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Do earthquakes shake the stock market? Causal inferences from Turkey's earthquake

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Abstract

This study's main purpose is to use Bayesian structural time-series models to investigate the causal effect of an earthquake on the Borsa Istanbul Stock Index. The results reveal a significant negative impact on stock market value during the post-treatment period. The results indicate rapid divergence from counterfactual predictions, and the actual stock index is lower than would have been expected in the absence of an earthquake. The curve of the actual stock value and the counterfactual prediction after the earthquake suggest a reconvening pattern in the stock market when the stock market resumes its activities. The cumulative impact effect shows a negative effect in relative terms, as evidenced by the decrease in the BIST-100 index of – 30%. These results have significant implications for investors and policymakers, emphasizing the need to prepare for natural disasters to minimize their adverse effects on stock market valuations.

Keywords: Stock market, Earthquake, Causal inference, Bayesian structural time-series, Counterfactual predicting

JEL Classification: E44, E66, G18

Introduction

Recent geopolitical and economic shocks in the form of the Russia-Ukraine war and COVID-19 have increased stock market volatility and uncertainty (Salisu et al. 2020; Pandey and Kumari 2021; Derindere Köseoğlu et al. 2023; Pandey et al. 2024). Moreover, natural disasters such as earthquakes may disrupt both economic activity and stock markets (Malik et al. 2020; Chen et al. 2023). This can adversely affect companies reliant on extensive supply chains, decreasing stock prices. Therefore, in the aftermath of a significant earthquake, the stock market may experience a reduction in value owing to the extensive damage inflicted upon infrastructure or the disruption of economic activity (Valizadeh et al. 2017; Pandey et al. 2024). Moreover, earthquakes can have extensive economic impact, resulting in increased uncertainty and negative investor sentiment, which may lead to the transfer of capital to safer assets (Shan and Gong 2012). Furthermore, insurance companies may increase their premiums following an earthquake, thus negatively affecting companies that rely on insurance to operate and decreasing their stock prices (Tao et al. 2019; Su et al. 2023a). However, the impact of an earthquake

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on the stock market is generally short-lived because markets tend to recover relatively swiftly following a calamity (Qin et al. 2023a; Pandey et al. 2024). Similarly, investors may perceive an earthquake as an opportunity to invest in companies that could benefit from reconstruction and recovery efforts.

Historically, the occurrence of an earthquake can cause significant damage to buildings and infrastructure, and can also affect the stock market. For instance, following the "Loma Prieta earthquake in 1989", the Dow Jones Industrial Average (DJIA) fell by 7.2% the following week (Aiuppa et al. 1993). Similarly, the Northridge earthquake in 1994 led to a 2.5% decrease in the DJIA on the day of the earthquake (Tao et al. 2020). Furthermore, the Kobe earthquake in 1995 was devastating and had a significant impact on the stock market, with the Nikkei index decreasing by 5%. The Shanghai Composite Index decreased by more than 15% after the 2008 earthquake in China (Shan and Gong 2012). Additionally, the earthquake in Chile in 2010 caused a temporary drop in the stock market (Ruiz and Barrero 2014), but it quickly recovered during the following days. The 2010 earthquake in Haiti was one of the worst humanitarian disasters internationally and significantly impacted the global stock market, while companies involved in relief efforts experienced increased stock prices. The Tohoku earthquake and tsunami in Japan in 2011 were among the most powerful earthquakes in recorded history (Takao et al. 2013), and insurance companies' stock prices decreased following the earthquake. However, the decline in stock values for non-life insurance businesses was less than that for life insurance companies. This event significantly impacted the Japanese stock market, leading to a greater than 10% decrease in the Nikkei index following the quake (Tao et al. 2019). Similarly, the earthquake in Christchurch in 2011 obstructed access to the New Zealand stock market, resulting in a 2.3% decrease in the index on the day of the earthquake (Orchiston and Higham 2016). The Kumamoto earthquakes that occurred in 2016 were a series of earthquakes that struck Japan, significantly impacting the Japanese stock market (Ding et al. 2021). The Nikkei index decreased by more than 3% in the days following the earthquakes.

In contemporary literature, studies have evaluated the impact of earthquakes on the stock market. However, many have focused primarily on correlation rather than causal inference. Some studies have employed the event study method, commonly found in past literature, to analyze the effect of disasters on the stock market. However, this technique has limitations because it estimates the impact pre- and post-event, which does not necessarily indicate a causal effect (Derindere Köseoğlu et al. 2023). Other studies have analyzed time series data to evaluate how conflicts influence stock markets. While these techniques are useful, they cannot directly estimate causal influence, as a well-designed counterfactual background is required for such an estimation (Xu et al. 2023). The literature also presents conflicting results. For example, studies by Tao et al. (2019); Scholtens and Voorhorst (2013), Takao et al. (2013); Kowalewski and Śpiewanowski (2020); Sakariyahu et al. (2023) and Pandey et al. (2024) demonstrated that earthquakes have adverse negative impacts on stock markets. However, earthquakes also lead to positive returns, due to expected post-earthquake reconstruction. Furthermore, earthquakes have an insignificant effect on stock markets. Finally, some sectors suffer enormous losses while others benefit (Valizadeh et al. 2017; Chen et al. 2023). Construction, infrastructure, retail, consumer, and banking stocks significantly react to earthquakes. The literature has not analyzed a scenario where no earthquake has occurred. Such analysis would enable comparisons between predicted and observed situations and offer a comprehensive understanding of the impact of conflicts (Derindere Köseoğlu et al. 2023; Su et al. 2023b). Although most studies have relied on traditional methodologies to detect the effects of earthquakes on relevant stock markets, studies that use methods to detect causal inference are rare. Thus, determining the causal link between earthquakes and the stock market is essential for controlling volatility and creating mitigation plans to lessen their effects.

The main objective of this study is presented as follows.

1. The primary purpose of this study is to evaluate the causal effects of earthquakes on the Borsa Istanbul stock exchange index (BIST-100) in Turkey.
2. We posit that the stock market would not have decreased in value if there had not been an earthquake.
3. To generate precise counterfactual predictions based on control time series that do not undergo any treatment.

Turkey has experienced several episodes of earthquakes, which have severe consequences, resulting in volatility and uncertainty. For example, the Marmara earthquake in 1999 caused extensive damage and loss of life. As a result, the Borsa Istanbul stock exchange was closed for several days, and the BIST-100 index decreased by 13%. Similarly, during the Van earthquake in 2011, the BIST-100 index decreased by 6.7% on the first day following the earthquake. More recently, the Elazig earthquake in 2020 caused the BIST-100 index to drop by 1.66% (Güleç 2020; Yildirim and Alola 2020). The stock exchange suspended trading for five days for the first time in 24 years in February 2023. The subsequent selloff erased $35 billion of valuation with a three-month state of emergency being declared for affected areas. The earthquake caused panic among investors after the massive death toll and at least $1 billion in construction damage. Consequently, the BIST-100 index fell by 16%, and the BISTs entered a technical bear market after falling from its January high. The slump in stocks was the worst weekly performance since the 2008 global financial crisis. Earthquakes have had a short-term negative impact on the stock market, with immediate declines in stock prices in the construction, infrastructure, retail, and consumer sectors (Pandey and Kumari 2021; Pandey et al. 2024). The government announced incentives to encourage corporations to repurchase their stock and directed pension funds to increase their stock allocation. Earthquakes can cause major stock market volatility and uncertainty, resulting in index decreases, as evidenced by previous earthquakes in various countries.

This study makes the following contributions to the literature: (1) It significantly adds to the body of knowledge about how natural disasters affect financial markets by comparing and verifying that earthquakes have negatively influenced the stock market. It underlines the need to consider external factors such as natural disasters in financial market analysis by confirming the detrimental effects of earthquakes on the stock market. (2) To the best of our knowledge, no study has attempted to determine the causal inference of earthquakes' influence on the stock market. Investors see the earthquake as disruptive news, causing fear in the market, and the market's reaction is sharp. They believe that stock market valuations would not have decreased in value if there had not been an earthquake. As a result, the findings are significant as a benchmark for nations facing similar challenges. (3) This study provides a somewhat reliable way to estimate stock market responses to earthquakes using causal inference. The study employs a counterfactual prediction model and includes control variables based on major stock exchanges worldwide to adjust for correlation with the BIST-100 index. This approach ensures the validity of the causal inference. Our results reveal a significant negative influence on stock market value during the post-treatment period. The outcome deviates sharply from the counterfactual predictions, highlighting the high uncertainty caused by earthquakes. The results indicate rapid divergence from counterfactual projections, with the real stock falling below what would have been predicted without an earthquake.

The literature review is presented in Sect. "Literature review and theory"; the methodology is outlined in Sect. "Methodology". The results are outlined in Sect. "Discussion" and the paper is concluded in the last section.

Literature review and theory

Theoretical framework

The contemporary literature consists of several theories that highlight the importance of natural disaster impact on the stock market. The theoretical framework consists of several theories. First is the efficient market hypothesis (EMH) that proposes that stock prices accurately represent publicly available information. It suggests that when appraising firms and assets, investors immediately weigh the possible effects of disasters, resulting in short-term market disruptions before reverting to stable conditions (Rossi 2015). This implies that although an earthquake is likely to cause short-term volatility, the long-term effects may be less pronounced if markets efficiently process information. According to behavioural finance theory, unpredictability and emotional arousal can contribute to cognitive and emotional biases such as panic, loss aversion, anchoring, and availability bias. This theory proposes that investor psychology influences market reactions to earthquakes, thereby aggravating volatility. Investors may overestimate the possibility of a repeat calamity, influencing asset pricing and anchoring return expectations (Kartini and Nahda 2021). The risk and uncertainty theory explains that disasters reshape how businesses, assets, and markets perceive risk, leading to either an overvaluation of risk-affected assets owing to ambiguity aversion or magnification of risk perceptions, necessitating higher risk premiums (Nisani et al. 2022). It suggests that disaster introduce uncertainty, prompting investors to reassess the risk associated with affected assets and potentially leading to market revaluation. Another theory, economic impact theory, assesses stock market reactions to disasters by considering infrastructure damage, productivity drops, and business interruptions. These consequences can cause cash flow to decrease, which can influence stock prices and growth prospects (Taranto et al. 2018). This theory emphasizes that the physical and economic damage produced by earthquakes has a direct impact on market performance. Similarly, contagion and propagation theory elucidate how disasters spread through trade, supply chain connections, and investor networks, impacting markets worldwide. This implies that ripple effects continue due to interwoven supply chains, investor risk preferences, and heightened global market uncertainty (Li et al. 2020).

Literature review

Takao et al. (2013) found that insurance companies' stock prices declined in the aftermath of an earthquake. However, the spread of this decline was narrower for non-life insurance company stock prices than for life insurance prices. Scholtens and Voorhorst (2013) used event methodology to examine financial markets' response to earthquakes in 21 countries. Their results showed that financial markets' reaction to earthquakes has recently become more pronounced. Moreover, the repones of financial markets are the same for all countries irrespective of the level of earthquakes. Ruiz and Barrero (2014) demonstrated that following the Chilean earthquake of 2010, stock market volatility surged dramatically over the next five trading days. Ferreira and Karali (2015) explained stock market reactions to earthquakes and confirmed that markets are robust to earthquake shocks. Jaussaud et al. (2015) examined stock price volatility before and after a disaster. Their results indicate greater volatility in the Japanese stock market a few weeks after the earthquake. Valizadeh et al. (2017) discussed earthquakes' impact on the stock market in 2011 in Japan. Their findings indicated that earthquakes have short-term impacts on all sector indices with heterogeneous components. Bourdeau-Brien and Kryzanowski (2017) confirmed that calamities significantly influence returns following the peak of disaster. Wen et al. (2019) showed that companies with greater retail presence have a minimum chance of a stock price collapse.

Lee et al. (2018) noted that the Sichuan earthquake in China had the most substantial contagion effect on the stock markets of neighboring Asian countries. Tao et al. (2019) investigated the impact of the Tohoku earthquake on the stock market, noting negative returns after the event. Construction is the only sector that responds favorably to individual equities, primarily those with high demand during recovery. Tao et al. (2020) examined the impact of the Northridge earthquake on the stock market. They found that the earthquake did not affect the whole market, with only 23 stocks reacting negatively. Güleç (2020) stated that earthquakes have no substantial association with Turkish stock markets, while Yildirim and Alola (2020) found that earthquakes have a dynamic effect on the stock market. However, earthquakes have no meaningful influence on stocks in the short run, while the long-term effects of earthquakes are significant and negative. Pagnottoni et al. (2022) investigated how different stock markets respond to natural hazard shocks and found that European countries' stock indices show greater responsiveness to such shocks.

Kowalewski and Śpiewanowski (2020) examined stock market reactions to disasters and found a cumulative drop in stocks' market value. Natural disasters impact the stocks of affected firms' current and future competitors. Sakariyahu et al. (2023) investigated the impact of the 2023 Turkey–Syria earthquakes on the stock market and noted significant adverse effects of the disaster on stock market returns. Bharath and Cho (2023) found that natural disasters adversely affect household portfolio choices. Derindere Köseoğlu et al. (2023) examined the Russia-Ukraine war's impact on the Russian stock market. The results demonstrated that the war negatively impacted the stock market and that the actual stock index was consistently lower than expected in the absence of war. Chen et al. (2023) demonstrated that natural disasters have a significant negative effect on financial firms. Pandey et al. (2024) showed that the Turkey-Syria earthquake considerably impacted the daily price volatility of publicly traded enterprises. Furthermore, their results revealed that larger organizations and those with less volatile stocks are more robust, but riskier enterprises suffer more substantial losses. To address this shortcoming, the present study employs the causal inference approach to generate precise counterfactual predictions based on control time series that did not undergo any treatment. By comparing predicted and observed situations, this study offers a thorough understanding of the effect of earthquakes on stock markets.

The studies conducted by Takao et al. (2013), Valizadeh et al. (2017), Lee et al. (2018), Sakariyahu et al. (2023), and Pandey et al. (2024) lack a strong theoretical framework to explain the differences observed, thus limiting the ability to apply their findings broadly. Tao et al. (2019) and (2020) fail to adequately integrate these observations into a broader theoretical context that could explain why certain sectors are more affected than others. In addition, Scholtens and Voorhorst (2013) and Jaussaud et al. (2015) do not sufficiently address the potential variability in market reactions based on different economic conditions, nor do they effectively link this volatility to specific factors. The studies conducted by Ruiz and Barrero (2014) and Bourdeau-Brien and Kryzanowski (2017) primarily focus on immediate aftermaths without delving into longer-term recovery patterns or differentiating between types of disasters and their distinct effects on the market. Ferreira and Karali (2015) do not adequately consider the variations in market responses across different sectors. The studies of Kowalewski and Śpiewanowski (2020) and Pagnottoni et al. (2022) lack a detailed exploration of the factors contributing to this heightened responsiveness. The studies by Güleç (2020), Yildirim and Alola (2020), Sakariyahu et al. (2023), Pandey et al. (2024), and Chen et al. (2023) do not incorporate a robust methodological approach to distinguish between the impacts of earthquakes of different magnitudes or types. Furthermore, these studies fail to provide detailed methodological justifications for their approaches.

Based on the literature review the following hypothesis can be formulated.

Hypothesis 1 Earthquakes have a negative impact on Turkey's stock market indexes.

The preceding literature has demonstrated that natural disasters can lead to immediate declines in stock market indices. Thus, the second hypothesis aims to validate and quantify the negative impact by examining changes in stock market indices following an earthquake. Thus, we posit:

Hypothesis 2 The stock market valuation would not have decreased if there had not been an earthquake.

The hypothesis is predicated on the assumption that stock market valuation reductions following an earthquake are directly related to the earthquake occurrence. By comparing actual post-earthquake stock market performance to model-predicted performance (assuming no earthquake happened), we can identify the earthquake's influence on market value.

Methodology

The difference-in-difference technique, as Brodersen et al. (2015) described, has limitations in examining causal impact. It requires independently and identically distributed data, as dynamic regression is not included, and generates results with a narrow uncertainty range when serially correlated data are fitted to static models (Solon 1984; Hansen 2007a, b). The causal inference method considers pre- and post-intervention periods but often overlooks the evolving effect over time. Previous research has highlighted limitations in creating synthetic control from forecaster variables for time series-based DD analysis. The regression discontinuity design technique is employed to estimate causal effects in non-experimental scenarios. Similarly, the synthetic control method uses a weighted collection of control units to generate a synthetic comparison unit. In contrast, an Event study investigates the influence of treatment throughout periods before and after the intervention and is effective for evaluating pre-trends and dynamic treatment effects. Finally, the instrumental variables approach employs an instrument to identify exogenous variations in the treatment variable.

This study examines the causal impact while avoiding such a situation (Feng and Li (2022). State-space models and the spike-and-slab method in fully Bayesian treatment can help overcome the disadvantages of difference-in-difference methods. They do this by defining temporal growth and preventing overfitting by incorporating uncertainty about variables' effects on forecasts. This study employs a causal inference approach, utilizing Bayesian structural time-series models to determine the relationship between an intervention and its corresponding outcome. The methodology compares observed results with counterfactual estimations of the outcome without intervention (Su et al. (2023c); Jia et al. (2024); Xu et al. (2024)), and estimates the intervention's causal impact. This approach emphasizes assessing the causal effect of an intervention rather than testing for causation only between two variables, unlike other research (Derindere Köseoğlu et al. (2023); Qin et al. (2023b)). Moreover, this approach considers control variables associated with the dependent variable to provide a more precise prediction of the hypothetical outcome without the intervention. This thereby mitigates any confounding variables that might influence the dependent variable.

The section then describes the regression models that form the basis of the method.

$$O_t = H_t^T s_t + \delta_t \tag{1}$$

$$s_{t+1} = T_t s_t + R_t \eta_t \tag{2}$$

where $\delta_t \sim N(0, \sigma_t^2)$ and $\eta_t \sim N(0, Q_t)$ are independent of all the other parameters. Equation 1 links observed data O_t to a d-dimensional state vector s_t, while Eq. 2 describes its evolution. Therefore, the time window in consideration is from time t to $t+1$. The model includes a scalar observation O_t, a d-dimensional output vector H_t, and matrices T_t, R_t, and Q. δ_t is a stochastic variance observation error, and η_t is a q-dimensional system error. The regression model provides crucial counterfactual predictions, and a synthetic control formed from untreated markets identifies nuanced market variations not captured by general sub-models.

This study uses linear regression to make precise counterfactual predictions using control time series without treatment and unobserved factors. The model considers various components and includes contemporaneous variables with fixed coefficients, demonstrating its ability to consider various components. These variables can be represented in state-space form by setting $H_t = \beta^t x_t$ and $s_t = 1$. The word θ is used to signify all the model parameters, while $s = (s_{1,\ldots\ldots\ldots}, s_m)$ is used to represent the complete state sequence. Brodersen et al. (2015) modified the Bayesian technique of inference by introducing a prior distribution $\rho(\theta)$ before the model parameters and a distribution $\rho(\theta)$ on the starting state values. The Markov chain Monte Carlo method is recommended to extract samples from $\rho(s, \theta_y)$.

The point-wise estimation of the impact is estimated as follows:

$$\vartheta_t^{\tau} := o_t - \sim o_t^{\tau} \tag{3}$$

is constructed for each draw τ and for each time point $t = n + 1, \ldots\ldots, m$, where n represents the time when the treatment occurs. This structure is used to collect information about the a posteriori causal impact. The cumulative sum of the causal variables is calculated as follows:

$$\sum_{t=n+1}^{t} \vartheta_t^{\tau} \forall t = n + 1, \ldots\ldots., m \tag{4}$$

Data

We use daily data of the BIST-100 index from 9th January 2023 to 28th February 2023 for the analysis. The earthquake prompted extreme uncertainty and fear, which negatively affected the stock market. Therefore, the period is divided into pre- and post-periods to compute a counterfactual estimate of what would happen if no earthquake occurred. In this regard, we select 9th January 2023 as the initial point and 28th February 2023 as the endpoint. The earthquake in Turkey occurred on 6 February 2023, the treatment date. Hence, we set 9th January 2023 as the pretreatment period and 6th February 2023 to 28th February 2023 as the post-treatment period. The data is obtained from Yahoo Finance. The behaviour of the BIST-100 index is highlighted in Fig. 1. The index declined after the earthquake, from 4997 to 4505, and the market ceased trading for five days, commencing on 15 February 2023.

This study aims to establish more rigorous and robust evidence of earthquake impact on the BIST-100 index by considering other confounding factors that may affect this index. To achieve this goal, the study proposes a well-designed causal inference process that utilizes time series related to the outcome of interest. These series are not affected by the treatment but are predictive of the results, suggesting they are excellent predictors. The study estimates a model to demonstrate a relationship in the pre-period, which is then applied to the post-period, with the prediction providing a counterfactual estimate. This approach helps to control for confounding factors and establish a more accurate causal relationship between treatment and stock market outcomes. The control variable must be similar, such as stock markets in other regions unaffected by the same events, to provide causal inferences. Similar variables may act as confounding factors, reducing

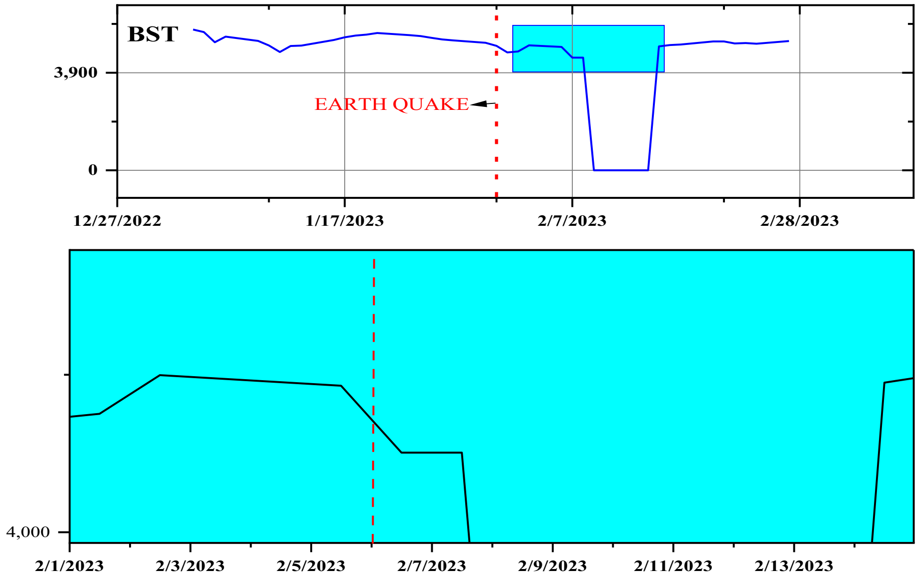

Fig. 1 BIST-100 index

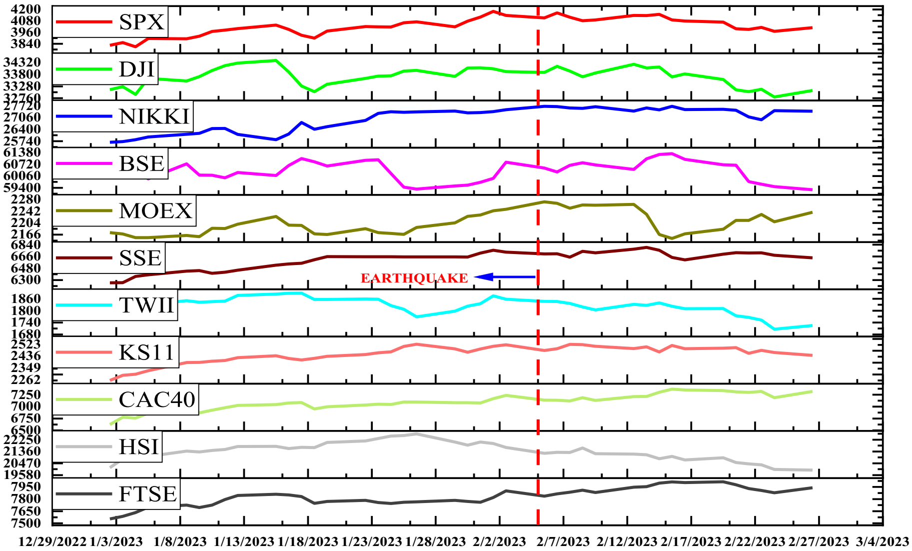

Fig. 2 Behaviour of the covariates

bias in causal estimates by controlling for these factors. This study uses 11 major global stock market indices as covariates to predict the BIST-100 index. The data is obtained from https://www.investing.com. The results show that during the pre-treatment period, the trends of the covariates are similar. This suggests that the covariates could be used to offer a better counterfactual prediction of the BIST index. The 11 covariates include the Jones Index (DJI), the S&P 500 index (SPX), the FTSE 100 index (FTSE), the French CAC 40 index (FCHI), the Nikkei 225 Index (N225), the Korea Composite Index (KS11), the Hang Seng Index (HSI), the Russia Index (MOEX), the BSE Sensex (BSE), the Shanghai Stock Index (SSE) and the Taiwan Index (TWII) (see Fig. 2).

The summary statistics are highlighted in Table 1. The results reveal that the BIST-100 index has the highest standard deviation compared to the remaining stock markets. The skewness values are negative except for those of the Russian stock market. The kurtosis values show both leptokurtic and platykurtic distributions. Similarly, most stock markets are normally distributed, as evidenced by the Jarque–Bera test.

Empirical analysis

Testing for stationarity is essential in time series analysis to avoid spurious regressions. Multiple tests, such as the Augmented Dickey–Fuller (ADF) unit root test (1981), the Phillips and Perron (PP) test (1988), and the Kwiatkowski (KPSS) et al. (1992) test are used for stationarity. The PP test is selected for its adaptability and suitability for structural breaks. This test is favoured over the ADF and KPSS tests because it correctly identifies the sequence of integration required for stationarity. It can be concluded that the variables are stationary in their first differences (Khan et al. 2022a). This suggests that taking the first difference of these variables removes the unit root, making them suitable for further time series analysis without the risk of spurious regression. The results are shown in Table 2.

The Bai and Perron (1998) test addresses the issue of structural breakdowns within the series. It is capable of detecting multiple breaks and identifying the exact breaking point (Khan et al. 2022b). Table 3 displays the results confirming multiple structural breaks in the BIST-100.

The cointegration test is used to detect the long-run relationship between BIST-100 and the control variables. The null hypothesis of no cointegration is tested against the potential cointegration between BIST-100 and the control variables. The cointegration test results reveal that BIST-100 and the control variables have a long-run relationship. The low statistical values suggest this relationship is statistically significant. The results are shown in Table 4.

The findings of the causal inference are exhibited in Fig. 3. The figure consists of three panels. In the first panel, the solid line indicates the data, while the dotted line denotes the counterfactual prediction after the earthquake period. The second panel

Table 1 Summary statistics

	Mean	Std. Dev	Skewness	Kurtosis	Jarque–Bera
BST-100	4597.643	1571.78	− 2.54	7.73	80.42***
FTSE	7827.818	113.82	− 0.30	2.68	0.76
HIS	21,363.69	690.45	− 0.14	2.49	0.56
CAC40	7093.645	172.78	− 0.53	3.07	1.86
KS11	2411.133	65.35	− 1.26	4.12	12.75***
TWII	1825.791	41.32	− 0.93	3.85	7.01***
SSE	6608.983	141.06	− 1.03	3.06	7.08***
MOEX	2203.217	36.79	0.41	1.85	3.32
BSE	60,364.05	591.01	− 0.26	1.94	2.30
NIKKI	26,987.36	666.31	− 0.71	1.96	5.13***
DJI	33,699.72	420.17	− 0.44	2.16	2.49
SPX	4022.181	94.16	− 0.43	2.53	1.61

***Denotes a significance level of 1%

Table 2 Unit root test

Variables	ADF	PP	KPSS
BST100	−2.277	−2.458	0.232***
ΔBST100 BST	−5.958***	−5.957***	0.065
BST30	−2.280	−2.468	0.244***
ΔBST30	−4.672***	−5.920	0.060
BIST	−2.258	−2.443	0.155***
ΔBIST	−5.979***	−5.979***	0.060
DJI	−2.116	−2.256	0.142***
Δ DJI	−6.020***	−6.019***	0.177
SPX	−2.282	−2.269	0.484***
ΔSPX	−6.178***	−6.186***	0.294
FTSE	−2.355	−2.342	0.652***
ΔFTSE	−5.261***	−5.211***	0.188
FCHI	−2.644	−2.786	0.742***
ΔFCHI	−7.919***	−8.309***	0.230
N225	−1.938	−2.064	0.631***
ΔN225	−6.080***	−6.242***	0.294
KS11	−3.455	−4.052	0.582***
ΔKS11	−6.555***	−6.616***	0.596
HIS	−0.980	−1.213	0.309***
ΔHIS	−6.380***	−6.421***	0.701
MOEX	−1.649	−1.790	0.362***
ΔMOEX	−4.989***	−5.017***	0.069
SSE	−2.786	−3.790	0.628***
ΔSSE	−5.088***	−4.965***	0.600
TWII	−0.539	−0.836	0.451***
ΔTWII	−5.405***	−5.404***	0.251

*** Denotes a significance level of 1%

Table 3 Bai-Perron test of L + 1 vs. L sequentially determined breaks

Break Test	F-statistic	Scaled F-statistic	Critical value**	break dates
0 vs. 1 *	44.5527	44.5527	8.58	2/9/2022
1 vs. 2*	2.45276	2.45276	10.13	2/22/2022

*Significant at the 0.05 level. **Bai and Perron (2003) critical values

shows that the point-wise causal effect is the difference between the observed and counterfactual predictions. Similarly, the cumulative effect of the intervention is plotted in the third panel by adding up the point-wise contributions. The vertical dashed line signifies the treatment dividing line. Before the treatment dates, the model displays an exceptional fit, incorporating original data and counterfactual estimates without treatment. To account for the correlation with the BIST-100 index, the model also includes control variables based on major stock exchanges worldwide. Consequently, the pre-period relationship is estimated and utilized during the post-period, with the prediction as a counterfactual estimate. In the absence of an earthquake, the actual stock indices are lower than anticipated, demonstrating considerable

Table 4 Cointegration test

	Tau-statistic	*P*-values	z-statistic	*P*-values
BST100	−5.225	0.000^{*}	−31.369	0.000^{*}
DJI	−5.528	0.043^{**}	−27.332	0.025^{**}
SPX	−5.302	0.041^{**}	−24.280	0.000^{*}
FTSE	−5.987	0.000^{*}	−30.065	0.045^{**}
HIS	−5.187	0.040^{**}	−31.215	0.032^{**}
KS11	−6.116	0.027^{**}	−35.735	0.021^{**}
MOEX	−4.665	0.020^{**}	−27.608	0.000^{*}
N225	−5.808	0.012^{**}	−22.601	0.039^{**}
FCHI	−7.366	0.000^{*}	−35.610	0.000^{*}
BSE	−6.572	0.001^{*}	−35.696	0.033^{**}
SSE	−4.848	0.003^{**}	−24.973	0.000
TWII	−5.292	0.000^{*}	−29.862	0.000

* and ** indicate significance at the 10 and 5% levels, respectively

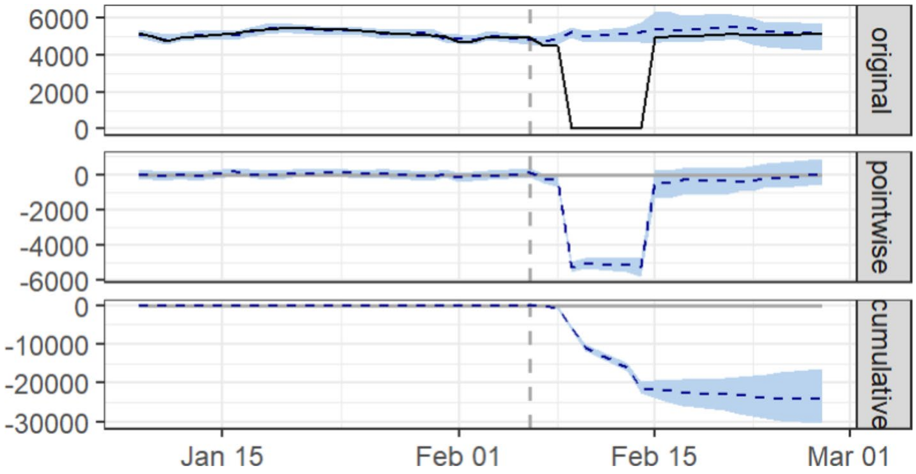

Fig. 3 Causal Effect of Earthquake on BIST-100

divergence from counterfactual estimates. The two curves suggest that a reconvening pattern in the stock market in the last week of February 2023 coincides with the resumption of stock market activities. This indicates that the earthquake induced a high level of uncertainty, resulting in a substantial negative influence on the stock market's value on the subsequent day. The stock market remained closed for more than five days and resumed on 15th February 2023. The reconvening patterns are observed when the market resumed trading, and the index gained some losses. The government announced incentives to encourage corporations to repurchase their stock and directed pension funds to increase their stock allocation.

The point-wise causal effect refers to the variation between the expected and actual data. It remains relatively stable near zero until the action is implemented, at which point it quickly decreases and then increases. The second panel represents the point-wise effect, showing an estimate of the BIST-100 index decline following the earthquake. Finally, the cumulative impact is obtained by incorporating the causal effect in

Table 5 Causal Effect of Earthquake on the BIST-100 Index

	Average	Cumulative
Actual	3645	54,676
Prediction (s.d.)	5240 (261)	78,605 (3908)
95% CI	[4725, 5663]	[70881, 84938]
Absolute effect (s.d.)	−1595 (261)	−23,929 (3908)
95% CI	[−2017, −1080]	[−30261, −16204]
Relative effect (s.d.)	−30% (5%)	−30% (5%)
95% CI	[−38%, −21%]	[−38%, −21%]

The average column reflects the average postintervention time. The data for each time point are totaled in the 'Cumulative' column

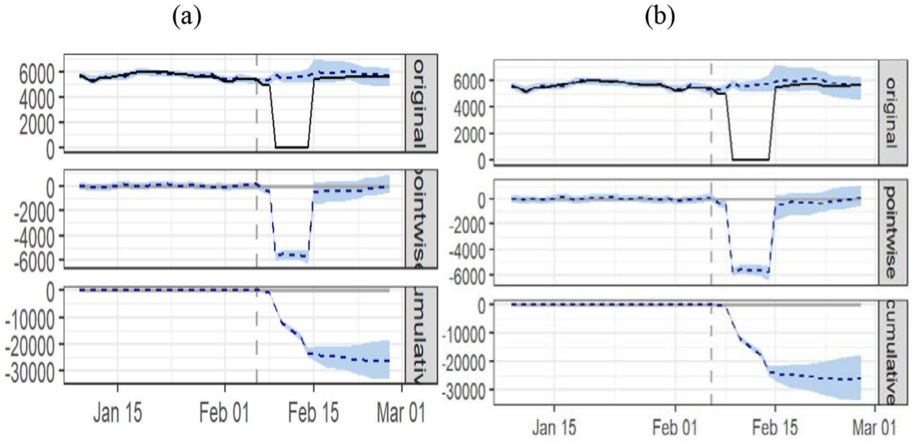

Fig. 4 **a**. The causal effect of earthquake of BIST-30. **b**. Causal effect of earthquake the BIST all indices

the third panel. In relative terms, the post-treatment period has a negative impact, as evidenced by the BIST-100 index decreasing by 30%.

Table 5 highlights the summary of Fig. 3. The column labeled "Average" pertains to the mean value observed for the duration of the post-intervention period. The column labeled "Cumulative" summarizes the distinct time points. It shows that BIST-100 has an average value of 3.65 K following the earthquake. Conversely, without intervention, the expected average response would be 5.24 K. The 95% interval of this counterfactual prediction is [4.73 K, 5.66 K]. The difference between the prediction and the observed response is −1.60 K, an estimate of the causal effect of the intervention with a 95% interval of [−2.02 K, −1.08 K]. After all the data points are added, the BIST-100 score is 54.68 K postintervention. The expected sum would be 78.61 K without an earthquake, with a 95% interval [70.88 K, 84.94 K]. In relative terms, the BIST-100 is seen to decrease by −30%. The 95% interval of this percentage is [−38%, −21%]. This finding implies that the negative impact caused by the earthquake is statistically significant.

Robustness checks

Figure 4 panels (a)–(b) illustrate the findings of the BIST-30 and BIST-All index causal inference. The empirical results show that the actual stock indices are lower than anticipated in the absence of an earthquake, indicating significant divergence from counterfactual predictions. The high uncertainty caused by the earthquake negatively impacts the BIST-30 and BIST-All indices. The point-wise causal effect between the expected and actual data remained relatively stable near zero until the earthquake occurred; at this point, it quickly decreased and then increased. The second panel represents the point-wise effect, indicating that the BIST-30 and BIST-all indices decrease following the earthquake. The cumulative impact is obtained by incorporating the causal effect over a period of time. In relative terms, the post-treatment period shows a negative impact, as evidenced by the decreases in the BIST-30 and BIST-All indices of − 30%.

Table 6 summarizes Fig. 4 panels (a)–(b). During the postintervention period, the BIST-30 index's average value is 4.05 K. The expected average response would be 5.79 K without an intervention. This counterfactual prediction lies within a 95% interval [5.22 K, 6.28 K]. The difference between the predicted and actual responses is -1.74 K, an estimate of the intervention's causal impact with a 95% confidence interval of [− 2.23 K, − 1.17 K]. The response variable has an overall value of 60.72 K in the post-intervention period, while the expected sum would be 86.82 K without an earthquake. The 95% interval of this prediction is [78.33 K, 94.15 K]. The BIST-30 index is seen to decrease by -30% in relative terms with a 95% confidence interval of [− 39%, − 20%], suggesting a statistically significant negative effect is observed during the intervention period. Similarly, the results for the BIST-All indices are highlighted in Table 3. The BIST-All index has an average value of 3.99 K during the post-intervention period. The expected average response would be 5.74 K without an earthquake with a 95% confidence interval of [5.21 K, 6.20 K]. The difference between the predicted and actual responses is -− 1.75 K, an estimate of the causal effect of the earthquake with a 95% interval of [− 2.21 K, − 1.22 K]. The BIST-All index has an overall value of 59.85 K during the post-intervention period when the various data points are added. Conversely, the expected sum would be 86.07 K without an earthquake with a 95% confidence interval of [78.14 K, 92.99 K]. In relative terms, the BIST-All index is seen to decrease by − 30% with a 95% confidence interval of [− -38%, − 21%]. The results reveal a statistically significant negative effect during the intervention period.

Table 6 Causal Effect of Earthquake on BIST-30 and BIST All Indices

	BIST 30		**BIST All**	
	Average	**Cumulative**	**Average**	**Cumulative**
Actual	4048	60,717	3990	59,852
Prediction (s.d.)	5788 (298)	86,825 (4473)	5738 (272)	86,069 (4074)
95% CI	[5222, 6277]	[78329, 94154]	[5209, 6199]	[78135, 92986]
Absolute effect (s.d.)	− 1741 (298)	− 26,108 (4473)	− 1748 (272)	− 26,217 (4074)
95% CI	[− 2229, − 1174]	[− 33437, − 17612]	[− 2209, − 1219]	[− 33134,18283]
Relative effect (s.d.)	− 30% (5.2%)	− 30% (5.2%)	− 30% (4.7%)	− 30% (4.7%)
95% CI	[− 39%, − 20%]	[− 39%, − 20%]	[− 38%, − 21%]	[− 38%, − 21%]

Discussion

The results reveal that earthquakes have a significant negative influence on stock market value during the post-treatment period, indicating a high level of uncertainty caused by earthquakes. The reconvening patterns observed when the market resumed trading suggest that an earthquake substantially negatively impacts the stock market's value on a subsequent day. Several factors contribute to the observed negative impact of earthquakes on the stock market. To begin with, earthquakes cause panic and fear among investors, leading to cognitive biases such as loss aversion and anchoring. This can result in irrational selling and significant market declines. Furthermore, earthquakes cause physical and economic damage, such as infrastructure destruction and productivity losses, which reduce cash flows and profitability for affected firms. This leads to lower stock prices as investors anticipate decreased earnings. The perceived risk associated with investing in affected regions increases, necessitating higher risk premiums. The impact of an earthquake can propagate through trade, supply chains, and investor networks, exacerbating market volatility beyond the immediate disaster area. These results are supported by Yildirim and Alola (2020), Kowalewski and Śpiewanowski (2020), Pagnottoni et al. (2022), Sakariyahu et al. (2023), Bharath and Cho (2023), Chen et al. (2023), and Pandey et al. (2024), who reported negative effects of earthquakes on stock market value. Moreover, results from Turkish studies, such as those by Güleç (2020), Yildirim and Alola (2020), and Derindere Köseoğlu et al. (2023), also support our findings, noting that earthquakes and war have negative effects on the stock market. Our study uses causal inference approaches to validate and accurately analyze market behavior after an earthquake. It compares observed behavior with counterfactual scenarios, distinguishing causal effects from correlations. Major stock market indices add reliability when used as control variables. Cointegration analysis confirms similar trends between control variables and BIST-100 index trends during the pretreatment period.

Therefore, our findings have significant implications for investors and policymakers, emphasizing the need to prepare for natural disasters to minimize their adverse effects on the stock market. Comparing our results with prior studies, we infer that the present study has distinctive characteristics in evaluating causal inference. The approach has unique features to analyze the scenario if an earthquake occurs, and vice versa. It predicts the stock market reaction if there was no earthquake. However, previous studies have emphasized traditional techniques (mainly event study), which estimate pre- and post-event impacts but do not necessarily indicate causal effects. Consequently, this study clearly distinguishes between causal inference and correlation. These findings are supported by the results demonstrating that the BIST-100 had an average value of 3.65 K following the earthquake. Without intervention, the expected average response would be 5.24 K. In relative terms, the BIST-100 score decreased by −30%. Moreover, this study differs in considering major stock market indices to establish more rigorous and robust evidence. These series are not affected by the treatment but are predictive of the results, suggesting they are excellent predictors. The results showed that during the pretreatment period, the trends of the covariates were similar. Moreover, the cointegration outcome indicated no relationship between the BIST-100 and the control variables, suggesting that these variables were not affected by the earthquake and are useful counterfactual determinants. This study contributes to the understanding of natural disasters' impact on financial markets by confirming the negative impact of earthquakes on the stock market. It also provides a reliable method for estimating stock market responses to earthquakes using causal inference, a counterfactual prediction model, and controlling variables based on major stock exchanges worldwide. The findings can serve as a benchmark for nations facing similar challenges.

Conclusion

The relationship between natural disasters and financial markets has garnered increasing attention from researchers, as the consequences of such events can have profound implications for investors and policymakers. This critical discussion focuses on the empirical analysis of the causal effect of earthquakes on the BIST-100 index and provides valuable insights by comparing the expected and actual results. Additionally, examining the duration and magnitude of the observed reconvening patterns would provide valuable information into market dynamics and the recovery process following an earthquake. The analysis of the causal effect of the earthquake on the BIST-100 index reveals a significant negative influence on stock market value during the post-treatment period. These findings exhibit a sharp divergence from the counterfactual predictions, indicating a high level of uncertainty caused by the earthquake. The reconvening patterns observed when the market resumed trading indicate that an earthquake has a substantial negative impact on the stock market's value on a subsequent day. The point-wise causal effect refers to the variation between the expected and actual data, which remains relatively stable near zero until the action is implemented; at this point, it quickly decreases and then increases. The cumulative impact obtained by incorporating the causal effect is negative in relative terms, as evidenced by the BIST-100 index decreasing by -30%. The robustness results indicate similar negative impact patterns for the BIST-30 and BIST-All indices. These robust results further prove the earthquake's significant negative impact on the stock market's value.

Policy implications

The policy implications are divided into theoretical and practical implications.

Theoretical implications

The study provides the following theoretical policy suggestions. First, the results are consistent with theories suggesting that natural disasters exacerbate uncertainty and negatively affect local financial markets. The sharp divergence between the counterfactual and actual stock values is consistent with theoretical predictions. Second, the duration and size of the reconvening patterns shed light on theoretical market functioning and recovery models following external shocks such as natural catastrophes. Our analysis can help refine these theories. Finally, the significant negative causal effect observed empirically is consistent with and strengthens theoretical disaster economic models predicting the weakening of asset valuation and trading of financial instruments following natural disasters.

Practical implications

The practical policy implications are presented as follows. First, the results indicate that earthquakes significantly adversely affect the stock market. Thus, policymakers should develop contingency plans to address such events and ensure that the stock market can resume trading as soon as possible to prevent prolonged adverse effects on the economy. This study highlights the need for adequate disaster management planning and preparedness. Second, investors should understand the risks of investing in the stock market during or after natural disasters. Investors should consider the increased level of uncertainty and the possibility of a decline in stock prices when making investment decisions. Similarly, investors should be aware of the risks of investing in regions prone to natural disasters. This includes considering the potential impact of natural disasters on the stock market and adjusting investment strategies accordingly. Moreover, the study highlights the importance of monitoring and regulating financial markets during periods of high uncertainty. Policymakers and law enforcement agencies must closely monitor financial markets during such periods and implement measures to ensure market stability and prevent panic selling. Third, the results suggest that control variables based on major stock exchanges worldwide can help account for the correlation with the BIST-100 index and improve the accuracy of the model's predictions. Thus, policymakers and investors should consider incorporating such variables when analyzing stock market behavior. Finally, policymakers and investors should consider the role of insurance in mitigating the impact of natural disasters on the economy. Insurance can provide a safety net for individuals and businesses affected by natural disasters and help to facilitate recovery efforts.

Future directions

The study can be extended to analyze the earthquakes, their impact on the BIST-100 index, and other factors and events that influence stock market performance. Future studies may also examine the relationships between earthquakes and other economic factors, such as investor sentiment or governmental initiatives, to offer a more thorough knowledge of the underlying dynamics. Furthermore, expanding the analysis to other stock markets globally would offer a broader perspective on the relationship between natural disasters and financial markets.

Abbreviations

BIST	Borsa Istanbul stock exchange index
DJIA	Dow Jones industrial average
DD	Difference-in-difference
MCMC	Markov chain Monte Carlo
DJI	Dow Jones index
SPX	S&P 500 index
FTSE	FTSE 100 index,
FCHI	French CAC 40 index
N225	Nikkei 225 index
KS11	Korea composite index
HIS	Hang Seng index
MOEX	Russia index
SSE	The Shanghai stock index
TWII	Taiwan Taiex index

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