medium- and long-run causal effects of global geopolitical risk on inflation and the real effective exchange rate in Türkiye, although they find no strong direct relationship between GPR and industrial production. Kızılkaya et al. (2024) examine the long-run effect of geopolitical risk on Türkiye's CO2 emissions using Fourier Shin cointegration, while Doğan et al. (2025) show that its effect on industrial productivity varies across quantiles and is more strongly negative at the tails.

The effect of the real effective exchange rate on industrial production is theoretically ambiguous because the export-competitiveness and imported-input-cost channels work in opposing directions. Real appreciation may weaken exporters' competitiveness and constrain industrial output, yet in economies with intensive use of imported intermediate inputs it may support short-run production by lowering input costs. The direction of the relationship is therefore an empirical question contingent on production structure and trade composition.

Studies of Türkiye employ a variety of methods. Mustafa Latif Emek (2021) finds unidirectional Granger causality from the real exchange rate to economic activity over 1995–2019. Aytekin (2020) identifies a long-run relationship among the real exchange rate, aggregate industrial production, and the economic confidence index for 2008M01-2020M03. Karakoyun and Özenç (2023) analyse oil prices, the real exchange rate, and industrial production within an ARDL framework and report results that vary across periods.

Taken together, the conceptual framework and prior evidence reveal limited research jointly examining the effects of geopolitical risk and the real effective exchange rate on industrial production within a Fourier ARDL model. The Türkiye-specific literature also indicates that the real exchange rate–industrial production relationship is sensitive to the method, sample period, and model specification. This study differs from earlier work by covering 2014M01–2024M12, including geopolitical risk and the real effective exchange rate in the same model, and using Fourier terms to accommodate smooth structural changes.

4. Data and Methodology

4.1. Data

This study analyses the effects of geopolitical risk and the real effective exchange rate on industrial production in Türkiye using monthly data for 2014M01–2024M12. The industrial production index is the dependent variable, while the geopolitical risk index and real effective exchange rate are the explanatory variables. Table 1 summarises the data.

Table 1
Variable definitions and data sources

Variable	Description	Period	Source
IPI	Industrial Production Index	2014M01-2024M12	TurkStat
GPR	Geopolitical Risk Index	2014M01-2024M12	Caldara & Iacoviello GPR database
REER	Real Effective Exchange Rate	2014M01-2024M12	Central Bank of the Republic of Türkiye (CBRT)

All variables were first seasonally adjusted using the Census X-13 procedure and then transformed into natural logarithms. The logarithmic specification allows the coefficients to be interpreted as elasticities. The baseline model is expressed as follows:

$$LNIPI_t = \beta_0 + \beta_1 LNGPR_t + \beta_2 LNREER_t + \epsilon_t$$

1

In Eq. (1), LNIPI denotes the industrial production index, LNGPR the geopolitical risk index, LNREER the real effective exchange rate, and “ε” the error term; the subscript “t” denotes time.

4.2. Methodology

The empirical analysis proceeds in four stages. First, the stationarity properties of the series are examined using the ADF and PP unit root tests. Second, the long-run relationship among the variables is tested using the ARDL bounds-testing approach. Third, Fourier sine and cosine terms are added to accommodate structural changes. Finally, the long-run coefficients, short-run error-correction model, and diagnostic-test results are evaluated.

Developed by Pesaran et al. (2001), the ARDL bounds-testing approach can be applied when variables are integrated of order I(0) or I(1), provided that none is I(2). The ADF and PP tests confirm that the variables in this study are a mixture of I(0) and I(1) and that none is I(2).

The baseline ARDL specification can be written as follows:

$$\Delta LNIPI_t = \beta_0 + \beta_1 LNIPI_{t-1} + \beta_2 LNGPR_{t-1} + \beta_3 LNREER_{t-1} + \sum_{i=1}^{p-1} \varphi_i \Delta LNIPI_{t-1} + \sum_{i=1}^{p-1} \delta_i \Delta LNGPR_{t-1} + \sum_{i=1}^{p-1} \vartheta_i$$

2

In this model, Δ is the first-difference operator, the lag orders are selected optimally, and the coefficients on the level variables are used to test for a long-run relationship. Cointegration is tested under the null hypothesis H_0: $\beta_1 = \beta_2 = \beta_3 = 0$. Rejection of the null indicates the presence of a long-run relationship among the variables.

Because the Turkish economy experienced numerous structural changes during 2014–2024 -including currency shocks, the COVID-19 pandemic, geopolitical tensions, and policy shifts -the conventional ARDL model is augmented with Fourier terms. Enders and Lee (2012) show that Fourier functions in the deterministic component can model smooth structural changes without prior knowledge of their number, timing, or form. Yılancı et al. (2020) extend the ARDL bounds test with Fourier functions to provide a more flexible cointegration framework in the presence of structural change. Subsequent applications-including Liu et al. (2022), Wu et al. (2022), Pata et al. (2023), Bozatlı and Akça (2024), and Güler (2025)-support the usefulness of Fourier-based approaches in structural-change-sensitive time-series analysis.

The specification augmented with Fourier terms can be expressed as follows:

$$\Delta LNIPI_{(t)} = \beta_0 + \gamma_1 sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 cos\left(\frac{2\pi kt}{T}\right) + \beta_1 LNIPI_{t-1} + \beta_2 LNGPR_{t-1} + \beta_3 LNREER_{t-1} + \sum_{i=1}^{p-1} \varphi_i \Delta LNIPI_{t-1} -$$

3

Here, “k” denotes the Fourier frequency, “T” the number of observations, “t” the time trend, and “γ_1” and “γ_2” the coefficients on the Fourier terms. The empirical model uses k = 2. Adding an error-correction parameter to Eq. (3) yields the following error-correction representation:

$$\Delta LNIPI_{(t)} = \beta_0 + \gamma_1 sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 cos\left(\frac{2\pi kt}{T}\right) + \beta_1 LNIPI_{t-1} + \beta_2 LNGPR_{t-1} + \beta_3 LNREER_{t-1} + \sum_{i=1}^{p-1} \varphi_i \Delta LNIPI_{t-1} -$$

4

Here, ECM denotes the error-correction term, while its coefficient measures the speed at which short-run disequilibrium returns to the long-run equilibrium. The coefficient is expected to be negative and statistically significant.

5. Empirical Results

5.1. Unit root test results

The ARDL bounds-testing procedure requires the variables to be I(0) or I(1), with none integrated of order I(2). The ADF and PP unit root tests are therefore applied in the first stage.

Table 2
ADF and PP unit root test results

	Variables	Test Statistic / Level (Intercept)	p-value	Test Statistic / First Difference (Intercept)	p-value
ADF	LNIPI	-1.5724	0.4938	-12.8126***	0.0000
	LNGPR	-6.3675***	0.0000		
	LNREER	-1.2136	0.6673	-9.6145***	0.0000
PP	LNIPI	-1.0698	0.7264	-21.1601***	0.0000
	LNGPR	-6.4349***	0.0000		
	LNREER	-1.1598	0.6904	-8.0011***	0.0000

Note: (***) denotes statistical significance at the 1% level.

The PP results indicate that LNGPR is stationary in levels, whereas LNIPI and LNREER become stationary after first differencing. The ADF results are broadly consistent: LNGPR is I(0), while LNIPI and LNREER are I(1). The absence of any I(2) variable supports the applicability of the ARDL bounds-testing procedure.

Table 3
Fourier ADF unit root test results

Variables	Frequency	F-statistic	Lag Length	FADF Test Statistic
LNIPI	1	1.299800	3	-1.938798
LNGPR	2	1.590219	3	-4.471099
LNREER	1	4.157036	4	-2.313721

Note: (***), (**), and (*) denote statistical significance at the 1%, 5%, and 10% levels, respectively. In Table 1b of Enders and Lee (2012), the 1% critical values for frequencies 1–5 are − 4.42, -3.97, -3.77, -3.64, and − 3.58, respectively; the corresponding critical value for testing the joint significance of the trigonometric terms is 10.35. At the 5% level, the frequency-specific critical values are − 3.81, -3.27, -3.07, -2.97, and − 2.93, and the joint-significance critical value is 7.58. At the 10% level, the respective values are − 3.49, -2.91, -2.71, -2.64, and − 2.60, while the joint-significance critical value is 6.35.

The Fourier ADF results in Table 3 accommodate possible smooth structural changes in the series. Because the reported F-statistics are below their critical values, the Fourier terms do not make a statistically significant contribution at the unit-root-testing stage. This does not, however, preclude the use of the Fourier ARDL model. Whereas the FADF test assesses the unit root properties of individual series, the FARDL approach accommodates smooth structural changes in the deterministic component of the long-run cointegrating relationship. During 2014–2024, the Turkish economy experienced major global and domestic shocks, including the 2016 coup attempt, the 2018 currency crisis and subsequent increase in exchange-rate volatility, the COVID-19 pandemic, the high-inflation period of 2021–2023, and the monetary tightening of 2024. Their effects on macroeconomic equilibria make it methodologically appropriate to test cointegration within a Fourier-augmented framework. Accordingly, the ADF and PP results are used to establish the orders of integration. Overall, the variables are a mixture of I(0) and I(1), and none is I(2), supporting application of the ARDL/FARDL bounds test.

5.2. Fourier ARDL bounds-test results

Following the unit root tests, the existence of a long-run relationship is examined using an ARDL bounds test augmented with Fourier terms. The selected specification is ARDL(4,2,2).

Table 4
Fourier ARDL bounds-test results

Test	Value	1% I(0)	1% I(1)	5% I(0)	5% I(1)	Decision
F- statistic	11.53369	5.15	6.36	3.79	4.85	Cointegration
t-statistic	-4.429641	-3.43	-4.10	-2.86	-3.53	Cointegration

The results in Table 4 provide strong evidence of a long-run relationship. The calculated F-statistic of 11.53369 exceeds the upper-bound critical values at both the 1% and 5% levels. The t-statistic likewise exceeds the relevant critical values in absolute terms. The null hypothesis of no long-run relationship is therefore rejected, indicating cointegration among industrial production, geopolitical risk, and the real effective exchange rate.

Normality, serial-correlation, heteroskedasticity, functional-form, and parameter-stability tests are applied to evaluate the econometric adequacy of the estimated model.

Table 5
Diagnostic test results

Test	Statistic / Probability	Decision
Jarque–Bera Normality Test	3.885487 [0.143310]	Residuals are normally distributed
Breusch–Godfrey LM Test	0.002654 [0.9589]	No serial correlation
Breusch–Pagan–Godfrey Test	13.16458 [0.4352]	No heteroskedasticity
Ramsey RESET Test	0.077013 [0.7819]	No functional-form misspecification
CUSUM	Stable	Parameters are stable
CUSUMQ	Generally stable	Variance stability is acceptable

The diagnostic results in Table 5 support the econometric adequacy of the model. The Jarque–Bera probability exceeds 0.05, indicating that the residuals are consistent with normality. The Breusch–Godfrey LM test detects no serial correlation, and the Breusch–Pagan–Godfrey test provides no evidence of heteroskedasticity. On the other hand, the CUSUM and CUSUM of Squares tests developed by Brown et al. (1975) were applied to assess the reliability of the findings. The left panel of Fig. 1 shows the results of the CUSUM test based on the cumulative sum of successive error terms. The fact that the CUSUM statistic remains within the confidence limits at the 5% significance level indicates that there is no significant structural break in the model. Furthermore, the results of the CUSUM of Squares test, which is based on the cumulative sum of successive error squares and is generally considered more sensitive in detecting structural changes, are presented in the right panel of Fig. 1. Since this test statistic also does not fall outside the 5% confidence interval, it can be said that the estimated parameters did not undergo a structural change during the period and, therefore, the coefficients are stable and eliable.

5.3. Fourier ARDL long- and short-run estimates

After confirming cointegration and the econometric adequacy of the model, the long-run coefficients and short-run error-correction model are estimated. Table 6 reports the results.

Table 6
Fourier ARDL long- and short-run results

Panel	Variable	Coefficient	Std. Error	t-statistic	Probability
Panel A: Long Run	LNGPR	-0.150374***	0.048082	-3.127432	0.0022
	LNREER	-0.571217***	0.062902	-9.081054	0.0000
Panel B: Short Run	C	1.345620***	0.225266	5.973469	0.0000
	ΔLNIPI(-1)	-0.196935***	0.056292	-3.498431	0.0007
	ΔLNIPI(-2)	-0.069940	0.054709	-1.278403	0.2037
	ΔLNIPI(-3)	-0.160008***	0.053490	-2.991372	0.0034
	ΔLNGPR	-0.015178**	0.005995	-2.531839	0.0127
	ΔLNGPR(-1)	0.010674*	0.005640	1.892573	0.0610
	ΔLNREER	-0.178014***	0.064675	-2.752433	0.0069
	ΔLNREER(-1)	0.189050***	0.065804	2.872915	0.0049
	ECM(-1)	-0.192211***	0.032393	-5.933642	0.0000
Panel C: Fourier Terms	COS	-0.008579**	0.003555	-2.412879	0.0174
	SIN	-0.001583	0.003774	-0.419479	0.6757

Note: (***), (**), and (*) denote statistical significance at the 1%, 5%, and 10% levels, respectively.

The long-run estimates in Table 6 indicate that geopolitical risk and the real effective exchange rate have negative and statistically significant effects on industrial production in Türkiye. The estimated LNGPR coefficient is -0.150374, implying that a 1% increase in geopolitical risk reduces industrial production by approximately 0.15% in the long run. This result is consistent with the investment-delay, financing-cost, supply-chain, and energy-cost channels.

The estimated LNREER coefficient is -0.571217 and statistically significant at the 1% level. Thus, a 1% increase in the real effective exchange rate reduces industrial production by approximately 0.57% in the long run. Because an increase in the index denotes a real appreciation of the Turkish lira, the finding indicates that appreciation has a contractionary effect on industrial production. It also suggests that Türkiye's industrial sector is sensitive to external competitiveness and that real appreciation may weaken the competitive position of export-oriented sectors.

The short-run estimates also yield important findings. The contemporaneous ΔLNGPR coefficient is negative and significant, indicating that an increase in geopolitical risk constrains industrial production in the current period. In contrast, the first lag of geopolitical risk (ΔLNGPR (-1)) is positive and statistically significant at the 10% level, indicating that short-run responses exhibit lag-dependent dynamics. Nevertheless, the strong negative long-run coefficient indicates that the overall effect of geopolitical risk is contractionary.

The short-run effects of the real effective exchange rate likewise vary across lags: the contemporaneous coefficient is negative and significant, whereas the first lag is positive and significant. This pattern suggests that cost and competitiveness channels can generate complex short-run responses. The negative long-run coefficient nevertheless indicates that real appreciation ultimately weighs on industrial production.

The error-correction coefficient is -0.192211 and statistically significant. It implies that approximately 19.2% of short-run disequilibrium is eliminated each month as the system converges toward its long-run equilibrium. In other words, following a deviation in industrial production associated with geopolitical risk or the real exchange rate, the system returns gradually to its long-run path.

The statistically significant COS coefficient suggests that smooth movements in the deterministic component matter to some extent. This is methodologically plausible given the currency shocks, pandemic, and geopolitical developments experienced by the Turkish economy during the sample period.

After the FARDL bounds test identifies cointegration, the robustness of the long-run coefficients is assessed using the Fourier Dynamic Ordinary Least Squares (DOLS) estimator. DOLS reduces potential endogeneity and serial correlation in cointegrating regressions by including leads and lags of the first differences of the explanatory variables, thereby yielding consistent and reliable long-run estimates (Saikkonen, 1991; Stock & Watson, 1993). Fourier DOLS adds sine and cosine terms to the standard DOLS equation to accommodate smooth and gradual structural changes in the deterministic component without requiring their dates to be known in advance (Gallant, 1981; Enders & Lee, 2012). In this study, Fourier DOLS is used to assess the sensitivity of the FARDL long-run coefficients to estimator choice. Table 7 reports the results.

Table 7
Fourier dynamic ordinary least squares (DOLS) results

Dependent Variable: LNIPI					
	Explanatory Variable	Coefficient	Std. Error	t-statistic	Probability
Panel A: Fourier DOLS	C	6.838002***	0.195634	34.95311	0.0000
	LNGPR	-0.107875***	0.028179	-3.828182	0.0002
	LNREER	-0.532162***	0.037720	-14.10814	0.0000
Panel B: Fourier Terms	Sin.	-0.051526***	0.011531	-4.468395	0.0000
	Cos.	-0.042060***	0.011016	-3.817972	0.0002
Note: (***), (**), and (*) denote statistical significance at the 1%, 5%, and 10% levels, respectively.					

The Fourier DOLS estimates in Table 7 broadly corroborate the FARDL results. As in the FARDL model, the geopolitical risk index (LNGPR) has a negative effect on the industrial production index (LNIPI), while the real effective exchange rate has a strong negative effect. Thus, the long-run results from both estimators support the relationship of industrial production with geopolitical risk and the real effective exchange rate and underscore the pronounced role of the latter. The significance of the Fourier terms further indicates that accommodating smooth changes in the deterministic component is appropriate for the sample period.

6. Conclusion and Policy Implications

This study analyses the short- and long-run effects of geopolitical risk and the real effective exchange rate on industrial production in Türkiye using monthly data for 2014M01–2024M12. The industrial production index is specified as the dependent variable, and the geopolitical risk index and real effective exchange rate as explanatory variables. Because the sample encompasses major structural changes-including the 2016 coup attempt, the 2018 currency crisis, the COVID-19 pandemic, high inflation, and monetary tightening-the conventional ARDL model is augmented with Fourier terms. This specification accommodates smooth changes in the deterministic component without requiring prior knowledge of their dates or number.

The results provide evidence of a long-run cointegrating relationship among industrial production, geopolitical risk, and the real effective exchange rate. The F-statistic exceeds the upper-bound critical values, while the t-statistic is more negative than the relevant critical values. The diagnostic tests detect no serial correlation, heteroskedasticity, or functional-form misspecification, and the residuals are consistent with normality. The CUSUM and CUSUMSQ tests indicate that the parameters are generally stable.

The long-run estimates indicate that geopolitical risk has a negative and statistically significant effect on industrial production. This finding underscores the sensitivity of Türkiye's industrial sector to geopolitical developments and is consistent with several channels: delayed investment, greater uncertainty, higher financing costs, supply-chain disruption, rising energy costs, and restricted access to export markets. The negative contemporaneous short-run effect of geopolitical risk is also consistent with these mechanisms.

The second principal finding is the negative long-run effect of the real effective exchange rate. Because an increase in the index denotes real appreciation of the Turkish lira, the negative coefficient suggests that appreciation constrains industrial production. This result points to the sensitivity of Türkiye's industrial sector to external competitiveness and to the possibility that appreciation weakens exporters' price competitiveness. The short-run coefficients vary in sign across lags, reflecting the simultaneous operation of cost and competitiveness channels; nevertheless, the long-run effect remains contractionary.

The negative and statistically significant error-correction coefficient confirms adjustment toward long-run equilibrium. Its magnitude of approximately –0.192 implies that about 19.2% of disequilibrium arising from geopolitical risk and the real exchange rate is corrected each month. Industrial production responds to these external-vulnerability channels, although adjustment is gradual. The negative and significant Fourier DOLS coefficients for geopolitical risk and the real effective exchange rate provide additional methodological support for the FARDL long-run findings.

First, policy measures should aim to enhance the resilience of industrial production against geopolitical risks. Given industry's dependence on imported intermediate and energy inputs, supply sources for critical inputs should be diversified. Alternative suppliers and regional production networks should replace excessive dependence on a single country or limited region. Expanding domestic capacity in strategic intermediate goods, energy inputs, machinery and equipment, and high-technology components could reduce the production effects of geopolitical risk.

Second, energy security should be a central component of industrial policy. Policies that reduce dependence on imported energy should be strengthened. Greater investment in renewable energy, wider adoption of energy-efficiency measures, and technological-transformation programmes that reduce industrial energy intensity would improve resilience to geopolitical-risk-induced energy price shocks.

Third, excessive appreciation of the real effective exchange rate should be avoided. The findings indicate that real appreciation may adversely affect industrial production in the long run. A competitive, predictable, and stable real exchange-rate framework is therefore important. Stronger coordination among monetary, exchange-rate, and industrial policies is needed, taking account of their simultaneous effects on price stability, export competitiveness, imported-input costs, and industrial output.

Fourth, the financial resilience of industrial firms to geopolitical-risk and exchange-rate shocks should be enhanced. Access to currency-hedging instruments should be facilitated for firms that use imported inputs or export, while long-term financing at reasonable cost should be expanded. Stronger financial risk-management capacity would help firms maintain more stable production and investment decisions during periods of exchange-rate volatility and geopolitical uncertainty.

Fifth, diversification of export markets could make industrial production more resilient to external-demand shocks. Given Türkiye's intensive trade links with Europe, the Middle East, the Black Sea region, and Asia, alternative market strategies should reduce excessive exposure to particular regional risks. Strengthening alternative logistics routes and trade channels during periods of elevated geopolitical tension could help safeguard continuity in production and exports.

The study has several limitations. First, it uses the aggregate industrial production index and does not examine manufacturing subsectors separately, although the effects of geopolitical risk and real exchange-rate movements may vary across industries. Second, geopolitical risk is represented by a single index; alternative uncertainty measures or regional risk indices may yield more detailed evidence. Third, the Fourier ARDL framework examines short- and long-run relationships but does not explicitly test asymmetric effects or time-varying coefficients. Future research could employ NARDL, TVP-VAR, QARDL, or sector-level panel methods to investigate these dynamics in greater depth.

Overall, the findings indicate that industrial production in Türkiye should be evaluated not only in relation to domestic demand, interest rates, and conventional macroeconomic indicators but also alongside geopolitical risk and real exchange-rate dynamics. Sustainable industrial production requires an integrated policy framework that improves macroeconomic predictability, safeguards real exchange-rate stability, strengthens supply-chain resilience, and makes the production structure more adaptable to external risks.

Declarations

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The author declare that they have no competing interests.

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Author Contribution

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Figures

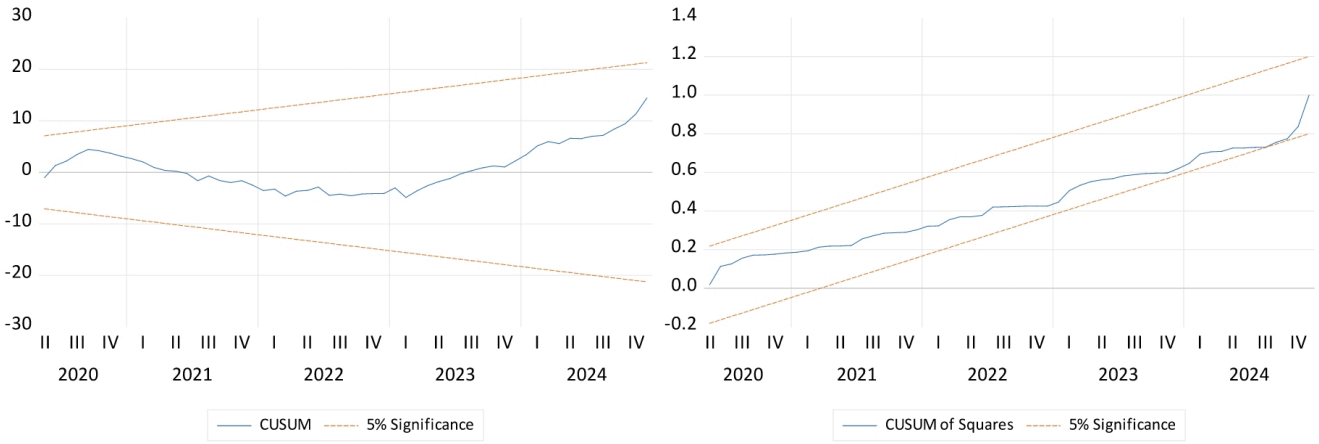


Figure 1

CUSUM and CUSUMQ graphs