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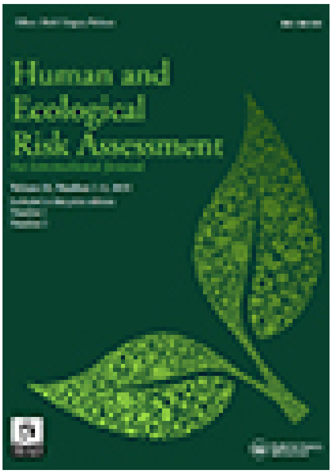

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# Disaster Risk Decision: A Dynamic Computable General Equilibrium Analysis of Regional Mitigation Investment

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# Disaster Risk Decision: A Dynamic Computable General Equilibrium Analysis of Regional Mitigation Investment

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**ABSTRACT**

For implementation of specific actions to reduce risks, there is lack of a unified tool to compare different mitigation investment strategies and to prioritize alternative mitigation measures. Organizations usually address some operational risks such as business interruption (BI) losses. Computable general equilibrium (CGE) models are state-of-the-art economic tools to account for BI losses. This study proposed a new, improved dynamic CGE model to analyze and compare mitigation investment measures that aim at reducing BI losses. The new model, a time-recursive dynamic model reflecting the recovery and reconstruction period, connects reconstruction investment with reconstruction funds source, such as from government, household, enterprise, or outside a disaster-affected area. The 2008 Wenchuan earthquake in China was selected as a case study to illustrate the new model. Some interesting topics about mitigation investment were analyzed: (1) the relative importance of pre-disaster reduction investment versus post-disaster reconstruction investment; (2) post-disaster economic recovery with the contribution of insurance compensation; (3) the optimal ratio between mitigation funds collected from the disaster-affected area and that collected from outside the disaster-affected area; (4) the rational division of limited mitigation funds to each year during the restoration and reconstruction period.

**Key Words:** vulnerability, resilience, indirect economic loss, business interruption loss.

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## INTRODUCTION

Disaster risk management comprises risk identification, risk reduction, disaster management, and governance and financial protection (Carreno *et al.* 2007; UNISDR 2009). Regional mitigation investment is fundamental to these four policies. Several key questions facing regional mitigation investment analysis are to determine: (1) how much to spend on pre-disaster reduction versus post-disaster reconstruction; (2) what is the optimal ratio between mitigation funds collected from the disaster-affected area and that collected from outside of the disaster-affected area; (3) how to rationally divide the limited mitigation funds to each year in the process of restoration and reconstruction, and so on. Recently, how to provide financial protection to victims from natural disasters has already became the topic of intense research within the arena of disaster risk management (Kunreuther 2001; Dodo *et al.* 2005; Xu *et al.* 2007; Olson and Wu 2010). Most published research has focused on finding new mitigation investment strategies and most of them belonged to qualitative analysis. For implementation of specific actions to reduce risks, it lacks a unified tool to compare different mitigation investment strategies and to prioritize alternative mitigation measure. The present article proposes a quantitative model, like a "physics laboratory," that can simulate the reduced disaster economic losses under different mitigation investment scenarios, then can compare advantages and shortcomings of different mitigation investment, and can aid decisions on optimal policy.

One purpose of mitigation investment is to reduce disaster losses. Although the disaster losses related to property damage are often obvious, the subsequent business interruption (BI) loss, such as output or gross domestic product (GDP), can similarly be quite substantial. Direct property damage occurs during an extreme disaster event. However, BI loss, as a flow variable, is highly variable and depends on the total length of the "economic disruption," which is typically synonymous with the length of the recovery and reconstruction periods. Hence, a sizable mitigation investment can be regarded as one of the best methods for shortening the recovery and reconstruction period and reducing BI loss. It is widely practiced by organizations to minimize risk and to address operational risks such as those of BI losses, production failure losses, and social impacts with mitigation investment decisions (UNISDR 2009).

The development of business interruption loss assessment models can be divided into three periods:

- During the first period, the input–output (IO) approach was widely used because it performed well in calculating and simulating the economic ripple effect of disasters (Tierney 1997; Brookshire *et al.* 1997; Okuyama 2004; Anderson *et al.* 2004). However, the IO model assumed linear interdependence between the sectors of the economy and gave no consideration to a regional economy's nonlinear behavior in response to a natural disaster;
- During the second period, the static computable general equilibrium (CGE) approach was developed (Narayan 2003; Horridge *et al.* 2005; Tirasirichai and Enke 2007; Tatano and Tsuchiya 2008). The strength of the CGE approach was the full consideration of the substitution of market products, price changes,



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and budget constraints. This strength meant that CGE model could reflect the regional economy's nonlinear behavior in response to a natural disaster. But the traditional CGE model has not yet incorporated disaster reduction measures (*e.g.*, the use of inventories and back-up equipment, the utilization of excess capacity during the post-disaster emergency period, and reconstruction during the recovery period) into the assessment framework;

- During the third period, the purpose of developing a new model was not only to assess the business interruption loss, but also for analyzing disaster reduction measures. The improved static CGE model, which increased substitution elasticity, was developed (Rose and Liao 2005; Rose *et al.* 2007, 2011; Ciscar *et al.* 2012). This model can simulate the substitution of non-disrupted inputs, the substitution of imports for locally produced goods, the substitution of exports for local demand, the use of inventories and back-up equipment, and the utilization of excess capacity. However, the static CGE model could only reflect disaster reduction actions at a given point in time.

For disaster management, we need to quantify more disaster reduction strategies, such as how to collect and allocate mitigation investments funds. These disaster reduction strategies are related to investment, and recovery and reconstruction period.

This article proposes a new improved dynamic CGE model. Our model, a time-recursive dynamic model reflecting the recovery and reconstruction period, connects reconstruction investment with reconstruction funds sources, such as from government, household, enterprise, or outside of disaster-affected area. The main features of our dynamic CGE models are: Direct loss is set as the amount of capital stock reduced on the supply side of economy; a portion of investments restore the capital stock in the current period; an investment-driven dynamic model is formulated on the basis of available reconstruction data, and the rest of a given country's saving is set as an endogenous variable.

The contribution of our study is to provide a new, improved dynamic CGE model with an emphasis on the impacts of post-disaster reconstruction investment. This quantitative model can be used to analyze and compare mitigation investment strategies within a unified framework.

## A NEW, IMPROVED DYNAMIC COMPUTABLE GENERAL EQUILIBRIUM MODEL

CGE models provide an *ex ante* simulation laboratory for conducting counterfactual analysis that allows us to establish different mitigation investment scenarios and choose the optimal disaster reduction policy. In this study, we discuss improvements to the traditional CGE model in order to factor in reduced capital stock and reconstruction expenditure. Standard CGE models are discussed by Hans *et al.* (2002).

### Improvement of Market Clearing

Traditional market clearing and macro-closure block is improved by Eq. (1). First, the total investment is divided into normal investment (*QINVn*) and reconstruction investment (the sum of *QINVh and QINVd*). Direct loss from damaged houses is the main component of total direct loss; thus, housing investment accounts for a relatively large proportion of the total reconstruction investment. Nevertheless, the capital stock restored from housing investment hardly contributes to expanded production in the next period (Hallegatte 2008). Thus, housing investment mainly exerts a positive impact on economic demand. Accordingly, reconstruction investment is further divided into housing investment (*QINVh*) and other reconstruction investments (*QINVd*).

$$XA_i = \overbrace{\sum_j XAp_{i,j} + QH_i + QLC_i + QGC_i + QINVn_i}^{\text{Local normal demand}} + \overbrace{QINVh_i + \sum_j QINVd_{i,j}}^{\text{Disaster-proof demand}} \quad (1)$$

where *XA* is total supply of goods; *XAp*, *QH*, *QLC*, *QGC* are intermediate demand, household demand, local government demand, and central government demand for goods, respectively; both $i$ and $j$ refer to the industrial sector.

Traditional CGE models close the labor market under either the "Neoclassical" assumption of full employment (perfectly inelastic supply) or "Keynesian" assumption of variable employment (perfectly elastic supply at a fixed wage). However, these two models cannot adequately factor the impacts of disasters on the economy because disasters have significant effects on both labor supply and wage rates, and the standard closure rules hold one of these constant. Thus, in our model, labor flows among the different sectors through the use of constant elasticity of transformation (CET) functions. Accordingly, we model labor as a variable factor whose endowment is price-responsive, which is achieved by specifying a short-run labor supply curve with elasticity $\omega^L$, which scales the labor supply from its benchmark level $\overline{\text{LS}}$ (Eq. (2)). Moreover, all industries suffer large stock losses after a catastrophe, but then they all increase investments during the reconstruction period. To incorporate this special aftermath into the CGE model, sector-specific capital is assumed within a short time period in our model.

$$LS = \overline{LS} * W^{\omega_L} \quad (2)$$

where $LS$ indicates the labor supply, $\overline{LS}$ indicates the labor supply in a base period, $W$ is salary, and $\omega_L$ indicates the price elasticity of the labor supply.

## Improvement of Macro-Closure Rules

The investment amount in each industry is exogenous, and the total amount saved is determined by the total investment endogenously. The exchange rate is endogenous, and foreign savings are exogenous. It should be noted that the model used in this study assumes the savings in the rest of the country to be endogenous because most investments are offered by the central government, other provincial governments, enterprises, and residents.

## Improvement of Dynamic Module

The total investments, excluding reconstruction investments, are roughly counted as normal investments. In this model, normal investments are distributed among various industries based on the industry investment structure during the

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base year, and then transformed into the capital stock (*XCn*) in the following period according to the investment coefficient matrix (*B*) (Eq. (3)). In addition, the disaster-proof investments can be transformed into capital stock (*XCd*). The distribution of transformed capital stocks among industries is determined by the proportion of the direct losses suffered by those industries. The disaster-proof investments of various industries can be achieved according to the investment coefficient matrix (*B*) (Eq. (4)).

The model presumes that there is a housing sector. The damage to the housing inventory caused by the disaster will bring newly increased investments but does not make a contribution to the capital stock of other industries. In each period during the recovery, the housing capital stock (*XCh*) is calculated by multiplying the total investments in that period by the ratio of direct losses in the housing sector accounting for total direct losses. Then, according to the investment coefficient matrix (*B*), the housing capital stock (*XCh*) can be converted to the investments of various industries (Eq. (5)).

$$XCn_i = B_{i,j}^{-1} QINVn_i \tag{3}$$

$$XCd_i = B_{i,j}^{-1} \sum_j QINVd_{i,j} \tag{4}$$

$$XCh = B_{h,j}^{-1} QINVh_i \tag{5}$$

Natural disasters cause a decline in capital stock in various industries (*Damage*) only during the year that the disaster occurred. Considering the actual circumstances of reconstruction in China, to accelerate the recovery process, floating assets, such as excavators used in the architecture industry, were imported from other areas instead of waiting for local production to replace the damaged assets. Hence, the model presumes that part of the disaster-proof investments (*Transfer*) can be directly transferred to current capital formation (Eq. (6)).

$$KStock_i = (1 - \delta_i)(KStock_{i,-1} - Damage_{i,-1} + Transfer_{i,-1}) + XCn_{i,-1} + XCd_{i,-1} \tag{6}$$

## CASE INTRODUCTION AND DATA NEEDED

### Introduction to the Earthquake

The Wenchuan earthquake occurred on May 12, 2008; the epicenter was located at Yingxiu Town, Wenchuan County, Sichuan Province of China (31.01°N, 103.40°E). The earthquake had a magnitude of Ms 8.0 (earthquake magnitude is usually measured on the popular Ms scale, which ranges from 0 to 10; an Ms 8.0 earthquake can destroy an area measuring 100 square miles) and a maximum intensity of 11°. It was the most destructive and widespread earthquake since the founding of the Peoples' Republic of China, with 69,226 dead and 17,923 missing. The total direct economic losses reached 845.2 billion Chinese Yuan (CNY) (the exchange rate of CNY to USD was 0.14 in 2008) for the combined Sichuan, Gansu, and Shannxi Provinces, 91.3% of which represented the direct economic losses of Sichuan Province, which

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**Table 1.** Direct economic loss due to the Wenchuan earthquake distributed by sectors in Sichuan (unit: 100 million CNY).

| ID | Sector | Loss |
|---|---|---|
| 1 | Agriculture | 120 |
| 2 | Mining Industry | 100 |
| 3 | Food Manufacturing | 180 |
| 4 | Textile, Sewing Machine and Leather Manufacturing | 45 |
| 5 | Wood Processing and Furniture Manufacturing | 45 |
| 6 | Coke, Gas and Oil Processing | 6 |
| 7 | Chemical Industry | 125 |
| 8 | Construction Material and Other Nonmetallic Mineral Manufacturing | 54 |
| 9 | Metallic Products Manufacturing | 130 |
| 10 | Mechanical Equipment Manufacturing | 220 |
| 11 | Electricity, Steam, Hot-Water Production and Supply | 800 |
| 12 | Building Trade | 25 |
| 13 | Transportation, Post and Telecommunications | 840 |
| 14 | Commerce and Catering | 90 |
| 15 | Finance and Insurance | 1100 |
| 16 | Specific Service Management | 60 |
| 17 | Public Utility and Resident Service | 550 |
| 18 | Room Service | 3000 |

was equivalent to 74% of Sichuan's GDP in 2007. For the direct economic losses of specific industries, refer to Table 1 (NCDR and MOST 2008).

## Introduction to Post-Earthquake Reconstruction

The government implemented many active policies to accelerate reconstruction and to mitigate the effects of the Wenchuan earthquake. In September 2008, 4 months after the earthquake, the government introduced a plan called *The State Overall Plan for Post-Wenchuan Earthquake Restoration and Reconstruction* to accelerate the reconstruction process. According to this plan, the government began to implement active fiscal policies: firstly, central finance was requested to establish reconstruction funds for post-quake reconstruction (CNY 300 billion, *i.e.*, 30% of total direct losses), and these funds were released over the 3 years following the earthquake. Secondly, the local government of Sichuan was requested to establish comparable funds. These funds were collected through various channels: local government allocation, counterpart assistance, social donations, domestic bank loans, foreign emergency loans on favorable terms, urban and rural self-possessed and self-collected capital, and so on. Thirdly, 18 assistance provinces (cities) were requested to offer assistance of at least 1% of their last ordinary budget revenues to their 18 counterpart counties (or districts) in Sichuan. Fourthly, the government was requested to provide various preferential policies for local enterprises and investors.

These policies included alleviating the tax burden on individuals, deducting partial administrative charges, supporting key enterprises and medium- and small-sized enterprises, and adjusting industry entrance permission (NDRC 2008). According

**Table 2.** Reconstruction investments supported by the government over the 3 years after the earthquake (unit: billion CNY).

| Year | 2008 | 2009 | 2010 | Subtotal |
|---|---|---|---|---|
| Reconstruction Investments | | | | |
| Central government | 49.9 | 108.6 | 61.9 | 220.3 |
| Provincial finance | — | 17.7* | 5.6 | 23.3** |
| Counterpart assistance | — | — | — | 84.4 |
| Donations | — | — | — | 76.0*** |
| Insurance | — | — | — | 1.7 |
| Total | | 49.9 | 126.3 | 67.4 |

*Accumulation of 2008 and 2009; **only Sichuan Province; ***among them, the special party dues amount to 9.73 billion CNY, and other donations amount to 55.582 billion CNY, and the material depreciation cost is 10.71 billion CNY, and all of them are included in the government allocation.

to the survey (Sichuan Bureau of Statistics, 2012), the actual reconstruction investments are listed in Table 2, where "—" indicates that the data for that year are unavailable. These preferential policies eased the burden on local reconstruction and accelerated reconstruction to some degree.

**Data Needed**

The model implemented in this study contains 17 sectors: 1 agricultural sector, 10 manufacturing sectors, 1 architecture sector, and 5 service sectors; the merger of the sectors is based on the industry classification of available direct loss data. A substantial amount of the data processed by the model was obtained from the detailed 2007 Social Accounting Matrix (SAM) for Sichuan Province, derived from the SAM database compiled by the Development Research Center of the State Council (DRC-SAM),[1] which is the most widely used database for generating SAMs in China. In the CGE model, some elasticity parameters must be derived from the literature (Hans *et al*. 2002). According to a synthesis of the literature (Rose *et al*. 2007; Vennemo *et al*. 2009; Oladosu 2000), the elasticities of transformation between export and domestic production are set as 1.4; in the second nest, the elasticities of transformation between in-province and out-of-province production are set as 1.5; the elasticities of substitution between import and domestic production in the Armington functions are set as 0.2; in the second nest, the elasticities of substitution between in-province and out-of-province production in the Armington functions are set as 0.1; and elasticities in the CES functions of the production block are set as 0.09. Other major parameters were specified during the model's calibration process.

[1]For details, see Social Accounting Matrix China (Internet). Beijing: Dept. of Development Strategy and Regional Economy, Development Research Center of the State Council. 2000 (cited September 1, 2012). Available at http://www.drcnet.com.cn/temp/20051228/hsjz/english%20version/index.html



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Using the traditional CGE model, a dynamic block was incorporated into this study. Capital stocks in the benchmark year were estimated using a standard perpetual inventory approach (Goldsmith 1951; Christensen and Jorgenson 1972). The investment data from 2007 to 2011 were obtained from the *Statistical Yearbook of Sichuan Province*, and the investment data after 2011 were estimated depending on the average investment amount from 2003 to 2007. Reconstruction investments were made only from 2008 to 2010. The average rates of depreciation of the sectors and the capital coefficients matrix were derived from authoritative reports or literature in China (Zhang *et al*. 2004; Liao and Ma 2009).

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### Data Analysis

During the Wenchuan earthquake, 10 counties labeled as extremely damaged areas covered an area of 26,400 km$^2$, as well as 26 counties labeled as seriously damaged areas covered 61,500 km$^2$. The sum number of these two kinds of disaster-affected counties (36) represented 20% of the total 181 counties of Sichuan Province. The sum area of these two kinds of disaster-affected counties (87,900 km$^2$) represented 18% of the total 485,000 km$^2$ of Sichuan Province. The sum GDP of these two kinds of disaster-affected counties accounted for 26% of the total GDP of Sichuan Province in 2007. Apparently, whether the ratio of the number of disaster-affected counties to the total number of all counties in Sichuan province or the ratio of the area of disaster-affected counties to the total area of Sichuan province is less than the ratio of the GDP of disaster-affected counties to the total GDP of Sichuan province, implying that the disaster-affected counties are important to the economy of Sichuan province.

Specifically, the 2007 SAM for Sichuan Province showed that the total gross output is 2526.5 billion CNY, including 1476.0 billion CNY in inter-industry transactions and 1050.5 billion CNY of total value-added. The net trading surplus (including both the domestic trading and the foreign trading) is about 35.2 billion CNY, implying that Sichuan Province is moderately self-sufficient. Total household income is about 685.1 billion CNY. Total provincial government income is about 174.7 billion CNY and expenditure is about 130.3 billion CNY, respectively. The government accounts show that local government ran a surplus of 44.4 billion CNY.

## RESULTS

### Model's Test and Reference Scenario

First, the base case for the CGE model was set. In the base case, the capital stock is reduced due to a disaster and there is normal investment and reconstruction investment, including housing and other investments. The same occurs after a real disaster. As was stated previously, our CGE model used reconstruction investment, tax preference, donations and paired-assistance published by the government as the model's inputs. The model does not require data processing, so the evaluation results are much more objective. To test the accuracy of the model, the GDP under the base case is compared with the GDP published by NBS (Figure 1). As indicated, the model and the NBS data are quite similar from 2007 to 2011. The differences

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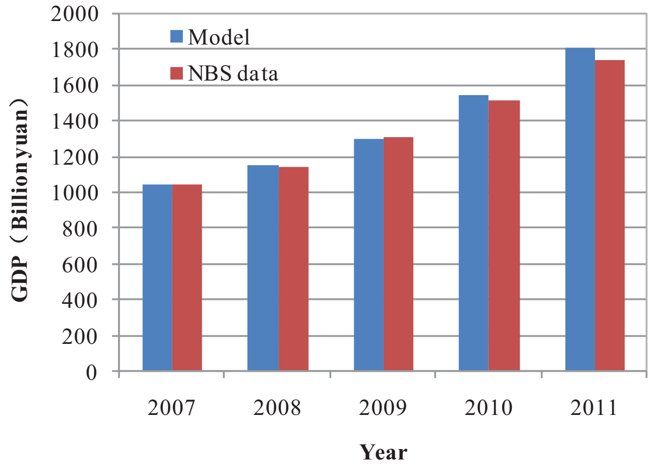


**Figure 1.** GDP of Sichuan Province from 2007 to 2011 according to NBS data and to scenario $S_1$ of the CGE model.

in certain years can most likely be attributed to the fact that during the simulation period, the distribution of normal investment in different sectors was assumed to be roughly the same as that observed in 2007. However, in reality, there may be some differences, but more detailed investment data classified by sectors at the provincial level were unavailable.

In a rapidly growing economy such as that of China, the post-disaster social and economic aggregate levels may surpass the pre-disaster level within 1 year. However, this does not mean that social and economic conditions have recovered because this economy experiences some economic growth. Therefore, all of the following BI losses are calculated relative to a non-disaster scenario in which the annual GDP growth rate from 2008 to 2011 in Sichuan Province is set to 15.5% according to the growth rate of those provinces whose economic development level is similar to that of Sichuan Province.

## The Economic Impact of Different Property Damage and Reconstruction Investment

To assess different scenarios, the direct property damage investment and the reconstruction investment are increased and decreased by 25% relative to their value in the base case. The economic impacts under the four scenarios tested are compared in Figure 2. This range is admittedly impressionistic, but our intent is to illustrate the model's ability to analyze the potential impact of uncertainty on the magnitude of property damage and reconstruction investments. As expected, decreased property damage and increased reconstruction investment shift the base case GDP loss trajectory upward in each period, while increased property damage and reduced reconstruction investment shift the base case GDP loss trajectory downward in each period. This result indicates that the post-disaster economy is more sensitive to property damage than to reconstruction investment. In fact, in our case

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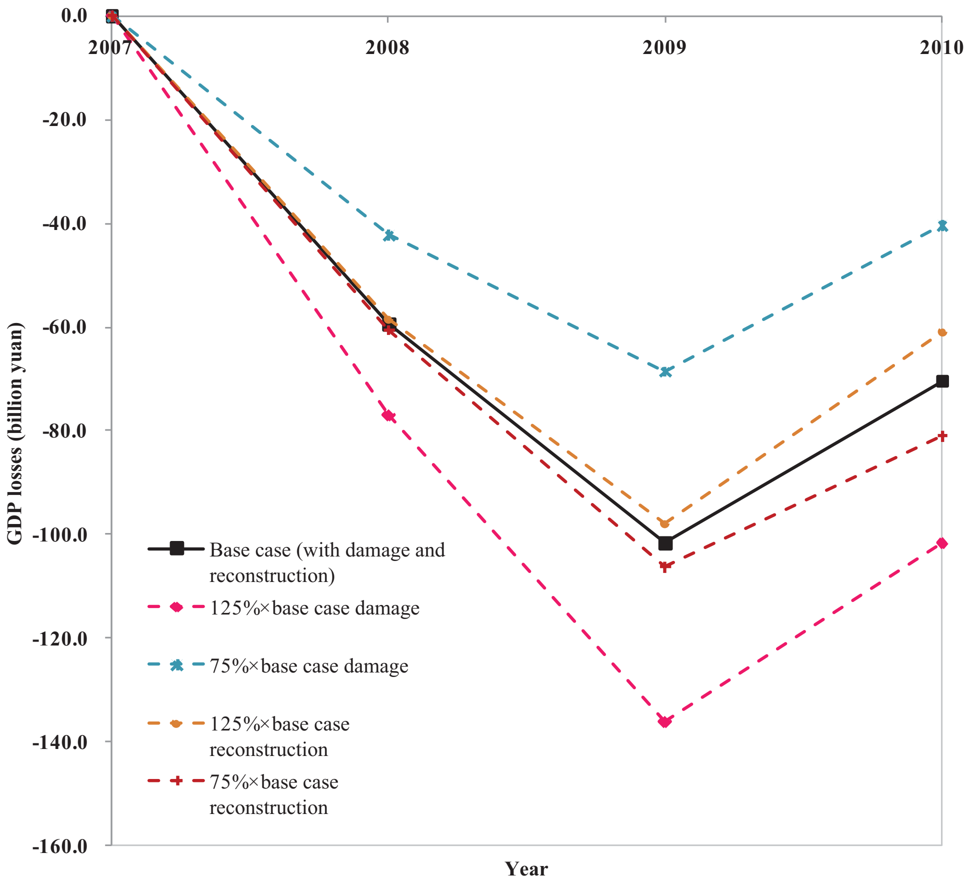


**Figure 2.** GDP losses: sensitivity to damages and reconstruction.

study, disaster-proof investment accounts for only 40% of property damage loss. Therefore, under the same increased or decreased ratio of property damage and investment, property damage experienced the lager absolute gain or loss.

Shown in Table 3 is the relative and absolute BI loss on the 3-year and 5-year time horizons. Reconstruction investment has a negative impact on post-disaster BI loss on both the 3-year and 5-year time horizons. Conversely, property damage has a positive impact on post-disaster BI loss on both the 3-year and 5-year time horizons. Under any case, the absolute BI loss on the 5-year time horizon is larger than that on the 3-year time horizon, but the relative BI loss on the 5-year time horizon is smaller than that on the 3-year time horizon, indicating that BI loss continues until the built environment is repaired and reconstructed to a point that it is equivalent to the no-disaster scenario. The GDP in the fifth year is closer to the GDP under the no-disaster scenario than that of the third year. In conclusion, BI loss is sensitive to the amount of damage sustained, the amount of investment and the time horizon being measured. Therefore, it is impossible to find a constant relationship between

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**Table 3.** The economic impact of different property damage investments and reconstruction investments.

| | BI loss on the 3-year time horizon | | BI loss on the 5-year time horizon | |
|---|---|---|---|---|
| | Billion 2007 CNY | % | Billion 2007 CNY | % |
| Base case with damage and reconstruction | −231.5 | −5.5 | −332.0 | −4.0 |
| 125% × base case damage | −315.0 | −7.4 | −467.6 | −5.7 |
| 75% × base case damage | −151.3 | −3.6 | −199.4 | −2.4 |
| 125% × base case reconstruction | −217.4 | −5.1 | −290.5 | −3.5 |
| 75% × base case reconstruction | −248.0 | −5.9 | −374.3 | −4.5 |

property damage investment and BI loss that would allow for a simple estimate of BI loss using the relationship after every disaster.

## Striking a Balance Between Vulnerability and Resilience

Recently, reducing vulnerability and increasing resilience become the two main methods of disaster risk management. However, the relationship between vulnerability and resilience is still not well articulated (White and Haas 1975; Rose 2004; Cutter *et al.* 2008). According to some researchers, resilience is imbedded within vulnerability, while others view resilience and vulnerability as separate but often linked concepts. A third perspective tries to construct an integrated large-scale disaster risk governance paradigm (Shi *et al.* 2013). This study attributes the essence of the relationship in question to how to allocate limited mitigation investment between pre-disaster reduced vulnerability and post-disaster increased resilience. The dynamic CGE model can simulate a post-disaster GDP loss trajectory under different combinations of reduced vulnerability investment and increased resilience investment.

It is assumed that the total mitigation investment equals the reconstruction expenditure in the 2008 Wenchuan earthquake. We quantify the relative importance of vulnerability and resilience by performing sensitive analyses around our base case with a 0%–100% division of total mitigation investment between vulnerability and resilience, and simulating cases with 50%–50% and 100%–0% vulnerability–resilience investment split. Presented in Figure 3 is the sensitive analysis for these two cases. If 1 dollar in investment to reduce vulnerability reduces property damage loss by 1 dollar, the post-disaster GDP loss ratio under the two simulating cases is smaller than that under the base case for each year. Therefore, vulnerability is more important than resilience. However, 1 dollar investment reduces different amount of direct property damage loss due to a different scale of earthquakes and different type of buildings. In the simulation case with the 50%–50% vulnerability–resilience investment split, when 50% total mitigation investment reduces direct property damage loss by 25%, the post-disaster GDP loss ratio in the first two years is lower than that in the base case, while in the third year, the GDP loss ratio is higher.

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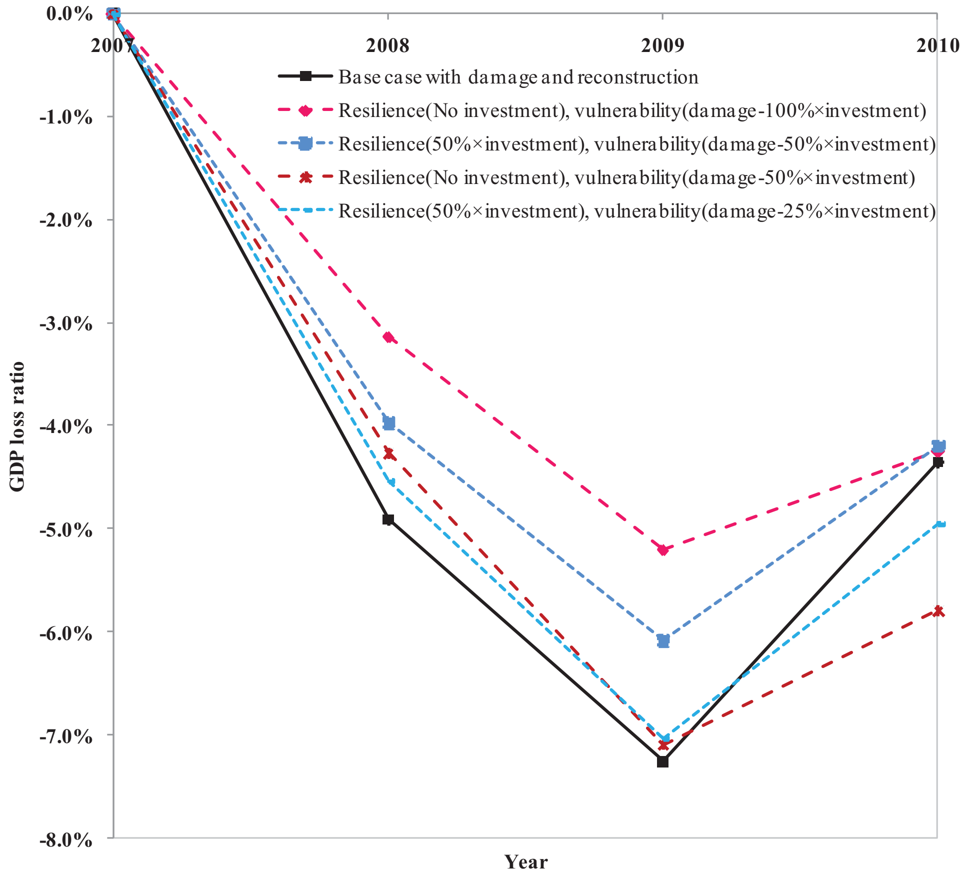


**Figure 3.** Striking a balance between vulnerability and resilience.

After simulating hundreds of different reduced property damage loss scenarios, it was found that vulnerability is more important than resilience only when 50% total mitigation investment reduces direct property damage loss more than 25%; otherwise, resilience is more important. A similar result was found for the simulation case with a 100%–0% vulnerability–resilience investment split. The quantitative model constructed by this study is feasible. Thus, government, businesses, and scientists can use this model to observe the economic impacts from a disaster under different mitigation investment policies, allowing them to make optimal investment decisions.

Summarized in Table 4 are the relative and absolute BI losses of simulating cases with a 50%–50% and a 100%–0% vulnerability–resilience investment split. Rows B and C illustrate the results of the simulation with a vulnerability investment of 1 dollar reducing property damage losses by 1 dollar on both the 3-year and 5-year time horizons. In rows B and C, the aggregate GDP losses are significantly reduced on both the 3-year and 5-year time horizons. The GDP loss is especially low in row C on the 3-year time horizon where it is estimated to be only 179.6 billion CNY, which is 20% lower than the GDP loss experienced under the

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**Table 4.** A summary of all the scenarios for disaster risk management.

| | BI loss on the 3-year time horizon | | BI loss on the 5-year time horizon | |
|---|---|---|---|---|
| | Billion 2007 CNY | % | Billion 2007 CNY | % |
| A. Base case (with damage and reconstruction) | −231.5 | −5.5 | −331.0 | −4.0 |
| B. Resilience (50% Í investment), vulnerability (damage-50% Í investment) | −201.2 | −4.8 | −312.1 | −3.8 |
| C. Resilience (No investment), vulnerability (damage-100% Í investment) | −179.6 | −4.2 | −302.0 | −3.7 |
| D. Resilience (50% Í investment), vulnerability (damage-25% Í investment) | −233.8 | −5.5 | −365.9 | −4.4 |
| E. Resilience (No investment), vulnerability (damage-50% Í investment) | −244.6 | −5.8 | −409.9 | −5.0 |
| F. Reconstruction with the compensation of insurance | −1905.9 | −4.5 | −1871.7 | −2.3 |
| G. Distribution proportion of reconstruction investment among the 3 years post-disaster: 3:4:3 | −1676.1 | −4.0 | −1683.0 | −2.0 |
| H. Distribution proportion of reconstruction investment among the 3 years post-disaster: 5:3:2 | −1520.8 | −3.6 | −1588.5 | −1.9 |
| I. Reconstruction with 50% internal financing | −2276.1 | −5.4 | −2421.0 | −2.9 |

base case. In rows D and E, the GDP losses on the 3-year and 5-year time horizons are the same or slightly higher than those in the base case due to a greater GDP loss in the third year post-disaster. However, as shown in Figure 3, the GDP loss in the first two years post-disaster under these two simulation cases are much lower than the loss experienced in the base case. In the first two years after a disaster, rapid economic recovery is crucial to relive unemployment and the fiscal deficit in the disaster-affected area. Therefore, policy-makers can make optimal mitigation investment decisions according to their different disaster mitigation purposes.

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**Post-Disaster Economic Recovery with the Contribution of Insurance Compensation**

In China, special catastrophe insurance has not yet been developed. Only a small part of earthquake and other disaster damage is compensated by property insurance. In the 2008 Wenchuan earthquake in China, less than 1% of direct property damage was compensated by insurance companies. The average level of property damage covered by insurance around the world is approximately 40% (Xie *et al.* 2012). Currently, China is developing catastrophe insurance. Both government and insurance companies focus on how the post-disaster economy will recover with the contribution of insurance compensation. Hence, a dynamic CGE analysis of insurance investment (where the increase in recovery funding is 40% of the direct loss of disaster) was simulated (Scenario F). When there is a large amount of mitigation investment available, another question that is raised is how to allocate available funds each year during the post-disaster reconstruction period. Here, the distribution proportion of total reconstruction investment in the years 2008, 2009, and 2011 after the disaster is similar to real conditions (*i.e.*, 2:4:4). In addition, we simulated the effects of two other counterfactual distribution proportions: 3:4:3 (Scenario G) and 5:3:2 (Scenario H). An important aspect of our simulation is our default assumption that all of the funds for repair and reconstruction come from outside of Sichuan province (principally central government assistance, other local government assistance, and donation). The use of "external" financing from outside Sichuan province results in a pure additive boost to the province's productive capacity, with no opportunity cost, while "internal" funds displace ordinary investment in plants, equipment and residential structures in the area affected by the disaster. We quantify this effect by performing sensitivity analyses around our base case with all of the financing coming from outside Sichuan province, as well as simulating cases with a 50%–50% internal–external financing split.

Shown in Figure 4 is the strong influence of insurance investment. In simulation case F, the GDP loss ratio in all years after the disaster is much lower than that in the base case. An interesting result was that high reconstruction investment in the first year after the disaster (scenario G) increases the initial GDP loss ratio but reduces the GDP loss ratio in the following 2 years relative to scenario F. Damaged factories, equipment, and infrastructure, combined with emergency rescue and reconstruction planning in the first year after a disaster, significantly reduces the supply ability of the disaster-affected economy. Too much reconstruction investment demand dampens normal household demand and ultimately results in economic decline. Fortunately, because of a greater accumulation of capital in the following two years, the GDP loss ratio is lower than in scenario F. Scenario H has a similar economic impact as scenario G. By comparing scenarios G and H, we found that increased investment in reconstruction in the first year after a disaster creates a much higher BI loss, but the economy can experience a gain in the following years and can also recover quickly. As expected, the GDP loss ratio for scenario I is higher than in scenario F, indicating that scenario F under a Chinese nationwide integrated large scale disaster risk governance (including programs such as central finance funds assistance, counterpart assistance and social donations) is helpful to mitigate post-disaster economic impacts.

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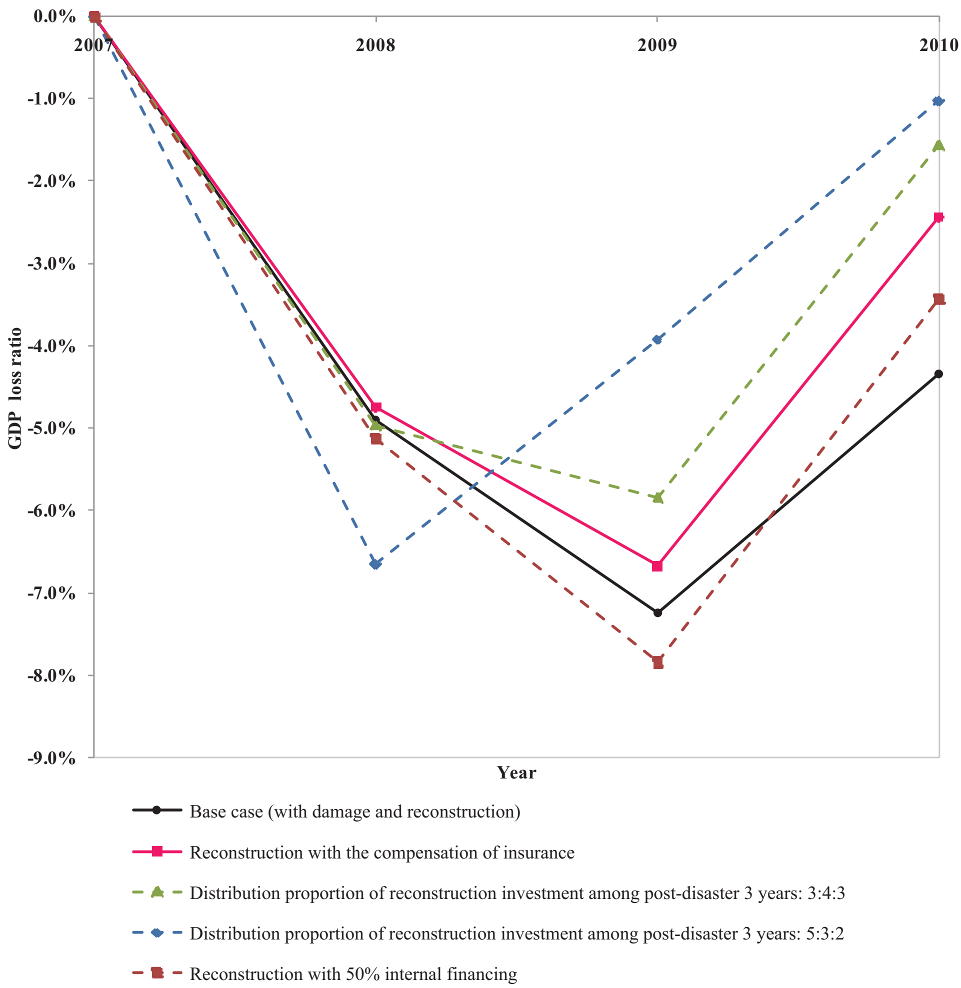


**Figure 4.** Post-disaster economic recovery with the contribution of insurance compensation.

In addition, summarized in Table 4 are the BI losses when there is compensation from catastrophe insurance. Consistent with previous analyses, BI losses on the 5-year time horizon are larger than those on the 3-year time horizon. With the recovery of the post-disaster economy, the BI loss ratio relative to the no-disaster scenario on the 5-year time horizon is lower. In scenario F, the GDP loss ratio on the 3-year horizon is 4.5%, and this value is reduced to 2.3% on the 5-year horizon. Although GDP losses in simulation cases G and H are smaller than the loss in simulation case F on both the 3-year and 5-year horizons, the GDP loss is large relative to case F in the first year after the disaster (Figure 4). In the early period following a disaster, the poor economy is terrible for employment, revenue and household welfare, especially for emergency rescue, reconstruction planning and other very vital and urgent tasks. Therefore, in addition to pursuing a quick recovery, governors are advised to focus on appropriate reconstruction investment in the early period following a disaster and the poor supply ability of the economy during the early period. In row I, where 50% of the mitigation investment was provided by the disaster-hit region, the GDP loss is 1.0% greater than in case F for the 3-year time horizon, and 0.6% greater on the 5-year time horizon. Overall, the GDP loss in scenario E is the largest of the nine scenarios, while the GDP loss in scenario H is the smallest. The GDP loss ratio in row E is 2.2% lower than that in row H on the 3-year time horizon, and 3.1% lower on the 5-year time horizon. Compared with the absolute GDP in row E, row H reduces the GDP loss by as much as 40% on the 3-year horizon and as much as 60% on the 5-year horizon. Additionally, it is apparent that due to the different time horizons and mitigation investment policies, the ensuing BI loss is different. Extreme disasters cannot be avoided, and direct property damage loss cannot be reduced. These characteristics of BI loss provide significant potential for disaster risk managers to reduce the total economic loss of disasters.

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## CONCLUSION AND DISCUSSION

After every disaster, direct property damage loss already exists and cannot be reduced, while optimal risk management policies have the potential to reduce business interruption (BI) loss. Many catastrophic events show that the amount of BI loss may rival direct property damage loss. Therefore, this study regards mitigating an amount of BI loss as the purpose of disaster risk management. Mitigation investment is the main choice of governors to reduce BI loss. To make optimal reconstruction decisions, it is helpful to observe the post-disaster economic impact of different decisions by using quantitative tools. The improved dynamic CGE model serves as a template for making mitigation investment decisions. The advantages of our model are the following: (1) most of the negative impacts of natural disasters are supply-side impacts; therefore, the model sets direct losses, such as losses due to damaged facilities, equipment or infrastructure, as the amounts by which capital stock is reduced, thus improving the common practices employed in regional economic models (*e.g.*, the multiplier model, the IO model and the Traditional CGE model) by incorporating shocks into the demand side of the economy. (2) With respect to macro closure, the dynamic CGE model was formulated as an investment-driven model; therefore, our model can describe the positive effects of reconstruction investment and catastrophe insurance. (3) Because this is a dynamic CGE model, it is capable of simulating the economic impact of different allocation schemes of limited funds over each year during the post-disaster reconstruction period. (4) In the model, money saved from the rest of China (*i.e.*, the net domestic trading surplus/deficit) was set as an endogenous variable, allowing for the BI loss under different internal–external financing splits to be simulated.

Property damage is a stock term, while BI loss is a flow term. As a result, property damage and reconstruction investment have an impact on the duration of recovery. In other words, the amount of BI loss depends on both the amount of direct property damage loss and mitigation investment. Some scholars and institutions try to build a relationship between direct damage loss and BI loss to evaluate BI loss after disasters. The previous analysis shows that this assumption is impossible. In this case study, only when the total mitigation investment reduces the direct property damage loss by more than half is vulnerability more important than resilience. Otherwise, resilience is more important. When the catastrophe insurance compensation's contribution to the direct loss in China reaches the average level of the rest of the world, the BI loss is reduced by as much as 43% in the 5 years after the disaster. In light of the poor availability of supplies in a disaster-hit economy in the early period after a disaster, it is unwise to make much more reconstruction investment to compete with other normal household consumption. Chinese nationwide integrated catastrophe risk governance encourages most of the investment funds to be provided by central government, other government agencies, individuals or groups outside quake-hit areas. This mode significantly reduces the BI loss compared with the mode in which only a part of the mitigation funds is provided from outside the disaster-affected area.

Overall, compared with the IO model, the static CGE model, and the improved static CGE model, this study developed a new improved dynamic CGE model with the ability to simulate more disaster reduction strategies. Even the simulation result of our new model was similar with the factual data, it still needs to be proved by other cases, such as simulation of more newly occurring disasters in order to forecast the optimal solutions for the coming years.

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