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ARTICLE

Study on Large-Scale Disaster Risk Assessment and Risk Transfer Models

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Abstract This article analyzes the risk assessment and risk transfer models of large-scale disasters in line with the characteristics of such disasters. A large-scale disaster risk assessment model based on the Regional Disaster System concept is developed: large-scale disaster risk (R_L) is a function of the disaster triggering hazard (H), the vulnerability of the concerned objects (V), and the stability of the contextual hazard-formative environment (E), or $R_L = f(H, V, E)$. Based on our discussions, we propose that large-scale disaster risk transfer in China should be supported by governments at all levels, operated by insurance companies, and the responsibilities should be shared by all stakeholders. At the global level, large-scale disaster risk transfer should employ a uniform definition and be characterized by government support, market operation, public participation, disaster mitigation, and risk sharing.

Keywords China, large-scale disaster risk, risk assessment model, risk transfer model

1 Introduction

A large-scale disaster (LSD) is any serious disaster that causes heavy human casualties, huge property losses, and affects wide areas; it is based on any hazard that occurs at intervals of 100 years or longer and cannot be coped with by the affected areas without external interventions (Shi and Liu 2009). Risk assessment of large-scale disasters is the basis for establishing a risk transfer model of such disasters as well as the key for establishing their risk governance models. Guided by the Regional Disaster System concept (Shi 2009) and starting with the conventional risk assessment model ($R_L = f(H, V)$) and taking into consideration the disaster chain characteristics of large-scale disasters (Shi 1991), this article establishes a risk assessment model of large-scale disasters to adequately reflect the intensity of hazards, the vulnerability of the exposed, and the stability of hazard-formative environment. Based on this model, the natural disaster risk transfer measures that have been taken by China and other countries, and the various cases of large-scale disasters encountered in China in recent years, the Chinese and global risk transfer models for large-scale disasters are set forth to provide a reference for regions and countries to establish the financial management system of large-scale disaster risks.

2 Disaster Risk Assessment

In view of increasing natural disasters, relevant organizations and experts around the world have conducted in-depth studies of disaster risks. The United Nations Development Programme (UNDP) has established the Disaster Risk Index (DRI), which is a country-level disaster risk assessment index with a global scale and emphasizes the relationship between national development and disaster risks (UNDP 2004). The DRI is a mortality-calibrated index that measures the risk of disasters causing human mortality. Based on the 1980–2000 data, the DRI is used to calculate the average mortality risk caused by large- and medium-scale earthquakes, tropical cyclones, floods, and droughts. As can be seen from the formula $R = H \bullet Pop \bullet Vul$ (R = death toll of potential disasters; H = hazards, depending on the frequency and intensity of hazards; Pop = total population of affected areas; Vul = vulnerability, depending on the social, political, and economic status of affected areas), the DRI is determined jointly by hazards, hazard exposures (affected population), and vulnerability, but lacks consideration of the effect of the hazard-formative environment in the disaster system, as well as of the property losses and the damages to the resources and the environment resulting from these disasters. In multi-hazard assessment, the DRI calculates the sum of all disaster losses (4 types in total). Therefore, it is a disaster risk assessment index with inadequate consideration of disaster risks, but it is easy to apply due to its low data requirement.

In response to some of the deficiencies in the DRI, the World Bank and Columbia University (Dilley et al. 2005)

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introduced the Hotspots Index. The Hotspots project mainly aims to identify high-risk areas of different disasters on a global scale and especially on the national and regional scales to provide a basis for decision making for disaster risk reduction. In assessing disaster risks, the Hotspots assessment index mainly takes into account mortality-related risks and economic risks caused by disasters. Hazards considered in Hotspots include six types of natural hazards, that is, floods, hurricanes, earthquakes, droughts, landslides, and volcanic eruptions; risk indicators include mortality, total economic loss, and proportion of economic loss in GDP; the disaster impact indicator indicates the areas affected by these hazards; the vulnerability indicator is obtained by calculating the loss rate of different natural disasters, using the historical loss data of 20 years (1981–2000) in the EM-DAT database maintained by the Centre for Research on the Epidemiology of Disasters (CRED). The unit assessed by Hotspots is the 2.5′×2.5′ grid. Hotspots has established the multi-hazard risk index, which is the sum of the risk indexes of disasters graded from 8 to 10, that is, those with relatively high risk significance, on the basis of classifying each hazard risk index into 10 grades. The Hotspots Index has overcome the problem in the DRI, which failed to consider the economic losses caused by disasters, and its spatial resolution has also been improved to some extent, but it still fails to take into account the role the hazard-formative environment plays and still shows inadequate concerns for the risks caused by disaster chains.

In view of the above disaster assessment index systems, the National University of Columbia and the Inter-American Development Bank have jointly developed a System of Indicators (SI) for disaster risk management (IDEA 2005), which consists of four index groups: the Disaster Deficit Index (DDI), the Local Disaster Index (LDI), the Prevalent Vulnerability Index (PVI), and the Risk Management Index (RMI). The SI aims to carry out a systematic quantitative evaluation of the disaster risk management in countries of the Americas in 1980–2000. The SI has, in a relatively comprehensive manner, characterized disasters and losses as well as the capacity of recovery and reconstruction, but still gives inadequate consideration to the regional environmental conditions of the affected areas and is mainly available for small- and medium-scale disasters. The SI has also included multi-hazard disaster risk assessment, using multi-hazard risk aggregation for calculation.

The U.S. Federal Emergency Management Agency (FEMA) and the U.S. National Institute of Building Sciences (NIBS) jointly developed a multi-hazard disaster risk assessment method, HAZUS (Hazards United States) (FEMA 2004). The HAZUS disaster risk assessment system is a standardized multi-disaster loss assessment system commonly used in the United States, which estimates losses on the basis of the scientific understanding of hazards such as earthquakes, floods, and hurricanes. The HAZUS software package is based on risk analysis tools on a Geographic Information Systems (GIS) platform. It contains seven software modules: the potential hazards (earthquakes, floods, and hurricanes), the hazard exposure database, direct loss (property loss), indirect loss (non-property loss), social loss (human casualties, evacuation and shelter, etc.), direct economic loss (the direct loss of the financial market), and indirect economic loss (the indirect economic loss of the financial market). HAZUS can provide basic and detailed loss estimates of the affected areas and more detailed loss estimates of the buildings. Compared to the DRI, Hotspots, and SI, HAZUS has a stronger capability of handling different loss estimates of disasters and pays special attention to disaster chains and indirect losses. It still uses aggregation for multi-hazard loss estimates. In terms of disaster risk assessment, it has strictly followed the quantitative model and given full consideration to hazard, exposure, and vulnerability, but it still gives less consideration to the hazard-formative environment in a disaster system.

The Europe Multi-Risk Assessment (EU-MRA) model developed by the European Union assesses risks of natural and technical hazards within the assessed region and carries out risk evaluation of the disaster system using the weighted sum method (Delphi Method) (Greiving 2006). The integrated disaster risk assessment of EU-MRA includes the compilation of single-hazard maps, integrated hazard maps (Delphi Method), integrated vulnerability maps (comprehensively characterized using regional per capita GDP, population density of the affected areas, regional natural fragmentation, and national per capita GDP), and integrated risk maps (by classifying integrated hazard and integrated vulnerability into 5 grades respectively to form a 5×5 matrix and then adding up to 9 integrated risk grades; the result is mapped). Beijing Normal University of China also adopted a similar method to launch several multi-hazard risk assessment projects in different areas (Shi et al. 2006; Wang et al. 2008).

This review shows that rapid progress has been achieved in the assessment of disaster risks. However, with regard to deepening the understanding of mechanisms and processes of risk formation of regional disaster systems, problems still exist in three main areas. First, risk evaluation of disaster systems lacks consideration of the hazard-formative environment. Hazard-formative environments have important influences on disaster formation. Especially in the risk assessment of disaster chains, it is extremely important to take the hazard-formative environment into account. For instance, the occurrence of an earthquake in a mountainous area is likely to trigger secondary geological disasters such as falling rocks and landslides. The spatial-temporal combination of hazards, exposures and hazard-formative environments may also amplify or reduce the severity of disasters. The fact that the 2008 southern China snowstorm became a large-scale disaster in the southern low-mountain and hilly areas was due to the combination of these three factors. Second, inadequate consideration has been given to disaster chains. For any serious natural disasters, along with the main disaster, there usually are a series of secondary disasters, forming disaster chains of different compositions. Various types of disaster

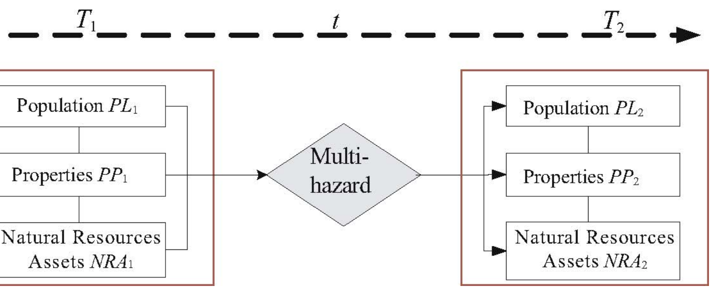

Figure 1. Social and natural state before and after the impact of regional multi-hazards

chains expand the scope of affected areas, exacerbate the severity of disasters, and affect the estimation of disaster losses. To estimate any losses caused by disaster chains, it is necessary to clearly define the affected area of each hazard during a large-scale disaster and to more accurately estimate the losses caused by different hazards. Third, despite of the attention given to multi-hazard disaster estimation, application of a simple sum or weighted sum method is a common practice in estimating losses, and it can hardly reflect objectively the losses arising from multiple hazards. The reason is that it fails to consider whether one hazard, happening in a specific time period, has any impact on the loss caused by the next hazard. If the interval between the two is short, as the loss resulting from the previous hazard reduces the total number or quantity of the exposed, the quantity of the exposed should be adjusted when assessing the loss caused by the subsequent hazard; otherwise, it will not be necessary to consider the change of the exposed between the two events.

Thus, to carry out any regional disaster risk assessment, it is necessary to consider the frequency and intensity of hazards, the spatial-temporal distribution and vulnerability of the exposed, as well as the stability of the hazard-formative environment, and the combination and overlapping of the three. It is also necessary to consider the disaster risk resulting from a single hazard as well as to pay close attention to the risk resulting from multiple hazards, especially the risk resulting from a disaster chain formed during major disasters. It is equally necessary to consider the vulnerability of the exposed in the face of a particular hazard or group of hazards in a specific time period as well as the possible sudden change in the vulnerability of the exposed due to the formation of disaster chains caused by the occurrence of multiple hazards within a short time period or a strong hazard.

3 Regional Multi-Hazard and Disaster Chain Risk Assessment

Shi (2009) has previously discussed how to conduct multi-hazard and disaster chain risk assessment and established a preliminary conceptual model of multi-hazard and disaster chain assessment. Based on the conceptual model ($R = f(H, V, E)$) and the above analyses, we propose a new method for risk assessment of multi-hazards and disaster chains.

3.1 Regional Multi-Hazard Loss Assessment Model

Multi-hazards refer to the phenomenon that an area can encounter several different hazards in a certain period of time. Assuming the area is P, P at time T_1 is in its initial state, the initial values of the concerned objects, or the exposed, are: population = PL_1, total property value = PP_1, natural resources assets = NRA_1. Multi-hazard impact evaluation is conducted at time T_2. The disaster-affected state of area P is: population = PL_2, total property value = PP_2, natural resources assets = NRA_2. As shown in Figure 1, the overall impact of multi-hazards is reflected in the difference between state $P(T_2)$ and state $P(T_1)$, which is expressed in formula (1):

$$L_{\text{multi-hazard}} = P(T_1) - P(T_2) \qquad \textbf{Eq. 1}$$

$L_{\text{multi-hazard}}$ represents the loss resulting from multi-hazards within the time segment (T_1, T_2), $P(T_1)$ represents the social and economic state (population, total property value, and natural resources assets) of area P at the moment of T_1, that is the pre-disaster initial state, $P(T_2)$ represents the social and economic state of area P at the moment of T_2. Generally, $L_{\text{multi–hazard}} \geq 0$.

Assuming the hazards encountered by area P are A, B, and C, Figure 2 shows the distribution of the three hazards by time and intensity in the time segment (T_1, T_2). On the horizontal axis, different hazards alternate; on the vertical axis, disaster intensity (values of the vertical axis are relative intensity) differs. Each disaster shows a different scope of impact. Figure 3 shows the scope of impact of multi-hazards (different patterns represent different hazards, areas covered

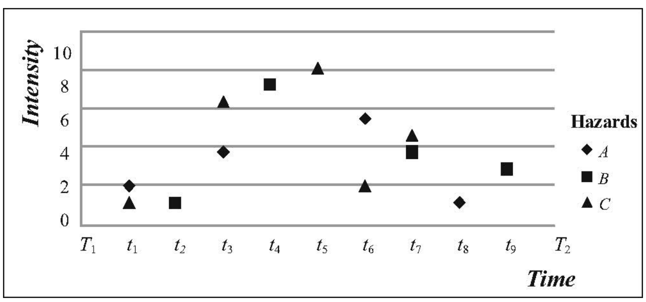

Figure 2. Distribution of multi-hazards in area *P* by time and intensity

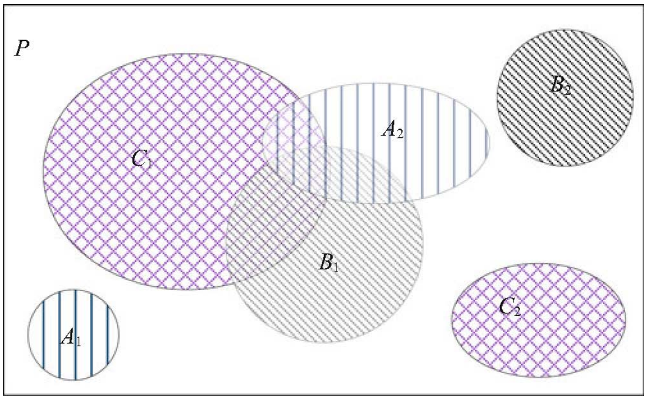

Figure 3. Illustration of multi-hazard affected areas in area *P*

represent the affected areas, and A, B, and C represent three hazards). The relationship between the affected areas of different disasters falls into two categories: one is the spatial overlapping of the affected areas, such as the case of A_2, B_1, and C_1. Impact of such overlapping on the calculation of total losses can be further divided into two types according to the different time intervals between the occurrences:

(1) For disasters with extremely short time interval, it is impossible to identify the loss caused by different disasters within the overlapping area. The total loss from A_2, B_1, and C_1 can be expressed as:

$$\begin{aligned} Loss(A_2 \cup B_1 \cup C_1) = {} & Loss(A_2) + Loss(B_1) + Loss(C_1) \\ & - Loss(A_2 \cap B_1) - Loss(A_2 \cap C_1) \\ & - Loss(B_1 \cap C_1) \\ & + Loss(A_2 \cap B_1 \cap C_1) \end{aligned} \quad \textbf{Eq. 2}$$

In Eq. 2, $Loss(A_2 \cup B_1 \cup C_1)$ represents the total loss caused collectively by A_2, B_1, and C_1; $Loss(A_2)$, $Loss(B_1)$, and $Loss(C_1)$ represent individually the loss from A_2, B_1, and C_1; $Loss(A_2 \cap B_1)$, $Loss(A_2 \cap C_1)$, $Loss(B_1 \cap C_1)$, and $Loss(A_2 \cap B_1 \cap C_1)$ represent the portion of duplicated calculation in working out the losses from A_2, B_1, and C_1.

(2) For occurrences with relatively long time interval that exceeds the recovery time of the earlier disasters, it is possible to identify the loss from different disasters. The total loss due to A_2, B_1, and C_1 can be calculated with the formula:

$$Loss(A_2 \cup B_1 \cup C_1) = Loss(A_2) + Loss(B_1) + Loss(C_1) \quad \textbf{Eq. 3}$$

The other category is the non-overlapping of affected areas, for example, the case of A_1, B_2, and C_2. The total loss of the three disasters can be expressed as:

$$Loss(A_1 \cup B_2 \cup C_2) = Loss(A_1) + Loss(B_2) + Loss(C_2) \quad \textbf{Eq. 4}$$

The multi-hazard losses of area P can be expressed as:

$$\begin{aligned} LOSS &= Loss(A_2 \cup B_1 \cup C_1) + Loss(A_1 \cup B_2 \cup C_2) \\ &= Loss(A_2 \cup B_1 \cup C_1) + Loss(A_1) + Loss(B_2) \\ &\quad + Loss(C_2) \end{aligned} \quad \textbf{Eq. 5}$$

Where, when due to the very short interval between the occurrence of A_2, B_1, and C_1 it is impossible to identify the losses resulting from different disasters in the overlapping areas,

$$\begin{aligned} Loss(A_2 \cup B_1 \cup C_1) = {} & Loss(A_2) + Loss(B_1) + Loss(C_1) \\ & - Loss(A_2 \cap B_1) - Loss(A_2 \cap C_1) \\ & - Loss(B_1 \cap C_1) + Loss(A_2 \cap B_1 \cap C_1); \end{aligned}$$

When the relatively long interval between the occurrence of A_2, B_1, and C_1 exceeds the recovery time of earlier disasters, it is possible to identify the losses resulting from different disasters,

$$Loss(A_2 \cup B_1 \cup C_1) = Loss(A_2) + Loss(B_1) + Loss(C_1).$$

With equation 5, it is possible to assess the losses of regional multi-hazards.

3.2 Regional Disaster Chain Loss Assessment

Disaster chains refer to the phenomenon of a series of disasters caused by another disaster (Shi 1991). We have proposed four common types of disaster chains: typhoon-storm, cold airmasses, droughts, and earthquakes (Shi 2002). Disaster chains herein refer to the natural disaster chains, which have three features. (1) Inducibility: a causal relationship exists between disaster chain components, that is, one or several types of disasters are induced by another type of disaster. Considering this inducible effect, disaster chains are classified as either sequential disaster chains or concurrent disaster chains (Shi 1991). Multiple disasters without such causal relationship do not constitute a disaster chain. (2) Time scale: due to the inducible effect within a disaster chain, disasters take place in sequence, that is, a main disaster comes before secondary disasters. Some disasters may induce another disaster several years, decades, and even hundreds of years later. Due to their excessively long time scale, such inducible effects can be ignored and these disasters can be treated as separate disasters to be assessed separately instead of being treated as part of a disaster chain. The time scale of disaster chains is comparatively short. (3) Spatial scale: a serious disaster will often generate secondary disasters and its affected area will be expanded. Different hazard-formative environments show different sensitivity to different hazards, while some environments are basically insensitive to a specific hazard. Therefore, different hazards have different affected areas. Figure 4 is an illustration of the affected area of a disaster chain, in which A represents the main hazard, B, C, and D represent different secondary hazards, and E_1, E_2, and E_3 represent different hazard-formative environments. After the main hazard A took place, its affected area falls in E_1, E_2, and E_3. As different environments have different sensitivity to different hazards, A may induce the secondary hazard B in E_1, whose affected area is not limited to that of A. When B has happened in its environment, a sub-secondary hazard may be induced, and so on. Similarly, the interaction between A and E_2 or E_3 induces the secondary disasters D and C.

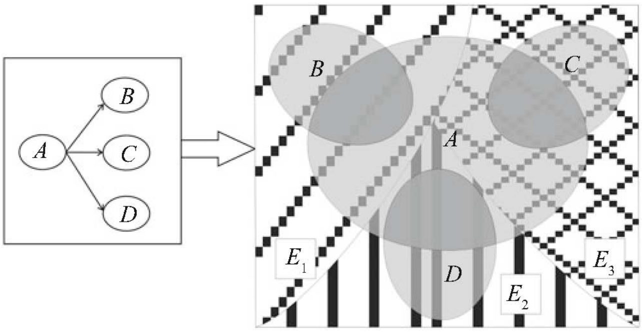

Figure 4. Illustration of the spatial relationships between disaster-chain affected areas and the environment

Based on the three features of the disaster chains, we developed a general method for disaster chain assessment as presented below.

3.2.1 Affected Area of Disaster Chains

Determining the affected area of a disaster chain involves assessing hazard H and environment E and their interactions. The intensity indicator of hazard H is $H_i = \{H_1, H_2, H_3, \cdots, H_n\}$ $(i = 1,2,3,\cdots,n)$, it indicates the strength of the hazard. The overall environment E can be divided into $E_i = \{E_1, E_2, E_3, \cdots, E_n\}$ $(i = 1,2,3,\cdots,n)$. When E encounters an initial disaster A, the affected area will differ with the different intensity of H_{Ai}. Given the hazard H of main disaster A and E_i in its affected area, H has a critical value H_{0i}. When $H > H_{0i}$, it will result in secondary disaster B. In a similar way, we can assess the affected area of H_i and E_i of secondary disaster B, and the affected area of the entire disaster chain, with the procedure shown in Figure 5.

In practice, a calculation can be made for each grid to determine the hazard intensity and environment type in the grid in order to define the affected area of disasters. With limited data the affected area can also be computed on a county basis.

3.2.2 Loss Assessment by Areas and Hazards

Within the affected areas of disaster chains, some areas are hit by a single hazard and some by multi-hazards. Therefore, loss assessment of disaster chains needs to be undertaken by areas and by hazards. As shown in Figure 4, the light grey areas are hit by a single hazard, the dark grey areas by two hazards, and the loss from each hazard A, B, C, and D is:

$$\begin{aligned} A_{\text{loss}} &= f(E_0, V_A, H_A + H_{AB} + H_{AC} + H_{AD}) \\ B_{\text{loss}} &= f(E_1, V_B, H_B + H_{AB}) \\ C_{\text{loss}} &= f(E_3, V_C, H_C + H_{AC}) \\ D_{\text{loss}} &= f(E_2, V_D, H_D + H_{AD}) \end{aligned} \qquad \textbf{Eq. 6}$$

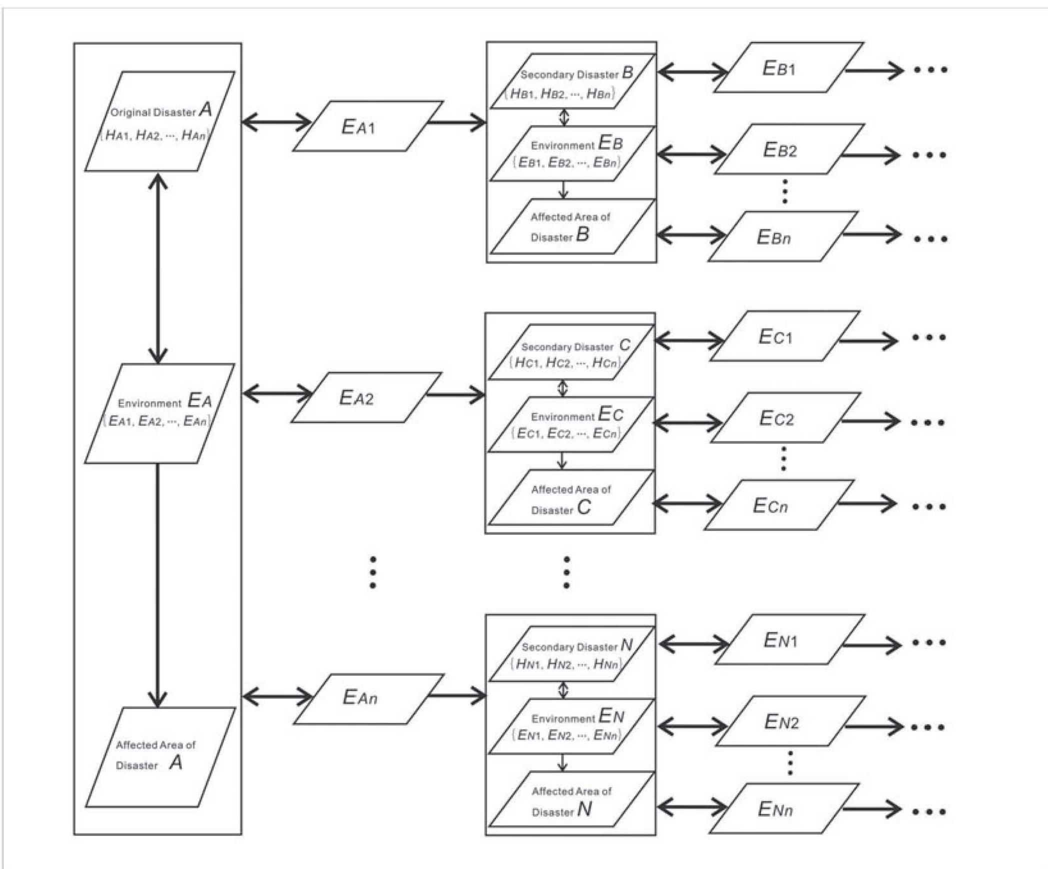

Figure 5. Assessment procedure for affected areas of disaster chains

In equation 6, $E_0 = E_{1A} + E_{2A} + E_{3A}$.

The total loss of a disaster chain is:

$$LOSS = f(E, V, H_A + H_B + H_C + H_D + H_{AB} + H_{AC} + H_{AD}) \quad \textbf{Eq. 7}$$

In equation 7, $E = E_0 + E_1 + E_2 + E_3$; $V = V_A + V_B + V_C + V_D$.

For the areas hit by multi-hazards, the multi-hazard assessment method is used, while for the areas hit by a single-hazard, the single-hazard assessment method is used.

3.3 Regional Disaster Risk Assessment

Based on the loss assessment of regional multi-hazards and disaster chains, the occurrence frequency and intensity of hazards within the region, and the changing trend of regional hazard exposure and hazard-formative environment, regional disaster risk can be assessed. In practice, we need to first identify the types of hazards in the region within a specified time period and the types of the hazard-formative environment, and identify the types of the regional disaster chains accordingly. Second, based on observation data of hazards, we need to calculate the exceedance probability of different hazards at different levels. Third, through correlation analysis or experiment and simulation, we need to prepare the vulnerability curves to different hazards. Fourth, by means of GIS, we need to prepare high spatial-temporal resolution maps of hazard exposures (such as population, property, resources, and so on). Based on the above, we can assess the regional disaster risk ($R_r = f(H_r, V_r, E_r)$).

4 Risk Transfer Model of Large-Scale Disasters

In line with the practice of LSD risk governance in China, we have proposed to integrate safety building (disaster protection), disaster relief, emergency management, and risk transfer to form the structural system of LSD risk governance and coordinate preparedness, emergency response, recovery, and reconstruction to form the functional system of LSD risk governance (Shi 1991). From these discussions, we conclude that establishing a risk transfer model of LSD is of critical importance in the structural system as well as the functional system of LSD risk governance. Losses caused by natural disasters show clear regional variations. Small hazards can cause huge damages and vice versa. Natural hazards also have temporal variations. High-intensity events occur at lower frequency, low-intensity events occur at higher frequency. Therefore, it is necessary to explore the transfer models for different disaster risks, especially the transfer approach of LSD risks. For any region, the formation of LSD risks is often closely associated with the overlapping of multi-hazards and the occurrence of disaster groups and disaster chains, which is one important reason that we discuss multi-hazard and disaster chain risk assessment.

In view of the experiences and lessons of China in coping with LSDs, it is crucial to establish LSD risk transfer models along with carrying out affordable disaster protection, disaster relief, and emergency management based on the current level of economic development. However, due to the aggravating regional disparity in economic development and the urban-rural divide in China, disaster protection levels also show a clear regional difference, overall disaster relief capacity is still comparatively low, and emergency management has just started. Therefore, on the basis of examining the LSD risk transfer models established in the Western countries, it is necessary to develop LSD risk transfer models suitable for the situations in China. In addition, further developing and improving the global LSD risk transfer models suitable for different national, regional, and global conditions based on the characteristics of LSDs is an important task of climate change adaptation and disaster protection and reduction at the global level.

4.1 A Chinese LSD Risk Transfer Model

In order to motivate the government, the public and local communities, and insurance companies to be actively involved in LSD risk management and considering the weak risk awareness, low insurance coverage, relatively low disaster protection levels, and generally high natural disaster risks that have been commonly observed in China, we have proposed, as a new LSD risk transfer model, that LSD risk transfer should be supported by governments at all levels, operated by insurance companies, and the burden shared by all stakeholders. Government supports include developing disaster protection measures of a certain standard in communities, granting certain premium subsidies to policy holders, exempting insurance businesses from relevant taxation, granting interest discounts to reinsurance companies for excess of loss, and stipulating compulsory insurance areas of LSDs through legislation. Insurance companies should determine regional premium levels for different hazards (such as earthquakes, typhoons, floods, and droughts) and establish insurance services for LSDs according to market-based rules; reinsurance companies should undertake reinsurance services for LSDs for insurance business; residents and organizations (enterprises, institutions, and so on) should purchase LSD insurance. As a result, small-scale disaster risk management will rely on communities, medium-scale disaster risk management will rely on local governments, serious disaster risk will be shared by the central government, local governments, insurance policy holders (natural persons or legal persons), and insurance and reinsurance companies, and LSD risk will be shared by the central government, insurance policy holders, insurance and reinsurance companies, and other international financial institutions (such as banks and securities companies) (Shi, Wang, Wang, et al. 2009).

4.2 Establishing a Global LSD Risk Transfer Model

In recent years, some international organizations have paid special attention to the establishment of LSD risk transfer models. The Organisation for Economic Co-operation and Development (OECD) organized LSD financial management consultants and experts to compile the book *Financial Management of Large-Scale Catastrophes* (OECD 2008), which discusses financial management models of LSDs for OECD countries and non-OECD countries and focuses on the interaction of risk reduction and insurance in reducing the impact of LSDs, and the importance of strategic governance against unforeseeable LSDs. Research fellows of the International Institute for Applied Systems Analysis (IIASA) focused on the governance of LSD risks by using financial instruments and enhancing LSD aid (Linnerooth-Bayer, Mechler, and Pflug 2005). The Swiss Re reinsurance company proposed to issue LSD bonds and to design different LSD risk transfer models for different grades of disaster risks caused by various hazards (Shi, Wang, Wang, et al. 2009). Based on the experiences and lessons of China in coping with LSDs, we propose to establish the following global LSD risk transfer model.

First, pay close attention to the trend of climate change and climate mitigation and instabilities in the global climate system: through energy saving, emission reduction, and sink enhancement, mitigate global warming and reduce the magnititude of instability of the global climate system (such as extreme dry and wet weathers, extreme cold and warm weathers, and increasing frequency of disastrous weather and climate events). To this end, on a global scale, strengthen the development of a green economy and increase the vegetation cover of the earth surface to slow the trend of global warming and reduce variabilities in the climate system.

Second, decide on the definition of LSDs: make use of the available data observed on major hazards and set forth the LSD-inducing intensity indicator of hazards; make use of available disaster loss data and set forth indicators for human casualties, property losses, and resources damage due to LSDs; use different earth observation technologies and GIS and GPS technologies and set forth indicators for the geographic scope of disaster-affected and disaster-stricken areas due to LSDs. By integrating the above three sets of indicators, we can define LSDs. At present, some financial institutions define LSDs only by the losses caused by the concerned disasters, which can hardly be generalized in countries and regions with major differences in income, territorial area, and degree of disaster impact. In response, we have proposed that LSD is any hazard that has a one-hundred year recurrence interval (including earthquakes with a magnititude of above 7.0), deaths of over 10,000 persons, direct economic losses of 10 billion Euros, or 100,000 km^2 of serious and extremely serious disaster-stricken areas. As long as any two of the four standards are met, a natural disaster can be defined as a LSD (Shi, Wang, Xu, et al. 2009).

Third, let both the market and the government lead the process: through market mechanisms, define reasonable premiums for LSD insurance; and through the government, increase the disaster protection level of insurance targets. Any LSD insurance ought to follow the "majority rule." Thus, the protection capacity of targets affected by high incidence must be improved. For example, for agricultural disaster insurance in China, experiences show that only when crops and animal husbandry disaster protection reaches the level that prepared for disasters of 10–20 year recurrence interval, or rural housing disaster protection reaches the level that prepared for disasters of 20–50 year recurrence interval, can disaster insurance products be designed. As for the world, only upon reaching the level of LSDs can global LSD insurance products (on human death, property loss, resources damage, and so on) be established. To this end, it is crucial to deploy adequately the financial resources of governments and increase the disaster protection level of targets to be insured.

Fourth, attach great importance to the diversification of financial management instruments for LSD risks: while making use of LSD insurance and reinsurance, LSD bonds, and LSD options, adequately mobilize the participation of funds and commercial banks. It is also necessary to make use of donations and various nongovernmental organizations such as volunteer organizations to increase the societal capacity in LSD risk transfer.

Based on the above four proposals, we believe that a mature model of global LSD risk transfer should be characterized by a consistent definition of LSDs, government support, market operation, public participation, disaster mitigation, and risk sharing. It requires that a uniform global definition of LSDs is agreed upon; that there is adequate financial support from national governments in increasing disaster protection levels; that the operational capacity of different financial institutions including insurance companies is adequately deployed; that public and community participation is mobilized in actions of LSD risk management; and that the disaster risk inducing and promoting effects of human activities is energetically reduced, and the integrated disaster prevention and reduction capacity is increased, in order to form a global integrated LSD risk transfer system of disaster risk and development achievements sharing.

5 Conclusion

We proposed a new LSD risk assessment model based on a scrutiny of the status quo of disaster risk assessment, which includes environment stability so that the impact of the environment on disaster losses are taken into account. Loss evaluation models of multi-hazards and disaster chains were also developed, which will facilitate regional LSD risk assessment by considering all the hazards that can possibly occur in a region, the vulnerability of the exposed, and the conditions of the environment.

LSD insurance is one of the effective ways to transfer LSD risks. We studied China's practice in governing LSD risks and proposed the LSD risk transfer model for China: LSD insurance should be supported by governments at all levels, operated by insurance companies, and responsibilities should be shared by all stakeholders. With this model, the government, businesses, communities, and individuals are supposed to play separate but equally important roles in mitigating LSD risks. Meanwhile, the global LSD risk transfer model should be characterized by a consistent definition of LSDs, government supports, market operation, public participation, disaster mitigation, and risk sharing, which motivates national governments, businesses, and citizens to improve capacities in disaster prevention and reduction.

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