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National vulnerability to extreme climatic events: the cases of electricity disruption in China and Japan

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Abstract:

Extreme climatic events are likely to adversely affect many countries throughout the world, but the degrees among countries may be different. China and Japan are the countries with high incidences of extreme weather/disaster, both facing with the urgent task of addressing climate change. This study seeks to quantitatively compare the impacts of extreme climatic events on socio-economic systems (defined as *vulnerability*) of the two countries by simulating the consequences of hypothetical the same degree of electricity disruption along with extreme events. To do that, two CGE (computable general equilibrium) models are constructed, by using which three stage scenarios are simulated for China and Japan respectively. The results reveal that China and Japan have unequal socio-economic vulnerabilities to extreme events. (1) Negative impact of the same degree of power outages is bigger on China's socio economic system than on that of Japan. And this difference is more obvious in the very short-run scenario. (2) The decline of China’s GDP, total output and employment levels is 2-3 times higher than that of Japan, while the difference of the resident welfare levels is sharper, which of China drops 3 to 5 times of Japan. (3) Structural factors is the main reason of vulnerability differences between China and Japan, including the differences of expenditure structure, factor input structure for production of life requirement sectors, material and energy dependence for production of industrial sectors, and usage structure of services outputs. Based on these findings, some policy implications and recommendations for fairness issues on climate change adaptation are proposed.

Keywords: Vulnerability; Extreme climatic events; Electricity disruption; China and Japan

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1. Introduction

In recent years, with the global climate and environmental change, observed extreme weather events and disasters occurred more frequently and their intensities increased in the worldwide (Parry 2007). Consequently, the impacts of climate change, climate change adaptation and vulnerability become hot topics and attracted much attentions (Ford et al. 2006; Füssel 2010; Heltberg et al. 2009; Tubi et al. 2012; McCarthy et al. 2001; Parry 2007), especially the famous IPCC Assessment Report (McCarthy et al. 2001; Parry 2007). According to the estimations by the United Nations and World Bank, the global disasters have made a total loss of approximately 2.3 trillion US dollars (2008) from 1970 to 2008, which accounts for 0.23 percent of the total global accumulating output. Their forecast shows by 2100 exacerbated frequency of tropical storms caused by climate change will drive an economic loss between 28 to 68 billion US dollars per year, which is 50% to 125% higher than the situation without climate change (UN and WB 2011). These high loss potential of climate change is warning the world for adaptation to climate change.

It comes to a question that whether the adaptation capacity and responsibility of different countries are different and how much the differences are. With respect to this, UNDP (2011) reports that more well-off countries can better address the impacts of climate change than poor countries, through the more financial capacity and advanced technology. However, like the UNDP report, few literatures provide concrete conclusion based on quantitative comparisons. In order to understand more deeply the different conditions when facing the climate change, this paper contributes to investigate the vulnerability to climate extremes in a quantitative way between different countries.

China and Japan are both Asian countries with similar geographies, similar seasonal climates and disaster-prone characteristics. According to our calculation based on EM-DAT database (EM-DAT, 2013), there were 703 and 319 disaster events recorded for China and Japan, including drought, earthquake, extreme temperature, flood, mass movement, storm, volcano and wildfire (only infectious diseases were excluded). These events have caused losses of 3,366 million dollars (2000 constant price) and 3,770 million dollars (2000 constant price) to China and Japan respectively. That means China and Japan have both been facing large potential threat of extreme events (of which a large proportion is related to extreme climatic events), aggravating their tasks for adapting climate change and preventing disasters. However, China and Japan have many distinctions in terms of development stages, economic structures, trade pattern and other aspects, and they are viewed as respectively typical developing and developed countries. Therefore, the two countries are selected as the studied objects.

It is pointed out that impact assessments of climate change on important sectors is conducive to a comprehensive understanding of the overall assessment of climate change

(McCarthy et al. 2001; Nordhaus 1994). So rather than cover all aspects of event damage, we chose to focus on one key area—electric utility lifelines. Electricity lifeline system is highly vulnerable to extreme climatic events, because it is societal necessity existing in the overall socio-economic networks and provided in linear links. Once a key node in the system or the chain disrupts, it will bring a very broad and far-reaching impact of higher order (Rose and Liao 2005).

Large-scale power outage had occurred in many countries throughout the world in history, scoping from a city (such as New York blackout in 1997) to an entire country (such as the 2012 blackout in India), and even to cross-border (such as the 2003 Northeast power failure), and with affected population ranging from several millions to several hundred millions. In particular, it should be noted that these power outages are generally caused by sudden extreme events that are difficult to control and by malfunction of aging equipment, of which the former includes frost (East US and Canada blackouts in 1998), snowstorm (China south blackout in 2008), drought(Greece blackout in 1993), rainstorm (France blackout in 1999), earthquakes(East Japan blackout in 2011) etc. Among them, there is no lack of extreme climatic events. Given that our earth is facing and will continually face climate change with a big probability in the future, we focus on the extreme climatic events as context of hypothetical power system damage.

Some scholars have studied on the economic impacts of extreme events. For example, Boyd and Ibarrarán set up the impact transmission mechanism of drought on agriculture, livestock, forestry and hydropower production industry, and used CGE model to simulate global economic impact of drought on Mexico (Boyd and Ibarrarán 2009); Hallegatte proposed an adaptive input-output model, and used it to simulate the economic impact of Hurricane Katrina Louisiana Louisiana on the United States (Hallegatte 2008); Steenge and Bočkarjova used input-output model to simulate and analyze the lack of productivity and economic impacts after a major disaster (Steenge and Bočkarjova 2007); Rose and Liao, and Berrittella et al. respectively used CGE model to simulate the impacts of water supply restrictions (Rose and Liao 2005). In these studies, just a single country or a region was focused on. Unlike them, this paper performs a new perspective by conducting an international comparison to reveal the vulnerability of power outages of China and Japan under extreme climate events.

In the present study, following questions are quantitatively answered. Are there differences between the socio economic impacts of power outage caused by extreme climatic events on China and on Japan? What are the differences? What are the reasons for these differences? We emphasized two aspects i.e. impacts on major national socio economic indicators and on key sector's output to answer these questions. The rest of the paper is organized as following: the second section describes the research methods and data sources, and the third section briefly introduces the scenario category and its introducing method. The fourth section analyzes and discusses the model results. Finally the conclusions, policy implications and future research directions are shown in the last section.

2. Methodology

In accordance with above mentioned literatures, most studies related to economic impacts assessment of extreme events adopt input-output (IO) model and CGE model (Anderson et al. 2007; Dwyer et al. 2006; Horridge et al. 2005; Okuyama 2007; Rose and Guha 2004; Rose and Liao 2005; Tatano and Tsuchiya 2008; Tsuchiya et al. 2007; Zhang and Peeta 2011). Compared with IO model, CGE model has a series of its own advantages. They can be summarized as follows: 1) substitution between inputs of production is allowed, which can reflect the behaviors to reduce losses in short run after disasters; 2) substitution between domestic products and imported production is allowed, which can reflect the consumption transition behavior after disasters; 3) CGE mode is nonlinear and that is more closed to reality conditions such as economics of scale and nonlinear loss function; 4) CGE models manage to capture the key features of price and markets, covering broader behaviors in order to simulate recovery activities; 5) the more important point is that CGE is especially better than other methods when measuring the role of infrastructure lifeline(Rose and Guha 2004; Rose and Liao 2005).Therefore, CGE model is used for simulation in this paper.

2.1 Framework of models

CGE is a multi-markets simulation model in which various consumers and firms simultaneously achieve optimization behaviors under certain constraints of economic account balance and resource in the equilibrium condition (Shoven and Whalley 1992). Referencing to previous models (Liang and Wei 2012; Paltsev 2004; Rutherford and Paltsev 1999), the physical and monetary flows in the model of this study are depicted in Fig. 1. Overall, three types of agents i.e. production firms, representative household and foreign account, and two markets i.e. factor market and commodity market are included. Of them, firms seek profit maximization under constraint of production technologies; representative agent maximize its utility under budget constraint; foreign account was supposed to follow small country assumption i.e. international commodity price would not be affected by imports or exports; factor market and commodity market reach clearance in the equilibrium, i.e. the total supply equals to total demand.

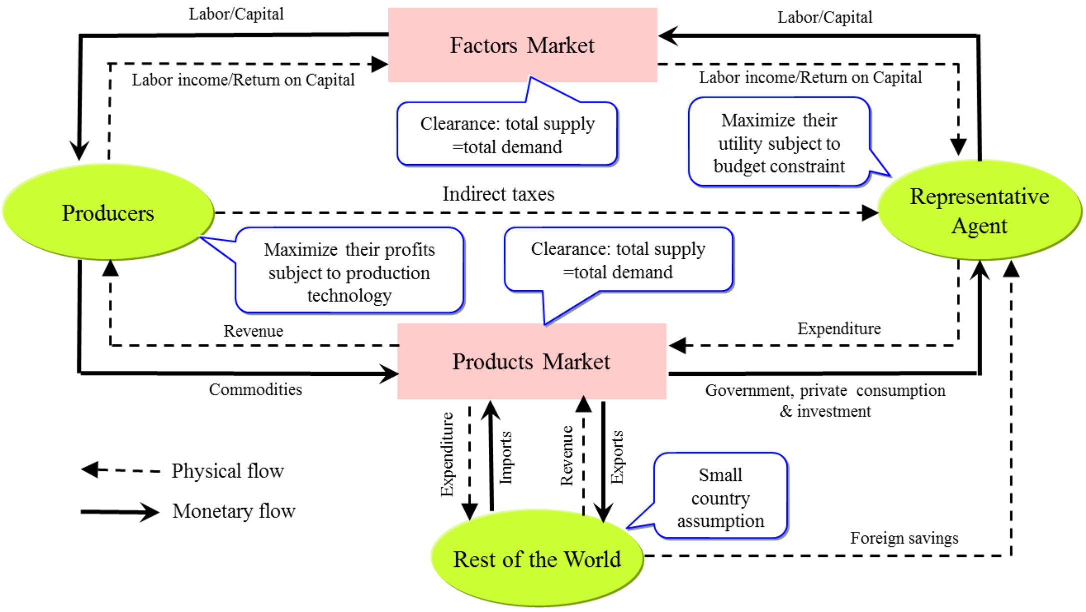

Fig. 1 Basic framework of the models in this paper

In addition, unlike the normal policy simulation study, that linked to events impacts assessment was required to modify the ordinary assumptions in order to better represent the conditions after extreme events. These special features along with other model assumptions are descripted in the following sections 2.2 and 2.3.

2.2 Key behavioral hypotheses

Firms' production technology is denoted by multilayer nested CES (Constant Elasticity of Substitution) function, which can be divided into two categories: ordinary production sectors and sectors with energy resource inputs. The latter includes three sectors, processing of petroleum, production and distribution of gas, and coking sector. CES function takes the form of Eq. (1),

$$Y = A(\rho)\cdot(\alpha_1 X_1^{\rho} + \alpha_2 X_2^{\rho} + \cdots + \alpha_N X_N^{\rho})^{1/\rho} \tag{1}$$

Where Y is the output level for aggregating nests, it is produced by N kinds of inputs $X_1 \cdots X_N$; $A(\rho)$ is efficiency parameter whose value is calibrated and represents the current technology level; α_i means the share parameter of input X_i and they keep the formula $\sum_{i=1}^{N}\alpha_i = 1$ to keep the assumption of constant returns to scale; an important exogenous parameter is elasticity of substitution σ, related to $\rho(\rho = (1-\sigma)/\sigma)$, the CES function is transformed into Cobb-Douglas (CD) function when $\rho = 0$ and Leontief (LOF) function when $\rho = -\infty$.

Production technologies of ordinary sectors are composed of five nested layers of CES functions (see Fig. 2): the bottom layer is the mix formed by fossil fuel inputs (coal, crude oil, natural gas and petroleum). It then forms energy composites together with electricity input; energy composites combine with capital and the new composites combine with labor force in higher layer. In the top layer capital-energy-labor composite together with intermediate inputs form a Leontief structure. Lastly, production sectors with energy resources input are supposed to use energy raw materials as additional input at the top layer instead of bottom.

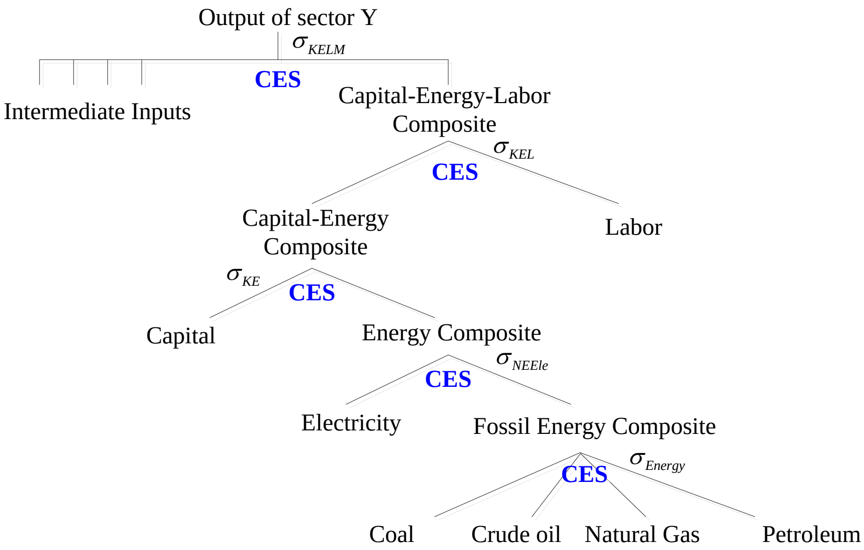

Fig. 2 Nested relationship of production technology

Utility level of representative household is taken by CD function, which is maximized under the budget constraint of factors incomes (see Eq. (2)-(4)).

$$Max: \quad U = \prod_i (C_i^h)^{\mu_i^h} \tag{2}$$

$$s.t. \quad \sum_i q_i \cdot C_i^h + S^h = Lincome + Kincome \tag{3}$$

$$S = mps \cdot (Lincome + Kincome) \tag{4}$$

Where U refers to household utility, C_i^h is the amount of household consumption for commodity i, μ_i^h refers to the consumption share parameter, q_i means market price of commodity i, $Lincome$ and $Kincome$ are labor force income and capital income respectively, S^h refers to the household savings and mps is the marginal propensity to save.

We adopt Armington assumption, i.e. imperfect substitutability between imports and domestic output sold domestically. The commodity that is supplied domestically is composed of domestic and imported commodities following a CES function (see Eq. (5)). As for export, this model uses a constant elasticity transformation (CET) function to allocate total domestic output between exports and domestic sales (see Eq. (6)).

$$Q_i = \gamma_i \left(\delta m_i M_i^{\eta_i} + \delta d_i D_i^{\eta_i} \right)^{\frac{1}{\eta_i}} \tag{5}$$

$$Z_i = \theta_i \left(\xi e_i E_i^{\Phi_i} + \xi d_i D_i^{\Phi_i} \right)^{\frac{1}{\Phi_i}} \tag{6}$$

Where Q_i is the composited commodity i supplied in domestic market, and Z_i is the total domestic output of sector i, γ_i and θ_i denote scale parameters of import function and export function respectively which are calibrated in the model, $\delta m_i, \delta d_i, \xi e_i, \xi d_i$ are corresponding share parameters, which are also calibrated in the model, M_i, E_i and D_i represent imported quantity, exported quantity and domestic use of commodity i respectively, η_i and Φ_i are elasticity of substitution parameter of Amington function and elasticity transformation parameter of export function.

In addition, labor factor and capital factor are supposed not to mobile among sectors in order to capture the short-term impacts more realistically. CPI is chosen as numeraire so that the real price would be output in the model.

2.3 Macro closure rules

There are three groups of macro closure rules, i.e. the options of endogenous and exogenous variables within account balances of government, investment-saving and the rest of the world. The models in this study follows the Johansen macro closure rule: fixed foreign savings, exogenous government consumption and exogenous real investment. Such a closure avoids the misleading welfare effects that appear when foreign savings and real investment change in simulations with a single-period model (Löfgren et al. 2002). Moreover the labor market is thought to follow Keynes closure and meanwhile the lowest wage is fixed at the CPI level, which means the real wage would not decrease under shock condition and then the labor force demand is satisfied by flexible supply. Besides capital market follows neoclassical closure which specifies exogenous capital supply and endogenous capital return rate.

2.4 Data source

The basic data of the models are producer price input-output (IO) table. They are respectively Chinese 2007 input-output table with 135 sectors (Department of National Account, 2010) and Japanese 2005 input-output table with 108 sectors (Ministry of Internal Affairs and Communications, 2010). In order to make the results comparable, we merge sectors in the same way to keep each sector concept consistent between China and Japan. 22 sectors for China and 21 sectors for Japan are formed, that is because two sectors (mining and washing of coal, extraction of petroleum and natural gas) in China’s 135 sectors IO table are only one single sector, namely energy mining sector. Sectors labeled in this paper and their corresponding IO codes can be seen in table A1 in Appendix section.

In addition, inputs substitution elasticity of each production nest, substitution elasticity between import and domestic products and export transform elasticity referred to Rose and Guha (2004) together with authors' adjustments, these values are shown in table A2 in Appendix section.

3. Scenario definition

3.1 Events introduction in the model

Because of the uncertainty of extreme events or disasters, extreme climatic events happened in history are almost impossible to repeat exactly from then on. Therefore, the purpose of this study is not to simulate the past or projected events accurately, but simulate the disruption matters of the power system which is likely to occur under extreme climate events, and as events to be introduced into the model.

Extreme climatic events such as hurricane, frost and snow disaster are likely to destroy the power infrastructure entities (such as cable crushing, voltage transformer freezing etc.), which is characterized in the models by capital stock losses of the power sector. According to basic input-output database, power generation system including various generation methods and electricity distribution/supply system are merged into one sector, and so is the capital stock. Therefore the power system damage hypothesized in this study include that of power generation system or electricity distribution system or both. In addition, because only capital stock in power sector is assumed to be destroyed in our simulation, when the power system is down (partly) the superfluous fuel storage would be redistributed in the domestic market through exchange behaviors.

To describe the intensity of extreme climatic events, we reference the situation that the power grid appears red warning when there is a severe shortage (GOV 2008). Here it is just regarded as a simulation scale reference rather than precise assessment based on actually occurred power outage. Because we tend to conduct a comparative study at the same condition for China and Japan, this scale is just deemed as a common reference for both courtiers and the reference is not accurate and can be flexible. That is to determine the power outage degree of 20% in the base scenario, which is achieved by calibration method in the model.

3.2 Cases classification

In this paper, we set up different scenarios according to the different response stages after extreme climatic events. Referencing to Rose and Guha (2004) [1], three stage scenarios are

[1] Although we cannot assure the modeling accuracy proposed by Rose and Guha (2004), especially on the stage

represented in the models by specifying three different sets of input substitution elasticity and import substitution elasticity with other aspects remaining unchanged. This kind of specification imply that we consider the recovery activities after events in terms of input adjustment for production and import adjustment.

There are some basic considerations of this specification. First of all, when the power supply is short, producers may choose other alternative fuel to replace the electricity, may also use other factor input to replace energy composite, or maybe increase the dependence on imported goods. These adjustments would further affect the prices of inputs, commodity price, the final consumption etc. Moreover, among above mentioned adjustments, adjustment on inputs substitution may obtain a more and more flexible mechanism in terms of learning ability, adjustment options, reducing production losses and reconstruction as the post-events time goes on. So the longer the post-disaster period is, the greater possibility of inputs substitution would be. Substitution between import and domestic products, however, is much stronger in the early stage of extreme events due to the decrease of domestic producing capacity. With destroyed assets recovery gradually, imports' competitiveness will also decline.

Based on the above considerations, each stage scenario definition in both models and its key substitution parameter are described in Table 1. Firstly, the base case seems close to long term scenario which reaches a new equilibrium after the events occurred where power supply capacity is almost fully recovered and here it is regarded as a control case. The parameter values under base case are depicted in Table A2. Secondly, very short-run scenario is defined like the stage when preliminary recovery activities are carried out within short time (around 1 week) after the events and electricity outage is relieved to some extent. The input substitution elasticity under this case is set at a very low level by 0.1, while the import substitution elasticity is set at a level of 10 times of that base case. Finally the short-run scenario is like the stage when a series of recovery and reconstruction activities are carried out within certain time (around 1 month) after the events and power supply capacity is recovered to a greater degree. The input substitution elasticity under this case is set at a slightly lower level than base case (half of it), while the import substitution elasticity is set at a level of 5 times of that base case.

parameter setting, just as mentioned by its authors it is deemed that this kind of accuracy problem is absolutely not of mortality unless the response function is extremely nonlinear. Moreover, our key point in this study is just to compare the response features of different economies, so it is believed that this modeling scheme is rational enough.

Table 1 Scenario description and definition under different post-event stages

Stage Scenarios	Electricity Capacity	Substitution elasticity	
		Input	Import
Base Case	Maximum outage and new equilibrium	base[a]	base
Very Short-Run(≤7days)	Maximum outage or some recovery	0.1	10X of base[b]
Short-Run(≤6 month)	Various stages of recovery	0.5 of base	5X of base[b]

a. The value of substitution elasticity of each sector is presented in Appendix Table A2.
b. 10X and 5X mean 10 times and 5 times of the base case elasticity.

4. Results analysis and discussion

The models are programmed and solved by using GAMS/MPSGE (Rutherford 1998, 1999). First of all, we run base cases model of China and Japan under which there is both 20% electricity shortage. Then the very short-run and short-run scenarios are run with keeping both capital reduction of electricity sector equivalent to that of the base cases of corresponding country[2]. In the following analysis, percentage forms are adopted in the simulation results in order to avoid incomparable problems caused by individual price system. In addition, unlike the analysis style of most CGE results, we focus on the differences of climatic extremes impacts on China and Japan and the corresponding reasons.

4.1 Comparison of impacts on macro economy

4.1.1 Changes of socio economic indicators of China and Japan

As shown in Fig. 3, whether in China or in Japan, GDP, total output, household welfare (Equivalent Variation), total employment, total import and total export decrease under all three scenarios and they all become slighter with time going on. For comparing results of China and Japan cases, we define the ratio of impact difference between China and Japan as the ratio of above indexes' change degree in China to that in Japan (difference ratio for short). So in the following results discussion, we focus on the China-Japan difference ratio of each index.

[2] Capital of power sector is reduced by 48.7% and 45.1% under the base cases in China and Japan respectively. The simulation results from Rose and Guha (2004) show that the largest capital reduction after earthquake in that region is 44.8%. Moreover, we also conduct the cases of 15% and 25% power outage as a sensitivity analysis, and the results not vary largely. Thus, there is reason to believe that the simulated cases are very likely to occur under the pressure of extreme events.

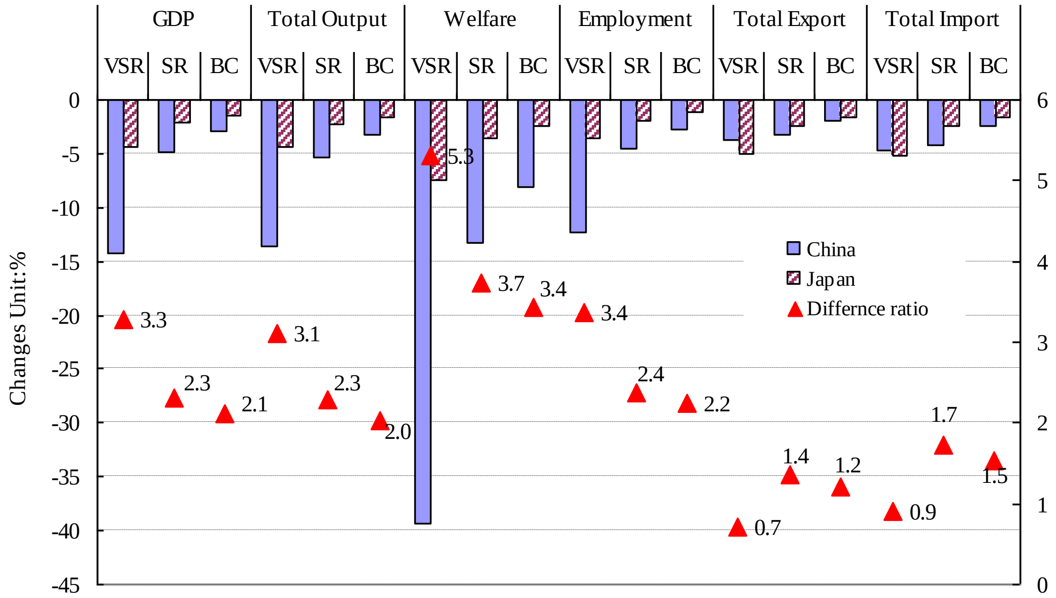

Fig. 3 Impacts on China-Japan's socio economic indexes under different scenarios

1) Whether from the indexes GDP and total output which take great importance on economy development, or from the indexes household welfare and total employment which are related to society stabilization, it is seen that the impacts on China is greater than that on Japan and difference ratio decreases as time flies. For example, in very short-run scenario, the GDP loss of China and Japan are 14.3% and 4.4% respectively, and the difference ratio is 3.3. However, in relatively long base case, the GDP loss are 2.9% and 1.4% respectively, and difference ratio decrease to 2.1.

2) Among these indexes, the one which has the highest China-Japan difference ratio is the household welfare, whose lowest difference ratio of three scenarios reaches up to 3.4, even higher than the highest one to other indexes. The loss difference of China-Japan household welfare goes the highest under very short-run scenario where the losses are 39.3% and 7.4% respectively, and the difference ratio goes to 5.31.

3) Compared with other indexes, the impacts on import and export under all scenarios show lower degree and their China-Japan difference ratios are fairly low. So we would not discuss more about the import and export indexes.

4.1.2 Analysis on the relationship of the major indicator changes

Under the assumption of the model closure rule, the losses of expenditure approach GDP depend largely on the household consumption ($\Delta HCon$ in Fig. 4), so the significant difference between Chinese and Japanese loss of household welfare could heavily explains why there is difference between the losses of GDP in China and Japan (shown as the dotted line no. 1). For instance, under the very short-run scenario there is dramatic differences between Chinese and

Japanese loss of household welfare (difference ratio reaches up to 5.31), consistent with which great differences between the losses of GDP in China and Japan (difference ratio is 3.3).

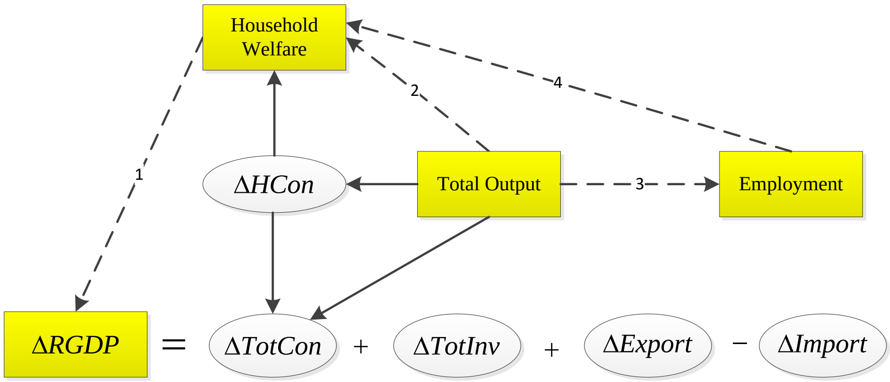

Fig. 4 Relationship of impacts on major indicators

However, in the aspect of loss of household welfare, why does it exist so obvious gap between China and Japan? Basically, the demand of total consumption ($\Delta TotCon$ in Fig. 4) originates from commodity supply, so the deficiency of domestic output will affect the total consumption. Under the assumption of the model closure rule, the slump of total consumption is reflected largely by the household consumption, in other words, residents are the main group who bear the losses of total consumption. The smaller share the household consumption accounts for the total consumption, the greater losses the residents will suffer from reducing the same proportion of total consumption. Therefore, the large differences of losses of household welfare between China and Japan are mainly because of their differences in total consumption. The proportion of Chinese household consumption in the total consumption (36.3%) is relatively small compared with Japanese (58.8%) so supply-side losses (falls in total output) make Chinese residents bear heavier burden (shown as the dotted line no. 2). Moreover, burden on Chinese residents' welfare will expand along with the increasing losses of total output, leading to abnormally large differences in the Sino-Japanese losses of resident welfare in the very short-term scenario.

In addition, the declines of total output bring about the decrease of the demand in input labor (shown as the dotted line no. 3). Compared with the Japanese, Chinese greater decreases of total output result in more employment losses, therefore, it exists differences in the degree of employment loss between China and Japan. To sum up, the negative influence on the socioeconomic system brought by the shortage of electricity is fundamentally caused by the decrease in production capacity. However, at the same degree of power outage, why are there obvious differences between the degrees of influence on Chinese and Japanese total output? Which sectors are these differences caused by? We will get more clear answers after the comparative analysis on key sectors.

4.2 Comparison of impacts on key sector outputs

It is found that the contribution distribution of sectors to the overall China-Japan difference performs similar under different scenarios. So, we compare the impacts on key sectors only under base case from the following aspects.

4.2.1 Comparison of energy price

Various energy is key fuel input for production of each production sector. Given the possibility of substitution among different kind of fuel inputs, when electricity supply is disrupted, firms would firstly seek to other fuels to replace for electricity, resulting in that fuels become relatively scarcity commodity. Therefore, energy price as an indicator of reflecting market condition plays a key role in the afterward analysis on other indexes.

First, for the primary energy input sector, although the output levels of coal, crude oil and natural gas sectors in both China and Japan have declined, the difference between them is small (as shown in Fig. 4). However, due to the fact of resource endowments, the Japanese domestic primary energy supply heavily rely on imports, accounting for 99.1% of the total domestic use (measured by the monetary value). For the foreign supply is not shocked under extreme events, the decline in domestic output has less impact on domestic supply, thus the user prices being less affected, with the base case rising only 0.29%.

Unlike Japan, the imports account for a relatively small proportion of 24.1% (measured by the monetary value) in China’s domestic primary energy supply. Therefore, the domestic output declines would have greater negative impacts on the domestic supply than in Japan, thus leading to a greater extent of user prices rising. For example, the market prices of coal, crude oil and natural gas under the base case would increase by 1.39% and 0.88%, which will lead to the Sino-Japanese difference ratios being 4.8 and 3.0.

Secondly, the difference of the changes in raw material costs or input costs for the production of secondary energy sector (including GasH, Petr, Elec sectors), further contributes to the China's secondary energy prices (gas, petroleum and electricity) increasing significantly greater than that of Japan.

4.2.2 Key sectors identification contributing to China-Japan difference

As seen in Fig. 5, as the output of power sector reduced by 20%, the decrease of other sectors output in China is basically greater than that of Japan, among which key contributors for the difference of total output would be selected in this section.

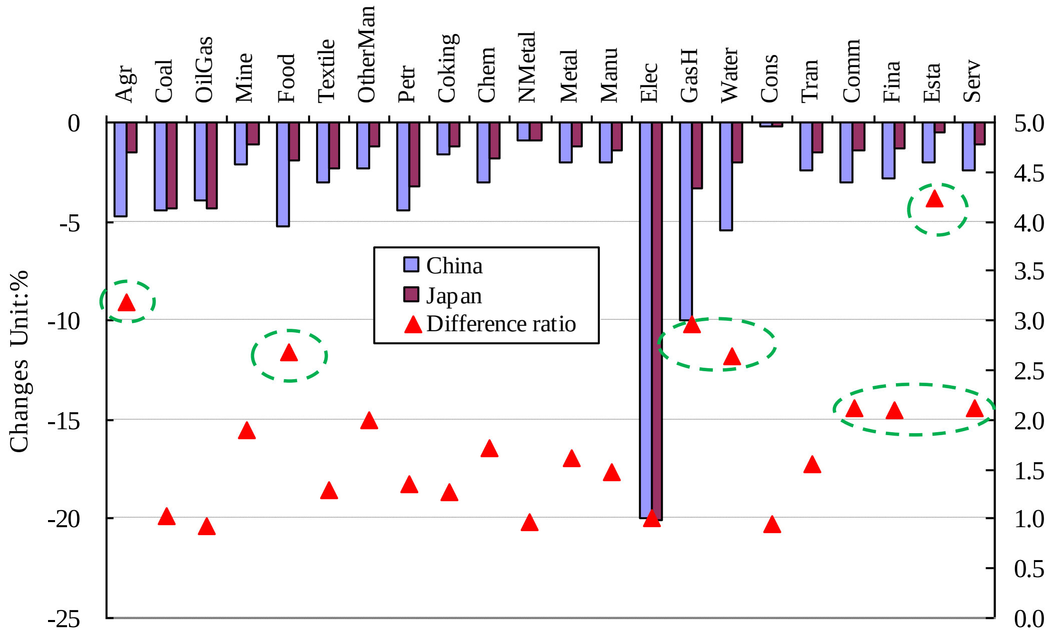

Fig. 5 Impacts on sector outputs and difference ratio under base case

1) Sectors which have higher difference ratios in the impacts on individual sector output between China and Japan may be the major contributors to the differences in national total outputs of the two countries. As shown in Fig. 5, those sectors with the difference ratio above 2 exhibited in the dotted circle include Agr, Food, GasH, Water sectors and several servicing sectors including Comm, Fina, Esta and Serv. However, the outputs of GasH and Water sectors account for less than 1% of the national total outputs in both China and Japan, so they are considered as the non-predominant sectors with limited effects. By contrast, other mentioned sectors or take a relatively large share in China or in Japan. In more detail, sector Agr and sector Food have higher shares (6.0% and 5.1% respectively) in the total outputs of China, and several servicing sectors hold the share of 50.4% in Japan.

2) Even though the difference ratio of impacts on sectoral output between China and Japan is not large enough (less than 2), those sectors of higher shares in national total outputs are very likely to contribute a lot to the difference of impacts on national total output. The predominant sectors of serving in Japan's total outputs are involved in the analysis above. So we additionally consider the sectors which play absolutely dominant roles in national total output. They are OtherMan, Metal, Cons, Chem sectors, accounting for 17.8%, 9.6%, 7.7% and 7.6% respectively. Due to its very little difference ratio between China and Japan (0.94), sector Cons is further excluded.

Therefore, 9 key sectors are selected as objectives who have great explanatory power on the reason why large difference of impacts on total output between China and Japan. According to features of these key sectors, we further divide them into three categories: life requirement category, industry product category and service requirement category. Fig. 6 displays the components of each category and their output share, different ratio of impacts on sectoral output.

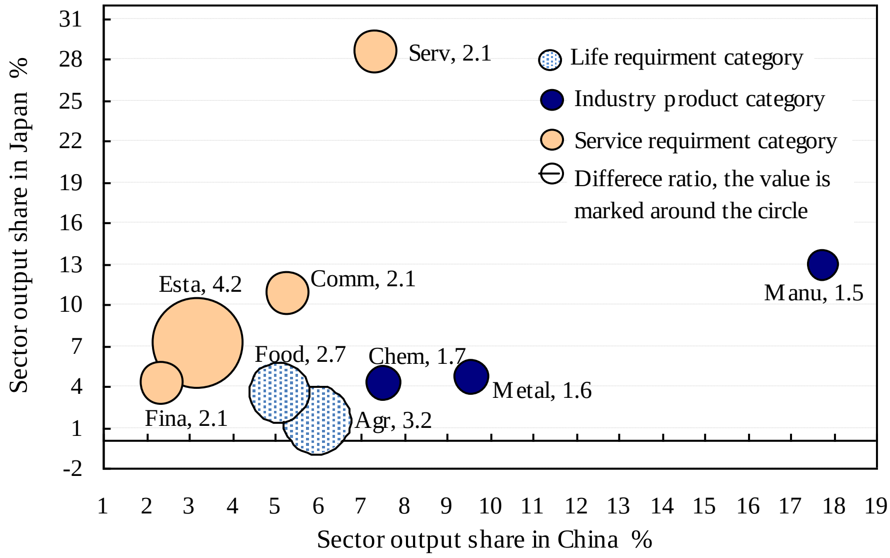

Fig. 6 Categories of key sectors, output share and difference ratio of impacts

4.2.3 Comparison and analysis of impacts on key sector output

Based on the input structure (see Fig. 7) and the changes of major sectoral variables of the three categories of key sectors (see Table 2), we further examines reasons for the difference in impacts on sector output between China and Japan. First as seen in Table 2, in terms of input factors, there is a decrease in both the return on capital and employment of all key sectors. That is because when production activities shocked by extreme event, capital of each sector is relatively sufficient, making sectoral return rate on capital decline. Demand on labor force of each sector would also shrink due to dropped producing capacity. Then three categories of key sectors are analyzed one by one.

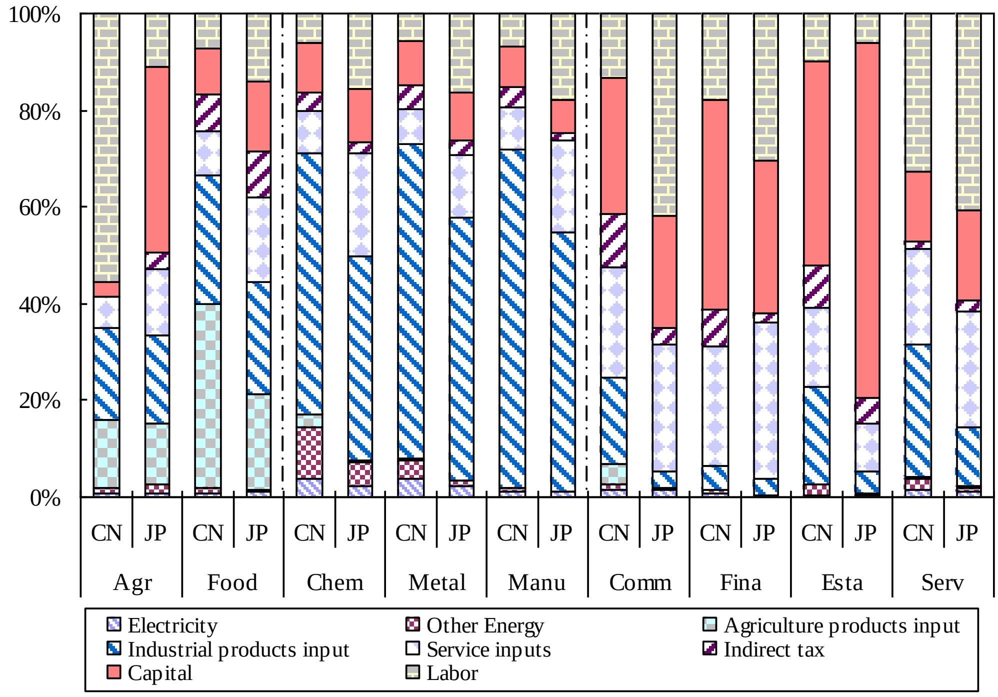

Fig. 7 Input structure of production of key sectors

1) Life requirement category

Capital takes a large proportion of Japan's input structure for agricultural production, up to 38.6% (Fig. 7), that may be reflected by the high degree of mechanization in agricultural production. Decrease of return rate on capital makes Japan’s agricultural production costs decline, resulting in the market price of agricultural products declining by 0.41% (Table 2). By contrast, for China’s agricultural sector which is with labor as dominant input rather than capital, its producing cost increases due to the more expensive intermediate inputs, resulting in the market price of agricultural products increasing by 0.38% (Table 2). Because of the close relationship between price and demand, the lower price of Japanese agricultural product will result in the relatively smaller decrease of agricultural production than that of China. In addition, this fact also leads to the difference between China and Japan in the decrease of production for food processing industry due to it is main raw material from agricultural products.

Table 2 Impacts on key sectors in China and Japan under the base case unit: %

	Employment		Capital price		Market price	
	China	Japan	China	Japan	China	Japan
Life requirement category						
Agr	-4.45	-1.98	-0.93	-1.81	0.38	-0.41
Food	-5.46	-2.04	-7.41	-2.62	-0.43	-0.09
Industry product category						
Chem	-1.55	-1.23	-1.85	-1.56	2.33	0.85
Metal	0.23	-0.35	0.92	-0.14	3.58	1.37
Manu	-0.96	-1.00	-1.17	-1.25	1.75	0.71
Service requirement category						
Comm	-4.23	-1.59	-6.44	-2.44	-2.36	-0.31
Fina	-5.62	-2.01	-8.52	-3.07	-4.42	-1.05
Esta	-3.54	-1.80	-5.39	-2.75	-2.55	-2.04
Serv	-2.41	-1.16	-3.64	-1.77	0.07	0.00

2) Industry product category

Compared to the other two categories, the sectors of industry product category have a higher proportion of material inputs. Also, there is a higher dependence on material and energy in China's production of these sectors than that of Japan, shown in Fig. 8. Thus, on one hand, due to the larger increase of energy prices and the consequent rising prices of industrial inputs, the production cost of Chinese industry product category will be higher than that of Japan, thereby followed by the more increase of industrial product prices (Table 2), more decrease of product demand and more decline of sector output than that in Japan. On the other hand, the higher dependence on intermediate inputs in Chinese industry will alleviate the decline in aggregate industrial demand. Therefore, based on the two points, there is a slightly smaller difference in the overall sector outputs of the industry product category.

3) Service requirement category

Because service requirement category is characterized by smaller intermediate material input and a larger proportion of factor inputs, its commodity price will be largely affected by the price of return on capital, which basically declines (Table 2). However, there is a huge difference in the influence level. The reason may lie on that compared with that of Japan, a larger proportion of the products of China's service requirement category are used for intermediate consumption (China and Japan, respectively, 49.0% and 37.8%) while smaller for final consumption. With this feature, even the same decrease degree in total output will cause more decrease of service demand and consequently the more sluggish output of service sector in China. In addition, it should be noted that since the dominated position of service sector in the Japanese economy, a lesser impact on the Japanese sectors of service requirement category will be one of the important reasons for the lower shock to the Japan's overall economy.

5. Conclusion and policy implication

5.1 Conclusions

The following conclusions are proposed base on the above analyses from five aspects.

(1) Overall, under the electricity disruption caused by extreme climatic events, all the socio economic indicators of China and Japan showed a decline. No matter the economic development related indicators such as GDP, total output and import & export trade, or the social stability related indicators such as household welfare and total employment both have declined, suggesting that the extreme climatic events would yield higher order negative impact on the entire socio-economic system even if it occurs locally. Moreover, the negative impacts are gradually alleviated over time, which is consistent with post-adaptation adjustment process.

(2) China suffers greater negative impacts on society and economy than Japan under the same degree of power shortage, showing unequal vulnerability to climate extremes. Quantitatively, the decrease degree of China's GDP, the total output and total employment 2-3 times of that of Japan; while the difference in household welfare is greater, with China’s 3-5 times of Japan’s. And the difference is gradually lessen over time, which emphasizes China’s much weaker conditions (or larger vulnerability) in a very short term after events.

(3) The difference in decline of output capacity is the fundamental cause of the different vulnerability between China and Japan. Moreover, due to Chinese household consumption take up smaller proportion in the expenditure structure than that of Japan, the difference in welfare loss between China and Japan is much larger than other indicators.

(4)The difference of energy self-sufficiency rate is the primary cause of making energy prices highly different between China and Japan. The increase of coal price and crude oil & natural gas price of China is 4.8 and 3.0 times of Japanese under the base case, which is because Japan's primary energy almost completely dependent on imports, resulting in limited impacts on domestic energy supply if only domestic production capacity is insufficient.

(5) There are three categories of key sectors which are the major contributors to the impact differences between China and Japan. Structural factors cause the unequal vulnerability to climate extremes between two countries, including the differences of factor input structure for production of sectors of life requirement category, the differences of material and energy dependence for production of sectors of industrial product category, and the differences of usage structure of services outputs.

5.2 Policy implications

The following policy implications are then proposed:

(1) The local destructive effect of extreme climate events will spread to the whole

socio-economic system through the inter linked industrial chain, and more destructive in the very short term. Therefore, it is essential to take the necessary actions to adapt to climate change and reduce climate change vulnerability. Apart from the local losses, the higher order losses caused by ripple effect also need to be concerned. In particular, improving the abilities of immediate response and emergency management after extremes should be strong emphasis in order to avoid huge losses in the short term.

(2) Developing countries like China have to face greater threat caused by climate change. Therefore, in order to keep the equal rights on sustainable development among countries, the principle of "common but differentiated responsibilities" is strongly necessary to be followed when taking international cooperation on addressing climate change and allocating the carbon emission allowances. Besides, developed countries should provide support for developing countries in funds, technology and capacity-building.

(3) Increasing production capacity in China is crucial for reducing the gap with Japan on the cost of adaptation to extreme climatic events. Raising the proportion of household consumption of national expenditure in China is also favorable for reducing the huge welfare loss brought by extreme events.

(4) Higher primary energy self-sufficiency rate brings greater impact on domestic energy supply security of China under the condition of power supply disruption. Therefore, in order to ensure energy persistent supply safety, it is necessary to diversify energy supply, such as obtaining more overseas energy.

(5) By raising agricultural production technology and capital input proportion, changing the extensive mode of production of industrial products which has large proportion of energy and material inputs, saving energy, improving energy efficiency, and spreading the end use of service product, the larger negative impacts on Chinese economy can be shrunken, compared with Japanese case.

5.3 Further perspective

In this paper, in the context of extreme climatic events which is the important aspect of climate change, a comprehensive comparison of impacts of power infrastructure destruction on socioeconomic system of China and Japan. However, it is just a preliminary attempt because some limitations exist. For example, the flexible consumer behavior and government intervention are not yet taken into consideration. What’s more, we simplified the modeling process due to the data limitation. These will be improved in the further research in the future.

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Appendix

Table A1 Account description and the related IO codes

Abbreviation	Description	China IO code	Japan IO code
Sectors classification			
Agr	Agriculture, Forestry, Animal Husbandry & Fishery	001-005	001-005
Coal	Mining and Washing of Coal	006	008[a]
OilGas	Extraction of Petroleum and Natural Gas	007	008 [a]
Mine	Other Mining	008-010	006-007
Food	Manufacture of Foods, Beverage & Tobacco	011-024	009-012
Textile	Manufacture of Textile, Wearing	025-031	013-014
OtherMan	Other Manufacture	032-036,090-091	015-019,048,063-064
Petr	Processing of Petroleum and Nuclear Fuel	037	028
Coking	Coking	038	029
Chem	Chemical Industry	039-049	020-032
Nmetal	Manufacture of Nonmetallic Mineral Products	050-056	033-036
Metal	Manufacture and Processing of Metals and Metal Products	057-063	037-044
Manu	Manufacture of Machinery and Equipment	064-089	045-062
Elec	Production and Supply of Electric Power	092[b]	069
GasH	Production and Distribution of Gas and Heat Water	092 [b]-093	070
Water	Production and Distribution of Water	094	071
Cons	Construction	095	065-068
Comm	Wholesale and Retail Trades, Hotels	108-110	073
Fina	Financial Intermediation	111-112	074
Esta	Real Estate, Leasing and Business Services and Catering Services	113-116	072,075-077
Tran	Transport, Storage, Post, Information Transmission, Computer Services & Software	096-107	078-086
Serv	Other Services	117-135	087-108
Value-added			
	Compensation of Employees	VA001	111,112 (Row)
	Return of Capital	VA003,VA004	113-115 (Row)
	Indirect Taxes on Production	VA002	116,117 (Row)
Final Consumption Expenditure			
	Household Consumption	THC	111.112 (Col.)

Government Consumption	FU103	113 (Col.)
Fixed Capital Formation	FU201	114-116 (Col.)
Changes in Inventories	FU202, ERR	117 (Col.)
Total Imports	IM	128 (Col.)
Total Exports	EX	122 (Col.)

a. The two sectors are merged into one.

b. Electricity and Heat are divided by proportion.

Table A2 Substitution elasticity under base case [a]

	σ_Q	σ_{EX}	σ_{Energy}	σ_{KE}	σ_{KEL}	σ_{KELM}	$\sigma_{NEE\text{le}}$
Agr	1.9	2	0.6	1.5	0.85	0.7	0.5
Coal	1.1	1.1	0.65	0.65	0.65	0.65	0.5
OilGas	1.1	1.1	0.65	0.65	0.65	0.65	0.5
Mine	1.1	1.1	0.65	0.65	0.65	0.65	0.5
Food	1.15	0.75	0.8	0.8	0.65	0.65	0.5
Textile	1.3	0.75	0.8	0.7	0.65	0.65	0.5
OtherMan	1.3	0.75	0.8	0.7	0.65	0.65	0.5
Petr	2	0.75	0.8	0.7	0.65	0.65	0.5
Coking	2	0.75	0.8	0.7	0.65	0.65	0.5
Chem	1.3	0.75	0.8	0.7	0.65	0.65	0.5
Nmetal	1.3	0.75	0.8	0.7	0.65	0.65	0.5
Metal	1.3	0.75	0.8	0.7	0.65	0.65	0.5
Manu	1.3	0.75	0.8	0.7	0.65	0.65	0.5
Elec	0.1	0.75	0.65	0.65	0.65	0.65	0.5
GasH	0.75	0.75	0.65	0.65	0.65	0.65	0.5
Water	0.75	0.75	0.65	0.65	0.65	0.65	0.5
Cons	0.75	0.75	0.65	0.65	0.65	0.65	0.5
Tran	0.75	0.5	0.65	0.65	0.65	0.65	0.5
Comm	0.9	1.1	0.65	0.65	0.65	0.65	0.5
Fina	0.85	2	0.65	0.65	0.65	0.65	0.5
Esta	0.85	2	0.65	0.65	0.65	0.65	0.5
Serv	1.1	0.9	0.65	0.65	0.9	0.65	0.5

a. σ_Q means substitution elasticity between import and domestic goods, σ_{EX} means transformation elasticity of export, other codes in the table header are consistent with that in Fig. 2.

References

Anderson CW, Santos JR, Haimes YY (2007) A risk-based input–output methodology for measuring the effects of the August 2003 Northeast blackout. Econ Syst Res 19 (2):183-204

Boyd R, Ibarrarán ME (2009) Extreme climate events and adaptation: an exploratory analysis of drought in Mexico. Environment and Development Economics 14 (3):371

Dwyer L, Forsyth P, Spurr R (2006) Assessing the economic impacts of events: A computable general equilibrium approach. Journal of Travel Research 45 (1):59-66

Füssel H-M (2010) How inequitable is the global distribution of responsibility, capability, and vulnerability to climate change: A comprehensive indicator-based assessment. Global Environmental Change 20 (4):597-611

Ford JD, Smit B, Wandel J (2006) Vulnerability to climate change in the Arctic: A case study from Arctic Bay, Canada. Global Environmental Change 16 (2):145-160

GOV (2008) [Online] Available at: http://www.zongyang.gov.cn/DocHtml/1/2011/1/12/20110112941544699.html [Accessed 20 February 2013]

Hallegatte S (2008) An Adaptive Regional Input‐Output Model and its Application to the Assessment of the Economic Cost of Katrina. Risk Analysis 28 (3):779-799

Heltberg R, Siegel PB, Jorgensen SL (2009) Addressing human vulnerability to climate change: Toward a 'no-regrets' approach. Global Environmental Change 19 (1):89-99

Horridge M, Madden J, Wittwer G (2005) The impact of the 2002–2003 drought on Australia. Journal of Policy Modeling 27 (3):285-308

Löfgren H, Harris RL, Robinson S (2002) A standard computable general equilibrium (CGE) model in GAMS, vol 5. International Food Policy Research Inst, Washington

Liang Q-M, Wei Y-M (2012) Distributional impacts of taxing carbon in China: Results from the CEEPA model. Applied energy 92:545-551

McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (2001) Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York

Ministry of Internal Affairs and Communications (2010) Input-Output Tables for Japan. [Online] Available at: http://www.stat.go.jp/english/data/io/io05.htm [Accessed 16 February 2013]

Department of National Account (2009) Input-output table of China 2007. China Statistics Press, Beijing (in Chinese)

EM-DAT (2013) The international disaster database. [Online] Available at: http://www.emdat.be/database [Accessed 26 April 2013]

Nordhaus WD (1994) Managing the global commons: the economics of climate change. MIT press Cambridge, MA, Cambridge

Okuyama Y (2007) Economic modeling for disaster impact analysis: past, present, and future. Econ Syst Res 19 (2):115-124

Paltsev S (2004) Moving from static to dynamic general equilibrium economic models. Notes for a beginner in MPSGE Technical Note (4)

Parry ML (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability: Working Group I Contribution to the Fourth Assessment Report of the IPCC, vol 4. Cambridge University

Press, New York

Rose A, Guha G-S (2004) Computable general equilibrium modeling of electric utility lifeline losses from earthquakes. Modeling Spatial and Economic Impacts of Disasters:119-141

Rose A, Liao SY (2005) Modeling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions. J Reg Sci 45 (1):75-112

Rutherford T, Paltsev S (1999) From an input-output table to a general equilibrium model: assessing the excess burden of indirect taxes in Russia. Draft, University of Colorado

Rutherford TF (1998) GAMS/MPSGE guide. GAMS Development Corporation: Washington: DC

Rutherford TF (1999) Applied general equilibrium modeling with MPSGE as a GAMS subsystem: An overview of the modeling framework and syntax. Computational Economics 14 (1-2):1-46

Shoven JB, Whalley J (1992) Applying general equilibrium. Cambridge [England]: Cambridge University Press

Steenge AE, Bočkarjova M (2007) Thinking about Imbalances in Post-catastrophe Economies: An Input–Output based Proposition. Econ Syst Res 19 (2):205-223

Tatano H, Tsuchiya S (2008) A framework for economic loss estimation due to seismic transportation network disruption: a spatial computable general equilibrium approach. Natural Hazards 44 (2):253-265

Tsuchiya S, Tatano H, Okada N (2007) Economic loss assessment due to railroad and highway disruptions. Econ Syst Res 19 (2):147-162

Tubi A, Fischhendler I, Feitelson E (2012) The effect of vulnerability on climate change mitigation policies. Global Environmental Change 22 (2):472-482

UN, WB (2011) Unite Nation, World Bank, Natural hazard and unnatutral hazard: economics of effective prevention, World Bank Press, Washington (in Chinese)

UNDP (2011) United Nations Development Programme, Human development report 2011: towards the sustainability and equality, United Nations Development Programme Press, Washington (in Chinese)

Zhang P, Peeta S (2011) A generalized modeling framework to analyze interdependencies among infrastructure systems. Transportation Research Part B: Methodological 45 (3)

:553-579