Economic Assessment of Natural Disasters in China: A Dynamic Spatial CGE Approach

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Abstract

On July 28, 1976 at 3:42 am local time, a moment magnitude 7.5 earthquake occurred below Tangshan city in the Hebei Province of northern China, causing extensive damage to the industrial city and its surroundings. The earthquake ruptured 100 km (62 mi) of the Tangshan fault, a right-lateral strike-slip fault trending in the north-northeast direction. The area experienced 10 km of extensive surface faulting running through downtown Tangshan with horizontal displacements up to 1.5 m.

Many buildings collapsed as a result of the intense ground shaking. Due to the earthquake’s occurrence in the middle of the night, this damage led in turn to very high casualties among the inhabitants of the city and the surrounding communities. The event also caused major damage in the city of Tianjin located 100 km southwest of Tangshan, and moderate damage in Beijing approximately 140 km to the west. The 1976 Great Tangshan Earthquake remains the deadliest earthquake in modern times with an official death count of approximately 242,400.

With over 2,000 years of chronicled history, the spatial and temporal occurrence of historical earthquakes is particularly well studied in northern China. Since 1000 C.E., strong crustal earthquakes have occurred in this region over four distinct high activity time periods, separated by decades of quiet seismic activity. The active periods span 1011 to 1076 C.E., 1290 to 1368 C.E., 1484 to 1730 C.E., and 1815 to the present. Research has found that over the four active periods, seismicity was concentrated in one or more distinct areas and the strongest earthquakes appeared to have been clustered. For example, during the fourth period, which is still active in 2006, one concentration of strong earthquakes occurred along the north-northeast trend from Tianjin to Tangshan. A series of major events also occurred between 1966 and 1976: the 1966 Xingtai earthquakes, the 1970 Tonghai Earthquake, the 1975 Haicheng Earthquake, and the 1976 Tangshan Earthquake.

In this paper, The CGE model is be used dynamic process of the Ms=7.8 Tangshan earthquake.China is subdivided into 30 cities/regions. All the cities/regions are connected by transportation networks.Our model is of a decentralized economy with utility-maximizing consumers and value-maximizing firms in a dynamic context.The model is calibrated for the regional economy using a multi-regional input-output table for China.As a case study,we estimate the impacts of a hypothetical earthquake in the Bohai Economic Rim on the regional economy.

We develop a spatial computable general equilibrium model to investigate the regional economic impacts of an earthquake. In our spatial model, China is subdivided into 30 cities/regions. All the cities/regions are connected by transportation networks. Our model is of a decentralized economy with utility-maximizing consumers and value-maximizing firms in a dynamic context. The model is calibrated for the regional economy using a multi-regional input-output table for China. As a case study, we estimate the impacts of a hypothetical earthquake in the Bohei Economic Rim on the regional economy.

Keywords: Disaster Evaluation, Indirect Economic Impacts, Large-scale Earthquake, Spatial CGE Modeling, China

1. Introduction

We develop a dynamic spatial computable general equilibrium model to investigate the regional economic impacts of earthquakes in China. Our model is of a decentralized economy with utility-maximizing consumers and value-maximizing firms in a dynamic context. The model embodies both the spatial interactions among regions and the dynamics of regional investments. A numerical simulation model is developed of an inter-regional inter-sectoral economy in which China is subdivided into 30 regions. All the regions are connected by transportation networks. The model is calibrated for the regional economy in China.

The economic impacts of disasters have been analyzed by computational modeling approaches, such as the input-output model, mathematical programming, CGE, and econometric models. Those studies mostly focused on assessing the economic impacts of damage to the public infrastructure such as transportation links, electric utility lifelines, water facilities, and telecommunications networks.

The CGE model gives us an excellent framework for analyzing disaster impacts and policy responses both across and between industries, households, and government. To assess the distribution impacts of a disaster in multi-regional settings, the spatial CGE model approach, which disaggregates the world or a country into a number of regions or counties, has also been developed. The models were characterized by the optimizing behavior of individual consumers and firms, subject to market balances and resource constraints in a static framework. The spatial interactions between regions are internalized by the transportation networks and trade costs. The spatial CGE (or CGE) model is widely recognized as a powerful tool.

China is located in the continent of Asia and is the world’s second-large country in terms of land area. In China, major disasters are drought, flood, earthquake, hails and typhoon. Several disasters have been assessed and empirical studies have adequately estimated direct and some indirect economic losses based on actual data (Tamura et al. 1982, Yaoxian 2002, Huixian et al.2002). Direct damage induced by catastrophic earthquake has significant impacts not only on the disaster-affected region’s economy but also on other regions. Wu et al.(2012) developed an interregional model and evaluated the indirect losses in and outside the disaster area caused by the Wenchuan earthquake. The distributional impacts across economic institutions and between regions caused by the direct economic loss in specific regions after an earthquake were estimated.

The paper is organized as follows. We outline the model in Section 2. In section 3 and 4, we provide scenarios and simulation results. Two cases are compared to a base case, which is a steady state solution for a 51-year period. Section 5 summarizes the paper and offers some concluding remarks.

2. Outline of the Model

The model is finitely set up in discrete time. The world is divided into a home country and a foreign country. These are subdivided by region. There are three kinds of industries, i.e. general, transportation and distribution industries. The general industry involves domestic and foreign trade between regions. All the regions interact with each other via the transportation networks. A transportation network is defined by nodes and links. A transport path connecting two regions is fixed and the transport link distance is exogenously given.

The model is based on dynamic macroeconomic theory with a multi-region and multi-sector specification. Each region has production and household sectors. Commodity trade flows are determined by the trade and modal share coefficients. We characterize the problems related to the maximization of the production and household sectors in this economy.

In the simulation model, the world is subdivided into 30 regions, which cover China’s cities/provinces. General industry is divided into three sectors, i.e. agriculture, manufacturing, and services. There are four kinds of transportation networks: road, railway, sea, and air. Then the transportation industry is also divided into four sectors. The network structure, which is defined by the distance between an origin and a destination, is given for each period. The simulation period is set at $t_F = 51$. Population growth and technological progress are also fixed over time. Utility, production, and investment functions are specified for the simulation analysis. Our simulation model is calibrated using the multi-regional input-output table in China (ref. Shi and Zhang 2012).

3. Simulation Cases and Numerical Examples

Our target area is the Bohai Bay Economic Rim (BER). It is the economic hinterland surrounding Beijing and Tianjin. In this study, we consider a situation where a large scale earthquake is occurred in the BER. In the past, there have been strong earthquakes in this area.

Since 1966, there have been four earthquakes of magnitude greater than 7.0: Hsingtai 1966, Bohai 1969, Haicheng 1975, Tangshan 1976. According to the history of earthquake in China, after 1000 B.C. four cycles of earthquake occurrence in the North China have been identified by Chinese seismologists. Each cycle spans roughly 300 years (Huixian et al. 2002).

Three cases are examined to evaluate the dynamic impacts of an earthquake in the Bohai Bay Economic Rim region. The primary physical damage is simply assumed in terms of the reduction in the industrial capital stock in each region.

(a) Base Case

The base case is the business as usual case where there is no earthquake. In this case, a steady state solution is derived. The population growth rate and the technical progress growth are also both given as zero percent.

(b) Case 1

We assume that an unpredicted earthquake occurs suddenly and hits the target area. In this simulation, the earthquake occurs in the 25th period. The level of physical damage is also assumed to comprise a reduction in capital stocks. In this situation, no industry can make a new investment to protect itself from the disaster before the earthquake.

(c) Case 2

In this case, it is assumed that an earthquake is accurately predicted. Here, the earthquake occurs in the 25th period. Then the capital stocks are reduced in the 25th period as shown in Table 1. The amount of the reduction is the same as in Case 1. In Case 2, each industry can make an additional investment to protect itself before the earthquake.

3. The Results of the Simulation

(a) Impacts on Capital Stock

The dynamic solutions for the capital stocks and the value of the capital stocks (i.e., the costate variable) of the manufacturing sector are examined. The BER region is directly affected by an earthquake and suffers great losses, especially Hebei province. Other regions are also indirectly influenced by the earthquake through the transportation network. Figure 2 shows the dynamic impacts of the earthquake on the capital stock and its value in Hebei province. In our dynamic simulation, the capital stock is accumulated by forward calculation, while the value of the capital stock (the costate variable) is solved by backward calculation.

Beijing and Tianjin are located inside Hebei province. In Heibei province, the capital stock suddenly decreases during the 25th period and is gradually restored after the earthquake in Case 1. The capital stock value is unchanged before the earthquake, and it increases unexpectedly during the 25th period due to the capital stock damage in Case 1. In Case 2, the capital damage seems to be more rapidly repaired after the earthquake by an increase in investment to protect against the earthquake. In Case 2, the capital stock value would increase more before the earthquake than in the Base case and Case 1. This implies that industrial sector would exactly estimate the value of the capital stock before the earthquake since it can accurately predict the occurrence of an earthquake.

Provinces which are not directly affected are severely influenced by the earthquake and are indirectly affected by the quake through the inter-trade between cities/provinces. In Case 1, some provinces experience an increase in investment due to the recovery activities in the BER region after the earthquake. By contrast, in Case 2, before the earthquake some provinces experience a decrease in investment and output, since the investments in the BER region increase to protect from the disaster. After the earthquake, similar changes can be seen.

(b) Impacts on GRPs

Figure 3 shows the results of the impacts of the earthquake on the GRP (Gross Regional Products) in all the regions (cities and provinces). The change in the GRP is defined as $\Delta x = (x_{\mathrm{Case}} - x_{\mathrm{Base}}) / x_{\mathrm{Base}} \times 100\%$. In both cases, the earthquake occurs in the BER region during the 25^{th} period. This figure shows the dynamic impacts of the earthquake in all the regions. In addition, the bold line depicts the change in the total GRP of China and it implies the average impact of the earthquake. It may be useful to compare a regional impact and a national impact. The industrial capital stocks in the BER region Heibei, Tianjin and Beijing, are directly reduced by the earthquake. In both cases, the BER region suffers damage from the earthquake and the percentage of damage in Hebei province appears to be greater than that of the whole of China.

It is assumed that the disaster hits in the 25th period, and the earthquake is accurately predicted. In Case 2, the production sectors can make an additional investment before the earthquake. Before the earthquake, the BER region experiences a positive impact owing to the increase in investment designed to protect the region from earthquake damage. In particular, the GRP in Heibei province is largely influenced by the additional investment before the disaster and the change in the GRP would be greater than that of China. After the disaster, the BER region in Case 2 is more rapidly restored by the investment from other provinces than Case 1.

(c) Impacts on Commodity Flows

Here, we examine the dynamic impacts of the earthquake on the commodity flows between regions. The changes in investment before and after the earthquake inevitably involve changes in the intra- and inter-trade commodity flows through the transportation networks. The intra- and inter-trade of manufactured goods during the 24^{th} and 26^{th} periods are shown in Figure 4. It shows the changes in the intra-and-inter trade commodity flows of manufactured goods for all the transport modes before and after the earthquake in Case 2. The change is defined as $\Delta x = (x_{\mathrm{Case}} - x_{\mathrm{Base}})$.

The diagonal line in the figure depicts the intra-trade commodity flows. The intra-trade flows increase before and decrease after the earthquake. Before the earthquake, the increases in the BER region are particularly noticeable. On the other hand, after the earthquake, the decreases in in the BER region are noticeable. In Case 1, after the earthquake, similar changes can be seen, i.e. there is a decrease in intra-trade commodity flows in the BER region.

The figure also presents the changes in the inter-trade commodity flows of manufactured goods for all the transport modes between provinces in Case 2. We observe that the changes in the commodity flows before the earthquake are smaller than those after the earthquake. Two kinds of major change can be seen in the figures. The first is a noticeable increase in commodity inflows to the BER region from other provinces. The second is a noticeable decrease after the earthquake in the inflows to the BER region.

6. Concluding Remarks

In this paper, we described a dynamic spatial general equilibrium model. A decentralized economic system, which linked with the transportation networks, was constructed in a dynamic framework. The main purpose of the paper is to assess the impacts of an earthquake in the BER area on the regional economy in China. We presented the results of three simulations: no earthquake, unpredicted earthquake and predicted earthquake in terms of the occurrence of an earthquake. We estimated dynamic and spatial impacts, i.e. industrial investments and commodity flows between regions before and after the earthquake. The indirect effects before and after a disaster were simultaneously solved. Our simulation results suggest the importance of investment in terms of protecting the regional economy in the event of a disaster.