The Impact of Marmara Earthquakes on Regional Economic Development
A Difference in Differences Analysis Using Nightlights

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List of Acronyms

DHS	Demographic and Health Survey
DiD	Difference in Differences
DMSP OLS	Defence Meteorological Satellite Program Operational Linescan System
DNB	Day/Night Band
IRF	Impulse Response Functions
MMI	Modified Mercalli Intensity
NAF	North Anatolian Fault
NASA	The National Aeronautics and Space Administration
POLS	Pooled Ordinary Least Squares
VIIRS	Visible Infrared Imaging Radiometer Suite

Abstract

This study provides empirical evidence on the impact of 1999 Marmara earthquakes on regional economic development. It employs nighttime light data as a proxy for economy activity which is an innovative tool to tackle with the limitations of traditional indicators such as GDP. Statistical analysis is based on the application of two-way fixed effects model within Difference in Differences (DiD) framework which was further strengthened with an event study analysis developed by Callaway & Sant'Anna (2021). According to the results, there is a considerable loss of economic activity in districts severely affected by the earthquakes. Post disaster aid creates a revival in regional economic activity which does not last long. The analysis provides valuable lessons for policymakers in the context of the heavy economic burden arose from deficiencies in urban planning and infrastructure inspections, the importance of post disaster relief efforts and how they create a boom in economy and the necessity of making robust economic policies that maintain sustainable economic growth after the disaster.

Relevance to Development Studies

This research contributes to the literature on development studies by revealing the economic impacts of a catastrophic natural disaster. The 1999 Marmara earthquakes were a significant economic shock to one of Türkiye's most industrialized regions. The region experienced rapid urbanization driven by industrialization and subsequent mass internal migration. This created an authentic context where the earthquake victims were not only from lower income groups but also included middle- and upper-income households. Hence, understanding the consequences of such a disaster in this socioeconomic environment provides a good opportunity for developing effective economic policies as well as disaster planning.

Keywords

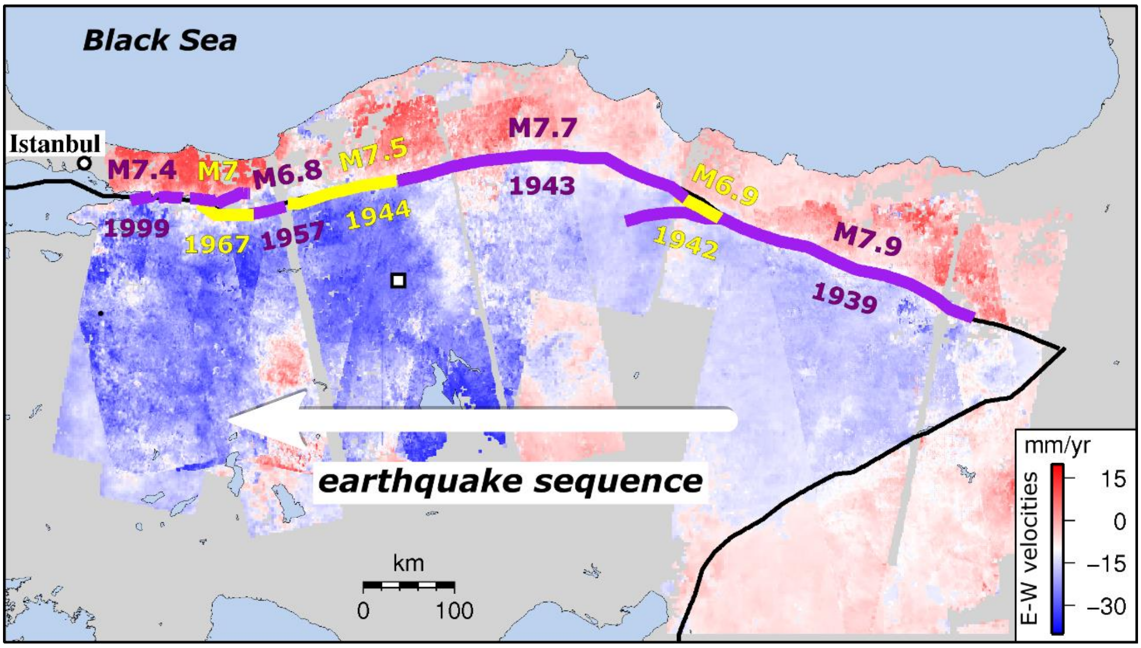
Natural Disasters, Economic Impact, Nighttime Light Intensity, Difference in Differences, Fixed Effects Model, Event Study Analysis

Chapter 1
Introduction

Natural disasters can lead to severe destruction such as extensive damage to infrastructure, loss of lives and physically and/or mentally affected human capital which brings about a heavy burden to economy amounting to billions of dollars. The impact of such disasters depends on a country's institutional quality, its level of economic development, the destructiveness of the disaster, and the proximity of the epicentre to densely populated areas and major economic centres. All these factors can determine whether the effects will be short-term or long-term and whether they will be confined to a specific region or have nationwide repercussions.

On August 17 and November 12, 1999, the Marmara region of Türkiye was hit by two catastrophic earthquakes with magnitudes of 7.6 and 7.2 on the Richter scale, respectively (EM-DAT , 2024). These earthquakes occurred along the North Anatolian Fault (NAF). The western segment of the NAF, which stretches from eastern to western Türkiye, runs through the Marmara region. NAF, Turkey's most active fault line, triggered by the compression of the Arabian, African, and Eurasian plates, caused 25 earthquakes over the past century (Şahin & Tari, 2000). Unfortunately, scientists still anticipate NAF to generate powerful earthquakes in the future for example, a magnitude 7 or higher earthquake is expected in İstanbul. The map shows the location of the North Anatolian Fault and marks the areas and years of major earthquakes that occurred along this fault line.

Map 1: North Anatolian Fault



Source: ESA/NASA/JPL-Caltech/University of Leeds (U.K.) provided by NASA (2018)

The Greater Marmara region consists of the provinces of Edirne, Kırklareli, Tekirdağ, Balıkesir, Çanakkale (Western Marmara), Kocaeli, Sakarya, Yalova, Bolu, Bursa, Bilecik, Eskişehir (Eastern Marmara), and İstanbul. The epicentre of the August 17, 1999 earthquake was Kocaeli (Derince), whereas the epicentre of the November 12, 1999 earthquake was Düzce, a district of Bolu. Düzce was proclaimed as a province after the 12 November earthquake. Map 2 shows the Marmara region's position within Turkey and name and borders of its 14 provinces.

Map 2: The Marmara Region

Source: FAO, 2015

The 1999 Marmara Earthquakes, which occurred along Turkey's most active fault line, caused immense damage to critical infrastructure, industries, and the regional economy. The earthquake stricken Eastern Marmara region is the backbone of Turkish economy, particularly in the industrial, financial, import, export, and tourism sectors. In the most severely affected four provinces - Kocaeli, Sakarya, Yalova, and Bolu (Düzce) - the dominant economic was industry.

The leading industrial sectors in these provinces include automobile manufacturing, petrochemicals, the production, maintenance, and repair of engines and railway vehicles, basic metal production, synthetic yarn and fabric production and weaving, as well as paint and varnish manufacturing (İnmez, 2005). Apart from the industry, tourism was prominent in Gölcük (Kocaeli) and Yalova, and agriculture and agro-based industry plays a significant role in Bursa and Sakarya. Istanbul, Bursa, and Eskişehir, though secondarily affected by the earthquake, have close economic ties with the severely impacted provinces. The 1999 Marmara earthquakes are an authentic case for examining the resilience of industrial regional economies to seismic shocks. The earthquakes led to substantial economic losses in both the short and long term because of the extensive destruction of the superstructure. Accordingly, this study aims to measure economic consequences of the disaster by using innovative satellite data and advanced econometric techniques.

Table 1 presents information about various socio-economic indicators of the earthquake-stricken region for the years 1997 or 1998. Kocaeli, the epicenter of the 17 August earthquake and also the most severely affected city, had a mid-sized population (1.2 million) however it alone contributed 11.3% to Turkey's total industrial value-added. The total population of the severely affected four cities were 2.6 million which equals to 4.2% of Turkey's population. As I mentioned, these cities were home to a large industrial base and contributed 13.8% to Turkey's industrial value added and 7.2% to its GDP. Extended disaster zone including Istanbul, Bursa and Eskisehir (7 provinces), contributed to 35% of the national GDP and nearly half of the country's industrial output (Bibbee, et al., 2000, p. 9).

Per capita income is another crucial indicator of economic strength. Kocaeli had the highest per capita income in the region which equals to $7,845. It was well above the national average of $3,031. This indicates that the city's economy is robust and highly productive. Yalova had the second highest per capita income, $4,966 which was also above the Turkey's average. Even though the city had a smaller population than Kocaeli, it created significant high value-added from its industries and tourism.

Table 1: Socio-Economic Indicators of the Earthquake Stricken Region 1997 or 1998

	Population	**Share in GDP**	**Share in Industrial Value Added**	**Per capita income**	**Share in Budget Tax Revenues**	**Share in Bank Deposits**	**Share in Banking Credits**
	Thousands	Per cent		US $		Per cent	
Kocaeli	1.177	4.8	11.3	7.845	15.8	1.4	0.9
Sakarya	732	1.1	1.1	2.734	0.4	0.5	0.2
Yalova	164	0.4	0.7	4.966	0.1	0.2	0.1
Bolu	553	0.9	0.7	3.104	0.3	0.3	0.2
Bursa	1.959	3.5	5.0	3.434	3.0	2.4	3.2
Eskişehir	661	1.2	1.1	3.335	0.8	0.7	0.7
İstanbul	9.199	22.8	26.8	4.728	37.5	44.1	41
Kocaeli, Sakarya, Yalova, Bolu	2.626	7.2	13.8	5.243	16.6	2.4	1.4
7 Cities Total	14.444	34.7	46.7	4.581	58	49.6	46.3
Turkey	62.866	100	100	3.031	100	100	100

Source: Turkish Authorities. From Bibbee, et al., 2000

Finally, financial indicators, such as the share in banking deposits and credits, further emphasize the importance of the region in Türkiye's economy. Istanbul stands out in these categories. It held 44.1% of Türkiye's bank deposits and 41% of its banking credits. Although cities like Kocaeli and Sakarya hold smaller shares, they still make significant contributions to the region's overall economy. One reason for their lower values could be that, in Türkiye, many firms are registered in İstanbul and keep their bank accounts there, even though they operate in other cities. Therefore, it can be assumed that the actual share of the four most severely affected cities is likely higher than it appears.

The 1999 Marmara earthquakes are remarkable seismic events that have both immediate and long-term economic consequences in Turkish history. These earthquakes had widespread effects in the region such as extensive physical damage, significant loss of life, and major disruptions to economic activities. The disaster economics literature indicates that consequences of such catastrophic events depend on a country's level of development, economic structure, and institutional capacity. We can identify the underlying factors and take the necessary precautions to prevent similar outcomes in the future if we properly quantify the causal relationship between disasters and their burden on economy. I could not find any online sources specifically discussing the economic impacts of the Düzce earthquake. Therefore, the data and analysis that follow focus on the economic effects of the August 17 earthquake.

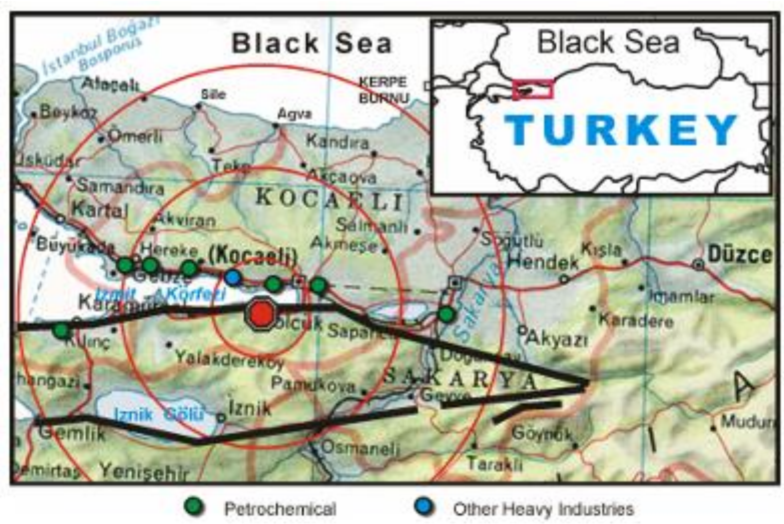
The negative impacts of the earthquake were felt immediately in critical areas such as infrastructure, industry, small and medium-sized enterprises (SMEs), and the macroeconomy in general. The damage to infrastructure was prominent. Major highways, such as the Ankara-Istanbul route, and several railway lines that connect İstanbul to Anatolia were become unusable and this led to a temporary paralysis in transportation (İnmez, 2005, p. 115).

Figure 1: Section of the Damaged Motorway and Railway

Source: J. Mander and https://www.koeri.boun.edu.tr/ from Bruneau, et al., 2000

Other critical sectors such as telecommunication and energy distribution were also negatively affected. For example, more than 3,400 electrical towers and 490 kilometres of power lines were fallen into pieces and oil pipelines and municipal gas distribution systems were suffered from midlevel damage (İnmez, 2005, p. 115). Figure 1 shows a view from E-80 motorway and a railway which were damaged due to the fault rupture.

Map 3: Industrial Facilities and 17 August Earthquake Epicenter



Source: Bruneau, et al., 2000

The industrial sector which holds significance for both Türkiye and regional economy, were also suffered from severe damage. As noted earlier, the region was home to major industrial complexes such as petrochemical plants, automotive factories, and steel manufacturing facilities. Map 3 indicates the epicentre of 17 August earthquake and the location of petrochemical and other heavy industries.

The estimated value-added loss of the manufacturing sector alone was between $600 to $700 million, and the total damage to the enterprise sector ranged from $1.1 to $4.5 billion, according to various assessments (İnmez, 2005, p. 116; The World Bank, 1999, p. 25). TÜPRAŞ, Türkiye's largest state-owned refinery, was severely affected by the three-day fire, which caused approximately $350 million damage (Erdik, 2000, p. 39). Other petrochemical factories, such as Petkim and İGSAŞ, also suffered from damage which resulted in financial losses due to production interruptions (Erdik, 2000, p. 31). The Hyundai and Toyota automotive factories experienced non-structural damages, which nonetheless brought about a temporary halt in production for a period (Erdik, 2000, p. 32). Apart from these damages, the earthquake also severely affected micro and small and medium size enterprises (SMEs).

SMEs and microenterprises were particularly vulnerable because many of them were lack of insurance coverage or enough capital to overcome such a disaster. According to the World Bank's estimates, 6,000 small shops and 1,500 service businesses were heavily damaged which resulted in both unemployment and disruptions in the supply of intermediate goods to larger firms (The World Bank, 1999, p. 27). The lack of capital and the absence of disaster insurance prolonged SMEs and microenterprises' recovery. Consequently, these factors weakened business relationships between small and large enterprises which further restraint the regional development.

The OECD report points out that job losses could range from 20% to 50% of the pre-earthquake work force in the affected provinces and the majority of these losses were among self-employed individuals and small businesses (Bibbee, et al., 2000, p. 12). On the other hand, many industries reported concerns about the potential loss of qualified labour due to death, disability and out-migration i.e. some qualified workers had already sought opportunities in other regions (Bibbee, et al., 2000, p. 10). The loss of skilled labour made it difficult for businesses to resume normal operations. When psychological problems arising from the destruction caused by earthquakes were added, regional development was further disrupted in the long term.

The tourism sector, particularly concentrated in Yalova and Gölcük (Kocaeli), was almost entirely destroyed. In these areas where tourism served as a major source of income, the sector nearly collapsed in the years following the earthquake due to a sharp decline in the number of visitors. When we consider the intensity of the earthquake and the destruction it caused, the halt of tourism activities is hardly surprising.

The earthquakes led to the collapse of 109,000 buildings that housed families and businesses, resulted in the death of 17,975 people, injured 49,101 individuals, left approximately 655,000 people homeless, and directly or indirectly affected a total of 1.58 million people (İnmez, 2005, p. 111; EM-DAT , 2024). This extensive destruction created an urgent need to provide accommodation for earthquake survivors. Despite severe budget constraints, the government agreed to repair the houses if possible, build prefabricated houses urgently and provide reinforced concrete houses to earthquake victims in the medium term (İnmez, 2005). It was estimated that meeting the accommodation needs of the disaster victims would require an expenditure of between $3.5 and $4 billion (İnmez, 2005).

While Turkey was beginning to recover from the global economic crisis triggered by Russia's financial collapse, the earthquake dealt a significant blow to the country's GDP and caused to a 5% contraction in 1999 (The World Bank, 1999, p. 15, Bibbee, et al., 2000, p. 12). Meanwhile, the monetary value of physical capital destruction was estimated at approximately $3 to $10 billion, while total wealth and income losses were projected to range between $5 and $14 billion (Bibbee, et al., 2000, p. 12). However, the actual cost of the earthquake far exceeded these projections. The total damage was estimated at around 38 billion USD which is a proof of an enormous economic toll such disasters can have, even in a well-developed region (EM-DAT , 2024). Approximately 40 to 50% of the losses were due to damages to housing and enterprises, while infrastructure accounted for the remainder (Bibbee, et al., 2000, p. 12).

Government intervention and international aid played a crucial role in the relief effort after the earthquake. The State Planning Organization (SPO) estimated that the reconstruction effort would cost approximately $6.2 billion and approximately $3.5 billion allocated for housing construction (Erdik, 2000, p. 34). The government introduced special earthquake taxes, and a paid military service scheme hence raised about $3 billion within a year, on the other hand, international organizations such as the World Bank and the European Union contributed an additional $2.5 billion to support the recovery (Erdik, 2000, p. 34). Despite these efforts, the recovery process was slow, particularly for SMEs, which faced challenges in accessing financial resources and skilled labour to rebuild their operations.

The 1999 Marmara earthquakes caused a heavy burden on Türkiye's economy, because critical infrastructure, industrial sector, and micro and small enterprises suffered from long lasting damages. Even though the government and international organizations provided financial support, individuals and businesses continued to face economic difficulties years after the disaster. Physical capital losses, disruptions to business operations, and labour market instability in the region actually revealed the vulnerability of Türkiye's economic system to natural disasters. Within this direction, my research aims to analyse whether these long-term impacts can be observed in the form of variation in nightlight intensity, which serves as a proxy for economic activity.

In this study, I evaluate the impact of the 1999 Marmara earthquakes on the region by using nightlight data as a proxy for economic activity. I apply the Difference-in-Differences (DiD) method with two-way fixed effects regression to identify the causal effect of the earthquakes on regional economic development. Furthermore, to see how the effect evolves through time in the post disaster period, I employ an advance DiD approach, event study analysis developed by Callaway & Sant'Anna (2021). While the consequences of disasters on national economies have been examined in previous studies, such as Noy (2009) and Cavallo et al. (2013), relatively few studies have utilized satellite nightlight data to assess how regional economies are affected, particularly in the context of Türkiye. To the best of my knowledge, this is the first study to employ the DiD technique combined with satellite data to analyse the impact of the Marmara earthquakes.

My research makes a significant contribution to the disaster economics literature by analysing the economic consequences of the 1999 Marmara earthquakes through an impact analysis method, event study analysis and utilizing innovative nightlight data as a more objective indicator of economic activity. Empirical studies that focus on the economic outcomes of disasters are often conducted at the cross-country level and use GDP as an indicator of economic performance due to the limitations of reaching sub national data. The lack of regional data often leads researchers who particularly aim to focus on one country or region to use remote sensing indicators such as nighttime light intensity to conduct statistical analysis. Nighttime lights provide impartial and reliable information about economic activity in situations where regional data is either unavailable or insufficient. It is possible to draw significant inferences regarding which areas are most affected by the disaster, the extent of damage to economic activities, and the outcomes of post-disaster relief efforts by analysing changes in light intensity.

To be more precise, this research seeks to:

1. Quantify the extent to which economic activity, as proxied by nightlight intensity, was affected in districts severely impacted by the earthquake compared to those that were not.
2. Investigate whether the effects of the earthquakes on economic activity were short-term or persistent over a long duration (1999-2020).

I test the following hypothesis in my analysis:

H1: Districts severely affected by the 1999 Marmara Earthquakes experienced a statistically significant reduction in economic activity compared to less affected districts.

H2: The economic impact of the earthquakes persisted in the affected regions throughout the period 1999–2020.

Understanding the long-term economic impacts of the 1999 earthquakes on the Marmara region can be particularly beneficial in preparing for the anticipated Great Istanbul Earthquake because the findings of this study are expected to shed light on the potential consequences of a similar earthquake in Türkiye’s key economic centres. In this way, policymakers can take more effective steps in terms of disaster preparedness and resilience. Moreover, the findings of the study may contribute to the global literature on disaster economics by offering insights into the economic vulnerabilities of industrial regions to disasters.

Chapter 2
Literature Review

Noy (2009) offers an extensive causal analysis of the impacts of disasters on macroeconomy for the first time in disaster economics literature. To be more precise, the researcher examines how GDP growth rate varies in response to disasters using a cross-country panel dataset covering the period from 1970 to 2003. A fixed effects model is employed to control for unobserved heterogeneity. According to the main results of the study, natural disasters have a statistically significant negative effect on economic growth in the short term. However, the severity of this impact varies based on factors such as the size of the economy, level of development and geography (Noy, 2009, p. 223). For example, small island states are more vulnerable to disasters than other regions. Furthermore, the analysis reveals that high illiteracy rates, weak institutions, lower per capita income, and limited trade openness are factors that exacerbate the negative economic consequences of disasters (Noy, 2009, pp. 227, 228).

Cavallo et al. (2013) examine the causal relationship between extraordinary natural disasters and economic growth using global data from 196 countries over the period 1970 to 2008. They adopt a comparative case study approach and, unlike other studies that use fixed effects regression, researchers prefer to apply the synthetic control method. This method enables comparisons between countries affected by natural disasters and a synthetic control group of similar countries that were not impacted. By doing so, they can isolate the causal effects of disasters and provide insights into what would have occurred in the absence of these events.

The study reveals three key findings. First, extraordinary natural disasters have long-lasting effects on countrys' GDP. In fact, GDP per capita declines by approximately 10% over a decade, whereas, without the disaster, it is estimated that GDP would have grown by around 18% (Cavallo, et al., 2013, p. 1556). Second, it is noteworthy that this substantial negative impact is statistically significant, particularly in cases where the disaster was followed by political revolutions. Third, if an extraordinary disaster is not followed by a political upheaval, its long-term effect on economic growth is negligible. The study challenges the conventional belief that catastrophic disasters result in long-term economic decline. Instead, the findings suggest that political developments and institutional factors are more critical in shaping the long-term economic consequences of a disaster.

These studies are prominent representatives of the strand of literature that faces challenges related to data quality and endogeneity issues in statistical analysis. They use GDP as a proxy for economic health and rely on the number of fatalities and the monetary value of material losses to measure the magnitude of a disaster. First, the data accuracy in developing countries is questionable because national governments tend to inflate casualty numbers to attract more aid from international donors (Noy, 2009, p. 223). Thus, measuring the severity of a disaster based on human or physical losses can lead to biased estimates. To obtain more reliable results, we need objective indicators such as MMI scale for earthquakes or wind speed for hurricanes. Secondly, Noy (2009) and Cavallo (2013) assume that these disaster measures mentioned above are exogenous to GDP measures. This assumption is problematic because the severity of disasters also depends on countries' economic conditions and they are indeed endogenous. For example, countries with low GDP and limited institutional capacity are generally more vulnerable to catastrophic outcomes of disasters. Thirdly, disasters can alter government budgets, investment plans, and public spending, which in turn affects GDP growth. These changes can either enable states to enter a recovery process that mitigates the negative outcomes of disasters or exacerbate the undesirable consequences, both of which, in turn, affect GDP growth. They might even affect the probability of experiencing political upheavals (Cavallo, et al., 2013, p. 1558). To address the issue of endogeneity between GDP and disaster impacts, it is essential to incorporate more exogenous measures of economic activity, such as nighttime light data. Unlike GDP, which can both influence and be influenced by disaster damage and subsequent policy responses, nighttime lights provide a more accurate and unbiased proxy for economic activity.

Henderson et al. further highlights the limitations of GDP as a proxy for economic activity in their 2012 article. GDP is indeed a problematic measure of economic conditions, particularly in developing countries, where it is often subject to significant measurement errors and unreliable official statistics. In contrast to developed nations, the informal sector represents a considerable amount of economic activity in developing countries, but it is typically not included GDP calculations (Henderson, et al., 2012, p. 996). Moreover, subnational GDP data is rarely available in developing countries. Therefore, researchers and policymakers must rely on alternative indicators to more accurately assess the spatial distribution of economic activity. For these reasons, Henderson et al. (2012) aims to develop a framework that integrates satellite data on nightlights with traditional income measures to improve the estimation of real GDP growth.

The researchers benefit from DMSP-OLS data, which measures the intensity of nightlights worldwide. Owing to these data, they estimate GDP growth in countries where data accuracy is problematic by calculating the elasticity of nightlight growth in relation to GDP growth. The findings show that the elasticity between nightlights and GDP is approximately 0.3, meaning a 1% rise in nightlight intensity is associated with a 0.3% increase in GDP growth (Henderson, et al., 2012, p. 996). This is an important study because it reveals that nightlight intensity can serve as a proxy for changes in GDP. Since nightlight data is an objective measure, it is not affected by issues such as informal sector activities. It allows us to analyse economic conditions in regions where there is unreliable or incomplete data. Hence, nightlight intensity values enable more accurate assessments of economic activity especially for developing countries.

In their research, Weidmann and Schutte (2017) investigate whether nightlight emissions can predict economic wealth at the local level within a country, as well as in other areas across different countries. They utilize annual nightlight emissions data from the DMSP-OLS satellite and economic wealth information gathered from DHS surveys, covering 39 developing countries worldwide. This study yields three important findings. First, nightlight emissions can predict local wealth with a correlation of up to 0.87 in some instances (Weidmann B. & Schutte, 2017, p. 126). Second, non-linear models perform better in predicting economic wealth which means that the relationship between nightlights and economic welfare is not linear. Third, predictions within countries are more accurate than cross-national ones. Overall, the study demonstrates the robustness of using nightlights as a proxy for economic wealth. The most significant implication is that it enables the estimation of economic conditions in areas lacking reliable or available data.

As we discussed in detail in previous studies, using nighttime lights as a proxy for economic activity is a valid approach. Nightlight intensity can reflect changes in economic performance, population movements, and even infrastructure development. This sensitivity to such factors makes this indicator a valuable tool that allows observing all these development from the space particularly in case of unexpected events such as disasters.

In this context, Levine (2023) examines the feasibility of using nighttime satellite imagery to map areas affected by the February 2023 earthquakes and quantify the extent of damage in Türkiye. The researcher utilizes NASA's VIIRS/DNB sensors to evaluate nighttime light levels before and after the earthquakes and interprets the variations as indicators of infrastructure damage and human activity. According to the results, regions experiencing an earthquake intensity of at least 7.5 magnitude, 27% of lit grid cells showed a statistically significant decline of 30% or more in their nightlight values following the 7.8 magnitude earthquake (Levin, 2023, p. 3). It important to emphasize that significant decreases in nighttime lights are strongly correlated with areas that experienced the highest levels of seismic intensity and severe building damage (Levin, 2023, p. 9).

The research is notable in terms of its robust methodology. The researcher uses t-tests and correlation analysis to assess the significance of changes. Comparisons of data before and after the earthquake, along with sensitivity analysis, strengthen the findings. However, this approach cannot precisely identify the causes of reduced nighttime lights, such as whether it is due to infrastructural damage or a power outage. Nonetheless, this method can enhance disaster response efforts.

Tveit, Skoufias, and Strobl employs VIIRS nightlight data as a proxy for economic activity to assess the impact of the 2015 Nepal earthquakes in their 2022 article. They evaluate differences in nightlight intensity between cells which represents areas that were damaged or undamaged by the earthquake. In the analysis, they apply two main methods namely the mean nightlight intensity comparison and double difference fixed effects regression model. They focus on the Central region and Kathmandu, which were severely affected by the earthquakes, as well as the rest of Nepal.

The regression results reveal a decrease in nightlight intensity immediately after the earthquake which signifies a negative impact on economic activity. However, the effect of earthquake fades away after a month then we observe an increase in nightlight intensity between 1- and 8-months post-earthquake (Tveit, et al., 2022, p. 7). In contrast, the mean comparison technique fails to identify a difference between damaged and undamaged cells which suggests that there is no significant difference between them (Tveit, et al., 2022, p. 11).

The researchers integrate population density and damage indices with VIIRS data to enhance the accuracy of the results. This method strengthens the analysis and can be evaluated as useful to overcome the problems of nighttime light data such as blooming effects and airglow contaminations, especially in rural areas where the nightlights may be less correlated with economic activity. On the other hand, researchers state that there is a considerable amount of noise in the nightlight data especially due to cloud cover and airglow contamination. This noise can lead to measurement errors and may bias the results. Furthermore, missing data problem caused by cloud covers necessitates interpolation, which further adds to the uncertainty of analysis.

Joseph (2022) investigates the causal impact and long-term consequences of the 2010 Haiti Earthquake on economic growth and recovery. The researcher uses nightlight intensity as a proxy for economic activity and analyse district-level variations in nightlights caused by the earthquake using the DiD method. Unlike similar studies, the researcher also applies a panel VAR method and obtains IRFs to reveal the long-term consequences of the earthquake and evaluate the effectiveness of recovery efforts.

According to the DiD estimation results, nighttime light levels significantly decrease in treatment districts where earthquake intensity exceeds 7 in MMI scale, compared to control districts in the short term (Joseph, 2022, p. 6). Panel VAR regression results confirm the negative relationship between nighttime lights and earthquakes in severely affected areas compared to less affected areas. The results also reveal that this negative impact on economic growth persists over a 10-year period (Joseph, 2022, p. 16). This finding is important as it demonstrates how deep and long-lasting a negative shock to the economy can be in a low-income country.

This is a significant study because nearly three decades of data is used before and after the earthquake which allows researcher to analyse long term economic impacts over a 10-year period following the earthquake. The application of IRFs helps to observe changes due this negative shock during the recovery period. However, there are some limitations to consider. First, districts in the treatment and control groups may have different economic structures which leads us to question comparability between these groups. The situation can introduce bias, even though the researcher employs several robustness checks. Second, the lack of alternative data sources, such as district-level GDP, prevents direct comparisons of the results. Relying solely on nightlight intensity may limit the study's accuracy.

The Haiti earthquake demonstrated that a severe negative shock, like a powerful earthquake, can have a devastating and long-lasting impact on the economy of a low-income country. However, this conclusion may lack external validity. In their research, Heger and Neumayer (2019) examine the short- and long-term economic effects of the 2004 Indian Ocean tsunami on Aceh province in Indonesia. Specifically, they investigate how an unprecedented amount of international aid for reconstruction after a catastrophic disaster affected the regional economic growth. To measure variations in the regional economy, the researchers use district-level GDP and subdistrict-level nightlight intensity data. They employ DiD and synthetic control methods to compare economic activity between districts affected by the tsunami and those that were not.

As expected, the immediate effect in the tsunami-stricken areas is a decline in economic output which results in lower GDP growth rates in 2005 compared to undamaged areas. The analysis shows that the damaged areas have growth rates between 8.1 and 8.6 percentage points lower than they would have been if the tsunami had not occurred (Heger & Neumayer, 2019, p. 8). Surprisingly, the long-term impact of the tsunami on the regional economy is positive in this case. Reconstruction efforts and aids funded by international donors and the national government led to higher growth rates in the affected districts. For instance, these districts grew between 9.6 and 23.7 percentage points more than unaffected districts, depending on the counterfactual (Heger & Neumayer, 2019, p. 8). This suggests that Aceh's economy not only recovered to its pre-tsunami level but also continued to grow at a high rate. The research adapts a strong causal identification strategy. The use of DiD and synthetic control methods together enhances the validity of the results. The use of district level GDP and sub district level nightlight intensity data allow researchers to conduct a detailed analysis of economic impact heterogeneity.

Different from studies that focus on a single devastating earthquake and its economic impact on a specific region or small country, Fabian, Lessmann, and Sofke (2019) analyse earthquakes that occurred worldwide from 1992 to 2013. To be more precise, the researchers aim to reveal the impact of earthquakes on nighttime lights, which serve as a proxy for economic activity. They examine regional development with geo-coded data, using various spatial scales such as small grids, rough grids and country level. Furthermore, to explain the heterogeneity of the results, they use interaction terms, including proxies for national institutions and economic structure, to investigate how these factors influence the earthquake's impact on the economy.

The study relies on dataset consists of detailed information about 360.000 earthquakes from the US Geological Survey and nighttime lights data totalling 700 million satellite year observations (Fabian, et al., 2019, p. 4) The researchers employ panel fixed effects regression to examine how earthquakes impact nighttime light levels.

The results show that earthquakes have a statistically significant negative impact on both light growth and light variation. For instance, an earthquake with a magnitude of 8.0 on the Richter scale causes light intensity in a 1 x 1 grid cell to decrease by approximately 2.5% (Fabian, et al., 2019, p. 4). The negative impact persists for up to 5 years, but there is no significant long-term effect beyond this period. It is important to note that the results vary depending on the size of the area under consideration. For example, the negative impacts are strongly felt at the local level but decreases when the area size increases. Finally, as expected, the researchers confirm that strong institutions, high income and savings rates, and a large government size help mitigate the negative impact of earthquakes on the economy.

The analysis is robust thanks to the extensive dataset covering the entire world over two decades and the solid methodological framework. These characteristics increase the generalizability of the results. However, this generalizability can also be evaluated as a limitation because each disaster creates different outcomes in different economies, political and cultural structures. Furthermore, the study challenges the orthodox belief that catastrophic disasters bring about long-term economic decline and demonstrates that strong institutional structures and favourable economic conditions can alleviate negative consequences of disasters.

Chapter 3
Data and Methodology

3.1 Data Sources

In this study, I utilize global nighttime light dataset which covers the period between 1992 and 2020. The data was harmonized and validated by Li, et al., 2020 and obtained by them. The dataset is composed of two key sources: DMSP-OLS and VIIRS. It allows for a long-term analysis of economic activity in the Marmara region before and after the 1999 earthquakes.

DMSP-OLS (1992–2013)

The DMSP-OLS dataset provides information about nighttime light intensity in the form of a digital number (DN) ranging from 0 to 63 for the years between 1992 and 2013. The satellite captures the Earth's surface between latitudes 65°S and 75°N, and longitudes 180°W to 180°E, with a spatial resolution of 30 arc-seconds (Li, et al., 2020, p. 2). The raw DMSP-OLS data has problems that prevent comparability such as satellite sensor degradation, atmospheric conditions, and satellite shifts, consequently, stepwise calibration approach was applied to create a temporally consistent dataset (Li, et al., 2020, p. 2).

VIIRS (2012–2020)

VIIRS data, on the other hand, offers more precise measurement of nighttime light intensity than DMSP-OLS owing to its higher spatial resolution (15 arc seconds) and improved radiometric accuracy (Li, et al., 2020, p. 2). The data is cleaned of stray light sources such as auroras, fires, and other non-human activities and is presented monthly basis from 2012 to 2020 monthly.

DMSP-OLS has certain advantages over VIIRS for interpreting human activities from space. For this reason, researchers have established a framework that utilizes sigmoid function to convert VIIRS radiance values into DMSP-like DN values. Hence, they maintained the consistency and were able to extend the data beyond 2013. The final harmonized dataset includes DMSP-OLS data from 1992–2013 and converted VIIRS data from 2014–2020. The harmonized global nighttime light dataset is a valuable tool to analyse human activities particularly in cases where the data is unavailable or unreliable. It facilitates the study of urbanization, carbon emissions, electricity consumption, and light pollutions (Li, et al., 2020, p. 7).

Earthquake Damage Reports

The data on the total number of buildings, the number of buildings by damage level, the district population for 1997, and the surface area of districts are mainly drawn from two key sources:

- *Damage Status of the August 17, 1999 Izmit Gulf Earthquake (with Numerical Data) the Turkish Earthquake Foundation* by Bülent Özmen.
- *Residential and Commercial Damages of the November 12, 1999 Düzce Earthquake (with Numerical Data)* by Bülent Özmen.

For specific districts such as Kaynaşlı, Avcılar, Bakırköy, Bayrampaşa, Güngören, Küçükçekmece, Maltepe, Sultanbeyli, Tuzla, and Yıldırım, surface area data was sourced from the Republic of Turkey Ministry of National Defence, General Directorate of Mapping. The 1997 district population data was also used for population estimation for districts where this data is available.

There are some exclusions that are worth mentioning. Derince was announced as a district in 03.12.1999 and lacks data on damaged buildings from the August 17 earthquake. Therefore, it is omitted from the analysis. Nightlight data for the central districts of Eskisehir is unavailable even though there are severely damaged buildings there. For this reason, the province is excluded from the analysis.

Population Data (1965–2020)

The population data for the districts in the Marmara region was obtained from the Turkish Statistical Institute (TUIK). TUIK provides district-level population data through the "Address-Based Population Registration System" (ADNKS) for the years between 2007 and 2020. These data were directly achieved from TUIK's website.

For the years between 1992 and 2006, population data were not available on a yearly basis. To address this, I interpolated and extrapolated when needed the missing values using available population census data for the years 1965, 1970, 1975, 1980, 1985, 1990, and 2000. I downloaded the data from TUIK and processed in Excel. I used STATA to interpolate and extrapolate the population size for the missing years.

3.2 Construction of Treatment and Control Groups

To categorize districts into treatment and control groups for the analysis, it is crucial to determine how much each district was affected by the earthquake. The intensity of the earthquake changes significantly across districts, and to capture this variation, I have constructed a damage index. This index allows for the measurement of the earthquake's impact by integrating various district-level factors.

The available data includes the total number of buildings, the number of damaged buildings (categorized as heavy, moderate, and low), population and surface area. By utilizing these data, the Damage Index is calculated with the following formula:

$$= \left(\frac{Severly\ Damaged\ Buildings}{Total\ Buildings}\right) \times \left(\frac{Severly\ Damaged\ Buildings}{Population} \times 1.000\right) + \left(\frac{Severly\ Damaged\ Buildings}{Surface\ area}\right)$$

The index provides a measure of earthquake intensity by reflecting both the density of damage and its distribution across each district. The ratio of severely damaged buildings to total buildings accounts for the extent of superstructure damage within each district. It gives information about how severely the built environment was affected. The ratio of severely damaged buildings to population, on the other hand, multiplied by 1,000 to standardize aims to include the social impact of the earthquake into calculations. Finally, the ratio of severely damaged buildings to surface area captures how concentrated the damage is relative to the district's geographical size.

The index value enables to categorize districts into treatment and control groups based on the severity of the damage they were exposed to. After calculating the index for all districts which are in the provinces affected by the earthquake, I excluded the ones that did not report any heavily damaged building. They were not considered either in the treatment or control group because including them would have diluted the effect of the earthquake. Then, I ranked them from the highest to the lowest in terms of earthquake impact. Initially, I selected the first 25 districts with the highest Damage Index for the treatment group and assigned the remaining districts to the control group. This selection includes districts from a geographical area that the impact was severe and heavily damaged districts frequently mentioned in the media such as the central districts of Kocaeli, Sakarya and Düzce, Çiftlikköy, Gölcük, Gölyaka, and Avcılar.

To ensure the robustness of my analysis, I expanded the treatment group to include the top 30 districts to perform a secondary analysis. This allows for an assessment of whether expanding the treatment group changes the estimated impact of the earthquake. I expect that the results are not sensitive to the specific cutoff of 25 districts. The proper classification of treatment and control groups is very important for conducting DiD analysis because only in this case the estimations reflect the true reaction of the economic activity proxied by mean nightlight intensity to the earthquakes.

3.3 Empirical Strategy

3.3.1 Panel Data Estimation and Difference in Differences (DiD) Method

Panel data refers to datasets that include various types of information related with different units, such as individuals, firms, states, or districts, which were observed over at least two different time periods. As the definition makes clear, they combine both cross sectional and time series aspects which provide distinct advantages over solely cross sectional or time series data. These characteristics of the panel data allow us to analyse changes across units and over time more comprehensively.

Panel data is widely preferred to evaluate the impacts of shocks such as policy changes, natural disasters etc. in quasi-experimental or experimental settings on specific units across a defined time period. For example, in this study, panel data enables for the investigation of how mean nightlight intensity of districts changed over time, specifically before and after the 1999 Marmara earthquakes.

As mentioned, panel data sets have two dimensions: cross-sectional units (individuals, firms, states or districts) and time periods (generally in years). The data set can be balanced if all units are observed through the same number of time periods or unbalanced if number of observations per unit changes (Gujarati & Dawn, 2009, p. 593).

Panel data offers several advantages over cross sectional or time series data alone. First of all, number of observations is relatively higher due to time and cross-sectional aspects which improves the precision of estimates (Wooldridge, 2016, p. 403). This allows for more degrees of freedom, less collinearity among variables, makes the estimates more efficient and reduces aggregation bias (Gujarati & Dawn, 2009, pp. 592-593). Second, panel data provides consistent estimates in case of an omitted variable which is constant over time even it is not homogenous across units (Cunningham, 2021). Finally, the panel data structure is particularly well-suited for investigating mechanisms of change, such as how an educational reform affects student success or how production subsidies influence output (Gujarati & Dawn, 2009, p. 592). In the context of this research, for instance, our panel data enables the examination of how the economic activity of districts which is proxied by mean nighttime light intensity, varies through time as a response to the earthquakes. There are three models to reveal causal relation among variables and to account for individual heterogeneity in panel data analysis. These are pooled ordinary least squares (POLS), fixed effects model, and random effects model.

POLS is a simple estimation method in which we pool all observations by disregarding the panel structure and unobserved heterogeneity across different units (Cunningham, 2021). This method assumes that all units are homogenous, and unit specific characteristics can be ignored. However, this approach is not usually realistic and does not account for heterogeneity among units and produces biased estimates if unobservable characteristics are correlated to variables in the model (Cunningham, 2021).

Different from POLS, the fixed effects approach foresee each unit in the model to have their own intercept which does not vary over time and by doing so it accounts for time-invariant heterogeneity (Gujarati & Dawn, 2009, p. 596). This model is useful when various unobserved characteristics that are constant over time such as cultural practices, mental capacity of adults or political stability etc. are likely to influence other variables in the model. For example, in this reasearch, each district has its own geographic and cultural characteristics that may not easily change over time and difficult to identify and measure but may still affect economic activities.

There are two types of fixed effects model namely one-way fixed effects and two-way fixed effects model. One-way fixed effects model controls for all time-invariant factors influencing variables in the model by forming a unit-specific intercept which isolates the causal effect of the independent variables on dependent variable (Gujarati & Dawn, 2009, p. 596).

The one-way fixed effects model can be expressed as:

$$y_{it} = \beta_i + \beta_1 x_{it} + u_{it}$$

y_{it}: dependent variable represent unit i at time t

β_i: represents unit specific intercept. It captures time invariant factors.

x_{it}: time varying independent variable

u_{it}: idiosyncratic error term

In this model, the unit-specific intercept (β_i) takes over all time-invariant characteristics that may influence dependent variable. This ensures that the change in dependent variable can be explained by time variant factors stand as an independent variable.

Apart from unit specific time invariant characteristics controlled by one-way fixed effect model, two way fixed effects model further accounts for time specific factors such as policy changes or technological improvement that may have equal impact on each separate unit (Gujarati & Dawn, 2009, p. 598).

Two-way fixed effects model can be expressed as:

$$y_{it} = \beta_i + \theta_t + \beta_1 x_{it} + u_{it}$$

y_{it}: dependent variable represents unit i at time t

β_i: represents unit specific fixed effects. It captures time invariant factors.

θ_t: time specific fixed effects. It accounts for changes or shocks equally affect each unit in a given year.

x_{it}: time varying independent variable

u_{it}: idiosyncratic error term

The two-way fixed effects method allows us to control for unobserved heterogeneity in both dimensions by combining unit and time fixed effects in the same model.

Finally, random effects method offers an alternative to the fixed effects method and it is an appropriate approach in situations where the unit specific effects are time variant and considered as random. The random effects model treats intercepts of the cross-sectional units as deviations from a common mean to allow for individual variation however it assumes that these variations are random and uncorrelated with the explanatory variables (Gujarati & Dawn, 2009, pp. 602-603).

Two-way fixed effects method is especially relevant to my analysis in which I evaluate the impact of the 1999 Marmara earthquakes over time across districts. This approach ensures that both district-specific factors such as culture or geographic structure and time-specific events i.e., policy changes or economic crisis are controlled. It allows for a more accurate estimation of the causal effects of the earthquake on economic activity.

As discussed in detail in previous paragraphs, the panel data structure is a suitable tool for analysing changes for different units in the model by taking account of both time and spatial dimensions. This is also an essential feature for the DiD approach. In particular, the integration of two-way fixed effects strengthens the DiD's ability to control for both unit-specific and time-specific variations. It is a proper way to achieve a better estimation for treatment effect by comparing pre- and post-intervention trends across groups. With that in mind, I will now explain the DiD method in detail.

The DiD approach is a widely used impact evaluation technique that aims to reveal the causal relationship, if there is any, between an outcome and a change or a shock. The technique is especially useful in situations where randomized experiments are not feasible. To be more precise, DiD framework is set up to quantify the impact of a change such as a policy change or a natural disaster by comparing the variation in outcomes over time between two groups namely a treatment group that exposed to this change and a control group that does not (Gertler, et al., 2016, p. 130). Treatment and control groups must share similar characteristics before treatment. If not, the estimates would be biased.

We calculate two differences to estimate the treatment effect in the DiD method. The first difference captures the change in a specific outcome for units in the treatment group before and after the intervention. The second difference does the same for units in the control group. The DiD estimator is the difference between these two differences which provides an unbiased estimate of the intervention's effect by controlling time-invariant heterogeneity between control and treatment group (Khandker, et al., 2010, p. 72). The method mitigates the issues related with heterogeneity between groups owing to this double differencing. Thus, it provides a more accurate scenario for the counterfactual with the help of the observed change in the control group and estimates what the change in outcomes for the treatment group would have been if there were no intervention (Gertler, et al., 2016, p. 132).

Parallel trends assumption is the key assumption for DiD method. It anticipates that the outcome we examine for its response to treatment exhibits similar trends in control and treatment groups prior to the intervention. If the assumption does not hold, the control group fails to serve as a counterfactual for the treatment group and we cannot obtain a valid and unbiased estimate of the intervention due to time-varying factors that creates dissimilar patterns in control and treatment groups (Gertler, et al., 2016, pp. 135-136). Regrettably, there is no definitive method to prove the validity of the parallel trends assumption however, we can only evaluate whether an evidence of parallel trends exists (Gertler, et al., 2016, p. 137). If both groups exhibit parallel trends in the pre-intervention period, the reliability of the assumption that these trends would have continued in tandem after the intervention is strengthened (Gertler, et al., 2016, p. 137). We can also perform a placebo test by applying the DiD approach to a fake treatment group or to a fake treatment group with fake outcome or using different comparison groups (Gertler, et al., 2016, pp. 137-138). If these tests show zero treatment effect, it means the parallel trend assumption is valid, and we can say that the observed treatment effect in case of our actual treatment and control group is a result of the intervention.

We can apply the DiD method within a regression framework which enables the inclusion of time varying covariates as well as unobserved time invariant heterogeneity (Khandker, et al., 2010, pp. 72, 74). The regression specification can be written as follows:

$$Y_{it} = \alpha + \beta_1 Treatment_i + \beta_2 Post_t + \beta_3 (Treatment_i \times Post_t) + \beta_4 \mathrm{X}_{it} + \varepsilon_{it}$$

Where;

Y_{it}: The outcome variable for unit i and time t.

α: time invariant, unit specific effects

$Treatment_i$: Takes the value of 1 if a unit belongs to the treatment group; otherwise, 0.

$Post_t$: Takes the value of 1 in case of post treatment period; otherwise, 0.

$\mathrm{Treatment}_\mathrm{i} \times \mathrm{Post}_\mathrm{t}$: The interaction term captures the DiD estimate in other words average treatment effect on the treated (ATET). β_3 quantifies the impact of the intervention.

X_{it}: vector of control variables

ε_{it}: The idiosyncratic error term

As we recall from the panel data section, we can also include time-specific fixed effects in this type of DiD regression framework. Owing to this set up, we can control for time invariant, unobserved unit specific characteristics as well as common time trends which allow us to achieve a clearer estimation of the treatment effect (Khandker, et al., 2010, p. 74, Gertler, et al., 2016, p. 134).

The DiD is especially useful when the other methods such as randomized controlled trials, instrumental variable and regression discontinuity design are not possible to apply because it allows us to assess average treatment effect even if we do not know explicit program assignment rules (Gertler, et al., 2016, p. 129). However, the main weakness of this method is that it requires stronger assumptions such as parallel trends compared to the methods mentioned above. DiD does not also account for time-varying unobserved factors that may differently affect the treatment and control groups (Khandker, et al., 2010, p. 77). For example, if an external shock occurs during the intervention period that affects the treatment and control groups unequally, it may bias the DiD estimate. Furthermore, if the parallel trends assumption does not hold, the DiD estimates may be invalid. Hence, we should apply robustness checks, such as re-estimating the model with alternative control groups or applying some placebo tests to support the validity of the findings.

3.3.2 Model Specification

In this study, I utilize DiD method and estimate a two-way fixed effects regression to find out the causal relationship between the 1999 Marmara earthquakes and mean nighttime light intensity which stands for regional economic activity. The model enables to compare the changes in mean nighttime light levels between districts severely affected by the earthquakes (treatment group) and those less affected (control group) through time by controlling both spatial and time specific unobserved factors.

The basic model to be estimated is presented as follows:

$$NL_{i,t} = \beta_0 + \beta_1 post_t + \beta_2 eq_i + \beta_3 post_t \times eq_i + \beta_4 ln\,(pop_{it}) + \gamma_i + \delta_t + \epsilon_{i,t}$$

$NL_{i,t}$: Natural logarithm of mean DMSP OLS night light in district i and year t.

$post_t$: dummy variable, 1 if year is greater than or equal to 1999 and 0 during pre-earthquake period (1992-1998).

eq_i: dummy variable, 1 for districts classified as "severely affected" based on the Damage Index and 0 for otherwise.

$posteq_{i,t}$: It is the interaction term that represents the treatment effect. The coefficient β_3 captures the Average Treatment Effect on the Treated (ATET).

$\ln\,(pop_{it})$: It represents the natural logarithm of the population of district i in year t. As a control variable, it accounts for population size and its influence on mean nightlight intensity to make sure that variations are not simply driven by the earthquake.

γ_i: district fixed effects to control for time invariant, unobservable characteristics at spatial level.

δ_t: time fixed effects to neutralize shocks or trends in a year basis across all districts.

$\epsilon_{i,t}$: error term.

3.3.3 Assumptions and Robustness Checks

The validity and credibility of the DiD approach depends on several key assumptions namely parallel trends assumption and time invariant unobserved heterogeneity. In this section, I will explain these assumptions that form the basis of the analysis and describe the robustness checks I will perform to guarantee the validity of the results.

As we recall from the section 3.3.1, parallel trends between treatment and control groups are the fundamental assumption of the DiD methodology. It states that in the absence of the intervention, 1999 Marmara Earthquakes in our case, the treatment and control groups would have followed the same trend in mean nightlight intensity over time. Based on the assumption, we infer that any deviation in mean nightlight intensity in the post treatment period between districts in two different groups can be ascribed to the earthquakes rather than other factors.

Another assumption underlying our framework is that unobservable changes with the potential to affect outcomes in the control and treatment groups remain constant over time for each group. The two-way fixed effects model further helps us to control for such time invariant unobserved heterogeneity, thus strengthen the validity of this assumption. Owing to the model, we mitigate the impact of unobserved shocks that may cause variations in outcome variables in two groups disproportionately.

I will apply a series of robustness checks to ensure the reliability of the DiD estimates. Initially, to test the parallel trends assumption, I will first include a graph that shows the change in mean nightlight intensity during pre-earthquake period in treatment and control group districts. The graph can visualize the trend between these groups and supports in the decision of the validity of this assumption. Second, I will estimate a regression that analyse trends between two groups in pre-treatment period. To be more precise, I will create a variable that represent linear time trend and regress mean nightlight intensity against the interaction between this time trend and treatment group with robust standard errors in pre-treatment period. I expect statistically insignificant results for the interaction term which validates the existence of parallel trends.

Secondly, I will include population size and lagged population size separately as control variables in alternative model specifications. This will confirm the robustness of the treatment effect if there is no significant change in the direction, magnitude, or significance of the estimated treatment effect.

Thirdly, I will re-estimate the model by including the first 30 districts with the highest damage index to the treatment group, rather than the 25 districts used in our initial analysis. This will expand the treatment group and allows us to evaluate whether the magnitude or statistical significance of the effect changes or not.

Finally, I will estimate the model both with and without fixed effects. Two-way fixed effects model control for unit specific and time invariant unobserved heterogeneity as well as unexpected developments such as financial crises or technological progress that may occur throughout the given period. Hence, we can estimate the treatment effect on expected outcome independent from these phenomena under statistically significant confidence intervals. However, when fixed effects are not included in the model, we expect the results to lose significance. This demonstrates that the statistically significant results obtained with the two-way fixed effects model are robust and not simply a product of model specification.

Chapter 4
Analysis and Discussion

4.1 Descriptive Analysis

Table 2 presents the percentage distribution of nighttime light intensity across various brightness ranges in the earthquake-affected provinces of the Marmara region from 1992 to 2020. It also includes the average DN values for the entire period and population in 1999.

İstanbul has a substantial portion of its nighttime lights in 21-62 and top coded DN category, in total 87%, which indicates a high level of economic activity and urbanization. The province's average DN of 48.1, the highest among all provinces in the Marmara region, further consolidates its status as an economic hub with extensive urbanization and developed infrastructure. There is no doubt that İstanbul is the economic centre of the region as well as Türkiye. The city, with a population of approximately 11 million, was also the largest city in 1999.

Table 2: Nighttime Lights in Earthquake Stricken Provinces 1992-2020

Digital Number (DN)	İstanbul	Kocaeli	Yalova	Bursa	Sakarya	Düzce	Bolu
0	0	0	0	0	0	0	0
1-2	0.3	3.9	6.3	19.7	9.9	11.2	48.7
3-5	1.8	12.3	16.7	19.9	27.3	14.2	20.3
6-10	2.7	26.1	24.7	26.2	27.3	39.7	24.5
11-20	8.3	34.5	36.2	19.9	23.9	25	6.5
21-62	66.8	22.7	16.1	14.4	11.7	9.9	0
63 (top coded)	20.2	0	0	0	0	0	0
Avg. DN values	48.1	13.1	12.3	10.8	9.7	9.5	3.5
Population in 1999	10.960.037	1.185.961	242.363	2.072.940	748.848	313.548	269.908

Source: The author's own calculations.

Kocaeli, the epicentre of the August 17, 1999 earthquake, has the majority of its nighttime lights concentrated in the 6-10 (26.1%) and 11-20 (34.5%) brightness ranges. The province also shows a presence in lower DN categories such as unsaturated (3.9%). This means that while some areas are economically highly active, others are less developed. With the highest average DN after İstanbul, the province stands out as region's industrial capital. Furthermore, the province has the third biggest population in our analysis.

Yalova is similar to Kocaeli because the most of its nighttime lights concentrated in the 6-10 and 11-20 categories. However, the province has a smaller percentage (16.1%) in the 21-62 category compared to Kocaeli which means relatively more moderate economic activity. Based on the distribution of these categories, we can say that Yalova shows varying levels of economic development across different areas. With an average DN of 12.3, the province ranks as the third highest in the region.

Bursa, the second largest city in our analysis, exhibits considerable activity in the lower DN categories, with 19.7% in the 1-2 range and 19.9% in the 3-5 range. This distribution indicates that, although the province has economically active areas, these activities are less concentrated compared to Istanbul and Kocaeli. One reason for the lower mean nightlight levels may be Bursa's strong agricultural tradition, which results in less nighttime light emission. Another reason may be that the night light intensity is more dispersed to Bursa's districts due to their large populations and economic development.

Sakarya demonstrates a relatively balanced distribution across different DN categories. The province has a significant share in both the 3-5 (27.3%), 6-10 (27.3%) and 11-20 (23.9%) ranges. On the contrary, Düzce the epicentre of the November 12, 1999 earthquake, has the majority of its nighttime lights concentrated in the 6-10 DN category (39.7%). The average DN values for Sakarya (9.7) and Düzce (9.5) suggest a moderate level of economic activity in these regions.

Finally, the 48.7% of Bolu's nighttime lights are found in the low DN range (1-2 category). This is an indication of low economic activity. The province has also the lowest average DN value among all other provinces. We can say that Bolu experiences relatively less economic activity in terms of its nighttime lights.

The table 3 shows the average nighttime light intensity in pre-earthquake period (1992-1998) in districts categorized as either treatment or control. Treatment group consists of the first 25 districts with the highest index value and the control group contains the rest which has at least 1 severely damaged building. Since nighttime light intensity serves as a proxy for economic activity, the data allows us to compare economic conditions between these two groups.

Table 3: Baseline Comparison of Nightlights Mean

Groups	Obs.	Mean	Std. Dev.	Difference (SE)	p-Value*
Treatment	175	21.6	23.3	-3.12 (2.28)	0.17
Control	231	18.5	22.3		

Source: The author's own calculations.

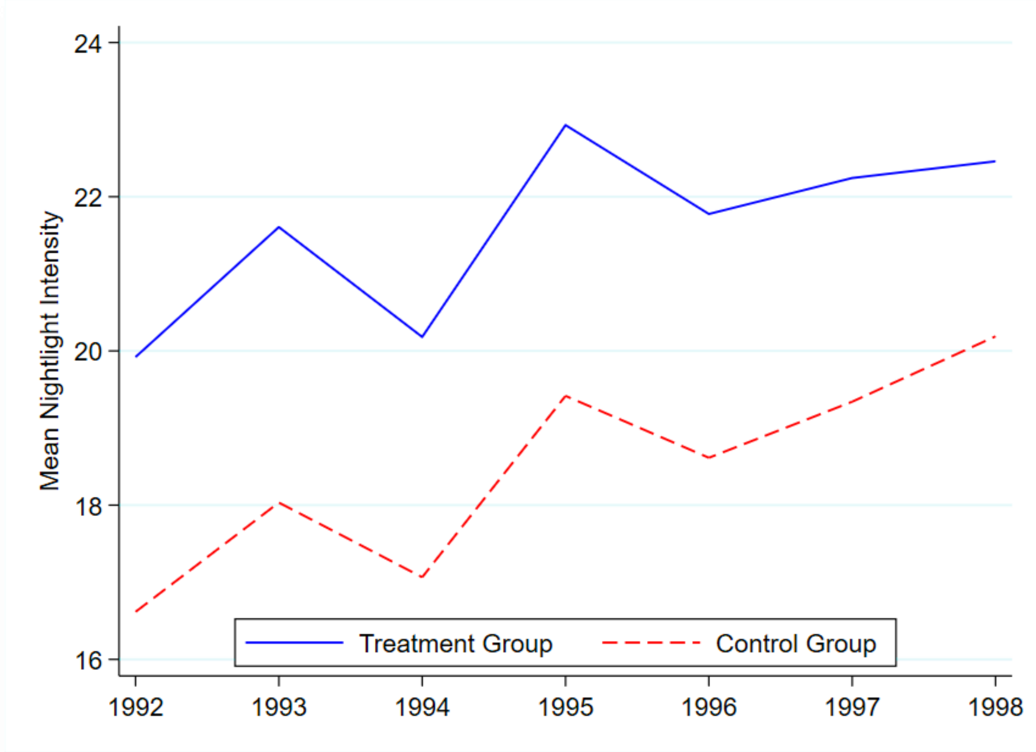
* two tailed p-value result is used in the analysis.

The average mean nighttime light intensity in control districts is 18.5 whereas in treatment districts, it is 21.6 which indicates a slightly higher levels of economic activity and urbanization. The relatively high standard deviation in each category suggests that there exists significant variation in the levels of economic development, types of economic activities and urban rural distribution across these districts. The difference in average nighttime lights between the groups is -3.12 (SE = 2.28) and corresponding two tailed p-value is 0.17 which means that there is no statistically significant difference in pre-earthquake nightlight intensity between the treatment and control groups. This result shows that groups are comparable at baseline.

When we analyse the districts that constitute control and treatment groups, we see that both groups include highly urbanized districts, industrial centres as well as rural and less urbanized districts. Before conducting the t-test, one might also claim the control group to have a higher mean nightlight intensity than the treatment group. There is no strong reason to assume that neither control or treatment group has greater or lower mean thus, in such cases it is appropriate to use a two tailed test results to evaluate baseline comparability (The Open University, 2024).

For DiD to be a legitimate model and to provide unbiased estimates, it is obligatory to meet parallel trends assumption. In our case, it is crucial that treatment and control groups follow similar trends in mean nightlight intensity during pre-earthquake period (1992 – 1998).

Figure 2: Pre-Earthquake Mean Nightlight Intensity: Treatment and Control Districts



Source: The author's own calculations.

Figure 2 shows the trends in mean nightlight intensity for both groups during the pre-treatment period (1992–1998). It can be seen from the graph that treatment and control groups exhibit similar patterns of variation during the indicated period and there is no obvious divergence. Although there are minor deviations especially after 1996, the overall trends appear to be parallel which supports the validity of the parallel trends assumption.

The regression model results presented in the table 4 indicate that the coefficient on the interaction term "time * eq" is statistically insignificant. Thus, we can state that there is no evidence for the existence of differential trends between the treatment and control groups. We can conclude that the parallel trends assumption holds in our model based on the visual assessment as well as regression results. This means that DiD method is appropriate to apply and can provide unbiased estimate of the effect of the 1999 earthquakes on mean nightlight intensity.

Table 4: Regression Test for Parallel Trends (Pre-Treatment Period)

Dependent Variable: Mean Nightlight Intensity	Results for Pre-Treatment Period
Trend (time)	0.531
	(0.737)
Treatment Group (eq)	3.591
	(4.104)
time*eq interaction	-0.157
	(1.151)
Observations	406

Source: The author's own calculations.

Robust standard errors in parentheses

Significance: *** p < 0.01, ** p < 0.05, * p < 0.1

4.2 Difference-in-Differences Estimation Results

Table 5 presents the summary of the results of six regression models which evaluate the impact of 1999 Marmara earthquakes on mean nighttime light intensity in severely affected districts relative to less affected control districts. In all models, standard errors are clustered at the district level and dependent variable is always the natural logarithm of mean nighttime light intensity which stands as a proxy for regional economic activity. I utilize two-way fixed effects by controlling for both district and year fixed effects from model 1 to 3 while I investigate alternative specifications with partial or no fixed effects from model 4 to 6 to assess robustness.

Table 5: The Impact of 1999 Earthquakes on Nightlight Mean, 1992-2020

Dependent Variable: log of mean nightlights	(1)	(2)	(3)	(4)	(5)	(6)
ATET (interaction term)	- 0,19**	- 0,19**	- 0,15*	- 0,14	-0,14	-0,14
	(0,098)	(0,099)	(0,088)	(0,103)	(0,093)	(0,104)
ln_population	-	- 0,08	-	-	-	-
		(0,16)				
lagged ln_population	-	-	-0,06	0,60***	0,31**	0,59***
			(0,14)	(0,061)	(0,15)	(0,62)
Constant	2,74	3,65	3,49	-4,58	-1,22	-4,09
District fixed effects	Yes	Yes	Yes	No	Yes	No
Time fixed effects	Yes	Yes	Yes	No	No	Yes
Observations	1.682	1.682	1.624	1.624	1.624	1.624
(Within districts) R^2	0,019	0,021	0,013	(0,57)	0,26	0,58

Source: The author's own calculations.

Notes: Standard errors clustered at the district level are shown in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The result given in parentheses in Model 5 is R-squared.

Model 1: Baseline DiD Estimation

The first model estimates the impact of the 1999 earthquakes without adding any additional control variables. The coefficient of interest, ATET, is negative and statistically significant at the 5% level. The estimated effect is -0,19 which means that, on average, the districts affected by the earthquakes experienced a 19% reduction in mean nighttime light intensity compared to the control group. This result provides strong evidence that the earthquakes had a negative impact on economic activity in the affected districts.

Model 2: Controlling for Population

I added the natural logarithm of the population as a control variable in model 2. The ATET remains negative and statistically significant at 5% level. The estimated effect is still -0,19. This indicates that the inclusion of population control does not significantly change the magnitude of the earthquakes' impact on mean nighttime light intensity. The coefficient on population is small (-0,08) and it is not statistically significant. We can say that current population size does not have a significant effect on mean nighttime light intensity in this model.

Model 3: Lagged Population

There may be a two-way relationship between current mean nighttime light intensity and population size because districts with higher economic activity (higher nightlight values) may attract more people and larger population can create more economic activity. To address this endogeneity problem, I included the lagged population variable as another control variable. In this scenario, ATET remains negative but decreases to -0,15 and it is only significant at the 10% level. The lagged population variable has a negative, small and non-significant coefficient, -0,06. This result suggests that past population size does not have a significant effect on current nighttime light intensity.

Model 4: Without Fixed Effects

I exclude district and year fixed effects to check the robustness of the results. In this specification, the ATET is still negative, -0,14 but insignificant. The results reveal that the exclusion of fixed effects weakens the model's ability to capture the true effect of the earthquake. However, it is also interesting to note that the coefficient on lagged population becomes positive and significant at 1% level. We can infer from that past population size may play a stronger role in affecting mean nightlight intensity when fixed effects are not controlled for.

Model 5: Without Time Fixed Effects

I add district fixed effects but remove time fixed effects to assess their influence. The ATET remains insignificant at -0,14. The coefficient on lagged population is positive and significant at 5% level. However, the magnitude of the estimate is decreased, as expected, after controlling for time invariant characteristics of districts.

Model 6: Without District Fixed Effects

The last model includes time fixed effects but excludes district fixed effects. The ATET is -0,14 and statistically insignificant similar to Model 4 and 5. The coefficient on lagged population is 0,59, positive and significant at the 1% level. Past population size has again a positive relationship with mean nighttime light intensity when district-specific unobserved factors are allowed in the estimation.

The ATET is insignificant, and the within-district R-squared values are higher in specifications that exclude fixed effects. However, higher R-squared values do not imply that these specifications are better. When unobserved and time-invariant characteristics are not controlled for, the estimates become biased. We obtain a more reliable estimate of the treatment effect by including fixed effects to control for these factors. Therefore, the significant ATET estimates in fixed-effects specifications indicate that controlling for unobserved heterogeneity is essential for valid and credible estimates of the earthquakes' impact on mean nightlight intensity. This is a further proof that including district and time fixed effects in the analysis is highly appropriate.

Table 6 presents the estimation results of our baseline model using both the original treatment group and an alternative treatment group. Alternative treatment group consists of the first 30 districts with the highest damage index. According to the results, ATET remains negative, statistically significant and has a similar magnitude to the original specification. The within R-squared value slightly improved. These results strengthen the robustness of our models. We can reiterate that 1999 Marmara earthquakes have persistent negative impact on nighttime light intensity in the affected districts.

Table 6: Robustness Check with Alternative Treatment Group

Dependent Variable: log of mean nightlights	**Original Treatment Group**	**Alternative Treatment Group**
ATET (interaction term)	- 0,19**	- 0,20**
	(0,098)	(0,102)
Constant	2,74	2,76
District fixed effects	Yes	Yes
Time fixed effects	Yes	Yes
Observations	1.682	1.682
(Within districts) R^2	0,019	0,021

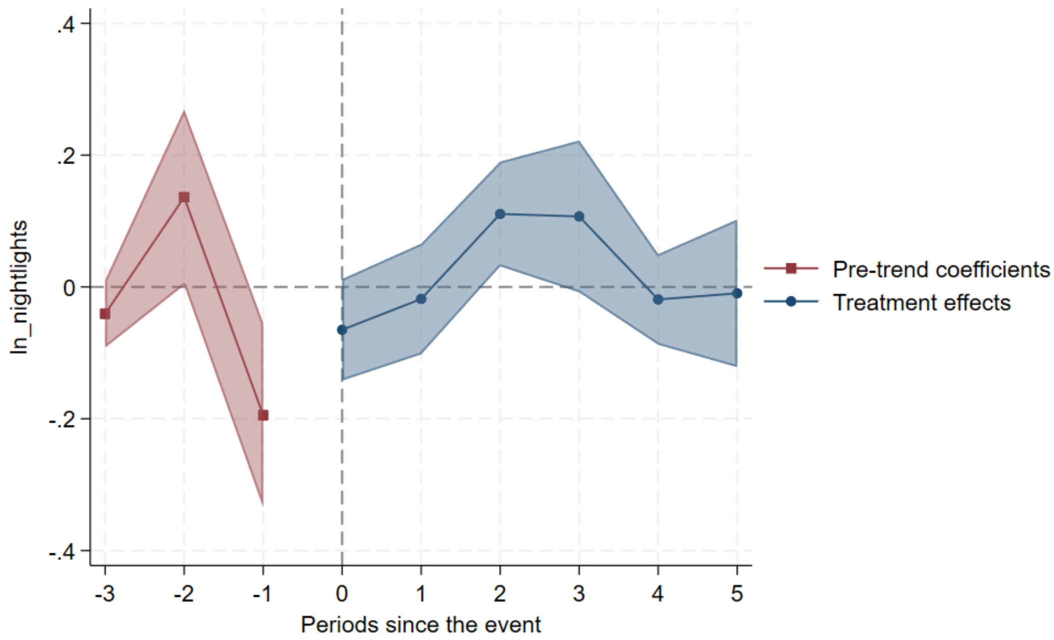
Source: The author's own calculations.

Notes: Standard errors clustered at the district level are shown in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The Callaway and Sant'Anna (2021) approach which is different from classical DiD method, enables the analysis of more than two time periods and differences in the timing of treatment among groups (Callaway & Sant'Anna, 2021, p. 201). It allows us to estimate the ATET for a specific group at any time period rather than a problematic weighting procedure of two-way fixed effects (Cunningham, 2021).

Figure 3 shows event study analysis of the impact of 1999 Marmara earthquakes on mean nightlight intensity. On the X-axis, zero corresponds to the year 1999, the beginning of treatment. Negative values represent periods before treatment whereas positive values stand for periods after treatment (e.g., 3 years before, 5 years after). On the Y-axis, we see natural logarithm of mean nightlight intensity. Shaded regions on the other hand identify the confidence intervals of estimated coefficients.

Figure 3: Event Study Analysis



Source: The author's own calculations.

We can examine time period before the beginning of the treatment to test the validity of parallel trends assumption. The coefficient estimates are close to zero and confidence intervals include zero which signify their statistical insignificance for the period -3 and -2. However, the coefficient for the period -1 is statistically significant which violates the parallel trend assumption. As we can remember from our parallel trends graph, there is a sharp increase in mean nightlight intensity in the control group relative to the treatment group from 1996 to 1998. This apparent upward trend disrupts the parallel trends between these groups.

The impact of the 1999 earthquakes on mean nightlight intensity is immediately evident as a shift starting from period 0. The coefficient increases until period 2 where it reaches its peak and becomes statistically significant. When we come to period 3, it is still positive but shows weak statistical significance. Increase in mean nightlight intensity may be attributed to national and international aid and reconstruction efforts after the earthquake. As we recall from the Chapter 1, national and international aids costs in total $5.5 billion. In period 4, the coefficient is close to zero and statistically insignificant which means that the increase in nightlight intensity observed in previous periods lose its effect and the difference between the treatment and control groups becomes minimal. Finally, the coefficient is zero and statistically insignificant in period 5. This suggests that the effect of the earthquake on nightlights intensity disappeared, in other words, there is no long-term impact detectable by this period.

4.3 Discussion on Findings

The baseline model (Model 1) shows statistically significant and negative impact of the 1999 Marmara earthquakes on regional economic activity. According to the results, there is a 19%

reduction in mean nighttime light intensity in the severely affected districts relative to the less effected control group districts. The magnitude of the effect is considerable; however, given that the Marmara region hosts some of Türkiye's most important industrial facilities, it is not surprising that damage to the superstructure and the loss of skilled labour brought about this outcome.

The inclusion of population size as a control variable in Model 2 does not change the magnitude and the statistical significance of this effect. Besides, it reinforces the robustness of the baseline result. The estimated coefficient of population is small and insignificant. Model 3 includes lagged population size as a control variable to address potential endogeneity concerns. The magnitude of the ATET decreased to -0,15 and its significance weakened but remained at 10% level. This indicates that the model is sensitive to past population dynamics. However, the coefficient of lagged population is small and insignificant. Consequently, neither current population size nor lagged population size has the power to explain the variation in nighttime light intensity. In other words, the negative change in economic activity resulted from the earthquakes and population size does not have the explanatory power on this.

To test the robustness of the two-way fixed effects DiD model, I also estimated alternative specifications by either excluding fixed effects entirely or including only one type of fixed effect. In model 4, the exclusion of both district and year fixed effects led to insignificant ATET which highlights the importance of controlling for unobserved heterogeneity. I keep district fixed effects but exclude time fixed effects in model 5 which results in a similar outcome: insignificant ATET. Finally, in model 6 where I allowed for time fixed effects but exclude district fixed effects, ATET is again insignificant. These findings prove the important role of fixed effects model to produce credible and unbiased estimates.

The results of two-way fixed effects model support our first hypothesis that the 1999 Marmara earthquakes caused a significant decrease in economic activity. The inclusion of population size or lagged population size as control variable still produce negative and significant ATET. The insignificant ATET values in alternative specifications where fixed effects are either totally or partially excluded further signify that controlling for unobserved, time invariant heterogeneity is crucial in disaster impact research.

The Callaway and Sant'Anna approach on the other hand provides a new perspective regarding the earthquakes' impact throughout time. The event study graph shows that pretreatment period coefficients largely support the parallel trend assumption. In the post-treatment era, nightlight intensity increases immediately in the 1st and 2nd periods; however, this change is statistically significant only in the 2nd period. The positive change in nightlight intensity can be interpreted as recovery which may arise from the national and international aid as well as reconstruction activities. Unfortunately, this boost is temporary, it loses its strength in 3rd period and totally disappear by 5th period. This result answers our second hypothesis, in which we test whether the economic impact of earthquakes is permanent. The increases in nightlight intensity that occur quickly after earthquakes is actually due to temporary economic incentives provided by post-disaster interventions rather than enduring economic strategies. In other words, the initial economic recovery does not lead to long-term and sustained economic growth.

The findings set an example for how a devastating earthquake in one of the most developed and industrialized regions of a developing upper middle-income country like Türkiye can have significant consequences. The Marmara region is not characterized by poor socioeconomic indicators; rather, it is home to middle and upper-income, skilled labourers and business owners. However, the region's rapid and uncontrolled urbanization which led to the construction of high-rise and low-quality buildings vulnerable to earthquakes worsened the disaster's impact. Low quality building structures indeed reflect broader issue of inadequate regulation and indulgence. The government overlooked unleashed urbanization because migration was meeting the labour demands of industry and municipal authorities, driven by economic interests, permitted constructions that violated regulations. This systemic neglect of building quality increased the disaster's human and economic toll.

Developing effective regional economic policies and post-disaster response plans necessitate careful consideration of the results and arguments in this study. The temporary revival in nighttime lights in other words economic activities after the disaster is in fact a result of national and international relief efforts. The lack of durability of these interventions suggest that they are only effective in meeting the immediate needs of the disaster area rather than maintaining the long-term health of the region's economy. To strengthen the region against future disasters, policymakers should also focus on and invest in long-term superstructure as well as infrastructure improvements. This includes enforcing stricter regulatory mechanisms to ensure that buildings are constructed in compliance with earthquake safety standards. Moreover, to promote economic diversification, government should especially increase infrastructure investments in areas with lower or no seismic risk and offer incentives to encourage the reallocation of industries to these places. Finally, the use of disaster insurance should be encouraged among small and micro enterprises.

Finally, when we examine the statistical analysis from a technical perspective, the varying results that emerge depending on different econometric models highlight the importance of method selection in studies evaluating disaster impacts. For example, the use of two-way fixed effects provides more reliable estimates by controlling for unobserved heterogeneity in our case. Moreover, the use of night light intensity as an indicator of economic activity made this statistical analysis possible because there is no data on economic indicators such as GDP at the district level in the specified time period in Turkey.

4.4 Limitations of the Study

There are several limitations of the research worth mentioning. First of all, as we recall from the section 3.3.1, the DiD analysis depends on the parallel trends assumption. In figure 3, the confidence interval belongs to the coefficient in period -1 does not include zero which means that it is statistically significant. This situation raises doubts about the validity of the parallel trend assumption even though it was further proved by the regression results presented in table 4.

Secondly, in regression models which allow for partial or full variation in unobserved time-invariant heterogeneity, the lagged population size variable becomes positive and significant. This finding signals the risk of omitted variable bias and call our attention to the limitations of the study's control variables. It is necessary to emphasize that district-level data for the period under discussion is very limited. Even district-level population data suffers from the problem of missing values; therefore, it had to be completed using interpolation and extrapolation techniques.

Thirdly, to ensure comparability between treatment and control districts, I apply t-test which only assesses similarity in terms of mean nightlight intensity. Since district level data for the period that is under consideration in Türkiye is highly limited, I cannot compare treatment and control groups in terms of the other socioeconomic indicators. This situation also restricts my options for different robustness checks for instance using GDP could have strengthened the statistical analysis.

Finally, the external validity of these results is limited because the study focuses on a specific case; the Marmara region which is characterized by high level of industrialization. The consequences of an earthquake can be different in regions or countries with different economic structures and urbanization patterns as we recall from Chapter 2.

Chapter 5
Conclusion

The goal of this study is to provide causal inference on the relationship between the 1999 Marmara earthquakes and mean nighttime light intensity which stands as a proxy for regional economic activity. To achieve this, I constructed two-way fixed effects DiD model and supported it with robustness checks and a further event study analysis developed by Callaway & Sant'Anna (2021). The findings from these empirical analysis as well as descriptive reports presented in Chapter 1 reveal the economic consequences of one of Turkey's most devastating natural disasters.

The earthquakes had a significant and negative impact on mean nighttime light intensity in the affected districts which can be interpreted as a substantial decline in economic activity. The baseline model estimates show a 19% reduction. The direction of the relationship stays the same, but magnitude decreases slightly when we control for population size. The robustness checks such as alternative model specifications and the use of an expanded treatment group, further validates the validity and the credibility of the results. Event study analysis on the other hand, signifies a quick recovery period caused probably by national and international aid and reconstruction efforts. However, this does not last long and lose its impact by period 5. Further research is needed to discuss the role of post disaster aid on economic recovery.

Even though the Marmara region is one of the most developed and industrially significant areas of Türkiye, governance failures which brought about unsafe buildings that violate regulations, increased the human and economic toll. Having been born and raised in Türkiye, I can verify that issues such as inadequate urban planning and corruption as the main culprits behind the destruction caused by the earthquake. Hence, to mitigate the impact of future disasters, superstructure and infrastructure quality should be increased, contractors should be monitored to ensure that buildings are constructed in compliance with building regulations and governance should be transparent.

In conclusion, the 1999 Marmara earthquakes are a good example of the vulnerabilities that even developed regions face when urban planning is inadequate, and control and penalty mechanisms do not process smoothly. Future research can focus on the impact of national and international aid on economic recovery after a disaster, the effect of changes in building regulations over the years on earthquake-related loss of life and property, or whether insured micro and small businesses recover more quickly compared to uninsured ones after a catastrophic event.

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