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# The Macroeconomic Effects of Earthquakes in Turkey and Sustainable Economic Resilience: A Time Series Analysis, 1990–2023

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## Abstract

This study examines the macroeconomic impacts of major earthquakes in Türkiye using annual data from 1990 to 2023. Despite growing global interest in disaster economics, evidence on how large seismic events shape national economic performance over extended periods remains limited, particularly in emerging economies. Using data from the World Bank, the Central Bank of the Republic of Türkiye, and the Disaster and Emergency Management Authority, the analysis incorporates real gross domestic product, gross fixed capital formation, consumer prices, and export capacity. A dummy variable identifies years with high-fatality earthquakes. After confirming stationarity, Johansen cointegration and a Vector Error Correction Model were applied. Results indicate that earthquakes exert a statistically significant negative influence on long-term economic growth. Based on the log-level specification, the long-run equilibrium level of real gross domestic product in earthquake years is approximately 45 percent lower than in non-earthquake years. Investment, price stability, and trade capacity support long-term growth. Model diagnostics confirm stability, normality, and no autocorrelation. These findings highlight the structural economic vulnerabilities created by major earthquakes and underscore that disaster risk reduction and resilient infrastructure policies must be integral components of sustainable growth strategies. The study contributes updated national time-series evidence from a structurally fragile context.

**Keywords:** earthquakes; macroeconomic effects; sustainable development; time series analysis; Türkiye

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## 1. Introduction

Natural disasters are sudden and nature-induced events that create profound and multidimensional impacts on human life, ecosystems, and economic systems [1]. As defined by the World Bank [2], disasters are characterized by significant losses in human and physical capital, often leading to the disruption of regional socio-economic structures. Among these, earthquakes (due to their abrupt onset and destructive consequences) remain one of the most severe and least predictable forms of natural disasters [3,4]. In countries situated along active tectonic zones, such as Türkiye, seismic events not only

damage physical infrastructure but also pose long-term threats to economic stability and development trajectories [5].

As both the frequency and severity of natural disasters have increased globally, there is a growing imperative to understand their macroeconomic implications, particularly in emerging economies with fragile institutional structures and limited fiscal capacity. Earthquakes in this context present a dual challenge: they trigger immediate humanitarian crises and impose prolonged economic burdens that can span decades.

Several high-impact natural disasters over the past two decades, such as the 2004 Indian Ocean tsunami, the 2005 Hurricane Katrina in the United States, the 2008 Sichuan earthquake in China, the 2010 and 2021 Haiti earthquakes, and the 2013 Typhoon Yolanda in the Philippines, have demonstrated the scale and complexity of disaster-induced socio-economic disruption [6]. Türkiye, similarly, has a long history of destructive seismic activity, which has had systemic implications beyond localized regions, contributing to macroeconomic instability [7].

The economic effects of earthquakes are heterogeneous and unfold across different time horizons. In the short term, they lead to the destruction of capital stock, infrastructure losses, and production disruptions. Over the longer term, however, recovery and reconstruction efforts may stimulate investment and partially offset initial losses [8]. Accordingly, previous studies reported different findings: while some studies identified prolonged negative economic impacts [9–12], others pointed to potential positive effects through technological upgrading or structural transformation [13–17].

Importantly, the economic consequences of disasters are not uniform but are shaped by contextual factors such as institutional quality, income level, and the effectiveness of post-disaster governance [18–21]. While some researchers suggest that disasters may act as catalysts for modernization and resilience-building, particularly when recovery efforts are well-managed [8], others emphasize that, in low-income countries, disasters often result in economic stagnation and vulnerability traps [22–24].

Recent studies extended the analysis beyond GDP effects to examine sectoral disparities, labor market disruptions, and fiscal pressures. For instance, Raddatz [25] and Loayza et al. [26] highlighted that disaster impacts differ across sectors and countries, while Cuaresma et al. [13] and Sawada & Takasaki [27] investigated how disasters might contribute to long-run transformation under specific institutional conditions. These findings underscore that disaster impacts must be assessed not only in terms of immediate damage but also within a broader macroeconomic and policy-oriented framework.

In Türkiye, seismic events have repeatedly caused substantial infrastructure losses, increased reconstruction costs, and exacerbated national budget deficits. These shocks have also affected employment, trade dynamics, and external borrowing needs [28]. While many studies investigated Türkiye's exposure to earthquakes, relatively few studies have systematically assessed their long-term macroeconomic impacts using formal time series econometric approaches.

This study primarily aims to analyze the long-term macroeconomic impacts of major earthquakes in Türkiye by utilizing a national-level time series framework covering the period between 1990 and 2023. In addition, this study also aims to address how seismic shocks influence key macroeconomic components, including investment, price stability, and trade capacity, while emphasizing the critical role of disaster resilience in long-term economic planning.

Assessing the macroeconomic impacts of earthquakes is critical not only for analysing economic stability but also for safeguarding sustainable development goals. Seismic shocks weaken the sustainable growth process through the loss of capital stock, infrastructure destruction and a decline in production capacity. Therefore, conducting a long-term

macroeconomic analysis of earthquake effects is of great importance, particularly in terms of strengthening sustainable economic resilience.

Within this scope, the research addresses the following core questions:

- To what extent do major earthquakes affect Türkiye's real GDP in the long run?
- How do post-earthquake dynamics in investment activity, consumer prices, and trade capacity interact with overall economic output?
- Do the macroeconomic effects of earthquakes emerge immediately, or do they accumulate over time?
- What policy insights can be drawn to strengthen macroeconomic resilience in earthquake-prone economies?

## 2. Empirical Literature

Earthquakes are widely recognized as one of the most disruptive natural hazards in terms of economic stability and development continuity, particularly in countries characterized by high seismic exposure and institutional fragility. In such contexts, disasters often act not only as physical shocks but also as systemic stress tests for economic structures, revealing the capacity (or incapacity) of states to withstand and recover from exogenous shocks. This is particularly salient for developing economies, where weak infrastructure, limited fiscal space, and low adaptive governance capacity amplify the long-term macroeconomic consequences of seismic events [19,22,28,29].

Türkiye represents a compelling and underexamined case within this context. Geographically situated on active fault lines and historically exposed to high-impact seismic events, approximately 43% of the country's territory falls within high risk of earthquakes [30]. Despite repeated large-scale disasters, the academic literature on Türkiye's macroeconomic vulnerability to earthquakes remains fragmented. Most of previous studies emphasized immediate sectoral losses or regional damages, with insufficient attention to national-level, long-term macroeconomic dynamics. This gap is particularly critical given Türkiye's structural vulnerabilities, such as urban density, fiscal imbalances, and institutional constraints, that may exacerbate the enduring effects of seismic shocks.

### *2.1. From Short-Term Shock to Long-Term Vulnerability*

Early empirical study carried out by Albala-Bertrand (1993) suggested that natural disasters, while disruptive in the short run, had limited statistical significance over the long term [31]. However, subsequent studies contested this view, particularly for low- and middle-income countries. Lackner (2018), using a panel of 195 countries, found that severe earthquakes could result in persistent reductions in GDP per capita, up to 1.6% below trend even eight years post-disaster [32]. Similarly, Noy (2009) and Raddatz (2009) demonstrated that macroeconomic consequences are not uniform but conditioned by structural features such as financial openness, governance, and demographic characteristics [24,25].

In contrast, some researchers argued that disasters can, under certain institutional conditions, act as catalysts for structural transformation. Skidmore and Toya (2002) introduced the "creative destruction" hypothesis, positing that well-managed reconstruction efforts may stimulate capital deepening and technological modernization [8]. Crespo Cuaresma et al. (2008) expanded on this by showing that disasters can reallocate resources toward more productive sectors, particularly in economies undergoing industrial transitions [13]. Nonetheless, such optimistic outcomes remain the exception, not the norm, especially in cases where post-disaster governance is reactive rather than anticipatory.

### *2.2. Türkiye in the Literature: A Methodological Gap*

Despite Türkiye's high disaster exposure and its relevance as a middle-income economy with chronic institutional constraints, there is a surprising paucity of rigorous national-level studies assessing the macroeconomic implications of earthquakes. Selçuk and Yeldan (2001) provided one of the few formal economic assessments by modeling the 1999 Kocaeli Earthquake within a general equilibrium framework, estimating a short-term GDP loss of up to 4.5%, highly contingent on policy choices [33]. Avdar (2017) offered further insights into sectoral impacts over the 1999–2011 period but did not extend the analysis into a longitudinal, macroeconomic framework [34]. These studies, while valuable, fall short of establishing a systematic, empirical understanding of how earthquakes shape national growth trajectories over time.

This methodological gap is further widened by the absence of time series econometric studies that capture both short- and long-run dynamics in Türkiye. Such an approach is critical for identifying not just immediate output fluctuations, but also cointegrated relationships that may reveal deeper structural linkages between disasters and macroeconomic fundamentals.

### *2.3. Cross-National Evidence and Comparative Lessons*

Cross-country studies offer important comparative baselines. Cavallo, Powell, and Becerra (2010) quantified the direct GDP losses originating from the 2010 Haiti Earthquake at approximately USD 8.1 billion, a shock that significantly altered the country's development trajectory [35]. Pereira (2009), studying the 1755 Lisbon Earthquake, found that although Portugal experienced a dramatic short-term contraction, the disaster also triggered institutional modernization and long-run recovery, a case that illustrates the potential for transformative outcomes under exceptional governance conditions [36].

Broader meta-analyses, such as Onuma, Shin, and Manag (2021), suggested that the medium-term effects of seismic disasters are more visible than their long-term impacts, though this finding is sensitive to income level, institutional resilience, and measurement methodology [37]. Conversely, Fisker (2012) concluded that, in most settings, earthquakes exert limited influence on long-term economic growth trends unless compounded by pre-existing structural weaknesses [38].

### *2.4. The Role of Local Vulnerabilities and Policy Context*

Recent studies emphasized the role of subnational heterogeneity in determining disaster impacts. Zhao, Zhong, and He (2018), drawing on data from 181 cities in China's Sichuan Province, identified significant short-term output losses following the 2008 Wenchuan Earthquake, but also observed signs of long-run economic resilience [39]. In Nepal, Shakya (2016) showed that the 2015 earthquakes not only reversed a decade of development gains but also exacerbated gender disparities [40]. These findings corroborated that earthquake impacts are shaped not only by physical magnitude but by institutional responses, policy coherence, and social vulnerabilities [40].

Türkiye's context is not different. Its centralized disaster response mechanisms, high urban density, and uneven infrastructure quality create a unique exposure profile. Yet, the absence of national-level, time series-based empirical research remains a major limitation in assessing policy effectiveness or forecasting long-run macroeconomic trajectories under recurrent seismic risk.

In sum, while global evidence on the economic consequences of earthquakes is rich and diverse, Türkiye remains underrepresented in this literature, particularly in terms of long-term macroeconomic evaluation. The existing literature lacks methodological consistency, national scope, and integration with sustainability frameworks. This study

addresses these limitations by employing robust time series econometric tools to assess Türkiye's seismic vulnerability within a sustainability-informed macroeconomic context. In doing so, it offers critical insights for integrating disaster risk reduction into long-run development and fiscal planning.

## 3. Materials and Methods

*Dataset and Variables*

This study examines the macroeconomic effects of major earthquakes in Türkiye using annual time series data covering the period 1990–2023. The dataset was compiled from the World Bank's World Development Indicators (WDI), the Electronic Data Delivery System (EVDS) of the Central Bank of the Republic of Türkiye, and the Instrumental Period Earthquake Catalog provided by Disaster and Emergency Management Authority (AFAD).

The model in Equation (1) represents the basic time series regression framework and does not include parameters to be incorporated under the Error Correction Model framework.

$$LOGGDP_t = \beta_0 + \beta_1 LOGGCF_t + \beta_2 LOGCPI_t + \beta_3 LOGEXPIMP_t + \beta_4 DUMEQ_t + u_t \quad (1)$$

In this model, $\beta_0$ denotes the constant term, $\beta_1$–$\beta_4$ represent the coefficients associated with the explanatory variables, and $u_t$ is the error term capturing unexplained variations in real GDP. This specification follows the standard macroeconomic growth framework, in which output dynamics are explained through capital accumulation, domestic price movements, and external trade capacity. Similar model structures are employed by Cavallo and Noy (2011) [29], Raddatz (2009) [25], and Loayza et al. (2012) [26], who analyze disaster-related macroeconomic effects using national-level time series data.

All variables were transformed using natural logarithms, consistent with standard practice in the macroeconomics and time series literature (Table 1). Log transformation ensures that coefficients can be interpreted as elasticities, provides greater numerical sta-bility, and reduces scale-related distortions between variables. It also helps bring distribu-tions closer to normality assumptions, which supports the validity of estimation tech-niques applied in this study [41].

**Table 1.** Variables.

| Variable | Explanation | Source |
|---|---|---|
| LOGGDP | Real Gross Domestic Product (Constant, 2015 US$) | World Bank |
| LOGGCF | Gross Fixed Capital Formation (current US$) | World Bank |
| LOGCPI | Consumer Price Index (2010 = 100) | EVDS |
| LOGEXPIMP | Export Volume as a Proxy for Import Capacity | World Bank |
| DUMEQ | Dummy variable = 1 for years with fatal earthquakes | AFAD Instrumental Period Earthquake Catalog |

## 4. Results

This section presents descriptive statistics and time series analysis results regarding the effect of major earthquakes on Türkiye's macroeconomic indicators. First, the stationarity and cointegration properties of the dataset were assessed, followed by the estimation of short- and long-term effects using the Vector Error Correction Model (VECM).

Table 2 presents the descriptive statistics for the variables used in the analysis. Each variable contains 34 annual observations for the period 1990–2023. The mean and standard deviation values indicate moderate variation across the data series, which is consistent with macroeconomic time series behavior. Skewness and kurtosis values were evaluated to assess distributional properties. Following widely accepted thresholds in the literature, skewness values within ±2 and kurtosis values within ±7 indicate that the variables do not substantially deviate from normality [42,43]. All variables fall within these ranges, suggesting that their distributional characteristics are suitable for parametric estimation procedures.

**Table 2.** Descriptive Statistics.

| Variables | Observations | Mean | Std. Deviation | Min | Max | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| LOGGDP | 34 | 27.062 | 0.456 | 26.389 | 27.859 | 0.171 | 1.74 |
| LOGGCF | 34 | 25.467 | 0.831 | 24.05 | 26.538 | −0.295 | 1.437 |
| LOGCPI | 34 | 3.162 | 1.021 | 1.818 | 4.832 | 0.119 | 1.345 |
| LOGEXPIMP | 34 | 25.939 | 0.689 | 24.552 | 26.839 | −0.647 | 2.234 |
| DUMEQ | 34 | 0.529 | 0.507 | 0 | 1 | −0.118 | 1.014 |

Multicollinearity among the independent variables was tested using the Variance Inflation Factor. The results, reported in Table 3, indicate that the VIF values are below commonly accepted thresholds, suggesting that multicollinearity is not a concern in the estimated model.

**Table 3.** Multicollinearity Test Results.

| Variable | VIF | 1/VIF |
|---|---|---|
| LOGGCF | 8.11 | 0.123 |
| LOGEXPIMP | 6.85 | 0.146 |
| LOGCPI | 2.12 | 0.472 |
| DUMEQ | 1.04 | 0.959 |
| Mean VIF | 4.53 | . |

Note: The cells marked with a dot (".") indicate cases where the corresponding statistical values were either not esti-mated or not reported due to model structure.

The VIF test was utilized to detect the presence of multicollinearity among the independent variables in the model. Considering the results presented in Table 3, the VIF values for all variables remain below the threshold of 10. In the literature, a VIF value exceeding 10 is generally considered to indicate multicollinearity [44,45]. The mean VIF value of 4.53 further supports the absence of strong linear dependence among the explanatory variables. Therefore, multicollinearity is not considered a concern in this model.

The ADF unit root test was performed to examine the stationarity properties of the time series. The results of the ADF tests, which are widely used in the literature and yield consistent results, are presented in Table 4. The test was carried out under two model specifications: one including only a constant term, and another including both a constant and a trend. Given the ADF test results at level values, the $p$-values for all variables exceed the 5% significance threshold. This outcome suggests that the null hypothesis of the ADF test ("$H_0 : \rho = 0$ and $\beta = 0$", indicating the presence of a unit root and thus non-stationarity) cannot be rejected at the 5% level. However, when considering the first differences of the variables, the ADF test statistics become significant, with all $p$-values

lower than the 5% critical level. These findings lead to the rejection of the null hypothesis, indicating that the series are stationary at their first differences. Hence, all variables in this study are determined to be integrated of order one (I(1)).

**Table 4.** Unit Root Tests.

| Constant | | ADF | | Trend + Constant | ADF | |
|---|---|---|---|---|---|---|
| | | t-Stat | Prob | | t-Stat | Prob |
| LOGGDP | Level | 0.424 | 0.982 | Level | −2.492 | 0.329 |
| | First Difference | −4.076 | 0.001 | First Difference | −4.118 | 0.006 |
| LOGGCF | Level | −0.887 | 0.792 | Level | −1.777 | 0.716 |
| | First Difference | −4.114 | 0.001 | First Difference | −4.059 | 0.007 |
| LOGCPI | Level | −1.147 | 0.696 | Level | 0.183 | 0.995 |
| | First Difference | −3.57 | 0.006 | First Difference | −4.117 | 0.006 |
| DUMEQ | Level | −2.66 | 0.081 | Level | −2.666 | 0.25 |
| | First Difference | −3.55 | 0.007 | First Difference | −3.479 | 0.042 |
| LOGEXPIMP | Level | −2.647 | 0.084 | Level | −1.856 | 0.677 |
| | First Difference | −3.465 | 0.009 | First Difference | −4.254 | 0.004 |

Given these findings, the Johansen cointegration test was chosen to address the presence of a long-term relationship between the variables. Before the test, it was necessary to determine the optimal lag length for the dynamic model. The lag length selection test results are presented in Table 5.

**Table 5.** Lag Length Selection Test Results.

| Lag | LL | LR | df | *p* | FPE | AIC | HQIC | SBIC |
|---|---|---|---|---|---|---|---|---|
| 0 | −53.152 | | | | 0.0001 | 3.752 | 3.827 | 3.983 |
| 1 | 106.1 | 318.47 | 25 | 0.000 | $5.2 \times 10^{-9}$ * | −4.908 * | −4.456 * | −3.521 * |
| 2 | 122.8 | 33.429 | 25 | 0.121 | $1.0 \times 10^{-8}$ | −4.374 | −3.545 | −1.829 |
| 3 | 150.93 | 56.254 * | 25 | 0.000 | $1.2 \times 10^{-8}$ | −4.575 | −3.369 | −0.875 |

Note: * indicates lag selected based on the respective criterion.

Determining the appropriate lag length is very important to accurately estimate the dynamic structure of the model. Thus, the test incorporates the Final Prediction Error (FPE), Akaike Information Criterion (AIC), Hannan-Quinn Information Criterion (HQIC), and Schwarz Bayesian Information Criterion (SBIC). The results are shown in Table 5.

Considering the results presented in Table 5, the AIC, HQIC, and FPE criteria all suggest that the optimal lag length is one (Lag 1), whereas the SBIC favors a shorter lag length. Nonetheless, the majority rule was followed, and the Johansen cointegration test was conducted using one lag.

The Johansen cointegration test was conducted to examine the existence of a long-run equilibrium relationship among the variables, and the results are presented in Table 6. The trace statistic indicates that the null hypothesis of no cointegration is rejected at the 5% significance level, confirming the presence of at least one cointegrating vector. This finding provides evidence of a stable long-term relationship among the macroeconomic variables in the model. Accordingly, the Vector Error Correction framework is appropriate for estimating both the short-run adjustments and the long-run equilibrium dynamics.

**Table 6.** Johansen Cointegration Test.

| Max Rank | Params | LL | Eigenvalue Statistic | Trace Statistic | 0.05 Critical Value |
|---|---|---|---|---|---|
| 0 | 5 | 71.996 | . | 84.80 | 68.52 |
| 1 | 14 | 93.732 | 0.732 | 41.33 * | 47.21 |
| 2 | 21 | 102.35 | 0.407 | 24.102 | 29.68 |
| 3 | 26 | 110.03 | 0.372 | 8.735 | 15.41 |
| 4 | 29 | 114.38 | 0.231 | 0.041 | 3.76 |
| 5 | 30 | 114.40 | 0.001 | | |

Note: * indicates lag selected based on the respective criterion. The cells marked with a dot (".") indicate cases where the corresponding statistical values were either not esti-mated or not reported due to model structure.

In this study, a VECM was estimated to analyze the short-term relationships among the variables and the long-term adjustment mechanism. The VECM results are presented in Table 7. Upon examining the VECM estimation results, the error correction term (ECM) in the LOGGDP equation was found to be positive and statistically significant (coefficient = 0.096; $p$ = 0.01). This finding indicates that when long-term disequilibria occur in real GDP, the system tends to revert to equilibrium in the short term. As for the short-term coefficients, no significant short-term effects of the independent variables (LOGGCF, LOGCPI, LOGEXPIMP, and DUMEQ) on LOGGDP were identified. In the other equations, the ECMs were found to be statistically significant only in the LOGEXPIMP and DUMEQ equations, suggesting that export capacity and the earthquake dummy variable are sensitive to long-term disequilibria. In particular, the ECM coefficient in the DUMEQ equation was negative and significant (−1.494; $p$ = 0.003), indicating that earthquakes play a decisive role in the long-term equilibrium dynamics. Overall, the insignificance of most short-term coefficients suggests that short-term effects are weak in the model, and that the economic system is predominantly driven by long-term relationships. These results support the notion that earthquakes have limited short-term, but significant and lasting long-term effects on the Turkish economy.

**Table 7.** VECM Model.

| | Coefficient | Std. Error | t-Value | *p*-Value |
|---|---|---|---|---|
| Dependent Variable: LOGGDP | | | | |
| ECM | 0.096 | 0.037 | 2.59 | 0.01 |
| LD. LOGGDP | 0.079 | 0.319 | 0.25 | 0.805 |
| LD.LOGGCF | −0.072 | 0.054 | −1.35 | 0.179 |
| LD.LOGCPI | 0.02 | 0.022 | 0.90 | 0.37 |
| LD.LOGEXPIMP | −0.132 | 0.091 | −1.44 | 0.149 |
| LD.DUMEQ | −0.002 | 0.016 | −0.10 | 0.918 |
| Constant | 0.055 | 0.013 | 4.25 | 0.000 |
| Dependent Variable: LOGGCF | | | | |
| ECM | 0.312 | 0.247 | 1.26 | 0.206 |
| LD. LOGGDP | −0.571 | 2.126 | −0.27 | 0.788 |
| LD.LOGGCF | −0.401 | 0.358 | −1.12 | 0.263 |

**Table 7.** *Cont.*

| | Coefficient | Std. Error | t-Value | *p*-Value |
|---|---|---|---|---|
| LD.LOGCPI | 0.042 | 0.146 | 0.29 | 0.771 |
| LD.LOGEXPIMP | 0.296 | 0.608 | 0.49 | 0.627 |
| LD.DUMEQ | 0.036 | 0.103 | 0.35 | 0.729 |
| Constant | 0.1 | 0.086 | 1.15 | 0.248 |
| Dependent Variable: LOGCPI | | | | |
| ECM | −0.226 | 0.411 | −0.55 | 0.582 |
| LD. LOGGDP | 5.905 | 3.541 | 1.67 | 0.095 |
| LD.LOGGCF | −0.273 | 0.596 | −0.46 | 0.647 |
| LD.LOGCPI | −0.115 | 0.244 | −0.47 | 0.637 |
| LD.LOGEXPIMP | −1.143 | 1.012 | −1.13 | 0.259 |
| LD.DUMEQ | 0.158 | 0.172 | 0.92 | 0.359 |
| Constant | −0.172 | 0.144 | −1.20 | 0.23 |
| Dependent Variable: LOGEXPIMP | | | | |
| ECM | 0.165 | 0.08 | 2.07 | 0.039 |
| LD. LOGGDP | −0.048 | 0.688 | −0.07 | 0.945 |
| LD.LOGGCF | 0.015 | 0.116 | 0.13 | 0.896 |
| LD.LOGCPI | 0.092 | 0.047 | 1.94 | 0.052 |
| LD.LOGEXPIMP | 0.111 | 0.197 | 0.57 | 0.571 |
| LD.DUMEQ | −0.012 | 0.033 | −0.35 | 0.728 |
| Constant | 0.063 | 0.028 | 2.24 | 0.025 |
| Dependent Variable: DUMEQ | | | | |
| ECM | −1.494 | 0.502 | −2.98 | 0.003 |
| LD. LOGGDP | 0.616 | 4.317 | 0.14 | 0.887 |
| LD.LOGGCF | −0.636 | 0.727 | −0.87 | 0.382 |
| LD.LOGCPI | −0.317 | 0.297 | −1.07 | 0.285 |
| LD.LOGEXPIMP | 0.006 | 1.234 | 0.00 | 0.996 |
| LD.DUMEQ | 0.108 | 0.21 | 0.51 | 0.609 |
| Constant | 0.057 | 0.175 | 0.33 | 0.743 |

The long-term coefficient estimates obtained from the VECM are shown in Table 8. These findings suggest that all independent variables have statistically significant effects on real GDP (LOGGDP). In the long-run equation, the coefficient of the earthquake dummy variable (DUMEQ) is estimated as −0.605. For dummy variables in logarithmic-level specifications, the percentage effect is calculated using the exponential transformation [exp(δ) − 1]. Accordingly, the equilibrium level of real GDP during earthquake years is approximately 45% lower compared to non-earthquake years, and the coefficient is statistically significant. This interpretation follows the widely accepted approach to evaluating dummy variables in log-linear models and is particularly appropriate in settings where small-sample bias may be present [46–48]. Furthermore, a 1% increase in gross capital formation (LOGGCF) is related to an approximate 37.3% increase in real GDP in the long run. Similarly, both the Consumer Price Index (LOGCPI) and export capacity (LOGEXPIMP) have positive and significant long-term effects on LOGGDP. These

findings indicate that major earthquakes have a persistent and negative long-term impact on Türkiye's economic output. At the same time, capital accumulation, domestic price dynamics, and external trade capacity play supportive roles in promoting long-run economic performance. Model diagnostics confirm that the VECM is stable, statistically valid, and free from autocorrelation, supporting the reliability of both the long-run and short-run results.

**Table 8.** Long-Term Coefficient Estimates from VECM.

| Beta | Coefficient | Std. Error | Z | *p*-Value |
|---|---|---|---|---|
| LOGGDP | 1 | . | . | . |
| LOGGCF | 0.373 | 0.134 | −2.67 | 0.008 |
| LOGCPI | 0.353 | 0.063 | −5.58 | 0.000 |
| LOGEXPIMP | 0.571 | 0.127 | −4.48 | 0.000 |
| DUMEQ | −0.604 | 0.091 | 6.66 | 0.000 |
| Cons. | −1.954 | . | . | . |

Note: The cells marked with a dot (".") indicate cases where the corresponding statistical values were either not esti-mated or not reported due to model structure. Specifically, this occurs for the normalized variable in the VECM frame-work and for the constant term, for which standard errors, z-statistics, and *p*-values are not directly computed or are omitted.

The moduli of the eigenvalues were examined to assess the dynamic stability of the estimated VECM. As shown in Table 9, all eigenvalue moduli, except those associated with the cointegrating relationships, lie strictly within the unit circle. The presence of a few eigenvalues equal to one is consistent with the existence of cointegration, while the remaining values being less than one confirms system stability. Thus, the model is dynamically stable and non-divergent over time, indicating that the long-run adjustment mechanism is well-defined and that the forecasts derived from the model are reliable. Accordingly, the estimated VECM provides a valid and stable framework for long-term analysis.

**Table 9.** VECM Stability Test Results.

| Eigenvalue | Modulus |
|---|---|
| 1 | 1 |
| 1 | 1 |
| 1 | 1 |
| 1 | 1 |
| −0.485 | 0.485 |
| 0.044 + 0.412 | 0.414 |
| 0.044 − 0.412 | 0.414 |
| 0.285 | 0.285 |
| −0.0218 + 0.227 | 0.228 |
| −0.0218 − 0.227 | 0.228 |

The Lagrange Multiplier (LM) test was utilized to test for the presence of autocorrelation in the estimated VECM. Since the model includes only one lag, autocorrelation was examined up to the first lag. Given the results presented in Table 10, the *p*-value obtained from the LM test ($p = 0.893$) is higher than the 5% significance threshold. Therefore, the null hypothesis of "no autocorrelation" cannot be rejected. Consequently, it was determined that the model does not suffer from autocorrelation and satisfies the assumption of error

term independence. The independence of the error structure supports the reliability and statistical validity of the VECM estimates.

**Table 10.** Autocorrelation Test.

| Lag | Chi2 | Df | Probability |
|---|---|---|---|
| 1 | 16.685 | 25 | 0.893 |

To assess whether the error terms of the VECM exhibit the characteristics of a normal distribution, the Jarque–Bera (JB) normality test was conducted. As shown in Table 11, the normality test results are reported individually for each equation and collectively for the overall model. Even though the *p*-value for the D.LOGGDP variable was found to be lower than the 5% significance level, the *p*-values for all other equations were well above the 5% threshold. Notably, the overall JB test statistics computed for the full model yielded a probability value ($p = 0.347$), which exceeds the 5% critical level. Based on this result, the null hypothesis stating that "the model's error terms are normally distributed" could not be rejected. Therefore, it can be concluded that the error structure of the VECM generally has a normal distribution, and the validity of parametric tests is preserved.

**Table 11.** JB Normality Test.

| Equation | Chi2 | Df | Probability |
|---|---|---|---|
| D.LOGGDP | 7.57 | 2 | 0.023 |
| D.LOGGCF | 0.055 | 2 | 0.972 |
| D.LOGCPI | 0.153 | 2 | 0.926 |
| D.LOGEXPIMP | 1.838 | 2 | 0.398 |
| D.DUMEQ | 1.519 | 2 | 0.467 |
| ALL | 11.134 | 10 | 0.347 |

## 5. Conclusions

This study examined the long-term macroeconomic effects of major earthquakes in Türkiye over the period 1990–2023 using Johansen cointegration and Vector Error Correction Model methods. The results achieved in this study indicate a statistically significant and persistent negative long-run relationship between earthquake years and real GDP. Based on the log-level dummy interpretation, the equilibrium level of real GDP is approximately 45% lower in years with major earthquakes. This reflects the long-term macroeconomic sensitivity associated with capital stock disruption and reconstruction pressures.

Furthermore, gross fixed capital formation, consumer price dynamics, and export capacity exhibit positive and statistically significant long-run effects on real GDP, suggesting that investment activity and external trade mechanisms contribute to economic resilience and recovery. It should be noted that these findings reflect the relationships captured by the macroeconomic variables included in the model; broader determinants such as fiscal policy choices, labor market dynamics, and institutional response capacity may also influence long-term outcomes but fall outside the scope of this empirical specification. Overall, the results underscore the structural vulnerability of the Turkish economy to seismic shocks and highlight the importance of integrating disaster risk reduction into long-term macroeconomic and development planning.

## 6. Discussion

The findings achieved in this study contribute to the expanding literature that highlights the persistent macroeconomic consequences of natural disasters, particularly

in economies characterized by governance constraints and uneven infrastructure quality. Consistent with those reported by Skidmore and Toya (2002) [8] and Cavallo and Noy (2011) [29], the results achieved in this study indicate that major earthquakes have a durable negative influence on long-term economic performance, especially when recovery capacity is constrained by structural conditions.

While the "creative destruction" hypothesis suggests that disasters can stimulate modernization or productivity-enhancing restructuring (Crespo Cuaresma et al., 2008 [13]), the Turkish case does not exhibit evidence of such transformative adjustment. Instead, the sustained reduction in the long-run equilibrium level of real GDP during earthquake years indicates that the economic disruption associated with seismic events outweighs any potential renewal effects in the absence of strong institutional coordination and strategic recovery planning.

Methodologically, the national-level time series approach employed in this study offers a comprehensive perspective on long-term macroeconomic adjustment dynamics. The lack of statistically significant short-term effects observed in the VECM further suggests that the economic consequences of earthquakes do not manifest immediately but accumulate gradually, reinforcing the need for systematic, forward-looking policy frameworks rather than reactive post-disaster interventions.

This limited short-term response may reflect the presence of economic and institutional shock-buffering mechanisms in Türkiye. Emergency fiscal support, public reconstruction subsidies, and credit easing policies are often mobilized rapidly following major earthquakes, softening the immediate macroeconomic impact. In addition, informal labor markets and household-level coping strategies help maintain short-term production and consumption stability. Consequently, while physical and human losses occur immediately, their measurable effects on aggregate economic indicators emerge more gradually, which aligns with the long-run adjustment pattern identified in the VECM.

## 7. Policy Implications

The empirical results demonstrate that major earthquakes reduce the long-run equilibrium level of real GDP by approximately 45%. This finding underscores the structural sensitivity of the Turkish economy to capital stock destruction. Accordingly, policy strategies must prioritize strengthening the resilience of physical capital. Improving the enforcement of building codes, expanding seismic retrofitting programs, and promoting earthquake-resistant construction directly address the long-run vulnerability captured by the negative coefficient of the earthquake variable.

The long-run positive effect of gross fixed capital formation indicates that investment recovery plays a central role in mitigating the macroeconomic impact of earthquakes. Therefore, targeted reconstruction financing, investment incentives, and long-term credit mechanisms should be designed to support capital accumulation during the post-disaster recovery phase.

Similarly, the positive long-run relationship between trade capacity and GDP highlights the importance of maintaining uninterrupted logistical and export operations following seismic events. Safeguarding port, transportation, and supply chain infrastructure should therefore be considered a core element of disaster resilience planning.

Finally, the absence of statistically significant short-term effects in the VECM suggests that existing stabilization measures already cushion immediate shocks but are insufficient to prevent long-term economic losses. This finding implies that policy design must shift from short-term crisis management toward sustained, forward-looking resilience and reconstruction planning.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| AFAD | Disaster and Emergency Management Authority of Türkiye |
| ADF | Augmented Dickey–Fuller Test |
| AIC | Akaike Information Criterion |
| CPI | Consumer Price Index |
| DUMEQ | Dummy Variable Representing Fatal Earthquake Years |
| ECM | Error Correction Mechanism |
| EVDS | Electronic Data Delivery System (Central Bank of the Republic of Türkiye) |
| FPE | Final Prediction Error |
| GDP | Gross Domestic Product |
| GCF | Gross Capital Formation |
| HQIC | Hannan–Quinn Information Criterion |
| JB | Jarque–Bera Test |
| LM | Lagrange Multiplier Test |
| LOGCPI | Logarithm of Consumer Price Index |
| LOGEXPIMP | Logarithm of Export Capacity (Proxy for Import Capacity) |
| LOGGCF | Logarithm of Gross Capital Formation |
| LOGGDP | Logarithm of Gross Domestic Product |
| SBIC | Schwarz Bayesian Information Criterion |
| VECM | Vector Error Correction Model |
| VIF | Variance Inflation Factor |
| WDI | World Development Indicators |
| WB | World Bank |

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