Urban Sprawl and Fuel Consumption in Post-Earthquake Period: A Quasi-Experimental Evidence

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Urban Sprawl and Fuel Consumption in Post-Earthquake Period: A Quasi-Experimental Evidence

Ahmet Duhan Yassa*

Abstract

This paper investigates the role of urban sprawl and urban mobility on long-term fuel consumption after the 2011 Van earthquake in Türkiye. Both province-level synthetic control and firm-level difference-in-differences (DID) analyses indicate a statistically significant increase in fuel consumption in Van after the earthquake, even though there was no dramatic change in the main determinants of fuel consumption in the province in this period. Findings from the satellite-supported population density images and sensor-level traffic density data reveal that rising population density in peripheral regions and increasing urban mobility within the province are the potential drivers of the rise in fuel consumption. While the impact of the Van earthquake on fuel consumption, the foreign trade deficit and greenhouse gas emissions was limited given the size of the city, the results highlight the potential impact of other major disasters that have occurred in the recent past and are expected to occur in the future.

JEL Code: Q54, R11

Keywords: Urban sprawl, fuel consumption, earthquake, synthetic control, greenhouse gas emissions, trade deficit

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Non-Technical Summary

Although most of the economic impacts of natural disasters wear off over time, some effects are permanent even in the long run. In this paper, we emphasize the phenomenon of excessive fuel consumption as a long-lasting effect of earthquakes and investigate the factors behind it.

In October 2011, a devastating earthquake occurred in Van, an economically small eastern province of Türkiye, and affected at least 25% of the population of the province permanently. After the disaster, Van's share in total fuel consumption in Türkiye increased significantly in the short run due to construction. Despite the fact that such construction diminished over time, fuel consumption has not reverted to its pre-earthquake level even after ten years. Findings from province-level synthetic control and firm-level difference-in-differences (DID) analysis indicate an average annual increase of 30-37 percent in Van after the earthquake.

In-depth examination shows that this permanent increase can be explained by rising urban sprawl and urban mobility after the earthquake. Satellite-supported land use images show that in the wake of the disaster the population of Van has been relocated to peripheral regions of the province, and consequently, traffic density has significantly increased within the province. The estimation obtained from sensor-level data suggests that traffic density increased by 16% in Van after the earthquake compared to other provinces in Türkiye.

Results of this paper have several economic and ecological implications. Economically, fuel consumption has a negative effect on the foreign trade deficit in Türkiye, which is import dependent in energy. Given the close relationship between the current account deficit, exchange rate depreciation and inflation, a surge in fuel consumption is also indirectly related to inflation. Ecologically, higher greenhouse gas emissions due to fossil fuel consumption and potential losses in agricultural land due to urban sprawl are the main concerns. Even though Van is a small province in terms of economic activity, the implications of this paper prefigure ex-post long-run impacts of other major earthquakes in the recent past (for instance the Kahramanmaraş twin earthquakes in February 2023) and the ex-ante impacts of earthquakes expected to occur in the future (such as the long-awaited Istanbul earthquake).

1. Introduction

The economic impact of an earthquake is a factor that compounds the human tragedy of the disaster. While the sudden destruction of physical and human capital suppresses production, rising needs for essential goods boost demand in the affected area shortly after the earthquake. As a consequence, economic activity slows down and a supply-demand disequilibrium sets in for many local industries. Over time, the impact of the shock spreads beyond the epicenter of the quake in proportion to the connectedness of the quake-hit region to other regions. The loss of many lives, continuing health problems, migration, financing needs and supply chain disruptions lead to long-run socioeconomic impacts in the affected region and other regions that have economic links to it.

Both the short and long-term effects of the disasters are extremely costly, and it seems that the only way to cope with disasters is to design pre-disaster prevention and post-disaster recovery plans. However, these plans require a large set of systematic empirical evidence based on previous experiences. Despite a growing body of literature on the consequences of natural disasters, there is limited research on the effect of earthquakes on local energy consumption, and this scarcity is more crucial for developing countries given the fact that the macroeconomic impacts are more dramatic in these countries (Noy, 2009; Strobl, 2012).[1]

In this paper, we highlight one of the indirect economic impacts of earthquakes that is not extensively studied in the previous literature: the rise in long-term fuel consumption through urban expansion and urban mobility. On 23 October 2011, an earthquake with a magnitude of 7.2 hit the province of Van in eastern Türkiye. The earthquake killed 650 people and injured more than 5,000. In addition, around 36,000 houses were heavily damaged or destroyed, and at least 250,000 residents were permanently affected by the earthquake, which constitutes almost 25% of the population of Van in 2011.[2] Against this background, this paper shows that the Van earthquake had a long-term impact on fuel consumption through urban expansion and urban traffic mobility using a natural experiment setting. The earthquake, which was an exogenous natural shock to the region, allows us to evaluate the impact of urban expansion on energy consumption in a causal framework.

In the empirical part, we deploy three estimation strategies that exploit three different datasets. First, we employ a synthetic control mechanism to estimate the effect of the urban

[1] Consequences of the natural disasters have started to arouse increasing interest for central banks since disasters' devastating impacts on the financial stability, supply chains, capital stock and productivity are inputs for optimal monetary policy (Fernández-Villaverde and Levintal, 2018; Klomp, 2020; Cantelmo et al., 2022).

[2] The number of permanently affected people is calculated by multiplying the number of heavily damaged or destroyed homes by seven, which is the average number of people in a typical household in Van in 2011 according to the Turkish Statistical Institute (TurkStat). Total number of people affected is much higher when moderately damaged houses are taken into consideration.

expansion in the aftermath of the earthquake by using the province-level data in ways that are similar to the previous literature (Abadie and Gardeazabal, 2003). To this end, we construct an artificial province that is similar to Van by weighting other provinces that are not affected by the earthquake considering their pre-treatment characteristics such as GDP per capita, population, number of tourists, construction activity, pre-treatment fuel consumption and number of motor vehicles. The comparison between Van and this synthetically constructed Van indicates that annual average fuel demand increased by 37.8 percent within five years after the disaster. Second, we substantiate the analysis using firm-level micro data in a difference-in-differences (DID) framework. We show that net sales of fuel retailer firms located in Van have increased by 30 to 37 percent within five years after the earthquake, corroborating the average number obtained from the synthetic control mechanism. Third, using a dataset that includes firm-to-firm sales of energy, we show that there is no statistically significant increase in fuel sales to corporate firms in the post-earthquake period. This finding suggests that the additional fuel consumption after the earthquake is directly related to rising household demand rather than rising corporate demand for construction and transportation.

Regarding this increasing long-term fuel consumption in the post-earthquake period, further questions center around the source of this excess fuel consumption, which cannot be explained by the main determinants of fuel consumption. Additional analysis demonstrates that the driving force behind the increase in fuel consumption may be rising urban expansion and urban mobility after the disaster. Satellite-supported land use images show that the urban bounds were extended significantly after the earthquake, and the population density on the urban peripheries increased permanently. Accordingly, the sensor-level traffic density dataset obtained from the Highway Directorate shows that the automobile traffic per day increased significantly in Van compared to other provinces after the disaster. Regarding the close relationship between urban sprawl, urban mobility and fuel consumption in the previous literature (Newman and Kenworthy, 1989; Johansson and Schipper, 1997; Karathodorou et al., 2010), these factors can explain excess demand for fuel.

The findings of this paper have important economic and ecological consequences. From an economic perspective, as a net energy importer, an increase in the fuel demand of Türkiye leads to a rise in the foreign trade deficit and puts pressure on the domestic currency. Besides, taking exchange rate pass-through to consumer and producer prices into account, the urban sprawl after earthquakes has an indirect effect on producer and consumer inflation. Ecologically, fossil fuel consumption is one of the causes of greenhouse gas emissions. Thus, post-earthquake urban sprawl has negative greenhouse gas impacts when not supported by sustainable investments after the earthquake (Mccarty and Kaza, 2015, Shim et al., 2006). Well-designed recovery projects based on renewable energy sources can attenuate reliance on fossil fuel and greenhouse gas emissions, encouraging sustainable transportation investments (Ludovico et al., 2020). As another ecological concern, the shrinkage of agricultural lands due to urban sprawl deserves a detailed urban plan after the earthquake (Brueckner, 2000).

Although the final effect of the Van earthquake on the country's total fuel consumption, foreign trade deficit, greenhouse gas emissions and inflation were negligible because Van is a small province in terms of population and economic activity, the findings of this paper constitute a benchmark for the long-term impacts of other major disasters.[3] Most of the highly populated and economically developed provinces (e.g. İstanbul, İzmir, Kocaeli and Bursa) in Türkiye are located along an active seismic belt, and earthquakes are major threats to economic activity on a large scale. The most powerful example of this is the earthquake that hit 11 southern provinces around Kahramanmaraş on 6 February 2023. In a back of the envelope analysis for the four most-affected provinces (Adıyaman, Hatay, Kahramanmaraş and Malatya), we estimate the long-run impacts of the earthquake on fuel consumption as 1.8 billion US dollars (USD) within five years of the earthquake under the assumption that the urban expansion will be proportional with the Van earthquake. This estimation can easily deviate upwards or downwards due to several factors. For instance, considering that the earthquake affected a much wider area beyond these four provinces, the cost could be economically more sizeable.[4] On the other hand, a restricting factor can be the government's incentives for the on-site transformation in quake-hit regions that allow the reconstruction of damaged building in the same place. Overall, as the urban sprawl is structural and not temporary, the cumulative impact of fuel demand in the very long run (e.g. in 30 years) may produce economically much more significant consequences.

In addition to ex-post effects, the ex-ante urban sprawl effects of earthquakes are important since the recent Kahramanmaraş earthquakes sparked debates about readiness for other expected major earthquakes in Türkiye. Turkish government has announced new urban transformation plans to accelerate preparedness for earthquakes, envisaging the establishment of new settlements in the earthquake-resistant areas and sale of Treasury lands, which may lead to urban sprawl before the earthquake occurs. In this framework, the recent law approved by the Parliament says that the population in risky buildings will be transferred to a "reserved building area", which refers to the development of new urban spaces that meet modern living requirements.

[3] In the recent past, there are no other disasters that have the massive within-province effect that the 2011 Van earthquake had. In the 2003 Bingöl and 2020 Elazığ earthquakes, the share of destroyed buildings in total buildings in the province was very low compared to the Van earthquake. The Gölcük and Düzce earthquakes had significant within-province impact, but reaching a proper historical dataset is a limitation.

[4] The earthquake had partial impacts on other large Turkish provinces: Adana, Diyarbakır, Elazığ, Gaziantep, Şanlıurfa, Osmaniye and Kilis.

This study is related with several strands of literature. First, it is related to the economic consequences of earthquakes. Extant literature has already shown that earthquakes have slowing-down impacts both on overall production (Noy, 2009) and consumption (Felbermayr et al. 2021, Yin et al., 2022). In a recent paper, Carvalho et al. (2021) emphasized the propagating role of earthquakes through supply chain disruptions. Kondo (2018) focuses on employment effects like lower earnings and working hours due to disrupted supply chains. Gassebner et al. (2010) show that natural disasters have widened the trade deficit depending on the geographic level of disaster and the level of democracy. The literature on quakes' consequences for energy focuses on energy supply rather than demand. Schnell and Weinstein (2012) show that production shock in the Tohoku earthquake had long-lasting impacts compared to Kobe earthquake due to different damage to energy supply infrastructure. The short-term energy deficit in Japan has increased electricity consumption and greenhouse gas emissions due to shifting electricity production methods after the Tohoku earthquake (Cho et al., 2016) and Fukushima earthquake (Cong et al., 2022). Similar to the Tohoku earthquake case, which increased the fossil fuel import dependency in Japan (Taghizadeh-Hesary et al., 2017; Aruga, 2020), this paper focuses on energy demand implications of earthquakes rather than energy supply.

This paper also unveils the causal relationship between urban sprawl and fuel consumption using the earthquake as exogenous shock to urban sprawl. Existing literature has already shown that earthquakes lead to urban sprawl (Ubaura, 2018; Sunbul, 2019) and urban sprawl is closely associated with fuel consumption. Newman and Kenworthy (1989), Johanssonn and Schipper (1997) and Karathodorou et al. (2010) exhibit the negative spatial correlation between urban density and fuel demand in various global cities. Using a household travel survey dataset, Kim and Brownstone (2013) show that households in the United States that live in denser neighborhoods consume less fuel than households in less dense neighborhoods.

Finally, this paper contributes to the literature on Türkiye's import dependency in energy and its consequences for the exchange rate and inflation. For many emerging market countries (including Türkiye), the current account deficit is an important source of pressure for domestic currency depreciation (Milesi-Ferretti and Razin, 1998; Kılınç et al., 2016). Moreover, it is a well-known fact that the depreciation of exchange rate can easily pass through to consumer and producer prices in emerging markets (McCarthy, 2007; Yüncüler, 2011; Ahn et al., 2017). Since Türkiye imports most of its energy needs, the demand for fuel and other petroleum derivatives are related to both the current account deficit and inflation (CBRT, 2023). This paper draws attention to negative impact of earthquakes on the structural current account deficit, depreciation of the Turkish lira (TL) and inflation through urban expansion in the aftermath of major disasters.

The plan of the study is as follows. Section 2 outlines data and methodology. Section 3 discusses the earthquake's impact on fuel consumption. Section 4 investigates rising urban sprawl and mobility in the long run in Van. Section 5 presents robustness checks. Section 6 discusses the role of the energy deficit on the current account deficit in Türkiye and calculates potential long-term fuel consumption impacts of the recent Kahramanmaraş earthquakes. Finally, the last section presents concluding remarks.

2. Data and Methodology

We use several datasets in this paper. We describe these datasets and provide the methodological details in the following subsections.

2.1 Province-Level Datasets

Province-level annual fuel consumption data is extracted from the yearly sector reports of the Republic of Türkiye Energy Market Regulatory Authority. The dataset covers sales of all types of fuel to retailers between 2010 and 2021. Other province-level variables including Gross Domestic Product (GDP) per capita, number of motor vehicles per million citizens, population, and construction spending are obtained from TurkStat. Data on the number of tourists is obtained from the Ministry of Culture and Tourism. This dataset includes arriving foreign visitors in cities with border gates. We obtained 972 observations for 81 provinces in Türkiye between 2010 and 2021 (Panel A in Table 1).

2.2 Micro Datasets

We also exploit several micro datasets in this study. We compile fuel retailers' net sales from the Revenue Administration dataset with quarterly frequency. This dataset includes all sales of fuel retailers (firms with NACE code 4730) to customers that may be households or corporate firms. To sustain consistency in the dataset, we keep firm-quarter observations if the firm reports income statements in all four quarters during a year. We also trim at 0.1 percent on upper tails to exclude outliers. The final dataset consists of 298,720 observations of 10,233 firms of which 127 are located in Van.

In addition to total sales data, we use the firm-to-firm sales dataset obtained from the Revenue Administration in order to identify fuel retailer firms' monthly sales to other corporate firms excluding households. The dataset originally covers both supplier and customers unique IDs and total amount of trade if firm-to-firm trade is above 5,000 TL in a month. We aggregate this dataset in quarterly frequency and trim at 0.1 percent on upper tails to exclude outliers.

We use traffic sensor tracks from the Highway Directorate of Türkiye, including the daily number of vehicles passing since 2007 at the sensor level. The dataset includes 530 sensors in

Türkiye with their latitude and longitude information. To identify the sensors located in Van, we choose the sensors situated between 42 degrees 40 minutes and 44 degrees 30 minutes east longitudes and 37 degrees 43 minutes and 39 degrees 26 minutes north latitudes. We also include only passing tracks of automobiles and exclude other trucks and commercial vehicle tracks. The descriptive statistics related to these variables are presented in Panel B of Table 1.

Table 1: Descriptive Statistics

	Min	Average	Median	Max	St. Dev.
Panel A: Province-Level Data					
Fuel Consumption	5219	284097	127182	5103356	539262
Number of Motor Vehicles	5283	250728	114752	4644743	482484
Population	74412	978661	527794	15840900	1759072
GDP per capita	2907	8152	7705	20883	3004
Number of Tourists	0	32546	57	1242222	138528
Construction Spending	22317	1295618	385896	46298558	4331704
Panel B: Micro Data					
Total Sales	1016	4260975	1832258	1726022528	13144944
Corporate Sales	5000	1671515	393311	103240893	5020944
Traffic Density	1	1051	297	103282	2941

Notes: Fuel consumption is in terms of tons. Number of motor vehicles is per million population. GDP per capita is in thousand USD. Total sales and corporate sales are denominated in TL. Number of tourists is arriving foreign visitors according to cities to which border gates are bound. Traffic density denotes monthly average number of vehicles' passes at sensor level.

2.3 Methodology

In this paper, we apply both synthetic control and DID methodologies using different datasets. Both methodologies have advantages over each other, and in this respect, they complement each other.

We first employ synthetic control methodology to see the causal impact of the earthquake on fuel consumption at the province level. The main purpose of the synthetic control methodology is to construct better counterfactual units that mimic treated units by weighting pre-treatment characteristics of the donor pool (Abadie and Gardeazabal, 2003) since simply calculating the average of the counterfactual units may not represent true counterfactuals for the treated unit. Synthetic control methodology inherently deals with parallel trend assumption in causal inference by constructing similar counterfactual units in pre-treatment characteristics. The methodology is advantageous when the number of observations is small, there is a single treated unit, and the outcome is not volatile over time (Abadie and Vives-i-Bastida, 2022).

The synthetic control estimator $\tau_{i,t}$ is the difference between the treated unit outcome $Y_{i,t}$ and its potential outcome in the absence of treatment $\hat{Y}_{i,t}$.

$$\tau_{i,t} = Y_{i,t} - \hat{Y}_{i,t}$$

Since $\hat{Y}_{i,t}$ is not observable, we synthetically construct the potential outcome by weighting the outcome of control units in the donor pool with W_k, which is a time-invariant non-negative weight matrix. The weights are constrained to be positive and sum to unity.

$$\hat{Y}_{i,t} = \sum_{k} Y_{k,t} W_k$$

Thus, a crucial point in synthetic control methodology is the selection of weight matrix W_k. In order to obtain W_k, we exploit treated and non-treated units' pre-earthquake determinants of fuel consumption. Using these determinant variables, we define a distance function as below.

$$||\mathrm{X}_1 - \mathrm{X}_0\mathrm{W}||_\mathrm{V} = \sqrt{(\mathrm{X}_1 - \mathrm{X}_0\mathrm{W})'\mathrm{V}(\mathrm{X}_1 - \mathrm{X}_0\mathrm{W})}$$

In the equation, X_1 denotes the $(jx1)$ pre-treatment covariate vector for treated unit and X_0 denotes (jxk) covariate matrix for control units in donor pool, where j is the number of predictor variables, and k is the number of units in donor pool. W is $(kx1)$ vector that contains weights for each donor k in donor pool. V is (kxk) symmetric and semidefinite diagonal matrix that represents the relative importance of the covariates. The distance function is minimized so that the outcome of synthetic control unit is similar to outcome of treated unit in the absence of treatment.[5] We extract W* and calculate $\tau_{i,t}$ synthetic control estimator. In this study, we use pre-treatment values of GDP per capita, population, number of tourists, construction spending, fuel consumption and number of motor vehicles as covariates in order to construct synthetic Van. Fuel prices, another important determinant of fuel consumption, are not included as covariate since the fuel prices are determined by the Energy Market Regulatory Authority and are almost the same in each province of Türkiye. While constructing synthetic Van, we drop the 10 largest and 10 smallest provinces from the donor pool in terms of annual fuel consumption. In final, Bitlis has 55%, Artvin has 6.8%, Şırnak has 3.9%, Sinop has 2.7% weights in synthetic Van. Other provinces have relatively smaller weights in synthetically constructed Van.

[5] Thus, the parallel trend assumption is inherently satisfied in this method.

Despite its significant advantages, synthetic control methodology can be inefficient when some critical assumptions are not satisfied. For example, synthetic control methodology requires that the shock on treated units should not be anticipated, and there is no interference between units after the disaster. These assumptions hold in our context since the earthquake in Van was an unexpected event and had limited effects on neighboring provinces. Considering the large surface area of the city of Van and the fact that the epicenter of the earthquake (Tabanlı village) was in the inner parts of the city, the impact of the Van earthquake on neighboring cities was quite limited.

On the other hand, in our setting, the pre-intervention data is limited to one year, which can be a problem to capture pre-intervention fit (Abadie and Vives-i-Bastida, 2022). However, when the underlying data generating process is in autoregressive structure, the synthetic control estimator can be unbiased even if data for only a single pre-treatment period is available (Abadie et al., 2010). In the previous literature, there is a great deal of evidence showing the autoregressive nature of fuel and energy consumption (Ruiz et al., 2016; Yuan et al., 2016). Correspondingly, permutation tests in Figures A5-A6 also show that our model is successful in explaining the non-treated units' post-treatment trends despite the short pre-treatment data. For most of the provinces (excluding the largest and smallest), the difference between actual provinces' fuel consumption and synthetically constructed counterpart provinces' fuel consumption fluctuates around zero.

Nevertheless, considering the limitations of the synthetic control methodology, we provide a firm-level analysis of the DID concept and a province-level analysis. We use the Revenue Administration dataset, which covers quarterly income statements of all corporate Turkish firms. We merge these statements with the firms' spatial information and estimate the DID model below.

$$Sales_{i,t,q} = \beta_1 Van_i + \beta_2 Postearthquake_{t,q} + \beta_3 Van_i \; x \; Postearthquake_{t,q} + X_{i,t} + \gamma_i + \theta_{t,q} + \varepsilon_{i,t,q}$$

In the model, the dependent variable $Sales_{i,t,q}$ is the net sales of the fuel retailer i in year t and in quarter q. Van_i is the categorical variable that takes the value of 1 if the firm is located in Van and 0 otherwise. $Postearthquake_{t,q}$ is the dummy variable that takes the value of 1 for the periods after 2011Q4 and 0 otherwise. In our case, the earthquake may not be completely exogenous and have an impact on other covariates that influence the fuel consumption. To this end, we include several time-varying covariates and fixed effects. $X_{i,t}$ is a province-year level control variable set including GDP per capita, population, number of tourists and construction spending. γ_i denotes firm fixed effects, and $\theta_{q,t}$ denotes year x quarterly fixed effects. $\varepsilon_{i,t}$ is the error term clustered at firm level.

To consider the variation of the impact over time, we use panel data event study methodology. Including the interaction terms between the treated units and leads/lags around treatment time, we estimate the event study specification below. In the specification, $D_{i,2011+j}$ is 1 for the treated units in year $2011 + j$ and 0 otherwise. $D_{i,2010}$ is 1 for the treated units in year 2010 and 0 otherwise. γ_i and θ_t denote firm and year fixed effects. $\varepsilon_{i,t}$ is the error term clustered at firm level.

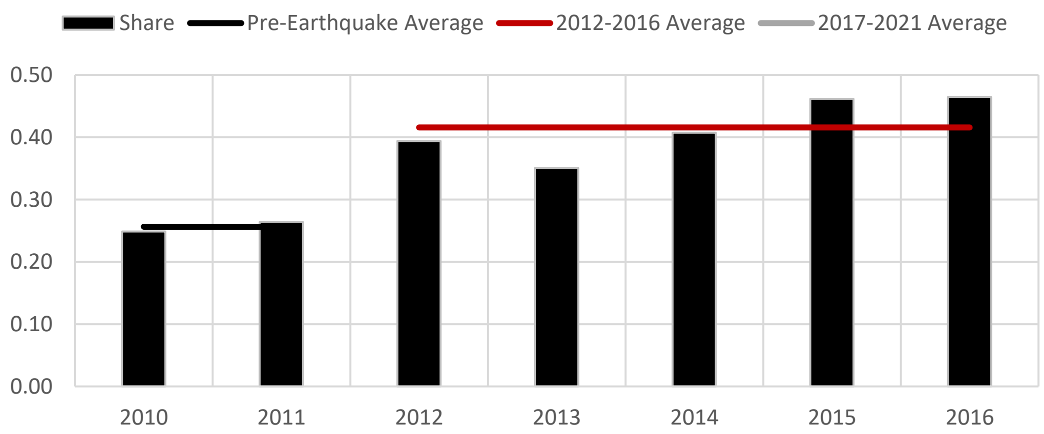
$$Sales_{i,t} = \beta_1 D_{i,2010} + \sum_{j=1}^{10} \beta_{1+j} D_{i,2011+j} + \gamma_i + \theta_t + \varepsilon_{i,t}$$

On the other hand, recent developments have also unearthed new methods of causal inference. Synthetic DID (Arkhangelsky et al., 2021) is one eminent example, which combines the strengths of DID and synthetic control methodology. In this methodology, while the control units are constructed synthetically, the estimation includes time and unit fixed effects. The methodology does not require the pre-treatment trends of treated and control units to match completely. Instead, it is sufficient that trends are parallel despite differences in levels. The differences in levels are absorbed by unit fixed effects γ_i in the model. Another difference of the methodology is that the model includes time weights in addition to unit weights used in synthetic control methodology. Synthetic DID methodology at firm level is also employed as a robustness check in this paper.

3. Rising Fuel Consumption in the Post-Disaster Period

Fuel consumption increased dramatically in Van during the post-earthquake period. While the pre-earthquake average share of fuel consumption in the province within the country was 0.26 percent, it has jumped to 0.43 percent with almost 0.17 percent increase in the five years after the disaster.

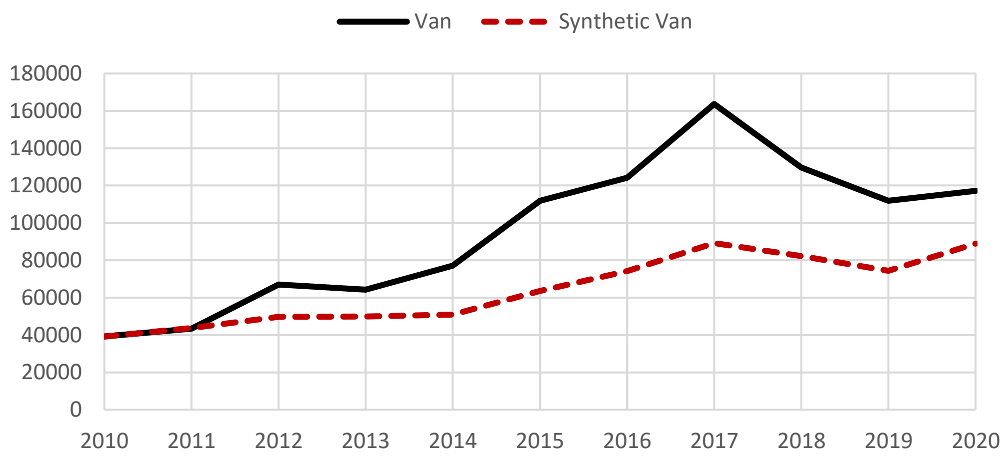
Figure 1: Fuel Consumption in Van: Share in Country (%)



Source: Energy Market Regulatory Authority.

Although Figure 1 gives an intuition about the province-level differences in fuel consumption between the pre- and post-period, the increase can be the consequence of another province-level shock in the post-earthquake period. Given this and other concerns mentioned in Sections 2.3, we apply synthetic control methodology to construct a synthetic province of Van in terms of several pre-disaster characteristics such as GDP per capita, number of tourists, construction spending and population. Figure 2 shows that fuel consumption increased dramatically after 2011 compared to synthetic Van. The differentiation between Van and synthetic Van becomes evident immediately in 2012, a year characterized by huge reconstruction activity (See Figure A3 in Appendix for increasing construction activities in Van). The difference, however, does not die off in the long run. As calculations from Table A1 in the Appendix show, the estimated annual impact of earthquakes on fuel consumption within five years is 37.78 percent.

Figure 2: Estimates of Impact on Fuel Consumption (Tons)



Source: Energy Market Regulatory Authority, TurkStat, Author's calculations.

Considering the limitations of synthetic control methodology summarized in Section 2, we also provide the DID model to corroborate the results in Table 2. The estimation of the DID model also implies that the net sales of the fuel retailers in the disaster area increased significantly in the aftermath of the earthquake. The coefficient of interest in Column 1 indicates that fuel consumption is 37.9% higher in Van compared to other provinces within ten years after the earthquake. The impact is also significant for the five years following the earthquake (Column 2). Even though 2012 is excluded from the dataset, there is still excess consumption of fuel retailers in the long term (Column 3). The results are similar when neighboring provinces that are structurally similar to Van provinces are used as control units (Columns 4-6). 6 On average,

[6] Neighboring provinces are eastern Anatolian provinces including Erzurum, Elazığ, Erzincan, Malatya, Muş, Bitlis, Ağrı, Hakkari, Tunceli, Kars, Iğdır and Ardahan.

there is 32.3% higher fuel consumption in Van compared to similar neighboring provinces in the long run.

Table 2: Impact on Fuel Retailers' Total Sales

	Dependent Variable: Total Sales (Including Households)					
	Van vs. Türkiye			Van vs. Neighbour Provinces		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Post X Van	0.379***	0.303*	0.375**	0.323**	0.234	0.327*
	(0.147)	(0.137)	(0.160)	(0.154)	(0.143)	(0.168)
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year X Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Period	All	2010Q1-2016Q4	Except 2012	All	2010Q1-2016Q4	Except 2012
Number of Observations	298,720	158,483	276,454	19,463	10,292	18,028

Notes: The dependent variable is the log of the net sales of the fuel retailer firms calculated as total sales minus sales deductions. Van is the categorical variable that takes the value of 1 if the firm is located in Van and 0 otherwise. Post is the dummy variable that takes 1 for periods after 2011Q4. Standard errors are clustered at firm level. Statistical significance at the 1%, 5% and 10% levels are denoted by ***, ** and *, respectively.

In order to examine the earthquake's impact on fuel consumption over time, we implement event study design. Figure 3 represents the coefficients obtained from event study regression for the five years after the disaster. While the statistically insignificant coefficient for the pre-disaster implies a parallel trend assumption between treated and control units, with the impact of the reconstruction activities following the earthquake, fuel consumption increased sharply in 2012 since fuel is an input for construction.[7] More interestingly, the effect remains statistically significant over more extended periods, although the construction activities regress to their historical average in these subsequent years (Figure A3 in Appendix). These results corroborate a long-term change in fuel consumption beyond construction that can be attributed to another source of demand.

[7] Full results of regression are presented in Table A3 in the Appendix. The insignificance of the coefficient for year 2010 in regression results supports parallel trend assumption.

Figure 3: Impact on Fuel Consumption Over Time (Event Study)

Source: Revenue Administration.

Table 3: Impact on Fuel Retailers' Sales to Other Firms

	Dependent Variable: Sales to Firms (Excluding Households)					
	Van vs. Türkiye			Van vs. Neighbouring Provinces		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Post X Van	0.182	0.195	0.154	0.067	0.111	0.032
	(0.136)	(0.126)	(0.147)	(0.145)	(0.134)	(0.157)
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year X Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Period	All	2009Q1-2016Q4	Except 2012	All	2009Q1-2016Q4	Except 2012
Number of Observations	334,148	182,518	311,069	22,654	11,750	21,242

Notes: The dependent variable is the log of the sales of the fuel retailer firms to other firms. Van is the categorical variable that takes the value of 1 if the firm is located in Van and 0 otherwise. Post is the dummy variable that takes 1 for periods after 2011Q4. Standard errors are clustered at firm level. Statistical significance at the 1%, 5% and 10% levels are denoted by ***, ** and *, respectively.

To further investigate the concern that corporate activities such as construction are the main driver of increasing fuel consumption, we also scrutinize whether households or firms drive the increase in fuel demand. Using the firm-to-firm trade dataset, we replace the dependent variable with fuel sales purchased by firms with more than 5,000 TL amounts. The statistically insignificant results in Table 3 show that fuel sales to firms are not different in the post-earthquake period in Van, indicating that excess fuel consumption originates from the household demand rather than corporate demand.

4. Urban Sprawl and Urban Mobility as Drivers of Fuel Consumption

In the aftermath of the earthquake, the city of Van expanded toward peripheral regions. We use urban population density images from the Oak Ridge National Laboratory's global population database known as LandScan to show this sprawl. The dataset has been compiled since 1999 using census information at the province level and four geospatial input datasets (land cover, roads, slope and night-time lights), and the population distribution is extracted from remote sensing and GIS data. Figure 4 shows the urban expansion of infrastructure and housing in the post-earthquake period using geospatial data. Although the population is constant after the earthquake (Figure A1 in Appendix), the people spread out to peripheral regions. The population density increased towards southwest, northeast and northwest right after the disaster (represented with black circles in the figure below).

Figure 4: Urban Sprawl in the Post-Earthquake Period

2010 **2012**

Source: Global Landscan, Oak Ridge National Laboratory, US Department of Energy.
Notes: Darkest pixels denote the areas with more than 5,000 people.

After the earthquake, households' home and workplace addresses permanently changed, and the distance between any two addresses within the province significantly increased. Both of these results may have spurred the transportation demand and traffic density. To test whether traffic mobility increased within the province, we first turn to the traffic sensor dataset from the Highway Directorate compiled from annual reports of the Highway Directorate. The reports include the yearly average number of vehicles passing by sensors around Türkiye. Table 4 compiles the excess rise in the annual average daily traffic of Van compared to other neighboring provinces in the same region. Traffic density growth is higher in Van compared to neighboring provinces.

Table 4: Impact on Traffic Density: Van vs. Neighboring Provinces

	Traffic Density Growth 2010-2012 (%)	Traffic Density Growth 2010-2015 (%)
Neighbouring Provinces	11.25	34.83
Van	19.12	49.94

Source: Author's calculations from annual reports of Highway Directorate of Türkiye.
Notes: Traffic density denotes monthly average number of vehicles passes at sensor level.

We also employ several DID regressions to elaborate on this argument using an extensive sensor-level micro dataset from the Highway Directorate of Türkiye. The methodology is similar to baseline fuel consumption specification, so the interpretations are identical. The results presented in Table 5 demonstrate that the traffic density increased in Van after the earthquake compared to all other provinces in Türkiye (Columns 1-3) and compared other provinces in the same region, such as Ağrı, Bitlis, Hakkari and Muş. Baseline specification in Column 1 suggests that the number of passes after the disaster is 16.2% is higher in Van compared to all other provinces in Türkiye. The results are similar for different time periods (Columns 2-3) and stronger when the neighboring provinces in the same region are considered as control observations (Columns 4-6).

Table 5: Impact on Traffic Density: Sensor-Level Analysis

	Traffic Density Growth					
	Van vs. Türkiye			Van vs. Neighbouring Provinces		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Post X Van	0.162***	0.135***	0.141***	0.387***	0.421***	0.435***
	(0.044)	(0.038)	(0.038)	(0.145)	(0.134)	(0.157)
Province Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year X Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Period	All	2009Q1-2016Q4	Except 2012	All	2009Q1-2016Q4	Except 2012
Number of Observations	42540	19792	40460	1788	848	1710

Notes: The dependent variable is traffic density which denotes monthly average number of vehicles' passes at sensor-level. Van is the categorical variable that takes one if the sensor is located in Van, zero otherwise. Post is the dummy variable that takes 1 for periods after December of 2011. Statistical significance at the 1%, 5% and 10% levels are denoted by ***, ** and *, respectively.

5. Robustness Checks

We apply several robustness and placebo checks. First, we use synthetic DID methodology that combines the strengths of the two methods. The results in Table A4 are quantitatively and qualitatively similar to the baseline specification.[8] Second, we saturated the baseline model with several province-year level control variables to capture economic growth, tourism and construction activity (Table A2 in the Appendix). After controlling GDP per capita, construction and tourism activities and change in the population, Van still has excess fuel consumption compared to other provinces. Third, the results are also similar when the variables are winsorized at 1 percent. Fourth, we replicated the yearly event study regressions at quarterly frequency. The coefficients in Figure A7 corroborate yearly event study results.

We also employed several placebo checks for the synthetic control analysis. We replicated the synthetic control analysis by assuming that the earthquake had hit other provinces rather than Van. Figures A5-A6 in the Appendix show a slight difference between actual and synthetic values for most provinces without treatment effect.[9] The vertical axes of the graphs represent the percentage difference between synthetically estimated and actual values. The horizontal line in each subgraph indicates that the synthetic control algorithm successfully reflects actual

[8] Synthetic DID regression methodology requires a strongly balanced dataset; thus the sample includes only firms with income statements in all periods. The placebo standard deviations are also used in the regressions.
[9] Backtesting by checking placebo treatment year is another test in synthetic control. However, our limited number of pre-treatment periods does not allow it.

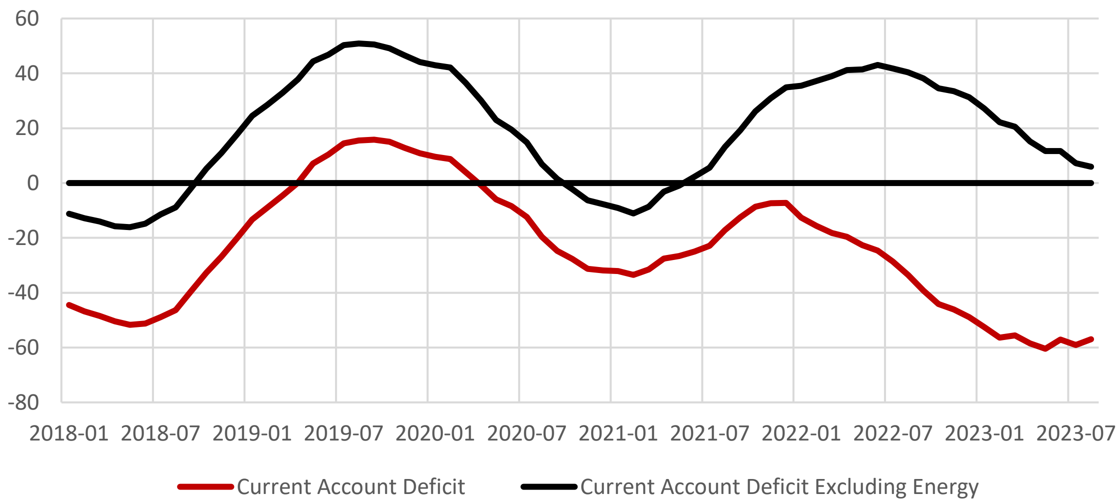
province fuel consumption trends. Although very small and very large provinces have higher deviation, the horizontal lines around zero are in the majority, indicating the power of synthetic control methodology. Synthetic control results are also robust to different pre-treatment determinant variable choice combinations. Moreover, since large donor pool can be a problem in synthetic control methodology, we restricted the donor pool by including only the 30 closest provinces in terms of fuel consumption. We obtain similar synthetic control results.

6. Energy Import and Foreign Trade Deficit in Türkiye

The current account deficit has a close relationship with the energy deficit in Türkiye. Figure 5 emphasizes this close relationship over time. Excluding energy imports, the foreign trade deficit turns to surplus. As of August 2023, while the 12-month cumulative sum of the current account deficit is 57 billion USD, the current account surplus without the energy account is 6 billion USD.

The close association between the trade and energy deficits makes the fuel demand impact of earthquake more important for economic stability in Türkiye. Recent literature shows that the trade deficit is a source of foreign exchange rate depreciation (Kılınç et al., 2016) and exchange rate depreciation is related with inflation (Yüncüler, 2011; Ahn et al., 2017). Through this channel, rising fuel demand may increase the structural foreign trade deficit and pressure on inflation in Türkiye.

Figure 5: Current Account Deficit (Billion USD, 12-Month Cumulative Sum)



Source: CBRT, TurkStat General Trade System.
Note: Energy net imports includes imports of HS-27 (Harmonized System) minus exports of HS-27.

As previously mentioned in the introduction section, the total impact of the Van earthquake on the Turkish economy is limited. However, within-province results of this earthquake can be a benchmark for the estimation of impacts of major earthquakes that happened in the recent past (such as the Kahramanmaraş twin earthquakes on 6 February 2023) and expected to occur in the future (the expected major Istanbul earthquake).

In this context, Table 6 shows the potential influence of the Kahramanmaraş earthquakes on fuel consumption for the 4 most affected provinces and the other 7 less affected provinces. Since the official data has not yet been published, we cannot compare either the short-term or the long-term within-province destructiveness level of the Van and Kahramanmaraş earthquakes. Instead, we ask "What would happen if an effect similar to the Van earthquake was seen in Kahramanmaraş?" and present back-of-the-envelope calculations. In 2022, total fuel consumption of the 4 provinces most affected by the earthquake was approximately 1.1 million tons and constituted 3.76 percent of total fuel consumption in Türkiye. The number rises to nearly 3.4 million tons with 11.49% share in total consumption of Türkiye when other less affected provinces are taken into account. If the earthquake causes a 40% increase in average annual fuel consumption in the 4 provinces most affected by the disaster, then an additional fuel consumption of 350 million USD can be expected. The figure rises to 1.78 billion USD at the end of 5 years, provided that a similar effect occurs every year. If the earthquake causes a 40% increase in average annual fuel consumption in all 11 provinces, additional fuel consumption of 1.09 and 5.43 billion USD are expected to occur within 1 year and 5 years, respectively. Given the permanent impact beyond 5 years, the total cost of earthquakes on fuel consumption can be much greater. However, an alleviating factor can be the on-site urban transformation campaign promoted by the government that intends to transform moderately or severely damaged houses in their own sites.

On the other hand, the annual fuel consumption of the province of Istanbul, the biggest Turkish province in economic terms and located on seismic belt, is 4.6 million of tons in 2022, making up 16% of total fuel consumption in Türkiye. Even a medium-sized earthquake may cause sizable impact on long-term fuel consumption through urban expansion. A 40% increase in long-term consumption due to urban sprawl leads to additional fuel consumption of 7.36 billion USD in the 5 years following a disaster. In fact, it may not be necessary for an earthquake to occur to see its effect. Anticipating the devastating impact of the disaster, rational agents can demand housing in unsettled neighborhoods or governments may encourage new settlements in the periphery of the province. It should be noted that the expansive impacts of the earthquakes can precede the earthquakes through this anticipation channel.

Table 6: Potential Impacts of Kahramanmaraş Earthquakes on Fuel Consumption

		1-Year Impact		5-Year Impact	
	Consumption in 2022 (Tons)	40% Increase (Tons)	40% Increase (Thousand USD)	40% Increase (Tons)	40% Increase (Thousand USD)
Adıyaman	150,473 (0.51%)	60,189	48,151	300,946	240,757
Hatay	515,316 (1.75%)	206,126	164,901	1,030,632	824,506
Kahramanmaraş	284,142 (0.96%)	113,657	90,925	568,284	454,627
Malatya	160,150 (0.54%)	64,060	51,248	320,300	256,240
Total Impact of 4 Provinces	**1,110,081 (3.76%)**	**444,032**	**355,226**	**2,220,162**	**1,776,130**
Adana	674,502 (2.28%)	269,801	215,841	1,349,004	1,079, 203
Diyarbakır	290,135 (0.98%)	116,054	92,843	580,270	464,216
Elazığ	163,114 (0.55%)	65,246	52, 196	326,228	260,982
Gaziantep	693,487 (2.35%)	277,395	221,916	1,386,974	1,109,579
Şanlıurfa	333,359 (1.13%)	133,344	106,675	666,718	533,374
Osmaniye	107, 201 (0.36%)	42,880	34,304	214,402	171,522
Kilis	22,847 (0.08%)	9,139	7,311	45,694	36,555
Total Impact of 11 provinces	**3,394,726 (11.49%)**	**1,357,890**	**1,086,312**	**6,789,452**	**5,431,562**

Source: Energy Market Regulatory Authority.
Notes: The share in total consumption of Türkiye is given in parenthesis. In the Platts European Market Scan the fuel oil USD/ton price was accepted to be around 800 USD based on CIF MED (Genova/Lavera) prices.

7. Conclusion

Earthquakes' economic impacts are not limited to the short term. While sudden shocks to physical capital, labor, supply chain, trade, productivity and consumption are destructive for economic activity in the short term, the subsequent structural socioeconomic changes can also have seemingly small but long-lasting impacts. Exploring these impacts is essential in order to design delineated preventive measures, recovery plans and also optimal monetary policy reactions before and after natural disasters. In this paper, we accentuate the long-lasting impact of the rising urban sprawl and urban mobility on fuel consumption in the post-earthquake period. Results from both province-level synthetic control methodology and firm-level DID setting indicate a persistent increase in fuel demand in Van after the disaster, even though there is no permanent change in the determinants of the fuel consumption. Using satellite-supported images, we show that land use in Van increased permanently after the earthquake. Correspondingly, the sensor-level traffic dataset indicates higher urban mobility in the post-disaster period compared to other provinces. We emphasize this rising urban sprawl and urban mobility as the potential drivers of the increase in fuel demand. Besides the obvious ecological effects, fossil-fuel demand is closely related with the current account deficit and inflation in Türkiye since energy imports constitute a large part of the trade deficit.

Even though the share of Van in the national economy is limited, the findings of this paper can be used as a benchmark for ex-post impact of other major disasters that have occurred economically sizeable regions in recent past (i.e. the Kahramanmaraş twin earthquakes in February 2023) and both ex-ante and ex-post impacts of expected disasters to occur in near future (i.e. an expected Istanbul earthquake). In this context, results of this paper also emphasize the crucial role of future research on the consequences of earthquakes in order to design pre-disaster prevention and post-disaster recovery plans to minimize ecological and economic impacts of earthquakes.

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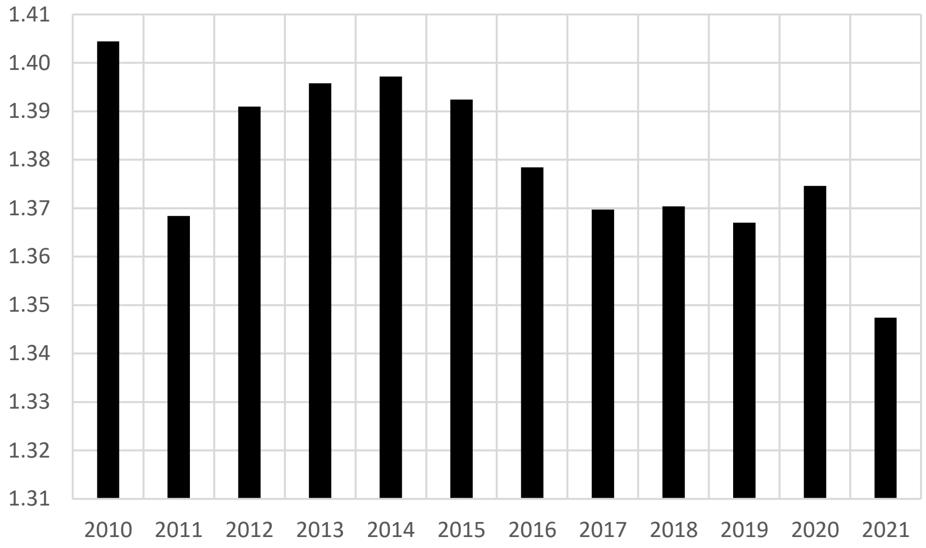
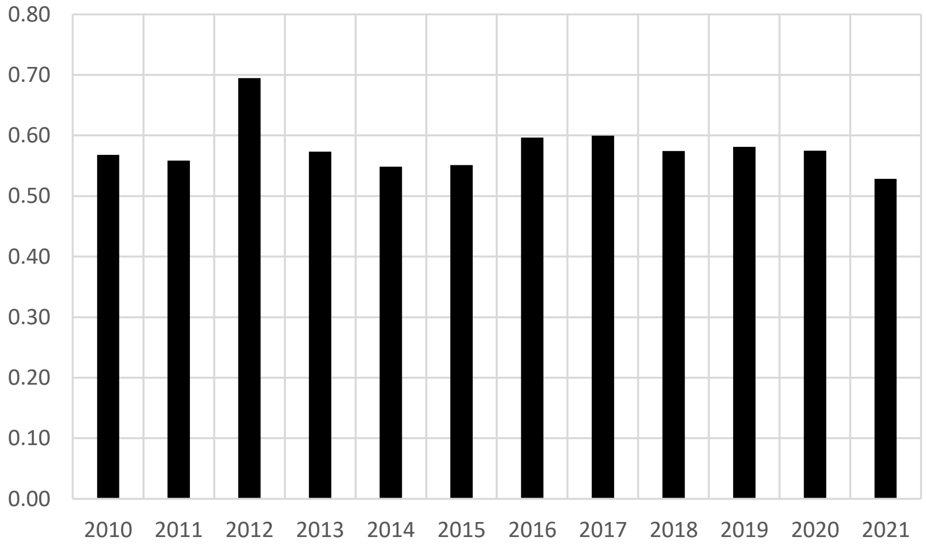
Appendix

Figure A1: The Share of Van's Population in Total Population (%)



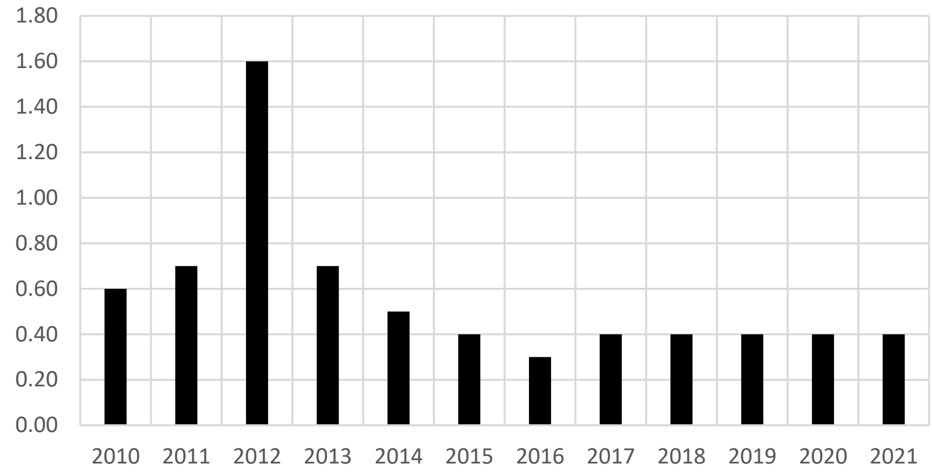
Source: TurkStat.

Figure A2: The Share of GDP Per Capita of Van in Total GDP Income (%)



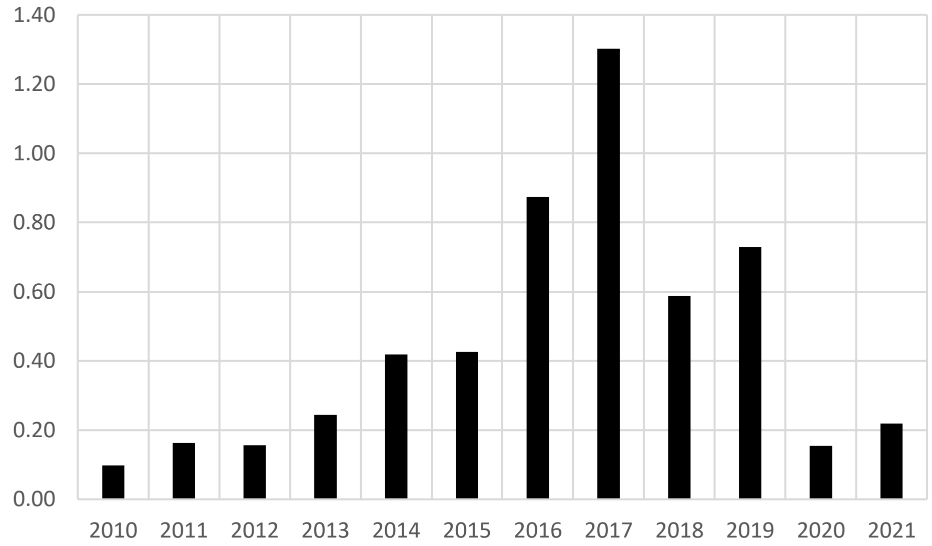
Source: TurkStat.

Figure A3: The Share of Construction Spending in Van in Total Construction Spending (%)



Source: TurkStat.

Figure A4: The Share of the Number of Tourists in Van in Total Number of Tourists (%)



Source: Ministry of Culture and Tourism.
Notes: Data includes arriving foreign visitors according to cities to which border gates are bound.

Figure A5: Fuel Consumption Placebo Runs by Provinces (A-IS)

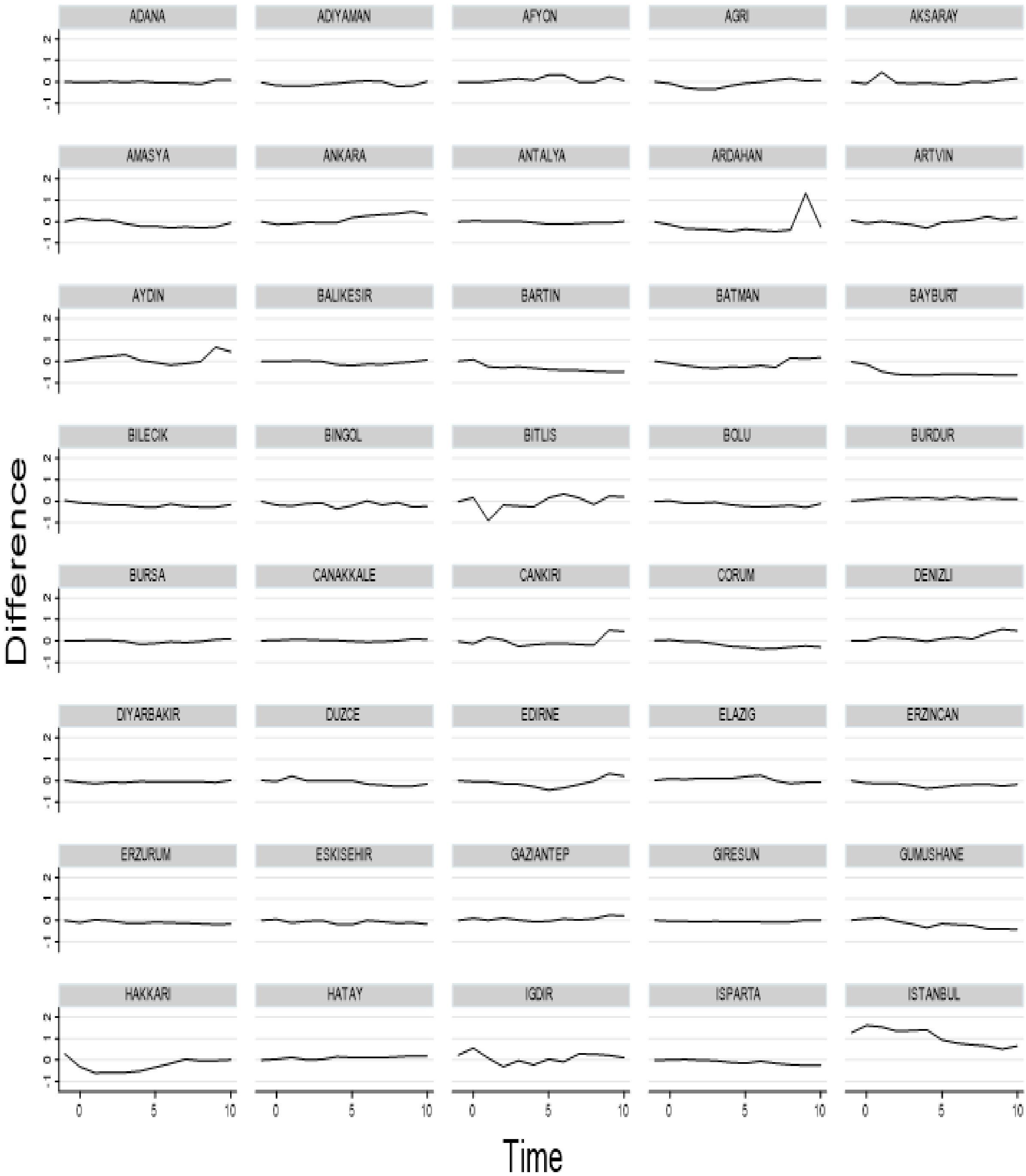


Figure A6: Fuel Consumption Placebo Runs by Provinces (IZ-Z)

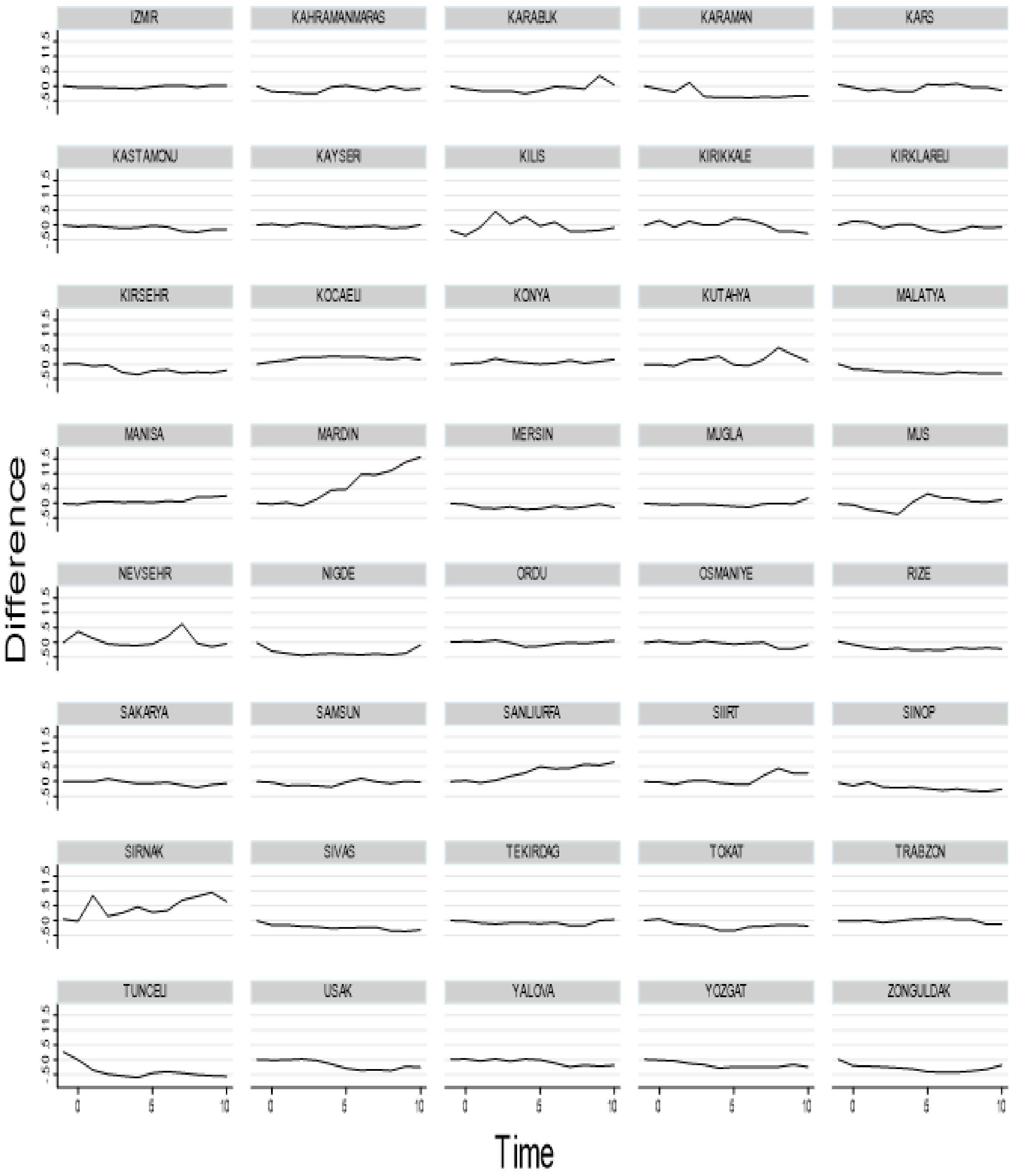
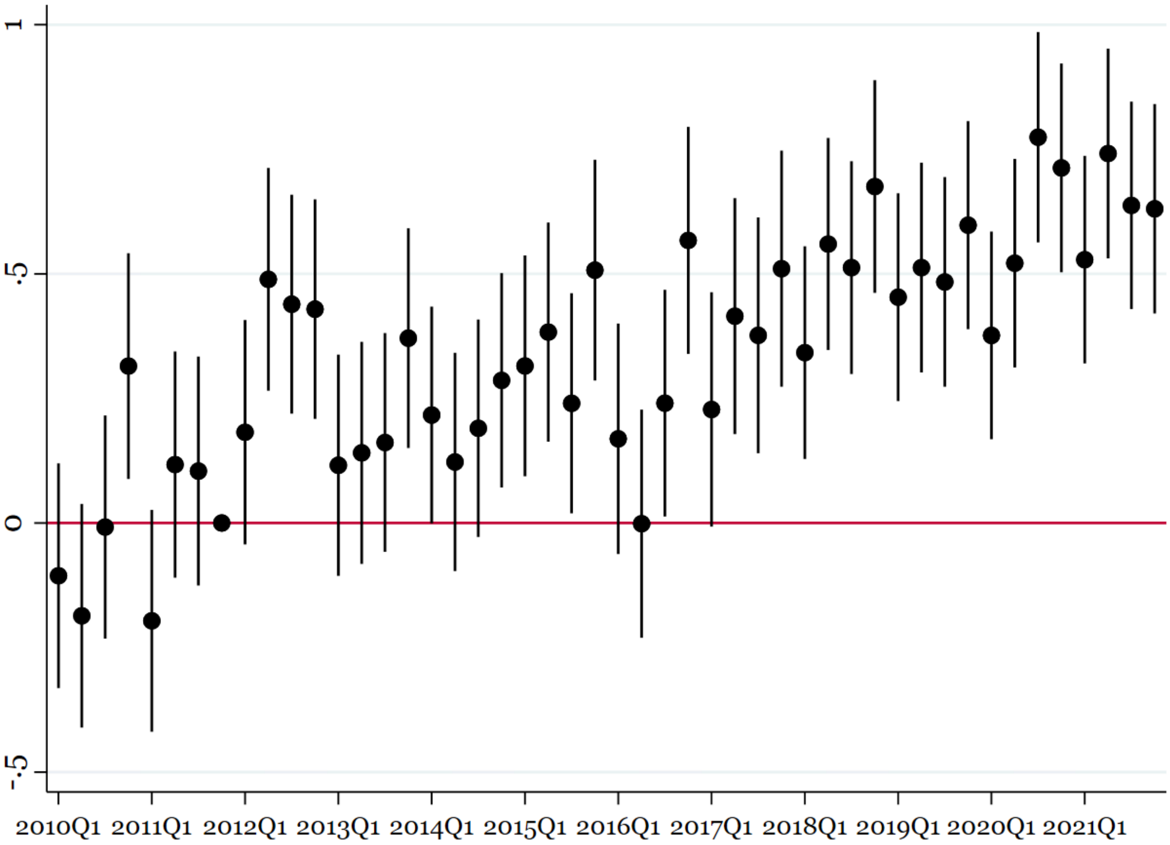


Figure A7: Quarterly Impact on Fuel Consumption Over Time (Event Study)



Source: Revenue Administration.

Table A1: Synthetic Control

	Fuel Consumption (Tons)			
	Van	**Synthetic Van**	**Difference**	
2010	39203	40012		
2011	43387	43290		
2012	66955	51121	30.97%	2012-2016 Average: 37.78%
2013	64194	56043	14.54%	
2014	77047	59617	29.24%	
2015	111868	75974	47.25%	
2016	124157	74392	66.90%	
2017	163667	82771	97.73%	
2018	129621	79820	62.39%	
2019	111847	79649	40.43%	
2020	117077	81482	43.68%	
2021	149449	88792	68.31%	

Table A2: Net Sales of Fuel Retailers: Additional Control Variables

	Dependent Variable: Net Sales		
	(1)	**(2)**	**(3)**
Post X Van	0.367**	0.320**	0.365**
	(0.146)	(0.137)	(0.159)
Year-Province Controls	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes
Year X Quarter Fixed Effects	Yes	Yes	Yes
Period	All	2009-2016	Except 2012
Number of Observations	298,720	158,483	276,454

Notes: The dependent variable is the log of the net sales of the fuel retailer firms calculating as total sales minus sales deductions. Van is the categorical variable that takes the value of 1 if the firm is located in Van and 0 otherwise. Post is the dummy variable that takes 1 for periods after 2011Q4. Standard errors are clustered at firm level. Statistical significance at the 1%, 5% and 10% levels are indicated by ***, ** and *, respectively.

Table A3: Event Study on Fuel Retailers' Net Sales

	Dependent Variable: Net Sales		
	(1)	(2)	(3)
2010 x Van	0.120	0.101	0.116
	(0.158)	(0.125)	(0.159)
2012 x Van	0.557***	0.556***	
	(0.158)	(0.125)	
2013 x Van	0.308*	0.296**	0.290*
	(0.160)	(0.128)	(0.163)
2014 x Van	0.244	0.273**	0.219
	(0.158)	(0.128)	(0.161)
2015 x Van	0.465***	0.523***	0.449***
	(0.163)	(0.134)	(0.166)
2016 x Van	0.319*	0.458***	0.300*
	(0.167)	(0.138)	(0.170)
2017 x Van	0.311*		0.305*
	(0.173)		(0.175)
2018 x Van	0.637***		0.621***
	(0.158)		(0.161)
2019 x Van	0.516***		0.500***
	(0.154)		(0.157)
2020 x Van	0.687***		0.669***
	(0.157)		(0.159)
2021 x Van	0.791***		0.772***
	(0.157)		(0.160)
Firm Fixed Effects	Yes	Yes	Yes
Year X Quarter Fixed Effects	Yes	Yes	Yes
Period	All	2010Q1-2016Q4	Except 2012

Notes: The dependent variable is the log of the net sales of the fuel retailer firms calculating as total sales minus sales deductions. Van is the categorical variable that takes the value of 1 if the firm is located in Van and 0 otherwise. Standard errors are clustered at firm level. Statistical significance at the 1%, 5% and 10% levels are indicated by ***, ** and *, respectively.

Table A4: Net Sales of Fuel Retailers: Synthetic DID

	Dependent Variable: Net Sales		
	(1)	**(2)**	**(3)**
Post X Van	0.413***	0.280**	0.449**
	(0.157)	(0.134)	(0.187)
Firm Fixed Effects	Yes	Yes	Yes
Year X Quarter Fixed Effects	Yes	Yes	Yes
Period	All	2009-2016	Except 2012
Number of Observations	131,616	76,776	128,874

Notes: The dependent variable is the log of the net sales of the fuel retailer firms calculating as total sales minus sales deductions. Van is the categorical variable that takes the value of 1 if the firm is located in Van and 0 otherwise. Post is the dummy variable that takes 1 for periods after 2011Q4. Standard errors are clustered at firm level. Statistical significance at the 1%, 5% and 10% levels are indicated by ***, ** and *, respectively.

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