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On the amount of counterpart assistance to be provided after natural disasters: from the perspective of indirect economic loss assessment

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ABSTRACT
China's counterpart assistance policy is of vital importance in providing guidance for emergency management and post-disaster reconstruction. However, the amount of assistance that partner provinces should provide as well as the criteria that partners should abide by in offering counterpart assistance remain a main challenge. The goal of this research is to fill this gap by proposing a new framework consisting of an interregional input–output (IRIO) model and a resilience index. Subsequently, the indirect economic loss is obtained by utilizing the index system of provincial economic resilience assessments, with measures of indirect economic loss developed from the IRIO. Furthermore, to examine the internal validity and systematic error, the reliability of the adopted models, the calculation methods, and the index systems are investigated. To assess the external validity of the proposed measures and resilience index of the framework, data from the 2008 Wenchuan Earthquake are applied for estimating parameter values of the framework, and a follow-up investigation was conducted for examining the fairness and enhanced effectiveness of the new counterpart assistance criteria. In summary, this paper attempts to present some new ideas about the analysis of economic motivations of mutual aid and the improvement of the counterpart assistance policy.

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Counterpart assistance; natural disaster; interregional input–output model; indirect economic losses; resilience and recovery; internal and external validity

1. Introduction

Counterpart assistance, a policy aiming to reduce the regional economic differences though local governments' participation, was initiated by the central government of China in the 1950s. Adopted in early 1960s and further developed in the 1980s, counterpart assistance still evolves in the new era. It was fully implemented in the post-disaster reconstruction after the Wenchuan Earthquake, measured 8.0 Ms, occurred on 12 May 2008, with 69,227 people killed, 17,923 missing, and 374,643 injured (State Council of

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the PRC, 2008). Shortly after the Wenchuan Earthquake, the State Council issued *The counterpart assistance scheme of restoration and reconstruction after the Wenchuan Earthquake* on 11 June 2008, started the counterpart assistance work for recovery and reconstruction, and designated 19 provinces and municipalities, in the central and eastern areas of China, and directly under the central government (hereinafter referred to as provinces and cities) as counterpart assistance partners. Based on the unified deployment of the central government, partner provinces were required to implement counterpart assistance in pairs immediately. Specifically, these selected provinces were obligated to transfer 1% of their local fiscal revenue to their partner counties for three consecutive years (2008–2010).

Disaster relief policies comprise an important safeguard for restoring to the normal production order of communities and for reducing the loss of life and properties of the victims (Kunreuther, 1986; May, 1982; Xu, Xie, Dai, & Rao, 2015). With a top-down governance structure, the Chinese society management was highly centralized (Zhang, 2006). In such a circumstance, the counterpart assistance policy plays an important role in the fast reconstruction after disasters.

However, with the chaotic distribution of monetary donations and relief supplies, the counterpart assistant policy has received a great deal of criticisms both in content and in manifestation. For example, Ni, Zhang, and Yu (2009) pointed out that the administrative system of counterpart assistance was inappropriate, that the participating provinces and cities lacked coordination, and that the overall financial arrangements were unbalanced. Wang and Dong (2010) indicated that relevant laws and regulations were either unavailable or far from implementable, that fund supervision was not in place, and that local governments played no role in the counterpart assistance. Cai (2012) commented that counterpart assistance is a non-institutionalized arrangement with no clear rules or procedures before the event. Bulte, Xu, and Zhang (2013) pointed out that the counterpart assistance disrupted the normal economic order of both sides and did not contribute to the recovery of economy in the long run, and that the recipients might even develop the Dutch disease. According to Wu (2012), the current counterpart assistance policy is highly directed when it emphasizes administrative obedience and humanitarian principles, with the over domination of administrative roles. Besides, the economy-driving mechanism of local governments at all levels and from relevant departments was not revealed. Consequently, there lacks a solid theoretical foundation for the counterpart assistance policy.

In summary, although problems in the design of counterpart assistance policy have been noticed in the literature and practice, most of the previous studies only described the phenomenon and gave speculative statements without developing appropriate quantitative measures of the indirect loss, resulting in the lack of empirical support and validation. In the current counterpart assistance policy, as the indirect economic losses are often neglected, the assistance levels of donors cannot be quantitatively determined. As a result, it is unfair for both sides of the partnership, with chaos frequently caused in the rescuing operations.

Although partner provinces and cities are not directly hit by a disaster (i.e. free from direct losses), they often suffer indirect losses incurred by the disaster due to damaged trading relationship with the disaster-hit areas. This fact is always utilized to determine/estimate the amount of counterpart assistance (generally speaking, the more the direct economic losses the directly hit areas suffer, the more the indirect economic losses the un-hit partner provinces and cities will incur). Therefore, this paper, by measuring and utilizing the indirect loss, attempts to develop an improved and applicable framework concerning approaches to and methodologies for guiding and tracking the post-disaster operations more effectively, analyzes the counterpart assistance quantitatively and provides a concrete example to illustrate and validate the assistance policy.

This goal will be achieved through the use of the following five strategies:

(i) The interregional input–output (IRIO) model is utilized (see Section 3.1).
(ii) The resilience index of provincial economic systems, a comprehensive computational procedure – principal component analysis (PCA) and the counterpart assistance evaluation index are introduced and utilized (Sections 3.2–3.6).
(iii) The indirect economic loss suffered by relevant partner provinces in the Wenchuan Earthquake is calculated through the IRIO model, and the resilience of every provincial economic system is calculated and used to modify the indirect economic losses so as to obtain the adjusted indirect economic loss (Section 4).
(iv) An index for assessing provincial counterpart assistance activity after the Wenchuan Earthquake is developed according to the counterpart assistance value and the adjusted indirect economic loss (Section 3.5).
(v) An assessment of the internal and external validity of the proposed counterpart assistance framework is conducted (Section 5).

Finally, a summary is provided in Section 6.

The flowchart of the proposed framework is presented in Figure 1.

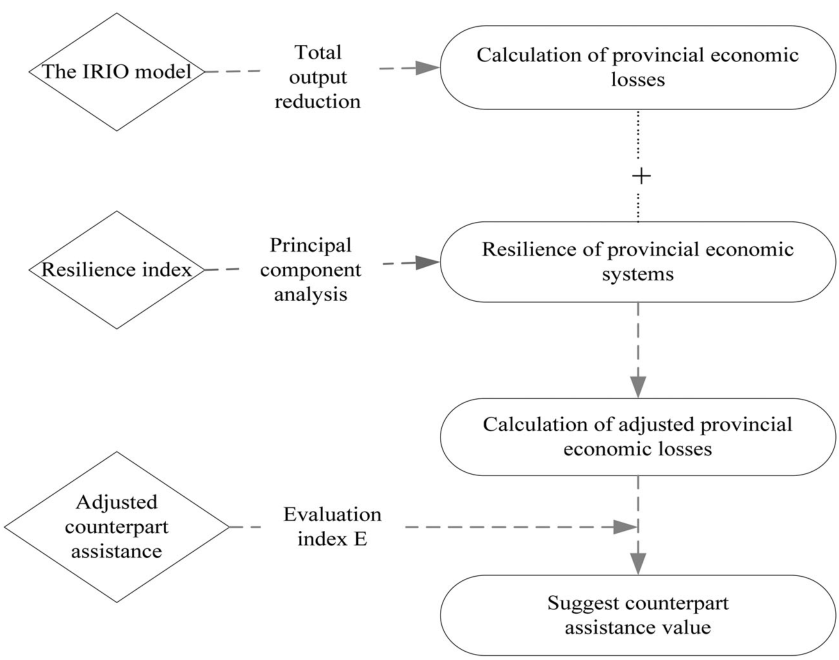

Figure 1. Flowchart of the proposed content.

The advantage of the above-stated framework is that it can be utilized to analyze the unfairness in the counterpart assistance of China as well as the fact that it makes up for the deficiency in counterpart assistance policy. It also offers some new ideas for researches on the motivation of mutual aid between countries and/or regions, such as the Indian Ocean Tsunami on 26 December 2004, the Wenchuan Earthquake on 12 May 2008, and the Northeast Japan Earthquake on 11 March 2011.

2. Literature review

The objective of this research is to develop an improved counterpart assistance framework, concerning approaches and methodologies. A brief introduction to the relevant researches on indirect economic loss and the assessment of resilience will be given in this section.

2.1. Indirect economic losses

The economic loss brought by earthquake can be grouped into two types, namely, the direct economic loss and the indirect economic loss. Generally, the direct economic loss is referred to as stock loss, whereas the indirect economic loss is referred to as flow loss (Brookshire et al., 1997; Burrus, Dumas, Farrell, & Hall, 2002; Lu, Wei, Fan, & Xu, 2002; Parker, Green, & Thompson, 1987). According to Hallegatte (2008), indirect economic losses are the reduction in the production of goods and function of services. Similar to Hallegatte's definition of indirect losses, in the Assessment Methods of Earthquake-caused Indirect Economic Loss (GB/T 27932-2011) issued by the Standardization Administration of China in 2011, the indirect economic loss brought by an earthquake is referred as to 'the economic loss caused by the indirect influence of the earthquake exerts on normal social economic activities, including the loss due to stop of production or reduction of output, sections-related loss, and loss of land price', and a formula for estimating the indirect loss of earthquakes is supplied (see Equation (6)). In the present paper, we adopt the definition of indirect loss given by the Standardization Administration of China's (2011), and use Formula (6) to calculate the indirect loss.

The main methods for assessing indirect economic losses can be divided into three types. The first is the econometric models focusing on building indicators for hazards, demographics, sociology, and economics in measuring the impact of disasters on economic development through changing the coefficients of independent variables (Coffman & Noy, 2012; Hallegatte & Dumas, 2009; Heatwole & Rose, 2013; Kellenberg & Mobarak, 2008; Noy & Nualsri, 2007; Skidmore & Toya, 2002). Being relatively crude, it is difficult for econometric models to characterize the affected channels of disasters, but it is suitable for them to assess the long-term economic impacts of disasters.

The second covers computable general equilibrium models (e.g. Chakkaphan, 2007; Hirokazu & Satoshi, 2008; Narayan, 2003; Rose & Guha, 2004; Rose & Liao, 2005; Wang, Li, Wu, & Yu, 2015). These models are used to deal with the combined effects on different sectors by taking product substitution, supplements, and price changes into account. However, the disadvantage of these models are that they focus too much on parameters and fail to consider the inertia and transaction costs existing in the economic system. Besides, the calculation is quite difficult and the data are hard to obtain. Moreover, the calculated values are usually relatively small and act as lower boundaries (Hallegatte, 2014; Miller & Blair, 2009).

The third contains input–output models which can be divided into the supply-driven I–O models (Ghosh, 1958; Oosterhaven, 1988) and the demand-driven I–O models (Hallegatte, 2008; Jung, Santos, & Haimes, 2009; Okuyama & Santos, 2014) that are suitable to assess short-term economic losses of linear systems. The supply-driven input–output model is also known as the Ghosh Model (Ghosh, 1958). There have been arguments about the plausibility of the Ghosh Model ever since it was proposed. Oosterhaven (1988) objects to use the Ghosh Model because he believes that most of these applications of the Ghosh Model suffer from more or less severe theoretical flaws. As the demand-driven input–output model is more complete in the theoretical basis and closer to the real situation than the supply-driven input–output model, and thus the former model is adopted in this paper. As for the demand-driven input–output models, it should also be noted that Hallegatte put forward the adaptive regional input–output model (see Hallegatte, 2008) and applied the model in many cases (Hallegatte, 2014; Hallegatte et al., 2011; Ranger et al., 2011; Wu et al., 2012), which contributes a lot to the further development of the input–output model. The input–output model is easy to understand as it has a simple structure. In addition, it is capable of describing the impacts of disasters for interdependent provincial economic systems (Santos, 2006). The I–O models are simpler and have easier access to data rather than Computable General Equilibrium models. Therefore, the IRIO method, one of the demand-driven I–O models, is adopted in this paper.

In I–O models, as the variation of inter-industry output coefficients in the long-term development, the changes in market prices, and the resilience of the affected regional economic systems (such as rescheduling production and self-sufficiency) are ignored, the evaluated values are relatively large and often act as upper boundaries. To make up for the deficiencies of a conventional linear approach in IRIO and to avoid the overestimation of indirect economic losses, this paper gives full consideration to the resilience of the associated provinces and cities, and builds an economic index system for the resilience recovery in the research framework, in an effort to obtain an enriched objective assessment on the indirect economic loss caused by disasters. The evaluation index system is presented in Table 1.

2.2. Evaluation of resilience

In the field of disaster loss evaluation, resilience has attracted wide attention (Eguchi & Adams, 2007; Kendra & Wachtendorf, 2003; Manyena, 2006; McEntire, 2007; Rose, 2004; Rose, 2007; Rose & Krausmann, 2013; Rose & Liao, 2005; Rose, Oladosu, & Liao, 2007a, 2007b; Rose & Wei, 2013; Tierney, 2007). When a socioeconomic structure is in disarray, Rose (2004, 2007) employs the terms 'static economic resilience' as the ability or capacity of a system to return to a state of equilibrium. Regarding the system resilience, in a relatively complete fashion, Rose (2004, 2007), Rose and Krausmann (2013), and Rose and Wei (2013) elaborated the concept, connotation, extension, and evaluation index system. But, so far, only a few sporadic researchers have concentrated on the resilience of provincial economic systems. In the literature assessing resilience, qualitative descriptions have been given more consideration (Comfort, 2010; Manyena, 2006; Paton& Johnston, 2006;

Table 1. Interregional input–output table.[a]

			Intermediate consumption							Final consumption						
			Region *1*			…	Region *m*			Region *1*		…	Region *m*			
			Industry 1	…	Industry *n*	…	Industry 1	…	Industry *n*	Final consumption expenditure	Total investment forming	…	Final consumption expenditure	Total investment forming	Export	Total output
Intermediate input	Region 1	Industry 1	$F^{rs}_{ik\,mn\times mn}$							$F^{rs}_{ik\,mn\times 2m}$					$S^{r}_{i\,mn\times 1}$	$X^{r}_{i\,mn\times 1}$
		…														
		Industry *n*														
	…	…														
	Region *r*	Industry 1														
		…														
		Industry *i*														
		…														
		Industry *n*														
	…	…														
	Region m	Industry 1														
		…														
		Industry *n*														
Value added			$S^{s}_{j\,1\times mn}$													
Total input			$X^{s}_{j\,1\times mn}$													

[a]From the theory and practice of making an interregional input–output table about the 30 provinces in China in 2007 (see Liu et al., 2012).

Tierney, 2007), quantitative evaluations, especially with an appropriate index system, are very scarce.

The regional differences are enormous because the recovery capabilities of various provinces vary a lot widely when facing to natural disasters. Considering these differences, this paper puts forward an innovative evaluation index system for assessing the resilience of the indirectly impacted provinces.

Here, the provincial concept of resilience is different from that of the direct hazard bearing bodies (such as Sichuan Province) defined in the previous cited references (Rose, 2004, 2007; Rose & Krausmann, 2013; Rose & Wei, 2013). In this paper, the provincial resilience refers to the system ability to recover to normal levels (i.e. to return to a state of equilibrium) in deploying various elements and resources, and to reduce or eliminate indirect outside disturbances. It is much broader than the concept of resilience defined for directly impacted provinces in that its connotation is more abundant, including economic ability, government regulation and control ability, financial resources, scientific and technological levels, human resource management, infrastructure building, and enterprise competitive ability of indirect hazard bearing bodies. According to Thomé (Thomé, Greiving, Kallio, Fleischhauer, & Jarva, 2006), it was difficult to develop an index system for measuring the indirect resilience of hazard bearing bodies and it was, in fact, hard to obtain relevant data. To fill the gap, in this paper, we will elaborate, from the perspective of economic capacity and six other aspects, an index system characterizing the provincial resilience for the indirect economic loss after the disaster, and provide the explanation and justification for the meaning of resilience reflected by various sub-indicators (see Section 3.2).

By combining the index system of economic resilience and the IRIO, we will be able to assess quantitatively the indirect economic loss for disaster affected provinces, particularly for those impacted by the Wenchuan Earthquake.

3. Methods, indicators, and data specification

In this section, the IRIO model is explained firstly. Then, the resilience index of provincial economic systems (see Section 3.2), PCA and the evaluation index for counterpart assistance (see Section 3.3) are utilized for calculating the indirect economic loss suffered by relevant provinces as well as the resilience of each provincial economic system. Finally, data used in the empirical analysis are described.

3.1. The interregional input–output model

The IRIO, put forward by American economist Isard in 1951 and also known as Isard model (1951, 1960), is an important tool for examining the economic relevance among different regions (Wu et al., 2012). The IRIO table (Table 1) is the empirical basis of the IRIO model. In the IRIO table, there are *m* different regions (often based on administrative boundaries), each of which has *n* different industries (such as agriculture and manufacturing). The classification method for industries in different regions is consistent. In the intermediate input section, the main vertical represents the internal economic structure of each region, and the adjoining describes economic and trade relations between regions. The final consumption section provides final consumption submatrices developed from different regions, which respectively record the products' usage in different industries of each region. Similarly, the value-added part is also divided into value-added submatrices, which respectively records the added values of each region (Chen & Yang, 2011).

In the intermediate input and intermediate consumption part of the table, F_{ik}^{rs} is the intermediate consumption matrix, with dimensions $mn \times mn$, and α is the general entry of β, representing the consumption of Industry j of Region s in Industry i of Region r.

In the final consumption part, E is the part of intermediate consumption matrix, with dimensions $mn \times 2m$. Each region has two items, that is, the final consumption expenditure and total investment forming. f_{ik}^{rs} is the general entry of F_{ik}^{rs}, representing the consumption of Item k of Region s in industry i of Region r. f_{ik}^{rs} correspondingly represents the usage of the products in different regions. S_i^r is the export matrix, with dimensions $mn \times 1$, and it is also a part of the intermediate consumption matrix, representing the export of Industry i in Region r, and the general entry is denoted by s_i^r .

The added value matrix V_i^s represents the added value of each region. For instance, v_i^s, the general entry of V_i^s, represents the added value of Industry i in Region s.

X_i^r is the total output matrix, with dimensions $mn \times 1$. Its general entry x_i^r records the total output of Industry i in Region r.

X_j^s is the total input matrix, with dimensions $1 \times mn$. Its general entry x_j^s records the total input of Industry j in Region s. In the IRIO table, the total input and the total output are balanced. That is to say, the matrix X_i^r is the transpose of matrix X_j^s and vice versa.

The data of the IRIO table are from Liu, Cheng, and Tang (2012). Regions represent provincial administrative units (or municipalities directly under the central government) in mainland China, including 30 provinces and cities with the exception of Xinjiang, with every region having 21 industries.[1] Among these 30 regions, Sichuan Province is the disaster area, whereas the remaining 29 provinces and cities trading with Sichuan Province in various ways are free from the disaster. Here, $m = 30$ (regions) and $n = 21$ (industries). By making full use of the matrix operation function in Excel 2010, the calculation of this 630×630 matrix is performed.

According to the row balance relationship in the input–output table, it has the following balance equation:

$$\sum_{s=1}^{m}\sum_{j=1}^{n} x_{ij}^{rs} + \sum_{s=1}^{m}\sum_{k=1}^{2} f_{ik}^{rs} + s_i^r = x_i^r, \quad \forall r, i, \tag{1}$$

$c_i^r = \sum_{s=1}^{m}\sum_{k=1}^{2} f_{ik}^{rs} + s_i^r$ represents the final consumption of Industry i in Region r, and x_i^rrefers to the total output of Industry i in Region r:

$$\sum_{s=1}^{m}\sum_{j=1}^{n} x_{ij}^{rs} + c_i^r = x_i^r, \quad \forall r, i. \tag{2}$$

The relationship in Equation (2) can also be expressed in the following matrix form:

$$X_{ij}^{rs}E + C_i^r = X_i^r, \tag{3}$$

where X_{ij}^{rs} is the intermediate consumption matrix ($mn \times mn$), E is an $mn \times 1$ column matrix whose entries are identically 1s, C_i^r is the final consumption matrix ($mn \times 1$), and X_i^r is the total output matrix ($mn \times 1$).

Technical coefficient matrix A is a $mn \times mn$ matrix, entries of which are defined as $a_{ij}^{rs} = x_{ij}^{rs}/x_j^s$. It refers to the ratios of the consumption of Industry j of Region s in Industry i of Region r to the total input of Industry j of Region s (also known as the intermediate consumption of the products by Industry j of Region s in Industry i of Region r, which is abbreviated as an intermediate consumption coefficient).

In the IRIO table, the total input is equal to the total output of each industry. Since matrix X_i^r is the transpose of matrix X_j^s, it holds that $X_{ij}^{rs}E = AX_i^r$. Then Equation (3) can be rewritten as follows:

$$AX_i^r + C_i^r = X_i^r, \tag{4}$$

which yields the matrix equation:

$$(I - A)^{-1}C_i^r = X_i^r, \tag{5}$$

where the matrix $(I - A)^{-1}$ is the Leontief inverse matrix.

The variable form of Equation (5) is

$$(I - A)^{-1}\Delta C_i^r = \Delta X_i^r. \tag{6}$$

3.2. Resilience index of provincial economic systems

With regard to the resilience of provincial economic systems, scientific principle, integrity principle, data availability, and comparability in developing the resilience index (Rose & Wei, 2013) are taken into consideration.

The Provincial Resilience Index refers to the ability of a province mobilize existing resources to offset the indirect perturbation of disasters and to recover the economic-social system to normal levels after indirectly disturbed by disaster events. This capability evaluation system contains seven second-level indicators about economy, government, finance, technology, human resources, infrastructure, and business, together with 21 third-level indicators. Each indicator is further explained below.

3.2.1. Economic indicators

As the basis for system resilience, economic capacity determines whether or not a region is able to mobilize sufficient resources to offset the impact of disasters and maintain sustainable and healthy development of the region. In accordance with the data availability principle, three indicators are selected in reflecting regional economic income, that is, average financial income, average wage of urban worker, and rural per capita net income, along with other three indicators reflecting the capacity of regional economic growth, that is, per capita GDP, total retail sales of consumer goods, and total investment in fixed assets.

3.2.2. Government regulatory capacity indicators

According to the data from the recent disasters, the impact of disasters can be minimized when the local governments and communities are at high risk to be aware and well prepared for disasters. China has a powerful government to control the disaster management system. Regulatory governance is of increasing importance in day-to-day regulatory management, rule-making, and enforcement. The government regulatory capacity includes the level of government expenditure, per capita fiscal expenditure, fiscal expenditure as a share of GDP, and the ability to protect the unemployed and maintain social stability, like providing insurance coverage for the unemployed.

3.2.3. Financial indicators

Money is another major challenge in the face of pressure. It was the driving force of economic recovery and the rapid recovery in sustaining the social and economic networks destroyed (Olshansky, 2006). Regional financial capacity refers to the use of financial instruments to allocate social resources to offset the indirect impact of disasters and resume normal social production and daily life. Three indicators are selected. They are the credit balance of financing institution at the end of the year, per capita savings deposits, and per capita insurance premium income.

3.2.3. Science and technology investment category indicators

As important factors in endogenous regional economic growth, science and technology continues to play a key role in recessive areas' returning to the normal. Here, the assessment is mainly conducted on the internal expenses of R&D budget and the number of employees engaged in activities of science and technology.

3.2.4. Human resource indicators

Human resources are the key elements of regional economic development. The level of human resources for post-disaster economic recovery and growth in the deployment of resources plays a dominant role. Here, we use per capita education spending, the number of college degrees or above holders as a share of population of six years old and average educational year.

3.2.5. Infrastructure indicators

Infrastructure, including roads, electricity, water, gas and other elements, is to maintain the economic operation of the system. Whether the region is directly or indirectly impacted by disasters, these factors will play an important role in the recovery of the system. Due to the limitation of data, the passenger volume and total electricity are utilized to reflect the level of regional infrastructure construction.

3.2.6. Enterprise-class indicators

Enterprises symbolize the viability of regional economic systems. The more the enterprises are and the higher the quality is, the higher the ability will be. In the face of external disturbances, enterprises can provide and regulate critical supplies automatically by following the market rules. To reflect the level of openness and that of active financial activities of the regional economic system, two indicators respectively show the number of foreign-funded enterprises and those of scaled domestic enterprises are adopted.

These indicators are shown in Table 2.

Table 2. Resilience evaluation index system of provincial economic systems.

First-level indicators	Second-level indicators	Third-level indicators	Functions
Resilience	Economic power	Average financial income Average wage of urban worker Rural per capita net income Per capita GDP Total retail sales of consumer goods Total investment in fixed assets	Reflect the economic foundation of regional economic system, as well as the reality and possibility of deploying resources
	Government	Per capita fiscal expenditure Fiscal expenditure as a share of GDP The coverage of unemployment insurance	Reflect the government management and the regulation effects on regional system resilience
	Financial	Credit balance of financing institution at the end of the year Per capita savings deposits Per capita insurance premium income	Reflect the capital of the regional economic system and financing ability
	Science and technology	R&D expenses within budget Number engaged in the activities of science and technology	Reflect the regional economy system of science and technology innovation ability
	Human resources	Per capita education spending Number of college degree or above holders as a share of population of six years old and older Average educational year	Human resources advantage of regional economic system
	Infrastructure	Passenger volume Total electricity	Reflect the assistance function in the infrastructure of the economy
	Enterprise	The number of enterprises with foreign investment The number of industrial enterprises above designated size	Reflect the economic vitality of the regional economic system

3.3. Principal component analysis

A certain number of evaluation indicators are utilized in assessing the economic resilience of each province. However, as these indicators (variables) are somehow related, some of the indicators are superfluous, leading to the overlap of information. The simplest and directest solution to the problem is to cut down the number of variables, which will inevitably lead to the loss of information. To find a method for requiring fewer variables in data modeling and not leading to the loss of a large amount of information, the widely used PCA proposed by Hotelling (1933) is adopted in this paper as it can effectively reduce the number of variables.

The basic idea of PCA is to recombine many originally related indicators $X_1, X_2, \ldots$ and X_p (for instance, p indicators) into a new aggregative indicator F_m composed of fewer linearly uncorrelated indicators. Let F_1 be the principal component indicator formed by the first linear combination of the original variables, namely, $F_1 = a_{11}X_1 + a_{21}X_2 + \cdots + a_{p1}X_p$. Then, the information extracted by this principal component can be measured by the variance of F_1. The larger the Var (F_1) is, the more the information F_1 contains. For the sake of convenience, the first principal component F_1 needs to contain the largest amount of information. Therefore, the F_1 selected from all linear combinations shall have the greatest variance in the linear combinations of $X_1, X_2, \ldots$ and X_p, thus making F_1 to be the first principal component. Provided that if the first principal component is unable to represent the information of the p indicators, the second principal component F_2 should be selected so as to reflect the original information effectively. It should be pointed out that the information already contained in F_1 shall not be covered in F_2. In other words, F_2 and F_1 should keep separate from each other, namely, the Covariance Cov(F_1, F_2) = 0. Thus, F_2 is the second principal component as it has the greatest variance in all the linear combinations of X_1, X_2, … , and X_p which are not correlated with F_1. The F_1, F_2, … , F_m obtained by such analogy, respectively, are the first, second, … , m principal component of the original indicators X_1, X_2, … , and X_P.

Due to space limitations, details are not introduced here. The above calculations could be achieved through SPSS (see Jolliffe 1986; He 2008 for specific steps).

Before the PCA, the KMO and Bartlett sphere tests are needed so as to assess the feasibility of PCA in data analysis. These can be operated in SPSS12.0. If the PCA is workable, the main components will be used as the resilience index of provincial economic systems.

The values of the aggregative indicator (usually only requires the first principal component) representing the resilience of each province obtained through PCA should be standardized for horizontal comparison. The standard formula is

$$\alpha = \frac{x - x_{\min}}{x_{\max} - x_{\min}}, \tag{7}$$

where $\alpha$is the standard value from the comprehensive evaluation of the resilience of a provincial economic system, x is the synthetic appraisal value of the resilience of a provincial economic system, $x_{\min}$ is the minimum value of comprehensive evaluation value of the resilience of a provincial economic system, and $x_{\max}$ is the maximum value of comprehensive evaluation value of the resilience of a provincial economic system.

According to the resilience index with 1 first-level indicator, 7 second-level indicators and 21 third-level indicators, the PCA method was utilized to evaluate the resilience of the 30 provincial economic systems.

3.4. Adjusted indirect economic loss

The resilience indexes are used to modify the indirect economic loss value of relevant provinces. In fact, the provincial economic system cannot be completely restored right after a disaster. According to the theories of Tierney (1995) and Rose and Lim (2002), it is assumed that the whole recovery of the provincial economic system is 1 and that the provincial economic system is restored to 0.8 of the pre-quake levels.[2] After subtracting from 0.8α, the irrecoverable proportion of the system, denoted byβ, is obtained. Then, the adjusted indirect economic loss value by β times can be worked out. The indirect economic loss value is calculated through Equation (6):

$$\beta = 1 - 0.8\alpha, \tag{8}$$

where β is the irrecoverable proportion of economic system function (0.8 is the largest ratio that a provincial economy system can be restored quickly after a disaster) and$\alpha$is the comprehensive evaluation standard value of the resilience of a provincial economic system.

The adjusted indirect economic loss value of different affected regions is calculated by the following equation:

$$\Delta\hat{X}_i^r = \beta \times \Delta X_i^r. \tag{9}$$

ΔX_i^r and β are from Equations (6) and (8), respectively. Then, the total adjusted indirect economic loss value resulting from the final demand reduction of each industry in Sichuan Province is calculated by

$$\Delta\hat{X} = \sum_{r=1}^{m}\sum_{i=1}^{21}\Delta\hat{X}_i^r. \tag{10}$$

Through Equation (10), the total adjusted indirect economic loss of provinces and cities is obtained.

3.5. Counterpart assistance evaluation index

The donations provided by the assistant province (not directly hit by disasters but suffered indirect losses) can be evaluated by comparing its adjusted indirect economic loss value with the amount of counter assistance that it has offered. Therefore, it can be known from the comparative results whether it is fair for the partner province in donations. A index for evaluating the fairness of counter assistance, denoted by E (the ratio of the amount of counterpart assistance to and its adjusted indirect economic losses), is put forward in this paper. The expression of E is

$$E = \frac{\text{The amount of counterpart support}}{\text{The actual indirect economic losses}}. \tag{11}$$

Equation (11) is used to calculate the ratio of counterpart assistance amount to the indirect economic loss. The adjusted indirect economic loss is obtained from the value of indirect economic losses calculated by using IRIO, with a modification by using the resilience (see Table 3 in Section 4).

Table 3. Evaluation results based on the indirect economic losses.

Partner provinces/ cities	α	β	Indirect economic loss (billion RMB)	Adjusted indirect economic loss (billion RMB)	Assistance amount (billion RMB)	E	Suggest assistance value (billion RMB)
Beijing	0.833	0.334	4.047	1.350	7.253	5.373	1.498
Jiangsu	0.912	0.270	15.535	4.195	11.000	2.622	4.655
Shanghai	0.814	0.349	9.801	3.417	8.250	2.414	3.792
Guangdong	1.000	0.200	25.756	5.151	11.200	2.174	5.716
Fujian	0.331	0.735	2.147	1.578	3.339	2.115	1.752
Shandong	0.706	0.435	13.333	5.798	12.000	2.070	6.434
Zhejiang	0.829	0.337	9.955	3.353	5.730	1.709	3.721
Jiangxi	0.146	0.883	1.196	1.056	1.300	1.231	1.172
Shanxi	0.224	0.821	3.032	2.488	2.150	0.864	2.762
Liaoning	0.445	0.644	7.838	5.048	4.027	0.798	5.602
Hubei	0.283	0.774	3.515	2.719	2.115	0.778	3.017
Anhui	0.208	0.834	3.560	2.968	2.130	0.718	3.294
Hunan	0.258	0.794	4.721	3.747	2.010	0.536	4.158
Tianjin	0.396	0.683	6.231	4.257	2.037	0.479	4.724
Jilin	0.180	0.856	2.098	1.795	0.820	0.457	1.992
Heilongjiang	0.201	0.839	4.672	3.921	1.550	0.395	4.351
Henan	0.367	0.706	10.982	7.757	3.000	0.387	8.609
Chongqing	0.164	0.869	6.370	5.532	1.700	0.307	6.140
Hebei	0.336	0.731	13.578	9.931	2.800	0.282	11.021

Note: The data collected by the author are based on public information. The assistance amount is the total amount from 2008 to 2010.

3.6. Data specification

The data, regarding the direct economic loss as a result of the Wenchuan Earthquake in Sichuan Province, was from the statistics released by the Bureau of Statistics of Sichuan Province and *the State Statistical System of Natural Disasters* as well as the related parameter table released by the Ministry of Civil Affairs in 2008. Information provided by the Bureau of Statistics of Sichuan Province indicated that the Wenchuan Earthquake had caused direct economic losses as high as 737.177 billion RMB. After converting the input–output table of Sichuan Province and merging the 42 industries into 21 ones, it could be known from the new table that 15 industries had suffered direct economic losses. Among them, other services suffered the most severe losses, reaching to 480.987 billion RMB and accounting for 65.25% of the total direct economic loss, followed by transportation and warehousing, food production and tobacco processing industry, and agriculture (including agriculture, forestry, animal husbandry, and fishery), accounting for 10.17%, 8.51%, and 4.95%, respectively.[3]

The data in the IRIO table are found in the work of Liu et al. (2012). The indirect economic loss of each province and city was calculated through Equation (6). The data about the amount of the provided counterpart assistance were derived from www.china.com.cn. In this study, the provinces and cities, including municipalities directly under the central government, are the subjects of assistance. Considering the aforementioned situation, the aid offered by Guangdong and Shenzhen was added. Guangdong assisted Wenchuan in Sichuan Province, while Shenzhen aided severely afflicted areas in Shanxi Province after the 2008 Wenchuan Earthquake.

Sichuan Province experienced direct economic losses caused by the Wenchuan Earthquake, accounting for 91.3% of the total loss. While Gansu and Shaanxi accounted for 5.8% and 2.9%, respectively. Many other provinces recorded much smaller direct economic losses than Sichuan Province. Thus, the direct economic loss caused by the Wenchuan Earthquake was only considered for Sichuan Province.

The data used to evaluate the resilience of provincial economic systems came from *the 2008 China statistical yearbook* (National Bureau of Statistics of China, 2008a), *Province & city statistical yearbook 2008* (National Bureau of Statistics of China, 2008b), and *China statistical yearbook on science and technology 2008* (National Bureau of Statistics of China, and Ministry of Science and Technology, 2008).

4. Results

In order to provide empirical evidence, the Wenchuan Earthquake is selected as a representative example for evaluating the compensation activities in all assistant provinces and cities after the earthquake. According to the elaboration of Section 1, the results are as follows:

(i) The indirect economic loss of 30 provinces in China was calculated by Equation (6) (Table 3).
(ii) Calculation and standardization of the resilience of each provincial economic system. According to the resilience index of provincial economic systems, with the KMO test coefficient being 0.824 and Bartlett sphere inspection's *p*-value being smaller than

0.05, the use of PCA in data analysis was justified. The comprehensive evaluation of the efficiency of 84.56% exceeded the threshold of 80%, indicating that the PCA has a good dimension reduction effect and can reflect the information of the original variables.

The values of the principal component of each province and city are standardized through Equation (7).

(iii) Modification of the indirect economic loss value of relevant provinces using resilience. Through Equations (8)–(10), the total adjusted indirect economic loss of 29 provinces and cities (apart from Sichuan Province), that is, 108.676 billion RMB, is obtained. During the following three years after the Wenchuan Earthquake, the total amount of the counterpart assistance of 19 provinces and cities is 84.411 billion RMB. The counterpart assistance activities of 19 provinces and cities after the Wenchuan Earthquake will be evaluated in the following section.
(iv) According to the evaluation index$E$ (Equation (11)), the values of the counterpart assistance provided by the 19 provinces and cities after the Wenchuan Earthquake were calculated. The calculation results are presented in Table 3.

Table 3 indicates that the total indirect economic loss of 19 counterpart assistance partners is 148.368 million RMB, the total adjusted indirect economic loss is 76.063 million RMB, and the total amount of counterpart assistance is 84.411 billion RMB. According to *the post-earthquake counterpart assistance scheme* issued by the central government, the amount of the counterpart assistance of provinces and cities should not be less than one percent of their local fiscal revenue in the previous year, and this continues for three years. Thus, it is estimated that the amount of the continuous assistance for the three years will exceed 70 billion RMB. In fact, in the following three years after the Wenchuan Earthquake, the other 19 provinces and cities implemented 4121 counterpart assistance projects and provided the a total amount of counterpart assistance of 84.411 billion RMB, meeting the provisions of *the post-earthquake counterpart assistance scheme*.

In Table 3, the 19 provinces and cities are also ranked by their E values. The top five regions are Beijing (5.373), Jiangsu (2.622), Shanghai (2.414), Guangdong (2.174), and Fujian (2.115). The histogram is given in Figure 1.

It can be known from the above results that the assistance amounts given by Beijing, Jiangsu, Shanghai, Guangdong, and Fujian are excessive, whereas the assistance amounts given by Jilin, Heilongjiang, Henan, Chongqing, and Hebei are insufficient. Therefore, the counterpart framework is unfair to both sides.

Based on the above calculation methods, the assistance amounts that should be provided by the counterpart partners in the rescue operations of the Wenchuan Earthquake were worked out (Table 3). Besides, the authors also interviewed the participants in counterpart assistance (including Officials of Leadership Committee of Jiangsu Province Counterpart Assistance working in Mianzhu earthquake disaster area and Jiangsu Province which was assigned to assist Mianzhu city by the Central Government of China after the Wenchuan Earthquake). Participants generally believed in that the counterpart assistance should fully consider the indirect economic loss and appropriately and proportionally allocate the supporting work on its basis. Their positive feedback on the proposed counterpart assistance framework validates the fairness of the IRIO and resilience model and the effectiveness of the approaches implemented in this study.

5. Discussions

The counterpart assistance framework proposed in this paper is an analytical approach to assessing the damage of natural disasters, and it comprises the IRIO for indirect economic losses, resilience index and PCA for provincial resilience, index *E* for level of assistance and I–O data. The framework provides an approximation of real-world problems. However, deviations are to a certain extent unavoidable. As such, it is necessary to investigate the limitations, especially the internal and external validity for spreading the proposed methods to similar cases in which counterpart assistance policies are critical for post-disaster operations.

5.1. Internal validity

This section will focus on managing more precisely in identifying the dynamics in the case studied, including the IRIO for indirect economic losses, resilience index and index *E* of assistance level. Suppose that the technical coefficient matrix *A* (see Section 2.1) remains constant throughout the evolution process of a disaster event. The resilience assessment index previously investigated by Hallegatte in 2014 and the index *E* of the level of assistance proposed in the present paper, along with other measures utilized by the IRIO model, constitute an internal static and monetary assessment essentially without implementing price changes and alternative and substitute items concerning the shortage of goods in the economic system (Hallegatte, 2014). This is true even if the resilience assessments of non-directly affected provinces were used to avoid the weakness of IRIO models (such as possible overestimations).

Besides, there are other issues that should be noted. First, the proposed resilience index (Section 3.2) may be subject to some limitations. For instance, like those from other expert systems, computation results could be affected by the contents of the index and the employed calculation methods. Second, simultaneously, errors or inaccuracy in the input data to the IRIO model, that is, the data of IRIO tables, may lead to results different from the status of the real economic system. Moreover, it should be pointed out that, as China's input–output table data updated once every five years, the data of IRIO tables of 2007 were utilized in the calculation. The Wenchuan Earthquake occurred in 2008, for which reason the IRIO data of 2007 may reflect an approximation of 'supply and use' relationship among the regions before the disaster happened. Third, the value of the counterpart assistance evaluation index *E* is defined by dividing the total required disaster aid (Sichuan Province) by the total adjusted indirect economic loss (29 provinces and cities), as given in Equation (1). Since there was no available official statistical data, the disaster aid required by the disaster area (Sichuan Province) is unknown. This was resolved by using the total assistance amount of the donors (29 provinces and cities).

Finally, in determining the resilience ratios of provincial economic systems (see Equation (8)), we referred to the research results by Tierney (1995) and Rose and Lim (2002), and took the ratio of 0.8. However, there is uncertainty in this ratio. To be more specific, the smaller the ratio is, the smaller the value of β and the adjusted indirect economic loss $\Delta\hat{X}_i^r$ (Equation (9)) will be. When the value of *E* remains unchanged, the calculated assistance amounts of the donors (29 provinces and cities) will be less and vice versa. In this case, however, the rank according to the assistance amounts may vary. Moreover, it is also noticed from the computation that when the resilience ratio has values of 0.7 and 0.9, the counterpart assistance levels and rank change accordingly.

5.2. External validity

In order to study the relevance or feasibility of the framework on similar disaster cases, that is, and to examine the external validity by the case study method, we substituted temporarily the *E* values obtained from the Wenchuan Earthquake for the 29 provinces (Equation (7)) and calculated approximate assistance amounts for the partner provinces and cities. In future applications, when determining the assistance levels for similar disasters, one should first estimate the required amount from the affected areas, then calculate the values of evaluation index *E* according to indirect economic losses computed by the IRIO model and finally determine the assistance amounts for the provinces and cities. Moreover, for applications that attempt to assess economic losses from other natural disasters by using the analytical framework proposed in this paper, researchers should apply this model with caution and consider the limitations of the IRIO as mentioned previously, completeness of the index system, availability of full data, and the accuracy of data.

6. Conclusions

China's counterpart assistance policy has been implemented in practice and strictly executed and controlled by the central government since its initiation 50 years ago. Since the original design of the counterpart assistance policy failed to address the inherent economic driving factors of the assistance provinces, assistance levels determined based on such a policy have always been criticized for their unfairness, resulting in poorly enforced support from assistance partners, and ultimately affecting and constraining the development of the policy regarding its sustainability. Focused on the counterpart assistance policy, this research investigates quantitative methods for measuring indirect economic losses incurred from natural disasters such as earthquakes. Subsequently, the paper reveals, in an innovative way, the driving mechanism behind the counterpart assistance policy: when the donors offered monetary aid and urgent disaster relief goods to the disaster impacted areas, the disaster impacted areas would receive immediate counterpart assistance and the donors would also benefit from it economically by reducing their own indirect economic losses. Therefore, donors should provide assistance, at appropriate aid levels, to the disaster affected regions/parties in due proportions.

In addition, when implementing IRIO models assessing indirect economic losses, in order to overcome the conventional IRIO's linear approach idea and avoid overestimations on the indirect economic loss, this paper gives full consideration to the resilience of the associated provinces and cities and establishes the economic index system for the resilience recovery.

Finally, the analytical framework, models and algorithms proposed in this paper are of significance in the following three ways. First, they may be used in optimizing the design of counterpart assistance policies and program implementations for other large-scale environmental disasters, such as earthquakes, volcanic eruption, tsunami, and nuclear leak, so as to reduce the unfairness in counter assistance. Second, the counter assistance policy developed in this paper has been redesigned from the perspective of indirect economic loss, and its adoption will help and improve governmental works. As a powerful administration, the Chinese government should fully consider the spontaneous factors about economy and adjust her traditional operation mode in implementing administrative power. Third, the economic motivation of ubiquitous mutual aids in the human society can be analyzed and further studied through the proposed analytical framework.

Notes

1. The 30 provinces and cities are Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.

   The 21 industries are: agriculture, mining industry, food processing industry, textile industry, wood processing and furniture manufacturing, papermaking industry, printing and stationery commodity manufacturing, toy manufacturing, petroleum processing and coking, chemical industry, cement, glass, ceramic, iron and mon-ferrous metal smelting and processing, metal product industry, boiler and other special equipment manufacturing, transportation equipment manufacturing, electrical machine, household appliance, and special equipment manufacturing industry, telecommunication equipment and computer manufacturing, instrument and apparatus and office machine manufacturing, other industries, production and supply of electricity, gas, heat, and water, construction industry, transportation industry, and service industry.
2. Tierney (1995) learned for questionnaires that after Northridge Earthquake, the power system resilience of SAN Fernando valley, California, USA is 77.1%. Rose and Lim (2002) studied the same region after Northridge Earthquake. The research found that the direct static resilience in this region is 95% with the simulation model. At the same time, Rose and Lim also found that the market resilience is 79.3% with I–O model calculation. Based on the above research, we might as well simply assume that after the Wenchuan Earthquake, the related provincial economic system can fully recover to 80% of pre-quake levels.
3. The data comes from the research – *Major natural disaster statistics and indirect economic loss assessment: Based on the study of Wenchuan Earthquake* (Sun, 2011). The direct economic loss assessment in Wenchuan Earthquake requires two steps: first, it should carry out the field survey according to the relevant national standards, which is the basis of the assessment work; second, the direct economic loss is obtained by using the specific methods in *The fourth part in earthquake field work – disaster direct loss evaluation (GB/T18208.4-2005)* (The national standard in China).

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