An evaluation of the indirect economic loss from a hypothetical catastrophe

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Abstract: In 2008, an unexpected Ms8.0 earthquake jolted Wenchuan County in Sichuan Province, China. This paper assumes that a hypothetical Ms8.0 earthquake also has occurred in Shanghai, which is a highly developed area in China, and studies the indirect economic loss (IEL) and their determinants in order to show the relationship between wealth and disasters. Specifically, IEL is divided into two categories based on the different causes: indirect economic loss I caused by companies' own property damage (IEL I) and indirect economic loss II caused by interindustrial linkages (IEL II). Then, an input-output model is used to assess the two types of IEL. Finally, the causes of the differences in the two different levels of wealth are analyzed. The research shows that (1) for every Chinese Yuan (CNY) 100 of direct loss, Shanghai suffers CNY 12 more in IEL than Sichuan; (2) as compared with Sichuan, Shanghai's magnifying power of IEL II is 4 times, while that of IEL I is 1.4 times; (3) the determinants of the abovementioned differences include the industrial

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structure, interindustrial linkage effects and trade among other factors. Hence, both physical and intangible structures should be taken into account when building an effective disaster relief system.

Key words: Indirect economic loss; Economic loss assessment; Natural disaster; Input-Output model; Earthquake

Abbreviation:

IEL, Indirect economic loss;

IEL I, Indirect economic loss I caused by companies' own property damage;

IEL II, Indirect economic loss II caused by interindustrial linkages;

1. Introduction

In 2008, a Ms8.0 earthquake jolted Wenchuan County of Sichuan Province, China, bringing a death toll of over 80,000 (NDRC, 2008), a total direct loss of Chinese Yuan (CNY) 845.2 billion for the combined Sichuan, Gansu and Shannxi Provinces (NCDR, 2008) and an indirect economic loss (IEL) of CNY 301 billion for Sichuan Province (Jidong Wu, et al., 2011). After this event, the disaster reduction organizations and the scholars in China begun to analyze the potential aftermath of a similarly severe earthquake occurring in a developed area in China, e.g., the Shanghai or Beijing municipalities. In fact, this concern can be reduced to a scientific issue about the relationship between disaster loss and economic growth. A number of previous researchers have developed their work around this topic (e.g., Tol and Leek, 1999; Burton, et al., 1993; Albala-Bertrand, 1999; Kahn, 2005; Benson and Clay, 1998, 2003; Kellenberg and Mobarak, 2008; Rasmussen, 2004; Toya and Skidmore, 2007; Raschky, 2008; Lester, 2008; Cavallo and Noy, 2010; Pelling et al., 2002; Okuyama, Sabin, 2009; Sanghi, 2010). Based on the statistics of previous natural disasters and economic growth, these researchers have studied the relationship between economic development and disaster loss using statistical surveys and have drawn a series of conclusions. Up until now, due to a lack of consideration for the types of losses and determinants, however, our knowledge regarding the relationship between disaster loss and economic growth is still limited.

The total disaster loss is defined as the economic, social and environmental impacts of a natural disaster event. The total loss usually consists of direct and indirect costs (Hallegatte 2008, Benson and Clay, 2003). The direct impacts arise from the direct physical damage caused by the natural disaster on private dwellings, small business properties, and industrial facilities among other settings. The indirect impacts refer to the loss of potential production due to the disturbed flow of goods and services, the loss of production capacities and the increased costs of production (ECLAC, 2003; World Bank/UN, 2010). The scale and intensity of the impacts of natural disasters on the economy can be estimated using the following factors (OAS, 1991; Mechler, 2004; Gurenko, 2004; Cummins and Mahul, 2008; Benson and Clay, 2004): (i) the type of natural disaster event; (ii) the population and the assets exposed to a specific disaster event; (iii) the intensity of the economic activities (e.g., large urban agglomerations); (iv) the size of the geographical area impacted; (v) the level of science and technology development; and (vi) the institutional capacity in risk management and governance.

The purpose of this paper is to study the relationship between disaster loss and economic development, given the types of disaster losses and their determinants. This paper compares the IEL caused by a hypothetical Ms8.0 earthquake and the determinants of Sichuan Province and Shanghai Municipality. This paper chose Shanghai as a study target because Shanghai is economically developed, forming a sharp contrast with Sichuan. Second, one earthquake of greater than Ms7.0 and five tsunamis have struck Shanghai during its history. Third, based on historical data, most of the earthquakes occurring in Shanghai are shallow focus earthquakes, which have fatal consequences. Also, we focus on simulating the IEL because the IEL has more to do with economic development. In this way, we can ignore those losses that have little to do with economic development, which will help us to better identify the relationship between disaster loss and economic development. Thus, this paper assumes a situation: an Ms8.0 earthquake simultaneously occurs in Shanghai Municipality (gross domestic production (GDP) per capita ranked 1st in 2008) and

Sichuan Province (GDP per capita ranked 24th in 2008). By collecting statistics related to disaster and economic growth, we use a quantified model (input-output model) to simulate the economic development of these two areas after the earthquake. Then, we will assess the different losses and the determinants.

This paper attempts to answer two questions: first, if an Ms8.0 earthquake occurred in Shanghai, how great IEL would it cause? Second, what are the determinants of the different IEL for Shanghai and Sichuan Province? This information can be useful in three ways: first, it can be a important reference for Shanghai's governance of disaster risks; second, this information can help us to reduce the total loss and recovery time during the recovery and reconstruction periods; third, this information can help to extend the domain of the vulnerability of the bearing bodies, including industrial structures, industrial linkages and so on. In the second part of this paper, we compare the definition of direct loss and indirect loss. To better master the relationship between IEL and economic growth, we elaborate on the causes of IEL. In the third part, we illustrate the adaptive regional input-output (ARIO) model and the data sources and we assess the effect of IEL and the determinants. In the fourth part, we will compare the economic systems of Shanghai and Sichuan Province, trying to understand the root cause of the relationship between IEL and economic growth. In the fifth part, we draw conclusions and summarize the paper's weaknesses.

2. Direct Economic Loss vs. Indirect Economic Loss

To study the relationship between the economic development level and IEL using the method of quantified simulation (input-output model), so as to provide scientific support for disaster risk management, we need to define both direct and indirect loss as well as find the cause of the latter.

In this paper, direct loss refers to the physical destruction of assets, including private dwellings, small business properties, industrial facilities and government assets. Indirect loss refers to the loss of potential production caused by the disturbed flow of goods and services, lost production capacities and the increased costs of production. Indirect costs include business interruption in the aftermath, production loss during the reconstruction period and service loss in the housing sector. In Fig. 1, the chart on the left shows the difference between direct and indirect loss. Here, we assume that the capital stock and the output value increase by degrees. For example, if a factory is damaged in an earthquake at time t_0, then from t_0 through the reconstruction the lost capital can be regained progressively (for instance, if 10 machines have been destroyed, first 3, then 5, then 8, and at last all machines will have been repaired); there is a tendency to specify the decline in capital stock value (for example, the replacement cost of the above-mentioned 10 machines) at a fixed term t_0 as a direct loss. Indirect losses are highly variable and depend upon the length of the 'economic disruption,' which is typically synonymous with the recovery and reconstruction periods. Indirect losses are the decline in output flow value during these periods, which can be calculated using the mathematical method of integration and which are equal to the area of Δabc in the chart on the left. According to the causes of the indirect loss, we can call Δabc indirect economic loss (IEL), and it can be divided into two parts: Δabd, indirect economic loss I caused by companies' own property damage (IEL I) and Δacd, indirect economic loss II caused by interindustrial linkages (IEL II).

In Fig. 1, the chart on the right shows the causes of IEL. We assume that there are three industries A, B and C in the economic system, as well as the final demand (FD).

The earthquake will bring different levels of damage to A, B and C, which will cause direct and indirect loss. Here, we focus on B’s IEL. First, we divide B into B_1 (representing the completely destroyed part) and B_2 (representing the basically intact part). Because B_1 has been completely destroyed, there are no IEL caused by the reduction of A’s supply to B or C’s demand for B. So B_1’s IEL is due to damage to the fixed capital and stock. B_1’s IEL is named as IEL I, represented by Δabd. Because B_2 is basically intact, there is no IEL caused by capital damage. B_2’s IEL is due to A’s reduced supply of sufficient raw material and C’s demand decline for up-stream products. B_2’s IEL is named as IEL II, represented by Δacd . The total IEL is represented by Δabc, which is Δabd and Δacd . Similarly, the IEL of sectors A and C can be divided into IEL I and IEL II.

3. Assessment of the IEL of Shanghai and Sichuan Province

This study primarily uses the adaptive regional input-output (ARIO, see Hallegatte, 2008) model to assess IEL. It had been applied to assess the indirect economic impacts of the hurricane Katrina on Louisiana, of the sea level rise on Copenhagen, of the flood on Mubai(Hallegatte et al.2011), and of the earthquake on Sichuan province(Jidong Wu, et al., 2011). Those simulation results were found consistent with available data.(Hallegatte, 2008; Jidong Wu, et al., 2011) This dynamic model takes into account the changes in production capacity due to productive capital losses, production bottlenecks due to both forward and backward propagations within the economic system and adaptive behavior in the aftermath of disaster. We can calculate IEL I by assessing production ability changes and IEL II by assessing production bottlenecks and adaptive behavior.

3.1 Introduction of Assessment Model

For the ARIO model in an economic system at equilibrium, the input-output coefficient matrix A describes the quantity provided by each sector to other sectors, and the production vector Y and the total final demand vector TFD are linked by the following relationship:

$$Y(i) = \sum_j A(i,j)Y(j) + \overbrace{LFD(i) + E(i) + HD(i) + \sum_j D(j,i)}^{\text{Total Final Demand}(TFD(i))} \tag{1}$$

where i, j = 1,…, N for all sectors; *Y* is the production vector; *A* is the local input-output matrix; *LFD* is the local final demand vector; *E* is the exportation vector; and *HD* and *D* represent the disaster damage to households and industries, respectively. The vector *TFD* is the total final demand.

From Equation (1), we can calculate the ideal production level for every enterprise:

$$Y^0 = (1-A)^{-1}TFD \tag{2}$$

To calculate IEL, we first assume an 'ideal demand:'

$$TD^0 = Y^0 \tag{3}$$

We can make the time step as long as a month and calculate the IEL I, IEL II and the total IEL during the recovery and reconstruction periods.

IEL I. According to the Leontief Production Function, the production loss due to fixed capital damage, i.e., IEL I, is

$$Indirect\ Loss(I) = \sum_t \sum_i \bar{Y}(i) \frac{\tilde{D}(i,t)}{\beta(i)VA(i)} \tag{4}$$

In the above function, *t* refers to the time step, *i* refers to the industrial sector;

$\bar{Y}(i)$ refers to the industrial sector i's production (month average) before the disaster, $\frac{\tilde{D}(i,t)}{\beta(i)VA(i)}$ can be regarded as the reduction percentage of industry i's production at time t; $\tilde{D}(i,t)$ refers to the disaster damage to the capital stock of industrial sector i at time t, $\beta(i)$ is the average productivity ratio of industrial sector i, $VA(i)$ refers to the value added(VA) of industrial sector i.

IEL II. Because every enterprise is affected by direct loss and industrial linkage, Function (2) and Function (3) have a relatively higher ideal production and demand. Here, we will try to reduce the production and demand volume so as to approach the production and demand seen in a real situation, and then we will calculate the IEL.

After taking IEL I and the capacity to overproduce $\alpha(i)$ into account, we can calculate the production：

$$Y^{\max}(i) = \bar{Y}(i)\left[1 - \frac{\tilde{D}(i)}{\beta(i)VA(i)}\right]\alpha(i) \tag{5}$$

Then the production of every industry：

$$Y^{1}(i) = MIN\left\{Y^{\max}(i); TD^{0}(i)\right\} \tag{6}$$

Next, we will focus on B2 of Fig. 1 to assess B's IEL II:

●Assessment of Industrial Forward-Linked IEL：

In Chart 1, after the earthquake, production of industrial sector A declines and can no longer meet the demand of industrial sector B. The supply reduction is named forward-linked impact of A. According to the rationing scheme in the ARIO model, If an industry cannot satisfy total demand, its production goes first to intermediate consumptions from other industries. Also, all industries are assumed equally rationed: what an industry gets is proportional to what it ordered. To assess the forward-linked impact, we loop over all commodities and, for each commodity i, we define $O^1(i) = \sum_j A(i,j)Y^1(j)$ as the first-guess amount of the orders requested from industrial sector i for the support of other industries. We then consider two cases:

If $Y^1(i) \geq O^1(i)$, then industry i is able to provide enough commodity to all of the other industries, and the production of the other industries is not affected.

If $Y^1(i) < O^1(i)$, then industry i is not able to provide enough commodity to all of the industries and each industry j sees its production limited by the availability of the material i. In that case, the production of industry j is bound by: $\left(Y^1(i)/O^1(i)\right)Y^1(j)$

In this process, we assume that there is no limit on import products. According to the Leontief Production Function, we can calculate every industry i's new production:

$$Y^2(i) = MIN\left\{Y^1(i); \text{for all } j, \frac{Y^1(j)}{O^1(j)}Y^1(i)\right\} \tag{7}$$

Then we can calculate a new production $\{Y^2(i)\}$.

●Assessment of Industrial Backward-Linked IEL：

After the assessment of the forward-linked impact, if $Y^2=Y^1$, i.e., there is no previously-mentioned linked impact, then Y^2 is the real production. Otherwise, we must account for the backward-linked impact. In Chart 1, after the earthquake, production of industrial sector C declines and can no longer need the supply of industrial sector B. The demand reduction is named backward-linked impact of C. Given this adverse impact, we can calculate a new final demand value $TD^1(i)$：

$$TD^1(i) = TFD(i) + \sum_j A(i,j)Y^2(j) \tag{8}$$

And we repeat the above steps, with $\{TD^1(i)\}$ instead of $\{TD^0(i)\}$. Because all of the industries are interlinked, we need to iterate the bottleneck calculation until convergence of the vector Y^k.

The final values for total demand will be referred as $TD^{\infty}(i)$ and the final values for production will be referred to as $Y^{\infty}(i)$. When $TD^{\infty}(i) = Y^{\infty}(i)$, the industry *i* can satisfy the demand and the industry recovers to its pre-disaster state; otherwise, this industry cannot meet the demand, i.e., $Y^{\infty}(i) < TD^{\infty}(i)$, and the customer's demand will be adjusted by the response system of the ARIO model.

At every time step of one month, each industry and family can recover $\Delta D(i)$ and $\Delta HD(i)$ through reconstruction. Thus, driven by these two factors, the economic system becomes a dynamic iterative model.

With all of the calculations above, we can develop the following:

$$Indirect\ Loss(II) = \sum_t \sum_i [\bar{Y}(i) - \bar{Y}(i) \frac{\tilde{D}(i,t)}{\beta(i)VA(i)} - Y^{\infty}(i,t)] \tag{9}$$

IEL. From the previous definitions and the classification of IEL, we can calculate the following:

$$Indirect\ Loss = Indirect\ Loss(I) + Indirect\ Loss(II) \tag{10}$$

$$Indirect\ Loss = \sum_t \sum_i [\bar{Y}(i) - Y^{\infty}(i,t)] \tag{11}$$

3.2 Data and parameters

In this paper, four sets of data were used for the ARIO model. First, the 2002 input-output (IO) tables for Sichuan Province and Shanghai Municipality, obtained from the Chinese Bureau of Statistics, were used for building the ARIO sectors. In the IO table, the former 42 sectors were merged into 14 new sectors (Appendix A). So, the local economy was composed of 14 productive sectors and one household sector. It's worth noting that Chinese IO table is surveyed one time per 5 years and 2007 IO table in every province is still in the stage of adjusting, so this manuscript uses correct

2002 IO table. This choice has little impact on the objectives of the work because the purpose is comparison of IEL between Sichuan and Shanghai, rather than estimating the absolute IEL of the two earthquakes.

Second, the sector-by-sector distributed direct loss of the Wenchuan earthquake was taken from the National Commission for Disaster Reduction and the Ministry of Science and Technology of China (NCDR and MOST 2008). These sources provided a comprehensive estimate of the direct losses. These data had been merged from the source data by sectors and had been revised to take into account any losses that could not be repaired, replaced or rebuilt (e.g., ecological losses).

Third, the direct loss to every industrial sector of Shanghai and Sichuan Province caused by a hypothetical Ms8.0 earthquake in 2002, using the direct loss to every industrial sector caused by Wenchuan earthquake in 2008, can be calculated as follows:

$$DL(s, p, 2002) = \frac{DL(s, sichuan, 2008)}{CAP(s, sichuan, 2008)} * CAP(s, p, 2002) \tag{12}$$

where s refers to the industrial sectors in Appendix A, and p refers to Shanghai or Sichuan Province. $DL(s, p, 2002)$ represents the direct loss of the s industrial sector in location p in 2002; $CAP(s, p, 2002)$ represents the capital stock value of the s industrial sector in location p in 2002. This method is, of course, a simplistic way of calculating the direct loss of every industry. But this manuscript aims to calculate the difference in the IEL for different economic systems given the same direct loss. So, as a first step, this rough estimate of the sector-by-sector distributed direct loss is assumed to be sufficient.

Fourth, parameter values are listed in Table 1. The maximum production capacity after the earthquake is set as 125% because of active government support. The modeling time step width was one month. These parameters are identical to those used in indirect economic impact evaluation of Wenchuan earthquake (Jidong Wu, et al., 2011). They take special Chinese disaster relief policy into account. So, they are credible.

3.3 Assessment Result

Based on the ARIO model, as well as on the above data and parameters, after the hypothetical Ms8.0 earthquake occurs in Shanghai Municipality and Sichuan Province, we can simulate how the value added recovers to the pre-disaster level and how the reconstruction needs change.

3.3.1 Macro-result

In Fig. 2, the chart on the left shows the changing rate of the value added. For most of the post-disaster period, we can see that the decline of Shanghai's value-added is greater than that of Sichuan. In Fig. 2, the chart on the right shows how the reconstruction demands change. During the reconstruction period, the capital demand for Shanghai is consistently greater than that of Sichuan. Regardless of the relative change rate of the value added or the capital demand from restoration, we can predict that Shanghai needs approximately 121 months to recover, while Sichuan needs 115 months. In other words, Shanghai will recover half a year later than Sichuan.

The IEL is measured in terms of value-added to avoid double-counting issues. After the earthquake, the respective direct and indirect losses of Shanghai and Sichuan Provinces can be seen in Table 2. When the two areas suffer CNY 100 of direct loss, the IEL of Sichuan is CNY 32, while that of Shanghai is CNY 44. In other words, for every CNY 100 of direct loss, Shanghai suffers CNY 12 more of indirect loss.

3.3.2 Micro-result

According to the definitions of direct and indirect loss, particularly the analysis of the causes of IEL, the ARIO model is used to assess IEL I and IEL II and to work out the quantitative relationship between the two IEL in Shanghai and Sichuan.

Table 3 demonstrates that all industries in Shanghai and Sichuan suffers from the reason caused by IEL I. If direct loss makes up the same proportion of fixed asset in every industry, as compared with Sichuan Province, all industrial sectors in Shanghai is magnified approximately 1.25 times by the reason caused by IEL I. On the whole, as compared with Sichuan, Shanghai’s IEL I has been magnified 1.44 times.

During the reconstruction period, the No.8 and No.12 industries in Shanghai benefit from the reason caused by IEL II; the No.6, No.8 and No.12 industries in Sichuan Province benefit from the reason caused by IEL II. The remainder of the industries suffers from the reason caused by IEL II. On the whole, when suffering an equal direct loss, as compared with Sichuan, Shanghai’s IEL II is amplified 4.09 times.

From the comparison of Shanghai and Sichuan, we draw the conclusion that IEL I is the external dynamic that leads to IEL but that the magnifying power of IEL II is much stronger than that of IEL I. Therefore, to minimize this risk, policy-makers are advised not to ignore the magnifying impact of the industrial linkages in the economic system during the reconstruction period.

4. Results Analysis

In this section, the differences in the industrial linkages, the industrial structures and the regional trade of Shanghai and Sichuan will be analyzed to discover which factors cause the marked differences in the IEL and in the length of reconstruction period so as to improve the disaster management ability of government.

4.1 Interindustrial Linkage

Industrial Backward Linkages (IBL) is the increase/decrease in total output of the system required to utilize the increased/decrease output from an initial unit of primary input into any one of the industrial sectors. Industrial Forward Linkages (IFL) is the increase/decrease in total output of the system required to supply inputs for an initial unit increase/decrease in any one of the industrial sectors. According to the input-output table of Shanghai and Sichuan in 2002 and the IFL and IBL calculation method of Leroy P. Jones (1976), the IFL and IBL of the 17 industries in Shanghai and Sichuan are calculated. The result can be seen in Fig. 3. Most of the indirect losses are caused by forward linkages. That is to say, due to damage to the factories and equipment, the up-stream industries cannot provide sufficient raw material for the down-stream industries. Therefore, forward linkages have more significant effects and should be considered more critical than backward linkages. In Fig. 3, the chart on the right shows that the forward linkages of 16 of the 17 industries in Shanghai are more significant than those of Sichuan, i.e., damage to any of the 16 will more significantly affect their supply to the other industries. As a result, in terms of the relative loss of the total production of the entire industry, Shanghai’s relative loss is larger than that of Sichuan. Even with backward linkage, over half of Shanghai’s industries are equal to or larger than Sichuan’s industries. After the earthquake, the demand for raw material from the up-stream industries declines, which, for a long period, will restrain the total production of the up-stream industries and, finally, will reduce the production of all of the industries. Thus, Shanghai's output drops more than that of Sichuan caused by backward linkage. So in Table 3, most of the industries in Shanghai see a higher IEL II than those of Sichuan. Comparing the total IEL II of all of the industries, Shanghai's IEL II is 4.09 times that of Sichuan. Suffering from the same hypothetical Ms8.0 earthquake and with direct losses making up the same proportion of the capital stock as compared with Sichuan, Shanghai's IEL I has been magnified 1.44 times. This magnification occurs because the industries in Shanghai are more closely linked, which slows reconstruction. Therefore, over the same period of time, Shanghai has greater difficulty restoring fixed capital such as damaged factories and equipment; these difficulties, in return, increase IEL I.

4.2 Industrial Structure and Trade

In terms of industrial linkage, we analyze the relative difference of IEL. To prove that the absolute value of Shanghai is larger than Sichuan, and to prove that reconstruction will take Shanghai longer, the industrial structures and trade of the provinces must be analyzed. In other words, the analysis of the industrial structures will show the weight of the industries, which proves that Shanghai's absolute IEL may be greater. Fig. 4 shows the industrial structures and trade of Shanghai and Sichuan. The width of the column denotes the sector share of gross output. The height of the column denotes the sum of domestic and export demand. Domestic demand is expressed as 100%. The dotted line between every pillar represents the degree of self-sufficiency. When the self-sufficiency degree is higher than the national demand

(100%), the industry is self-sufficient; otherwise, the industry requires export supply.

In terms of industrial structure, the output proportions of the secondary and tertiary industries in Shanghai are larger than those of Sichuan. Particularly the output proportions of the secondary industries in Shanghai are 10% larger than those of Sichuan. From Fig. 3, we can see that most of the industries with larger forward and backward linkages are secondary industries. These two phenomena prove that Shanghai’s IEL II is larger than Sichuan’s in terms of absolute value. In addition, as can be seen in Fig. 4, the pillar representing Shanghai is higher than that of Sichuan, and many of the industries in Shanghai have a self-sufficiency of less than 100%. These two marked differences prove that Shanghai’s foreign trade intensity is much stronger than that of Sichuan. The ARIO Model simulates the impacts of mutual trade between a disaster-hit zone and the outside areas on indirect losses. For Shanghai, which has intense foreign trade, the break-down of infrastructure such as communications and traffic can damage regional trade, making the import of reconstruction materials, as well as the export of products, difficult. This difficulty will magnify the direct loss of the disaster and the indirect economic damage.

Once the disaster occurs, neither the direct loss nor the IEL I can be reduced, while the IEL II can be reduced through non-structural measures such as industrial linkages, industrial structures and regional trade. Also, IEL II is much larger than IEL I. Thus, to reduce total economic losses during the reconstruction period, it is a bright road to reduce IEL II via non-structural measures.

5. Conclusions and Discussions

Using the simulation from an input-output model, this paper showed the relationship between the level of economic development and the indirect losses created by a natural disaster in a quantified way. According to the comparison between industrial structures, industrial linkages and regional trade, the potential causes of the different relationships has been analyzed. First, one figure was drawn to demonstrate the difference between direct and indirect economic loss intuitively; the other figure was drawn to explain that IEL can be further divided into the endogenous capital damage and the exogenous industrial linkage. Second, by collecting disaster and economic data, we found an appropriate model, the ARIO model, which could assess these two types of IEL. The simulation provided results that allowed the comparison of the evolution of production from the time of the shock to full recovery, the reconstruction needs and the recovery time. More importantly, the magnifying power of the economic development level connected to IEL I and IEL II was compared. Third, we analyzed the causes of IEL in terms of industrial linkages, industrial structures and trade, to explain why the magnifying power of IEL II is larger than that of IEL I.To disaster risks governance, four conclusions were drawn in this essay.

From the perspective of relative loss, and on the assumption that the direct losses are the same for Shanghai (1st in terms of per capita GDP) and Sichuan (24th per capita GDP), Shanghai would suffer greater indirect losses than Sichuan. Of the per CNY 100 direct loss, Shanghai suffers CNY 12 greater indirect losses than Sichuan. During the reconstruction period, it will take Shanghai half a year longer to recover. Therefore, policy makers are advised to pay attention to the potential for indirect loss in developed areas.

Indirect loss caused by industrial linkage is much greater than the loss from endogenous capital damage. Compared with Sichuan, Shanghai's indirect loss due to endogenous capital damage would be magnified 1.44 times, while the effect of industrial linkages would be 4.09 times. Thus, to reduce indirect losses, policy makers are advised to take steps to manage industrial linkages by adjusting forward linkage, backward linkage and trade.

Shanghai's development in recent years demonstrates that an optimized industrial structure and closely linked industries are very significant for regional economic growth. But this same industrial structure will also magnify the impact of a disaster. Therefore, to achieve regional sustainable development, policy makers are advised to strike a balance between economic growth and disaster prevention. The simulation of indirect loss and industrial linkages in this paper is a valuable reference for formulating strategies to optimize the industrial structure.

The reduction of indirect loss should be a part of the overall process of disaster risk governance. Before the disaster, adjust and optimize the industrial structure; during the disaster, guarantee the smooth import and export of relief goods; after the disaster, give priority to the industries with more linkages so as to promote economic recovery.

Of course, there are weaknesses in the paper. Due to the lack of necessary data and the assessment method, this paper has only studied the relationship between indirect loss and economic development. In a future study, using a model that can estimate all of the impacts of a natural disaster (such as direct loss, indirect loss, damage to historical relics, ecological environment and the victims' psychology) and that can provide an analysis of the relationship between the economic development level and the entire disaster impact will provide more value. However, the simulation method in our essay works well for comparing the relative value of an indirect loss. To find an accurate absolute value for the indirect loss, there is some space to improve the linear relationship of the input-output model.

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Appendix A. ARIO Model Sectors

Sector No.	ARIO sector
1	Agriculture
2	Mining Industry
3	Food Manufacturing
4	Textile, Sewing Machine and Leather Manufacturing
5	Wood Processing & Furniture Manufacturing
6	Coke, Gas & Oil Processing
7	Chemical Industry
8	Construction Material & Other Nonmetallic Mineral Manufacturing
9	Metallic Products Manufacturing
10	Mechanical Equipment Manufacturing
11	Electricity, Steam, Hot-water Production & Supply
12	Building Trade
13	Transportation, Post & Telecommunications
14	Commerce & Catering
15	Finance & Insurance
16	Specific Service Management
17	Public Utility & Resident Service

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Table 1 Parameter values in the ARIO model

Name	Value	Description
a_b	100%	Production capacity pre-earthquake
a_{max}	125%	Maximum production capacity post-earthquake
τ	6 months	Adaptation time
ε	0.9	Elasticity of local final demand with respect to the commodity price

Table 2 Comparison of the Respective Direct Loss & Indirect Loss of Shanghai and Sichuan

Area	Direct Loss (in ten thousand CNY)	Indirect Loss (in ten thousand CNY)	Direct/Indirect
Shanghai	5549.1	2415.3	44%
Sichuan	4311.3	1382.8	32%
Δ (Shanghai-Sichuan)	——	——	12%

Table 3 Economic Impact of an Earthquake Occurring in Shanghai and Sichuan Provinces, 2002

Sector No.	**Output Baseline**		**Output Change after Earthquake**					
			IEL I[a]			IEL II[b]		
	Shanghai (in 100 million CNY) (1)	Sichuan (in 100 million CNY) (2)	Shanghai[c] (3)	Sichuan[c] (4)	Shanghai/Sichuan[d] (5)=(3)/(4)	Shanghai[c] (6)	Sichuan[c] (7)	Shanghai/Sichuan[e] (8)=(6)/(7)
1	249.8	1615.4	-0.03%	-0.03%	1.25	-1.09%	-0.90%	1.21
2	32.6	405.3	-0.10%	-0.08%	1.25	-0.84%	-0.54%	1.54
3	597.9	848.1	-0.18%	-0.14%	1.25	-1.60%	-1.04%	1.54
4	819.4	166.5	-0.18%	-0.14%	1.25	-1.67%	-1.08%	1.54
5	524.4	305.7	-0.18%	-0.14%	1.25	-1.47%	-0.58%	2.55
6	258.2	18.9	-0.08%	-0.06%	1.25	-0.41%	1.79%	-0.23
7	1341.9	515.7	-0.18%	-0.14%	1.25	-1.57%	-0.42%	3.74
8	258.2	499.0	-0.18%	-0.14%	1.25	0.88%	0.60%	1.47
9	802.8	515.6	-0.17%	-0.14%	1.25	-0.75%	-0.26%	2.92
10	4671.7	1065.0	-0.18%	-0.14%	1.25	-1.59%	-0.90%	1.77
11	345.9	389.2	-0.18%	-0.14%	1.25	-1.40%	-0.76%	1.85
12	1154.2	1361.7	-0.10%	-0.08%	1.25	4.92%	3.61%	1.36
13	1429.5	662.1	-0.16%	-0.13%	1.25	-0.97%	-0.78%	1.24
14	1338.7	1064.3	-0.16%	-0.13%	1.25	-1.12%	-0.75%	1.50
15	1729.7	561.4	-0.14%	-0.11%	1.25	-1.25%	-1.08%	1.16
16	256.9	88.6	-0.07%	-0.05%	1.25	-0.77%	-0.99%	0.78
17	937.2	893.4	-0.18%	-0.14%	1.25	-1.63%	-1.41%	1.16
Total	16748.9	11510.8	-0.16%	-0.11%	1.44	-0.90%	-0.22%	4.09

[a] Indirect loss because of companies' own property damage [b] Indirect loss because of interindustry linkages [c]From the ARIO simulation
[d] IEL I's magnifying power [e] IEL II's magnifying power

Figures

Fig. 1 Direct Loss vs. Indirect Loss

Fig. 2 Change in total VA (% of the pre-earthquake level, left panel) and reconstruction needs (in billion CNY, right panel) as a function of time, for a hypothetical Ms8.0 earthquake in Shanghai and Sichuan Province

Fig. 3 Comparison of IBL and IFL for the 17 industries in Shanghai and Sichuan

Fig. 4 Comparison of the Industrial Structures and Trade in Shanghai and Sichuan Province (Please refer to the 10th industry of Shanghai)(Primary Industry: No.1; Secondary Industry: No.2 through No.12; Tertiary Industry: No.13 through No.17)

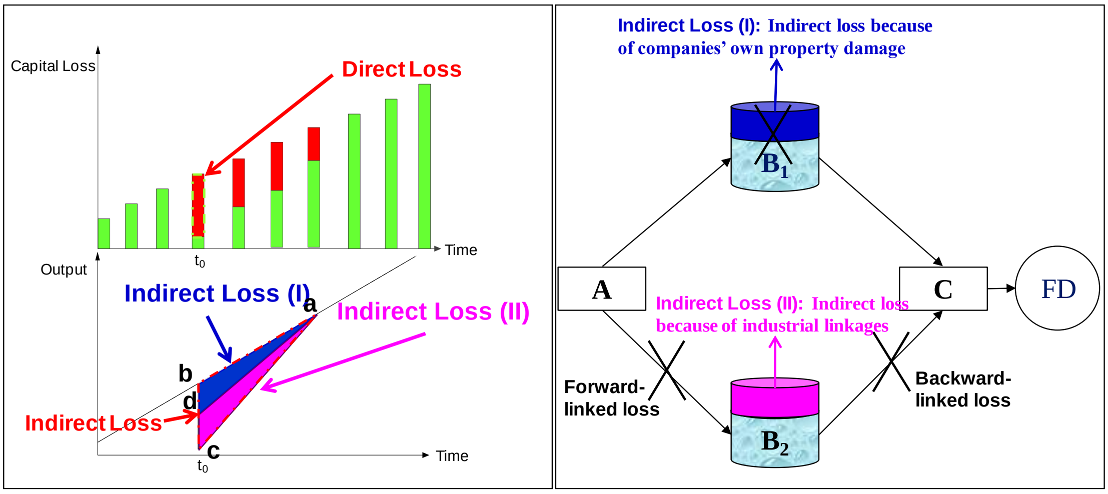


Fig. 5 Direct Loss vs. Indirect Loss

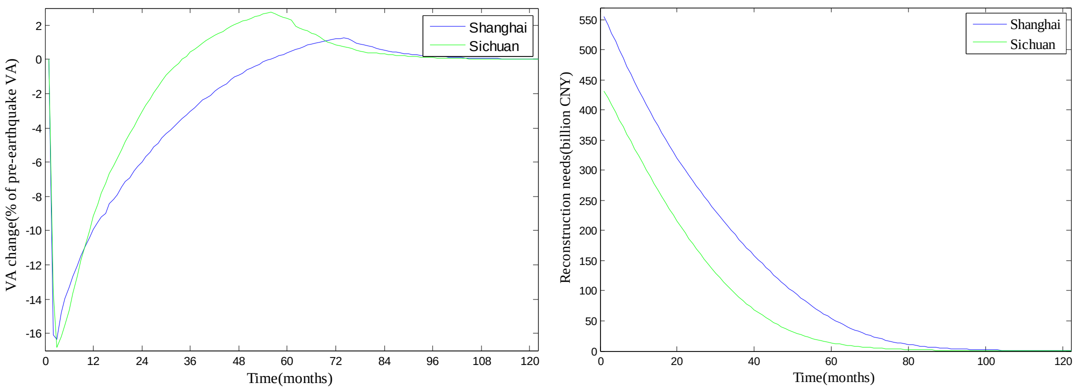


Fig. 6 Change in total VA (% of the pre-earthquake level, left panel) and reconstruction needs (in billion CNY, right panel) as a function of time, for a hypothetical Ms8.0 earthquake in Shanghai and Sichuan Province

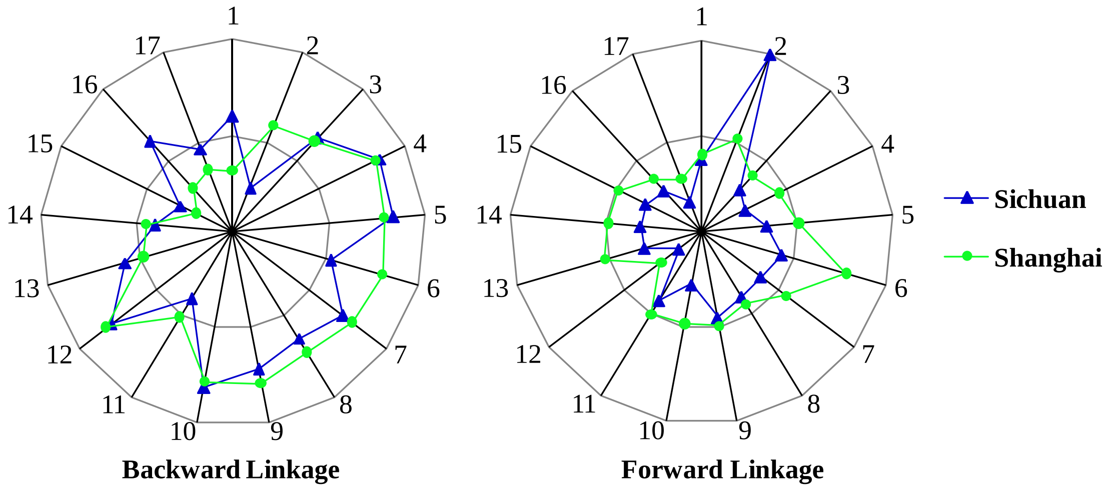
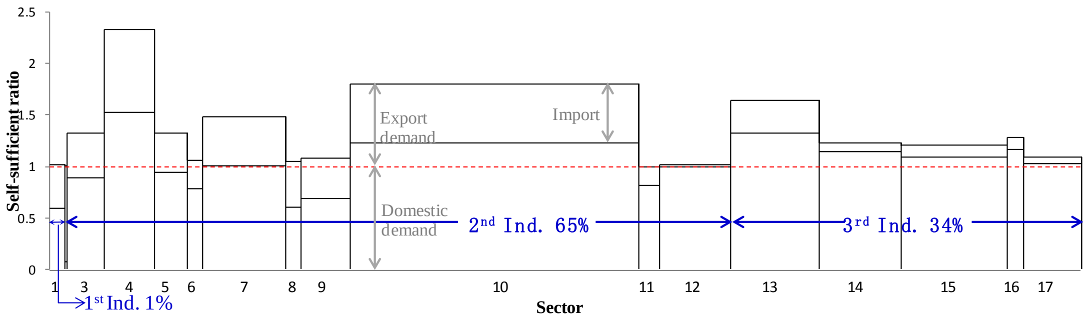
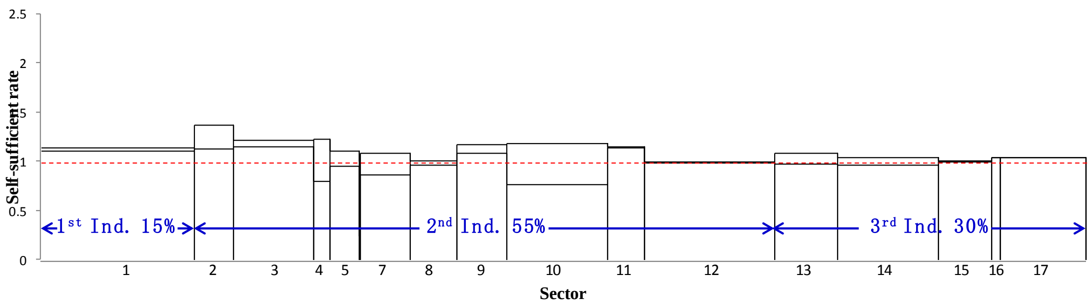


Fig. 7 Comparison of IBL and IFL for the 17 industries in Shanghai and Sichuan



Shanghai Municipality



Sichuan Province

Fig. 8 Comparison of the Industrial Structures and Trade in Shanghai and Sichuan Province (Please refer to the 10th industry of Shanghai)

(Primary Industry: No.1; Secondary Industry: No.2 through No.12; Tertiary Industry: No.13 through No.17)