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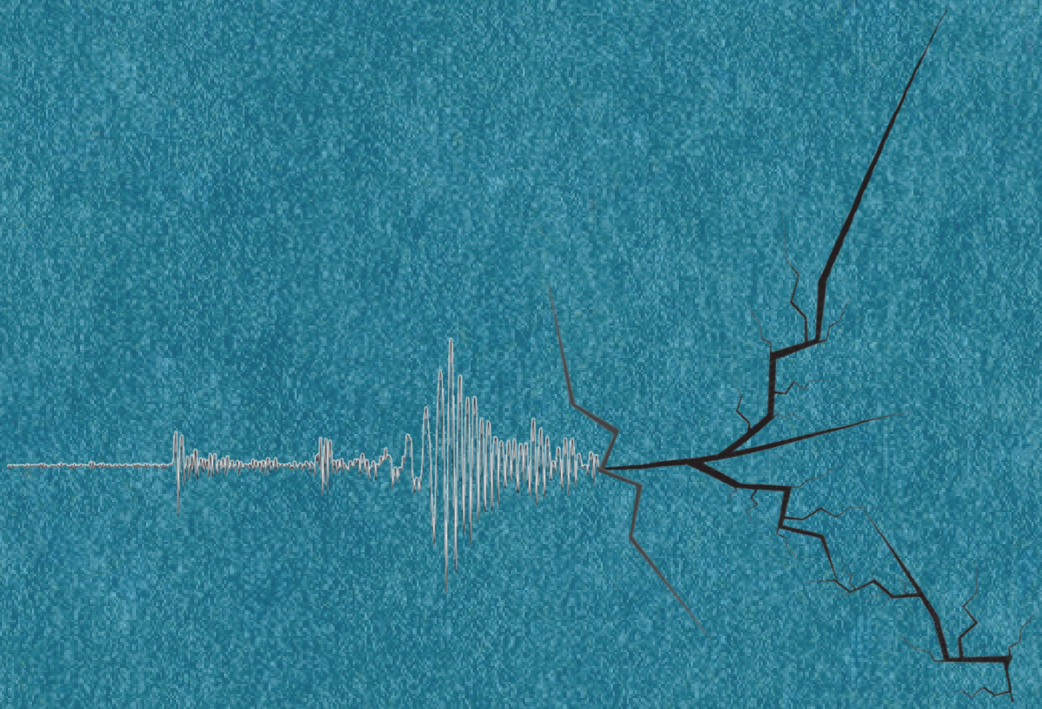

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Preface

Istanbul is a potential location for a great earthquake. Istanbul produces more than 30 % of GDP and iplies the existence of agglomeration at the spatial scale for Turkey. An earthquake in this region may cause a catastrophic result in the whole country. Analyzing the economic loss of an expected earthquake will shed light on the development of policies to reduce the destructive effects of the earthquake.

In this book, the economic loss of the slowdown in the transportation network that may occur due to the collapse of the bridges and viaducts on the highways, as well as the effects of natural gas, water and electricity outages will be discussed using a spatial computable general equilibrium (SCGE) model framework. The definition of loss is limited to indirect losses that arise due to damaged bridges in the highway and lifeline network of the Istanbul metropolitan area. We firstly focus on the role of infrastructure and its interaction with the metropolitan economy by combining the interregional highway network with the intraregional highway network of Istanbul. An interrupted transport network in the metropolitan can cause an increase in distance travelled between two points across the transportation network of the country, generating increases in both time and cost. As a consequence of damage to the transport network, changes in accessibility in each county of Istanbul and in other regions of Turkey are converted into transport margin shocks in the SCGE model. Using a simulated earthquake of magnitude 7.7, the model indicates that welfare losses due to damaged transport network in Istanbul ranges from 1.9% to 5% of Istanbul's GRP according to three different simulations. These losses are distributed over regions as a consequence of intra and interregional trade. Results also reveal that the road link (E-5) in first simulation is economically more important than the road link (E-80) in second simulation. This result provides support for a decision-making process on the optimal retrofit priority of bridges and links on the metropolitan transportation network to minimize the negative effects of an earthquake on the economy. Results of the lifeline outages indicates that sectors in Istanbul experience a significant output decline. The analysis also showed that non-negligible losses also occur in remote regions of the Turkey. Neighboring regions and remote ragions suffer indirectly via the interregional trade linkages. The estimated losses can be useful to prioritize urban transformation plans in Istanbul.

Dr. Metin Pişkin (m.piskin@ucl.ac.uk)
March 2023, London

CONTENTS

1. INTRODUCTION

Istanbul, located between Asian and European continents is both a metaphorical and an actual bridge between these regions. The most important east-west highway routes, which link the Asian and European continents, pass through the Istanbul metropolitan region; they also serve important roles in connecting the Istanbul region through interregional trade with the rest of Turkey and, of course, they serve as important connectors for intra-metropolitan trade within Istanbul. However, Turkey is frequently subjected to earthquakes and the Istanbul metropolitan region is considered to have an enhanced probability of experiencing a strong earthquake (JICA, 2002).

The 1300 km-long North Anatolian fault (NAF) is an active intracontinental fault system extending from East side through the West side of Turkey (Ketin 1948). NAF runs through highly populated areas in Turkey, and especially for the Istanbul metropolitan region with 16 million inhabitants, the fault poses a substantial seismic hazard and has an active earthquake history (Bohnhoff *et al.*, 2016). Historical earthquake data show that Istanbul has been affected by a moderate intensity earthquake every fifty years and a high intensity earthquake every 300 years (Ambraseys and Finkel 1991). According to Konukcu *et al*. (2016), several scientific studies forecast that the high probability of Istanbul facing a major earthquake in the near future (see Ambraseys and Finkel 1991; Le Pichon *et al.*, 2003). The earthquake source representation for Istanbul exists in southern coast of mega region and runs from east to north west of the city (see Figure 1). The likely effected surface of this source includes a broad, densely populated area of central Istanbul metropolitan.

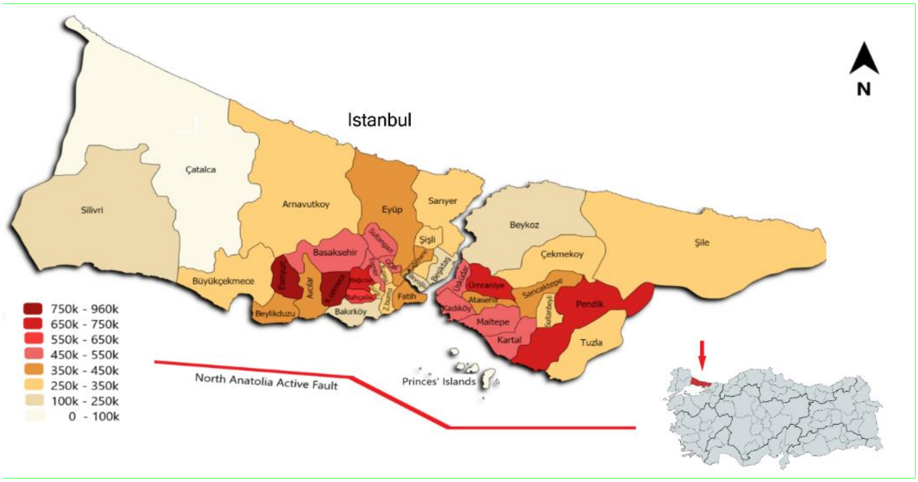

Figure 1: Population distribution by county and demonstration of the earthquake source (active fault).

On the other hand, one of the most obvious features of the topography of Istanbul is the Bosphorus Strait, which separates Istanbul as part of both Asia and Europe. Both sides of the strait show steep mountainous topography. Further, most of the rivers in Istanbul flow in a north-south direction generating the need for bridges to connect the two sides of the Bosphorus. Any disruption generated by physical failure of these bridges would be felt not only within the Istanbul metropolitan region but throughout Turkey creating interruptions in in supply chains, difficulties for employees to reach their jobs, households to buy goods and services and so forth. There will also be a ripple effect on the economy resulting from increasing transportation costs. According to Rose (2004), losses from a disaster are classified into direct effects and indirect or higher-order effects. Direct effects pertain to business production that is damaged by the hazard itself, and indirect economic loss in this study is the loss that occurs just from the damage bridges, besides the repair or replacement cost. Damaged bridges will reduce the highway transportation capacity, or even completely close some of the routes in the network. This will obviously increase the transportation time and distance in the highway network, as well as the transportation cost. On the production side of the economy, this additional cost will cause an increase in the cost of acquisition of inputs and the distribution of intermediate and finished products to other markets, generating an increase in the price of commodities. For the consumers, this additional cost will reduce their effective purchasing power (not to mention the possibility of loss of income from inability to reach places of work) that will eventually reduce the final demand for commodities. The increased price for the commodities, along with possible spending reductions, may cause additional economic ripple effects. Toyoda and Kochi (1997) have shown that the indirect effects were not small compared with the direct effects from stock losses after the Hanshin-Awaji earthquake. In addition, households tend to become more risk adverse, allocating more spending to necessities and decreasing spending on discretionary goods together with a high probability that they will decrease spending in total.

A comprehensive project named “A Disaster Prevention/Mitigation Basic Plan for Istanbul” was carried by Istanbul Metropolitan Municipality in cooperation with Japan International Cooperation Agency (JICA, 2002). The JICA Project assumes a simultaneous break of the entire 170 km section of the NAF in the Marmara Sea (see Figure 3). The moment magnitude is assumed to be 7.7 which would be the largest magnitude that this area has ever experienced (the maximum magnitude of historical earthquakes in the Marmara Sea area is 7.6). The vulnerability of 480 bridges were investigated in JICA (2002) with the result that 24 bridges were estimated to have a higher possibility of collapse and 2 viaducts were calculated as having a higher vulnerability to an expected earthquake. All these bridges are located along the two most important East-West highway routes in Istanbul.

In this book, we use an integrated, operational model to estimate the indirect economic losses due to damaged bridges within the highway system of Istanbul metropolitan area. A spatial computable general equilibrium (SCGE) model is selected as the tool to capture the spillover or distributional effects throughout the entire economic system; the model is described in section 3. Further, we add a sub model that is integrated with the SCGE model to address transportation costs both within Istanbul metropolitan region and also between the other aggregated regions in Turkey. The costs and their changes are modeled endogenously and consistently. Since our model involves the transportation networks, we can also evaluate dynamic distributional impacts through the intra- and interregional trade before and after an earthquake. This study is a first attempt to estimate the indirect losses due to an earthquake in Istanbul using a spatial computable general equilibrium model. Two different sets of simulations are presented for a region-wide outage of lifelines and labor and capital stock losses following a hypothetical earthquake. We believe that the most important contribution is the simulation results obtained with this model. Results can provide valuable inputs in ranking the importance of critical links to be protected by priority retrofitting in the transportation network of Istanbul through an enhanced program to help ensure a higher probability of minimizing economic disruption from an anticipated earthquake.

2. LITERATURE REVIEW

The literature in this field is relatively recent but there has been an increasing interest among scholars in assessing the indirect impacts of disasters and unexpected events (such as COVID-19) on national and regional economies. Three frameworks provide the main methodologies to assess the economic impacts of natural disasters: input-output (IO), computable general equilibrium (CGE) and econometrics. These three methodologies have different advantages and disadvantages. Most econometric approaches are rooted in partial equilibrium analysis. According to Tatano and Tsuchiya (2008), the major drawback with an econometric approach is that infrequency of occurrence and wide range of individual magnitudes of disaster events may create estimation issues. Further, econometric models cannot describe the systemic economic channels through which they propagate within and between the economies affected (Carrero *et al*., 2015). IO and CGE approaches take advantage of their more general equilibrium foundations, and these two approaches are capable of transmitting localized shocks to directly unaffected sectors in the economy through industrial linkages and income-consumption channels. A smaller set of models, econometric-input-output models has been used to provide this integration with transportation network models in a space-time framework (see Sohn *et al*., 2003)

Both IO and CGE models are well suited for assessing the propagation of an initial shock resulting from a natural disaster onto the economy (Okuyama and Santos, 2014). IO models, on the one hand, are mainly praised for their simplicity and ability to reflect the economic interdependencies between industries and regions within an economy through intermediate supply and final demand for deriving indirect effects. CGE models, on the other hand, include supply side effects and allow for much more flexibility due to their non-linearity generated by substitution effects following relative price changes. As a result of the different economic mechanisms, the outcomes often differ as well (see Crawley and Hewings, 2021 who provide a comparison using CGE and econometric-input-output models).

In terms of estimates of the indirect economic losses due to seismic transportation disruption, several disasters have been assessed for different regions with spatial CGE models used to capture spatial and distribution impacts. The Spatial (multi regional) CGE model is more comprehensive than IO since it provides decision makers with spatial information on how much the losses spread into each region resulting from intra- and interregional trading disruption after the occurrence of a disaster (Tsuchiya *et al,*. 2007). For instance, Tatano and Tsuchiya (2007) present a spatial computable general equilibrium (SCGE) model integrated with a transportation model for assessing the economic impact of disruption in transportation networks. As a case study, the model reviews the large Niigata-Chuetsu earthquake of 2004. The model indicates the extent of the economic losses arising from the earthquake distributed over regions as a consequence of the intra- and interregional trade in a regional economy. Tsuchiya *et al*. (2008) present another case study on the economic impacts of transport infrastructure disruptions caused by an hypothetical Tokai-Nankai earthquake in Japan. Their case study shows the impacts of disruptions in major transportation networks and the importance of network redundancy with transport-related economic losses corresponding to several scenarios from disasters and network levels of development.

Some studies investigate the impact of the transport disruption without an explicit transportation network in a national scale CGE model. Chen and Rose (2017) develop and apply a CGE framework to investigate the role of resilience in the economic consequences of transportation system failures. The model is applied to the transportation system failures in the aftermath of Hurricane Katrina to illustrate its capabilities. Infrastructure damages are modeled as capital stock reductions in Chen and Rose (2017). Shi *et al*., (2015) apply a regional computable general equilibrium model to simulate the business interruption impact triggered by the disrupted highway network in Shifang city of China. Tirasirichai and Enke (2007) proposes a CGE model framework to estimate the indirect economic loss due to damaged bridges within the highway system of St. Louis metropolitan area. The increased travel costs that would occur in the St. Louis metropolitan area due to damaged highway bridges were allocated only onto two sectors within the CGE model; i.e., the domestic households and the truck transportation sector.

Attention has also been paid to the identification of important transportation links on the network by measuring the impacts of highway disruptions. For example, Sohn *et al*. (2003) explored the economically significant links on the network in the context of analysis of the potential impacts of an earthquake centered in the lower Midwest of the US. This study provides a general guideline for the retrofit priority of the links and bridges on highway networks by integrating transportation network model and a final demand loss estimation model based on a multiregional econometric input–output model. Haddad and Hewings (2007) identified strategic transportation links in Brazil in various contexts of regional/national policy goals based on regional efficiency and welfare. Kim *et al* (2004) analyzed a transportation link's importance in welfare terms for an ambitious highway expansion program in Korea. The analysis was conducted by integrating a multiregional CGE model and a transportation network.

Rose and Liao (2005) assessed lifeline system outages after disasters, including a water supply system disruption in Portland and electricity outages in Los Angeles within the framework of USCGE.

There are relatively few studies of the role of infrastructure and its interactions with the metropolitan economy under conditions of disruption. Istanbul, which has an area corresponding to around 0.6 % of the country and includes 19 % of the population, produces around 34 % of GDP. Any disruption in East-West highway routes, which link the Asian and European continents, pass through the Istanbul metropolitan region will not only impact the interregional transport cost but also impact the intra-regional transport cost in the main economic engine of the country (Istanbul). One of the features of the approach in this paper is the integration of the interregional transportation network with the intraregional network of Istanbul. Considering damage to the transportation infrastructure, the model estimates the extent of the economic losses arising from the earthquake that are then distributed over regions as a consequence of the intra and interregional trade in a regional economy. Our study differs from the previous studies in this aspect. Finally, following Haddad and Hewings (2007), we also look at the impacts on regional welfare for Istanbul and ten aggregated regions in order to specify retrofit priority.

3. OUTLINE OF THE TURKISH MULTIREGIONAL COMPUTABLE GENERAL EQUILIBRIUM MODEL

The model framework in this study based on the TurksCGE model developed by Piskin *et al*. (2020). The TurkSCGE model is static rather than dynamic. Therefore, our estimation of indirect impacts should be considered as short-term effects only and thus, it will undoubtedly underestimate losses. A more detailed description of model equations can be found in Appendix.

Figure 2 shows the methodological framework used in this paper to estimate the economic losses induced by disruptions of and damage in transportation networks due to an earthquake event. In this system, the physical damages to the transportation networks are calculated by inputting the earthquake scenarios; the outputs are then used as a set of inputs in further models to estimate regional economic losses.

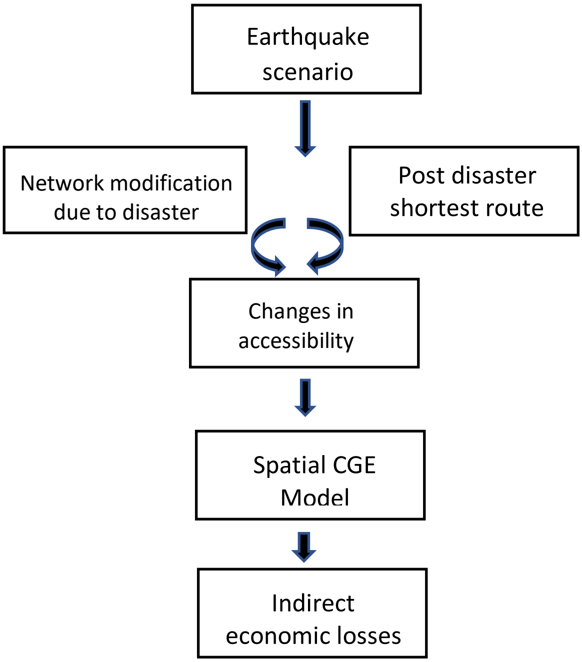

Figure 2: Methodological framework

For the model, 11 regions for Turkey have been created as aggregations based on the European Union NUTS 2 classification. The three largest metropolitan areas, Izmir, Istanbul and Ankara, are extracted as separate regions and excluded from the aggregation process. This model utilizes the notion of representative economic agents as is standard in most CGE modeling. Accordingly, the behavior of households or industrial sectors in the economy will be as the behavior of many identical representative households or firms for each region in Turkey.

In each region, 8 production sectors are identified together with one representative household, regional investment for each sector, one transport and trade service sector (essentially the most important margins in the production system) and a regional external trade sector. There is a single government agent at the national level. In each region, final demand is composed of public and private expenditure and also demand for investment across goods. Decisions about the allocation of resources are decentralized, and the behavior of the representative agents, such as the regional household or regional sectoral investment, follows a canonical microeconomic optimization framework. According to this assumption, consumers will maximize welfare subject to a budget constraint and producers will combine intermediate inputs, and primary factors (labor and capital) to minimize cost for given technology.

The production technology in the TurkSCGE model combines intermediate inputs from the 8 different sectors with labor and capital inputs. Capital and labor is also assumed to be immobile between regions, an assumption that is usual in short-run CGE-based analyses. The unit cost of value-added for each regional sector will be simply a constant elasticity-of-substitution (CES) composite of labor and capital inputs into production, net of taxes. Here, intermediate inputs are not demanded as region-specific sectoral goods, but rather as generic sectoral goods taken from regional good “pools” (see figure

2). According to the pooling concept (see Nijkamp *et al*., 1987 based on the idea originally developed in Leontief and Strout, 1963), all commodities produced by sector *i* in all regions that are transported to region *s* are aggregated into a pool of commodity *i* in region s; from this pool, deliveries are made to intermediate and final consumers. Since pool goods are not differentiated by region of origin, the link between the production side and the consumption side is indirect. In more recent models, this assumption has often been replaced with the Armington assumption that similar goods from different regions are imperfectly substitutable (see Bröcker, 1998 for a discussion of SCGE modeling).

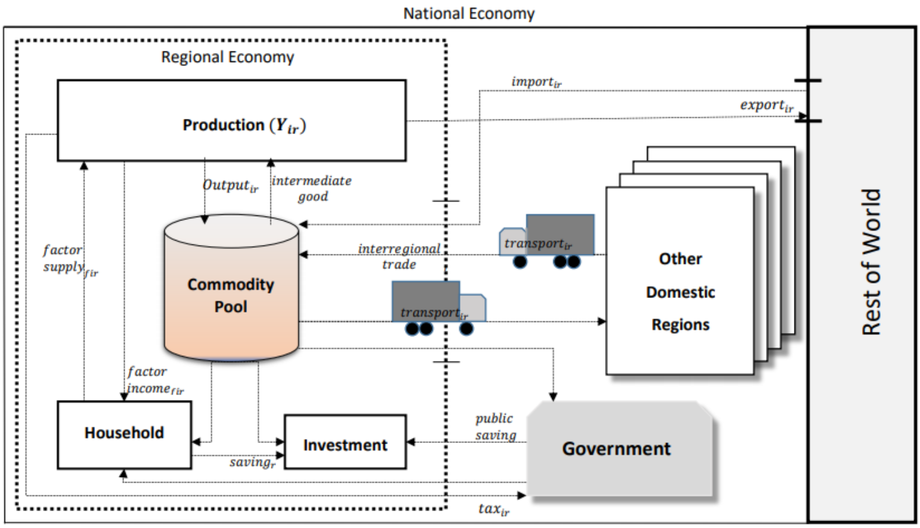

Figure 3: Conceptual framework of the model.

The sources of commodity *i* produced locally or imported from other regions via the transport sectors are first merged into a local commodity pool, and then firms and households in that region obtain goods from that local commodity pool. These pools exist for each commodity/sectoral good in each region. The movement of the commodity between the producer and the regional pool is provided by a transport sector with an associated cost. This latter price will include the transport costs markup. However, goods shipped from region *k* will have a different delivery price than those from region *m*. Further, regional transportation sectors are assumed to operate under constant returns to scale using sectoral commodities, capital and labor as inputs as for other production sectors. Transportation output is produced according to a regional optimization problem. The explicit modeling of such transportation services based on the movements between origin-destination pairs represents a major theoretical advance (Isard *et al*., 1998). We assume that transport costs are paid at the origin. Since transport costs explicitly appear as an impediment to interregional trade, this study is confined to the regional welfare effects resulting from a change in transport costs for trade in goods and services. Use of the links for purposes other than trade, such as commuting, tourism, leisure trips etc., is not considered.

Finally, CGE models (especially multi regional CGE models) require comprehensive data. A Social Accounting Matrix (SAM) provides the underlying data framework for this type of model and analysis. A SAM includes both input-output and macroeconomic accounts in order to depict the detail of transactions among different economic agents, e.g., producers, consumers, governments, and the rest of the world. The availability of regional employment data, interregional trade flows data and TurkStat's varied regional data permit us to extend the national level Social Accounting Matrix (SAM) to a Multi-Regional SAM. The Multi Regional Social Accounting Matrix (MRSAM) used in this study is based on MRSAM generated by Piskin and Hannum (2017), calibrated to a base year of 2015.

4. ECONOMIC IMPACT OF HIGHWAY DISRUPTIONS

In the study area, within the entire Istanbul metropolitan, there are three ring roads that form the main road axes, stretching from East to West. The roads running in the north to south direction are connected to the ring roads in the east-west direction. Both sides of the Bosphorus are connected by East-West ring roads that play an important role in human and freight transport; all these roads serve local, interregional and intercontinental transport. Any damage in one part of the transport network may cause the severe disruption in the entire transportation system. According JICA (2002), two important bridges in the network, indicated by numbers in figure 4, are likely to collapse in an earthquake of magnitude 7.7.

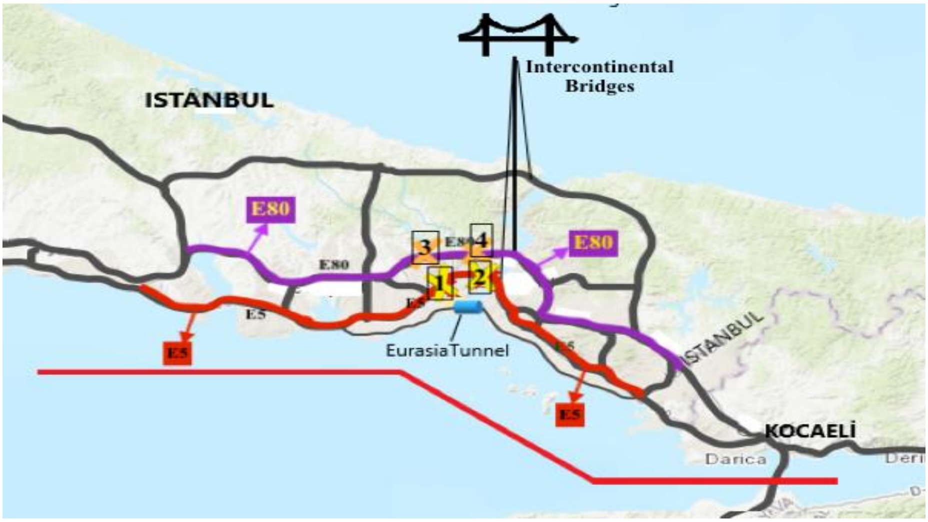

Figure 4: Map of the Istanbul metropolitan area described in terms of the transportation network.

As an input to the model, this paper considers trip time or accessibility, which varies as a consequence of damage to the transportation infrastructure (see Rokicki *et al*. (2021), for a review of accessibility measures in transport-CGE models). Changes in transport margins after the earthquake scenario in the network is assumed to be a linear function of transit time between regions. Compared to the interregional transport, the trip time for intraregional commodity transport is not easy to set, since the most model treats each zone as a centroid. In this study, shortest route or trip time computations through 39 county centroids and 26 connection nodes within the Istanbul metropolitan region and also the other 49-nodes in other regions of Turkey connecting Istanbul with rest of Turkey follow Dantzig's (1958) shortest path approach cast as a linear programming problem (see Appendix B). The Index values are aggregated into 10 aggregated region and Istanbul metropolitan region. Changes in the accessibility index in Istanbul and interregional accessibility changes with other regions of Turkey are converted into transport margin shocks in the TurksCGE model. Nodes outside the Istanbul Road network corresponding to important cities in other 10 aggregated regions; all of the link lengths both within Istanbul and between other nodes in other regions are taken from Google Maps.

We use average weighted trip time (WATT) as an accessibility measure in this study. WATT is the average weighted travel time from a given location *i* to other locations that are connected to location *i*. Location size will be measured by population in this study as in Gutiérrez and Gómez (1999). The mathematical expression of WATT is presented as follows:

$$WATT_i = \frac{\sum_{j=1}^{n} T_{ij} * M_j}{\sum_{j=1}^{n} M_j}$$

where T_{ij} is the transit time between locations from location *i* to *j*, *n* is the number of locations in the study area, and M_j is the mass of the destination location (population in this study). Consequently, the mass of the urban agglomeration is used as weight in order to value the importance of the minimal-time routes within the Istanbul metropolitan. Our study calculates network travel time based on physical network distances between distances. This contrasts with Kim *et al.* (2011 and 2017) where they focus on the increase of competitiveness or attractiveness of cities in terms of enhancing accessibility (using the concept of distance measure instead of travel time reduction). By combining information about open transport network after earthquake with this procedure, the decreased accessibility within and between regions for 3 simulations were estimated.

Simulation 1: The simulation scenarios in this study were selected based on the resulted presented in JICA (2002). According to this report, two important structures of the Istanbul network are very likely to collapse. One is the Ortakoy viaduct located just before the Bosporus intercontinental bridge. And the other is Halic bridge on the Golden horn estuary. These two important structures (highlighted as red crosses in figure 3) impact one of the three ring roads in the east-west direction (E-5 highway). This route passes through the densely populated southernmost regions of Istanbul. In addition, this part of Istanbul is a strategic location from the viewpoint of traffic; although interregional and international transport vehicles are prohibited on this route, any disruption on this route will increase the volume of traffic on the other two highway routes in the East-West corridor. Compared to the base case, the weighted average of travel time in Istanbul metropolitan region increases 10% if the Halic bridge and Ortakoy viaduct at D100 highway collapse.

Simulation 2: Venezia Mall Overpass and Hasdal Viaduct on E-80 located before the second intercontinental bridge collapse. According to this scenario, the weighted average of travel time in Istanbul metropolitan region increases 6% if E-80 highway is disrupted.

Simulation 3: In this scenario, we assume that both the E-5 and E-80 highways are disrupted after the earthquake. Lastly, we assume that it will take one year to resume operations on these two structures, although this may be optimistic.

Further details are provided in Appendix C.

5. SIMULATION RESULTS OF HIGHWAY DISRUPTIONS

The mechanism behind the inferences is based on two effects. Transportation costs increase due to network disruptions will decrease households' welfare by generating an increase in pool prices and decreasing households' real income. This is the real income effect and will affect regional welfare levels. Another important effect of increasing prices is the *substitution effect* in trade flows between regions. For example, purchasing some goods from region *A* can be more expensive for region *B* and therefore, region *B* can import more goods from other regions instead of region *A*. Regions that have lower production costs will tend to increase their market share within the economy. This is the *substitution effect* and any change in transport cost will affect regional market shares. However, spatial substitution assumes excess capacity in production in other regions; recent experience with disruptions in domestic and global supply chains due to COVID-19 suggests that in some cases, alternatives may be severely limited or non-existent.

The model presented in this study incorporates the effects of transport costs in only the interregional trade part. The welfare benefits calculated in the presented model are not complete since they do not capture any of effects on private car trips. If we consider this factor in household budget constraint, welfare losses would even higher. Welfare will be measured as the *monetary change* of benchmark income since it can also be described as the post-simulation utility under benchmark prices. In addition, there would be additional indirect effects if transportation disruptions prevented or significantly delayed journey-to-work trips, potentially depriving households of a major source of income from employment.

We look at the impacts on regional welfare for ten Turkish aggregated regions and for Istanbul metropolitan region. The spatial results are considered in order to specify retrofit priority after the earthquake. The spatial distribution of welfare losses arising from the disrupted road network in Istanbul are shown in table 1. The impact of the East–West transportation disruption in Istanbul increases transport cost in the local area that eventually spreads all over country such that other regions experience negative impacts on their welfare level after the earthquake.

Table 1: Regional Welfare Losses for Each Simulation

	Simulation 1	**Simulation 2**	**Simulation 3**
Istanbul	-2,2%	-1,9%	-5,0%
Ankara	-0,3%	-0,3%	-0,7%
Izmir	-0,4%	-0,3%	-0,8%
Aegean	-0,5%	-0,4%	-1,0%
Marmara	-0,8%	-0,2%	-1,1%
Central Anatolia	-0,8%	-0,6%	-1,6%
Mediterranean	-0,4%	-0,4%	-1,0%
Southeast	-0,2%	-0,2%	-0,6%
East Anatolia	-0,9%	-0,8%	-1,9%
West Black Sea	-0,9%	-0,6%	-2,1%
East Black Sea	-0,8%	-0,6%	-1,7%

As can be seen from Table 1, all regions experience a decrease in regional welfare. In each simulation, most of the regions in Turkey do not suffer the same relative loss as experienced in Istanbul since the major indirect losses occur in the Istanbul metropolitan region, the center of the earthquake. The results reveal that regional welfare losses due to damaged transport network in each simulation are respectively 2.2%, 1.9% and 5% for Istanbul. Non-negligible losses reach rather remote zones of the country such as the East Black Sea, West Black Sea and East Anatolia region for all of the three simulations. The Marmara region where industrial production is concentrated suffers as much as Central Anatolia, East Black Sea, West Black Sea and East Anatolia according to the first simulation.

Regional welfare losses are higher for all regions due to a disruption in E-5 highway. It is obvious that a higher welfare loss reflects a more important link in an economic sense and as a result, has higher priority of retrofit in the decision making Sohn *et al*. (2003). The results obtained for each simulation indicates that the road link (E-5) in the first simulation is economically more important than the road link (E-80) in the second simulation and, results show the retrofit priority of the links and bridges on highway network in Istanbul.

5.1. Impacts on Commodity Flows

Here, we examine the impacts of the earthquake on the commodity flows between regions. The changes in transport cost after the earthquake inevitably involve changes in interregional trade flows through the transportation networks. Tables 2-4 show the changes in the interregional trade flows of manufactured goods after the earthquake.

Table 2: Interregional trade flows after simulation 1

		Destination										
Origin		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Istanbul	**(1)**		5,7%	4,2%	-0,1%	3,7%	-2,5%	1,8%	0,7%	-0,3%	-0,3%	1,1%
Marmara	**(2)**	-7,6%		5,8%	15,9%	4,1%	1,8%	1,1%	3,8%	3,1%	3,2%	5,1%
Izmir	**(3)**	-76,7%	3,4%		15,5%	5,6%	1,2%	2,2%	2,7%	5,6%	2,8%	9,7%
Aegean	**(4)**	2,4%		2,0%		-0,4%	1,8%	1,5%	3,2%	2,6%	2,6%	0,2%
Ankara	**(5)**		5,9%	5,8%	-0,8%		-5,1%	-3,6%	-0,3%	-1,4%	0,8%	0,0%
Central Anatolia	**(6)**	-0,4%		1,5%	16,0%	1,6%		1,9%	2,7%	5,1%	3,3%	5,0%
Mediterranean	**(7)**	4,8%	5,9%	1,9%	-0,8%	-4,0%	-5,1%		-0,3%	-1,4%	0,8%	-0,1%
Southeast	**(8)**	3,3%	3,4%	1,7%	7,0%	-2,5%	1,2%	-5,6%		0,5%	-4,2%	1,3%
East Anatolia	**(9)**	4,9%	-0,1%	1,7%	2,8%	-4,0%	1,2%	3,3%	0,7%		2,2%	-0,2%
West Black Sea	**(10)**	10,8%	-0,1%	2,4%	4,0%	2,4%	3,7%	2,4%	1,8%	1,3%		1,6%
East Black Sea	**(11)**	10,6%	3,4%	0,9%	2,8%	2,7%	-1,1%	1,8%	2,7%	3,1%	2,6%	

Table 3: Interregional trade flows after simulation 2

Origin		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		Destination										
Istanbul	**(1)**		5,0%	2,8%	0,1%	0,2%	-1,8%	-0,6%	-0,6%	-2,0%	0,2%	-1,0%
Marmara	**(2)**	-11,0%		2,3%	20,5%	1,0%	1,4%	0,3%	1,9%	1,6%	1,2%	5,0%
Izmir	**(3)**	-85,5%	1,2%		20,0%	3,5%	1,3%	0,0%	1,1%	1,2%	0,8%	14,6%
Aegean	**(4)**	1,1%		0,5%		-1,3%	1,4%	0,3%	1,5%	1,6%	1,0%	0,2%
Ankara	**(5)**		5,3%	6,0%	-0,2%		-3,3%	-3,7%	1,0%	-0,8%	1,2%	0,6%
Central Anatolia	**(6)**	-7,5%		0,4%	20,7%	0,3%		0,2%	1,1%	1,4%	1,2%	7,8%
Mediterranean	**(7)**	3,7%	5,3%	0,6%	-0,2%	-3,5%	-3,3%		1,0%	-0,8%	1,2%	0,1%
Southeast	**(8)**	-0,2%	1,2%	0,3%	9,4%	-2,1%	1,3%	-4,7%		-1,3%	-4,2%	1,3%
East Anatolia	**(9)**	3,7%	0,4%	0,3%	1,4%	-3,5%	1,3%	0,0%	-0,6%		1,3%	0,0%
West Black Sea	**(10)**	9,9%	0,4%	0,5%	1,7%	-0,8%	1,2%	-0,2%	-2,1%	-2,5%		-1,1%
East Black Sea	**(11)**	8,2%	1,2%	1,2%	1,4%	1,0%	-0,7%	0,2%	1,1%	1,5%	1,0%	

Table 4: Interregional trade flows after simulation 3

Origin		Destination (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Istanbul	**(1)**		11,6%	9,5%	0,1%	9,2%	-3,9%	6,5%	3,3%	1,7%	0,1%	3,3%
Marmara	**(2)**	-32,6%		8,6%	14,9%	5,7%	3,5%	2,8%	5,6%	4,2%	6,0%	2,6%
Izmir	**(3)**	5,3%	5,6%		14,5%	9,5%	3,3%	3,7%	3,7%	5,5%	4,7%	-2,0%
Aegean	**(4)**	-7,7%		3,4%		-3,4%	3,5%	3,2%	4,6%	4,4%	5,6%	-1,7%
Ankara	**(5)**		12,0%	12,7%	-1,4%		-9,4%	-8,6%	-0,2%	-1,1%	2,7%	0,2%
Central Anatolia	**(6)**	-4,2%		2,9%	15,0%	2,1%		3,7%	3,7%	5,9%	6,1%	-2,1%
Mediterranean	**(7)**	0,5%	12,0%	3,4%	-1,4%	-12,4%	-9,4%		-0,2%	-1,1%	2,7%	-2,1%
Southeast	**(8)**	2,5%	5,6%	2,9%	6,7%	-8,1%	3,3%	-12,4%		-3,6%	-10,1%	-3,1%
East Anatolia	**(9)**	0,5%	0,5%	2,9%	4,5%	-12,4%	3,3%	5,2%	3,3%		4,5%	-2,4%
West Black Sea	**(10)**	5,3%	0,5%	5,4%	8,7%	4,7%	8,9%	8,0%	6,9%	6,2%		5,4%
East Black Sea	**(11)**	-5,1%	5,6%	2,5%	4,5%	6,1%	-2,3%	3,5%	3,7%	5,7%	5,6%	

Istanbul commodity outflow to all regions decreases substantially after the earthquake (see table 2). A noticeable increase in commodity inflows to Istanbul comes from the Mediterranean, East Anatolia, West Black Sea and East Black Sea in all scenarios. According to scenario 1 and 2, results indicate the substantial decrease in commodity inflows to Istanbul from Marmara and Izmir where industrial production is concentrated.

There are also decreases in the interregional commodity flows between other regions such as Marmara, Izmir and East Black Sea regions, adjacent to the Istanbul. The other major change is a decrease in commodity outflows of Ankara and increases in the interregional trade with only Izmir and Marmara in all simulations. All these changes show that the commodity flows between regions can be influenced by an increase in transport cost due to an earthquake in Istanbul.

6. ECONOMIC IMPACT OF LIFELINE OUTAGES

Lifeline disruptions can cause significant loss of production capacity even though the facilities themselves are not damaged. Guha (2011) refers to lifelines as neural or cardio-vascular networks sustain life within a human body. Any disruption in this system can have devastating effects on an agglomerated economy like Istanbul. And also it is inevitable to see the damage to other regions that are not directly affected but are economically linked to Istanbul.

Information on the lifeline disruption was collected in units of neighborhood as the smallest available spatial scale just like in labor and capital shocks. We cumulated all the neighborhood lifeline outages to county level (as can be seen at Figure 5 below) as a first step and then we aggregated the county level effects and find the total weighted average of outage in metropolitan by using population weights of counties. Even if the lifeline stopped in some parts of the neighborhood, it is assumed that total neighborhood area suffered from relevant lifeline disruptions. We assume that overall loss of electric power, naturel gas and water affect uniformly all economic sectors (firms, household and government) as a percentage of weighted average of outages. And lastly, we assume complete restoration is spread over three months.

Based on earthquake loss estimation of lifeline interruptions in the county level in two different research programs pursued by Japan International Cooperation Agency (JICA) and Istanbul Metropolitan Municipality, we assess indirect economic losses due to lifeline disruptions like below.

Simulation: Research of Istanbul metropolitan municipality estimate the lifeline outages as a weighted sum of total population are as follows, 43% for natural gas, 50.7% for water and 3.9% for electricity. And we assume that lifeline outages will last for 3 months.

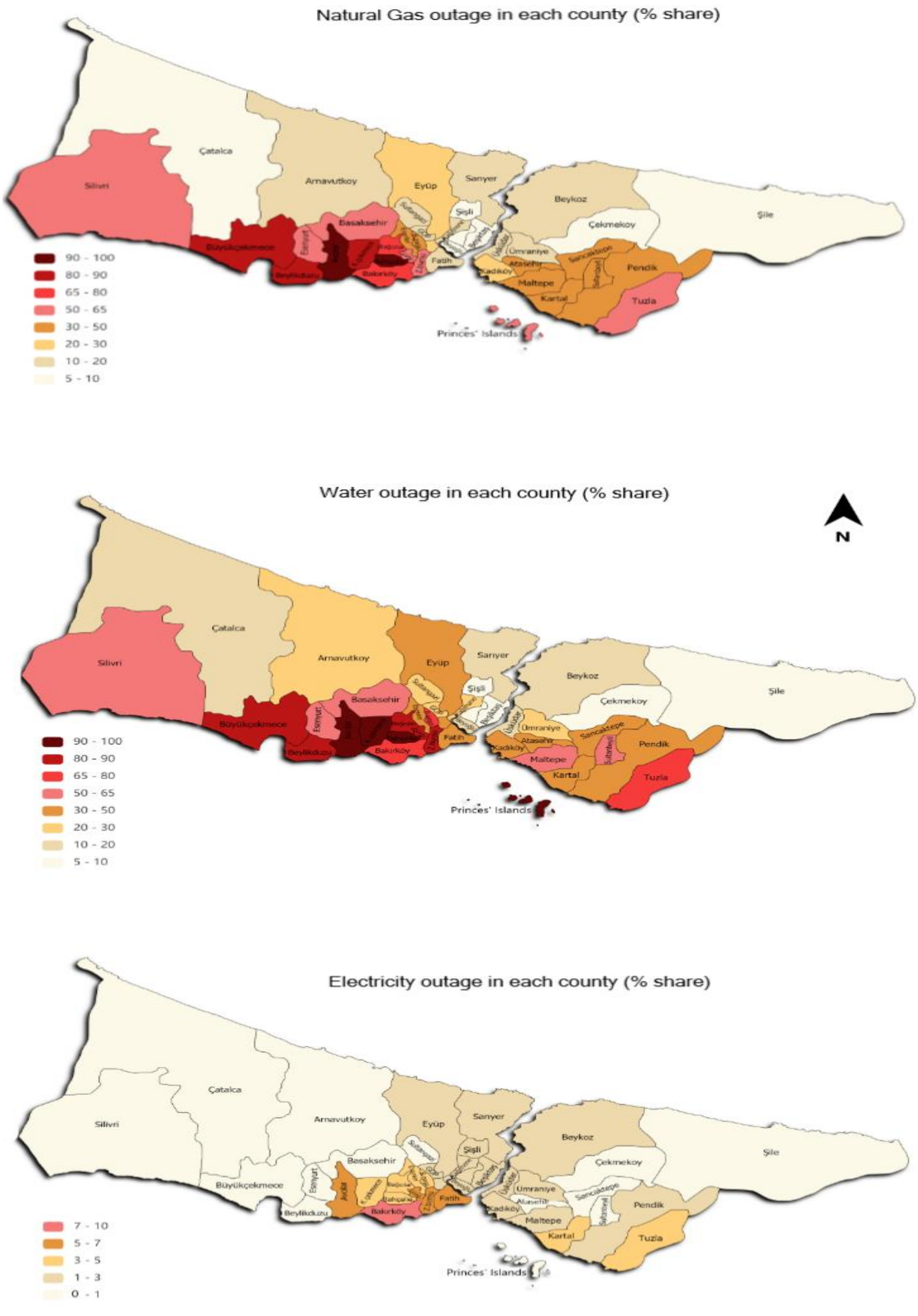

Figure 5: Distribution of lifeline outages in county level for both scenario

6.1. Spatial Results

The results indicates that biggest output losses occur in Istanbul metropolitan region for both scenarios (see Table 5). According to lifeline outage simulation, majority of the regional production losses occur in Istanbul metropolitan. As can be seen at Table 5, non-negligible losses reach rather remote region like East Anatolia region and East Black Sea region.

Table 5: Impact of lifeline disruption in regional production

	Regional Output
Istanbul	-1.97%
Ankara	0.63%
Izmir	0.04%
Aegean	-0,08%
Marmara	-0.09%
Central Anatolia	-0.24%
Mediterranean	0.31%
Southeast	-0.09%
East Anatolia	-0.42 %
West Black Sea	-0.28%
East Black Sea	-0.34%

Ankara and Izmir, biggest two cities after Istanbul, experience an increase in their production. Mediterranean region also experience a production increase and this indicates that Ankara, Izmir and Mediterranean region try to compensate the production decline in Istanbul whereas the rest of the country experience a negative result with Istanbul.

7. Conclusion

Istanbul is the main economic engine of Turkey. Disruption in East-West highway routes that link the Asian and European continents, pass through the

Istanbul metropolitan region will not only impact the interregional transport costs but also impact the intra-regional transport cost in Istanbul. By combining interregional transportation network with the intraregional network of Istanbul, these local (Istanbul) and interregional effects of an earthquake in the Istanbul region can be estimated. Our integration of spatial CGE model with transport sub-model permits the study of how the economic impacts of a disrupted transport network are distributed across regions within Turkey.

We applied the TurkSCGE model to estimate the economic loss from network disruption generated by a hypothetical earthquake disaster in the Istanbul metropolitan region. We look at the impacts on regional welfare for ten Turkish aggregated regions and for Istanbul metropolitan region. Most of the indirect losses occur in the Istanbul metropolitan region as the center of the earthquake. Welfare losses in Istanbul range from 1.9% to 5% according to three different simulations. After running different scenarios, the analysis also identifies the most important link on the network in economic terms. Our study shows that regional welfare losses are higher for all regions due to a disruption in E-5 highway which passes through densely populated counties of Istanbul. The road link (E-5) in first simulation is economically more important than the road link (E-80) in second simulation and, results show the retrofit priority of the links and bridges on highway network in Istanbul.

Results of the lifeline outages indicates that sectors in Istanbul experience a significant output decline. The analysis also showed that non-negligible losses also occur in remote regions of the Turkey. Neighboring regions and remote ragions suffer indirectly via the interregional trade linkages. The estimated losses can be useful to prioritize urban transformation plans in Istanbul.

Future work will need to extend the indirect effects to account for disruptions in labor supply (inability to reach workplaces), loss of production and distribution facilities damaged by the earthquake and the disruptions in household expenditures (limitations of access to retail locations and an increase in risk-adverse behavior). These impacts are likely to be greater in magnitude, more spatially extensive and longer-lasting. To accomplish this exploration, the SCGE model will require conversion to a multi-period model, greater disaggregation of the household sector and a more detailed consideration of journey-to-work flows by different transportation modes. In addition, some limitations on spatial substitution possibilities will need to be considered as the processes of spatial fragmentation of production have increased capacity utilization (to further exploit economies of scale) limiting the ability of alternative sources of supply to be accessed.

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Appendix A.

A1. Variable Definitions

vdm_{ir}	Regional Production
vxm_{ir}	Regional Export to Rest of World
$vxma_{irs}$	Domestic Interregional Trade Flows
vim_{ir}	Regional Import
vst_{ir}	Value of Regional Transport Sales
$vtwr_{isr}$	Transport Services
io_{ir}	Intermediate Input Demand
vfm_{fir}	Factors of Production
$evoa_{ir}$	Factor Income
vpm_{ir}	Regional Household Consumption
vgm_{ir}	Government Consumption
inv_{ir}	Regional Investment
out_{ir}	Regional Production
DG_{ir}	Regional Output after export and interregional trade
DSG_{ir}	Regional Supply
DDG_{ir}	Regional Demand
$HHbudget_r$	Household Budget
$gtrans_r$	Government Transfers
hr_r	Remittance income
$hsav_r$	Household Saving
gbr	Government Borrowing
fsv	Foreign Saving
gsv	Government Saving
trx_{ir}	Sum of Regional Trade Flow in Each Sector
SSI_r	Social Security Income (pension)
SSP_r	Social Security Premiums
cie_r	Profit Transfers of Foreign Companies
SI_r	Saving Income
p_{ir}^A	Armington Composite Price
p_{ir}^T	Marginal Cost of Transport Services
p_{ir}^E	Export Price
p_{fir}^F	Factor Prices
p_{ir}^D	Supply Price
p_{ir}^{DD}	Price of domestically supplied goods
tY_{ir}	Output Tax

ti_{ir}	Taxes on Products
tim_{ir}	Import Tax
$tinc_r$	Income Tax

A2. List of Key Equations in Multi regional Social Accounting Matrix

(1) $out_{ir} = io_{ir} + vfm_{ir} + tY_{ir}$

(2) $DG_{ir} = out_{ir} - vxm_{ir} - \sum_s vxma_{irs}$

(3) $DSG_{ir} = DG_{ir} + ti_{it} + \sum_s vxma_{irs} + \sum_s vtwr_{irs} + vim_{ir}$

(4) $DDG_{ir} = io_{ir} + vapm_{ir} + vagm_{ir} + inv_{ir} + vst_{ir}$

(5) $HHbudget_r = \sum_i vfm_{ir} + gtrans_r + hr_r + cie_r + hsav_r + \sum_i vpm_{ir} - tinc_r$

(6) $GovBudget = \sum_{ir} tY_{ir} + \sum_{ir} ti_{ir} + \sum_{ir} tim_{ir} + \sum_r tinc_r + gbr - \sum_{ir} vgm_{ir} - \sum_r gtrans_r - gsv$

(7) $\sum_r inv_r = \sum_r hsav_r - gsv - fsv$

(8) $\sum_{ir} vxm_{ir} + gbr + \sum_r hr_r + fsv = \sum_{ir} vim_{ir} + cie$

(9) $trx_{ir} = \sum_s vxma_{irs}$

A3. Behavior Equations in Model

Production

$$(10) \quad \min_{int.input,K,L} c_{ir}^{int.input} + c_{ir}^{K} + c_{ir}^{L}$$

$$s.t. \quad c_{ir}^{int.input} = \sum_i p_{jr}^{A}(1 + tY_{ir})\, vdfm_{jir}\,, \quad c_{ir}^{K} = \sum_i p_{ir}^{F} K_{ir}\,, \quad c_{ir}^{L} = \sum_i p_{ir}^{F} L_{ir}$$

$F_{ir}\,(vdfm, K, L) = Y_{ir}$

Supply of Goods to Domestic and Export Markets (CET function)

(11) $\max_{DG,vxm,trx} p_{ir}^{DD} DG_{ir} + p_{ir}^{fx} vxm_{ir} + p_{ir}^{tr} trx_{ir} \quad s.t. \quad TR_{ir}(DG_{ir}, vxm_{ir}, trx_{ir}) = Y_{ir}$

Trade (Armington Aggregation)

(12) $\min_{Trade,Marg} (p_{ir}^{DD}(1 + ti_{ir})DG_{ir}) + (p_{ir}^{tr} trx_{ir} + p_i^T vtwr_{isr}) + (p_{is}^{DD} vxma_{i,s=r} + p_i^T vtwr_{i,s=r}) + (p_{ir}^{fx}(1 + tim_{ir})vim_{ir})$

$s.t. \qquad A_{ir}(trx,\ vtwr, vim) = Trade_{ir}$

Transportation Services

(13) $\min_{margin} \sum_r p_{ir}^{A} vst_{ir} \qquad s.t. \quad T_r(vst) = Transport_r$

Household Consumption

(14) $\min_{C_{ir}^{HH}} \sum_i p_{ir}^{A}\ vpm_{ir} \qquad s.t. \quad FD_r(vpm_{ir}) = C_{ir}^{HH}$

Government

(15) $G_r = G_r(vgm_{ir})$

Investment

(16) $I_r = I_r(inv_{ir})$

Equilibrium conditions

Zero profit condition

(17) $p_{ir}^{D} XD_{ir} + p_{ir}^{X} vxm_{ir} = \sum_j vafm_{jir} + \sum_f vfm_{fir} + Tax_{ir}^{Y}$

Market Clearance Condition

Armington Aggregate Supply

(18) $$XD_{ir} + \sum_s Trade_{isr} + \sum_s vtwr_{isr} + vim_{ir} = \sum_j vafm_{jir} + vst_{jr} + vpm_{ir} + inv_{ir} + vgm_{ir}$$

Trade

(19) $\sum_s vxma_{isr} + \sum_s vtwr_{isr} = \sum_r vxma_{irs} + \sum_r vtwr_{irs}$

Primary Factors

(20) $\sum_i F_{fir} = \sum_i Y_{ir} \alpha_{fir}^{F}$

Income Balance Conditions

Private Demand and its budget

(21) $HHB_r = evoa_r + (GTrans_r - Tax_r^H) + (SSI_r - SSP_r) + (hr_r - Rtrans_r) + (SI_r - Sav_r)$

(22) $HHB_r = \sum_i vpm_{ir} = C_r$

Public Demand and its budget:

(23) $R = \left(\sum_r T_r^Y + T_r^p + T_r^H\right) + gbr - (\sum_r Gtrans_r + \sum_r SSIdef) - Gsav$

(24) $R = \sum_{ir} vgm_{ir} = G$

Investment Demand and its budget:

(25) $Inv_r = Sav_r + Gsav + Fsav$

(26) $Inv_r = \sum_i inv_{ir} = I_r$

B. Shortest Route Algorithm

Dantzig algorithm finds the shortest path between each pair of vertices in the network.

Let T be a rooted spanning tree on $\{1,\ldots,\text{n}\}$, with root 1. For each i $= 1,\ldots,$ n, let u_i be equal to the length of the path from 1to i in T. Now if $u_j \leq u_i + d_{i,j}$ for all i,j, then for each i, the $1-i$ path in T is a shortest path. If $u_j > u_i + d_{i,j}$, replace the arc of T entering j by the arc (i,j), and iterate with the new tree.

Change in the distance between nodes in the network was found according to this algorithm and results was used in the margin changes (see appendix D). Changes in the transportation margins ($vtwr_{isr}$) after the improvement in the network is assumed to be a linear function of distance between regions.

C. Accessibility Changes Between Regions

C.1. Accessibility changes between regions in simulation 1

	Istanbul	Ankara	Izmir	Aegean	Marmara	Central Anatolia	Mediter.	Southeast	East Ana.	West B. Sea	East B. Sea
Istanbul	10%										
Ankara	5,1%	0									
Izmir	4,4%	0	0								
Aegean	4,3%	0	0	0							
Marmara	10,2%	0,3%	2,8%	0,1%	0						
Central Anatolia	4,1%	0	0	0	0,2%	0					
Mediterranean	2,7%	0	0	0	0,2%	0	0				
Southeast	1,8%	0	0	0	0,1%	0	0	0			
East Anatolia	2,2%	0	0	0	0,1%	0	0	0	0		
West Black Sea	4,2%	0	0	0	0,2%	0	0	0	0	0	
East Black Sea	2,1%	0	0	0	0,1%	0	0	0	0	0	0

C.2. Accessibility changes between regions in simulation 2

	Istanbul	Ankara	Izmir	Aegean	Marmara	Central Anatolia	Mediter.	Southeast	East Ana.	West B. Sea	East B. Sea
Istanbul	6%										
Ankara	12,5%	0									
Izmir	10,9%	0	0								
Aegean	10,5%	0	0	0							
Marmara	28,3%	0	0	0	0						
Central Anatolia	10,2%	0	0	0	0	0					
Mediterranean	6,7%	0	0	0	0	0	0				
Southeast	4,4%	0	0	0	0	0	0	0			
East Anatolia	5,4%	0	0	0	0	0	0	0	0		
West Black Sea	10,3%	0	0	0	0	0	0	0	0	0	
East Black Sea	5,1%	0	0	0	0	0	0	0	0	0	0

C.3. Accessibility changes between regions in simulation 3

	Istanbul	Ankara	Izmir	Aegean	Marmara	Central Anatolia	Mediter.	Southeast	East Ana.	West B. Sea	East B. Sea
Istanbul	30%										
Ankara	17,4%	0									
Izmir	15,1%	0	0								
Aegean	14,6%	0	0	0							
Marmara	38,5%	2,5%	0,3%	1,1%	0						
Central Anatolia	14,2%	0	0	0	2,1%	0					
Mediterranean	9,3%	0	0	0	1,6%	0	0				
Southeast	6,2%	0	0	0	1,1%	0	0	0			
East Anatolia	7,5%	0	0	0	1,3%	0	0	0	0		
West Black Sea	44,3%	0	0	0	2,1%	0	0	0	0	0	
East Black Sea	7,1%	0	0	0	1,2%	0	0	0	0	0	0

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