Appendix 4.A Sensitivity Analysis

In CGE analysis, simulation results often depend on assumptions of key parameters. To examine the robustness of the results, sensitivity tests are conducted with respect to (1) the depreciation rate *dep*; (2) the rate of return of capital *ror*; (3) the population growth rate *pop*; (4) the elasticity parameter for investment allocation ζ; (5) the elasticity of substitution among energy sources σ^e; and (6) Armington's (1969) elasticity of substitution/transformation σ_i/ψ_i.

We shift these parameter values from those used in the main text (Table 4.2.2). The results generally show that the findings are qualitatively robust. Quantitatively, smaller fiscal and social costs would be generated by assuming a larger *dep* and ζ, which makes investment and capital adjustment more flexible, and with a larger *pop*, which makes capital less important. On the other hand, the impact of shifting *ror*, σ_i, ψ_i, and σ^e are found to be small.

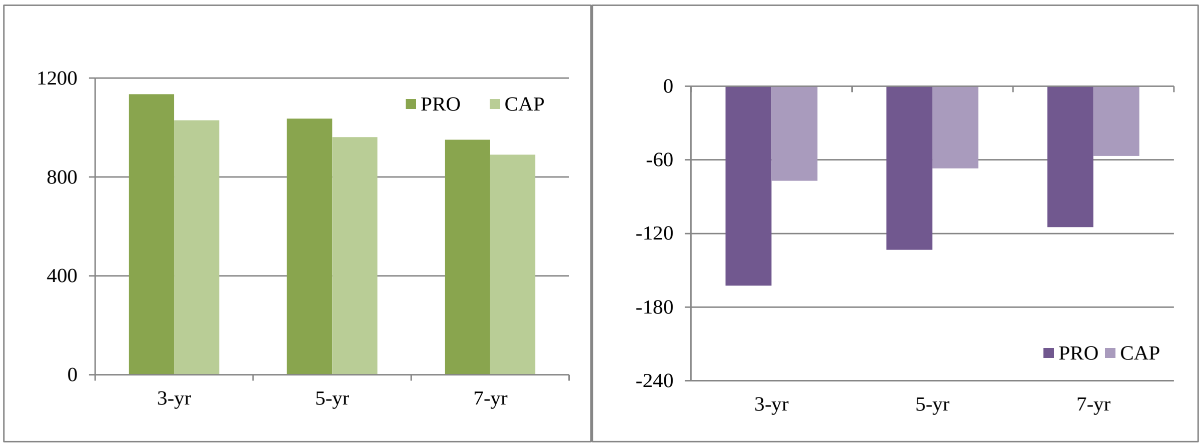

Figure 4.A.1: Fiscal (Left Panel) and Social Costs (Right Panel) of Recovery Programs for Semiconductor Sector with δ=0.05 (unit: billion TWD)
Note: The total fiscal costs and social costs measured by the Hicksian equivalent variations in Periods 1–10 are discounted at a rate of 4%.

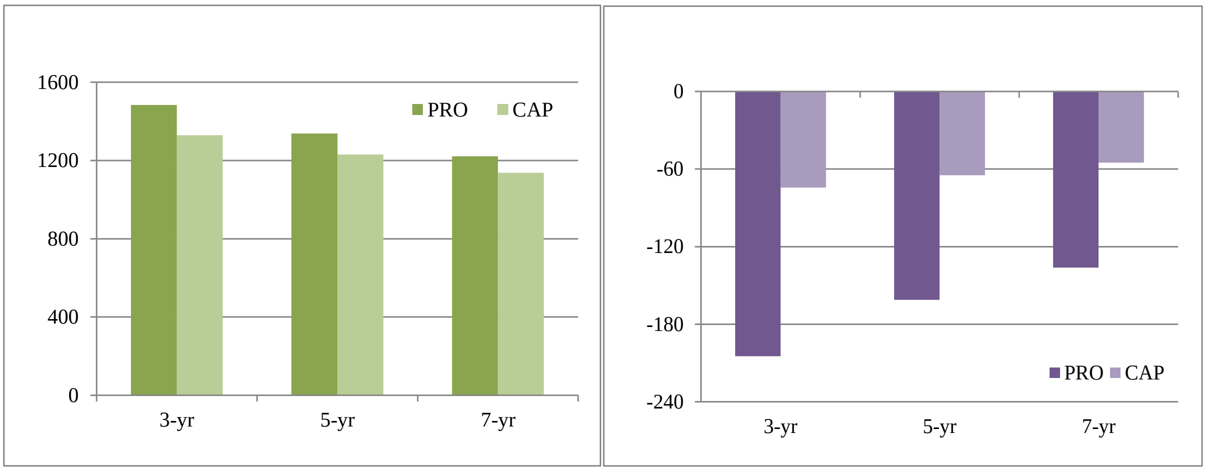

Figure 4.A.2: Fiscal (Left Panel) and Social Costs (Right Panel) of Recovery Programs for Semiconductor Sector with *ror*=0.06 (unit: billion TWD)

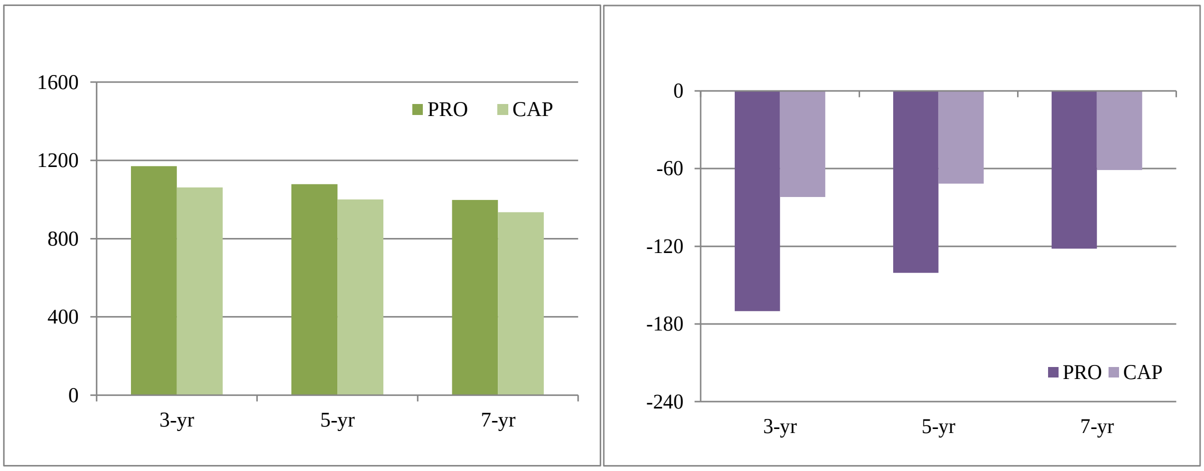

Figure 4.A.3: Fiscal (Left Panel) and Social Costs (Right Panel) of Recovery Programs for Semiconductor Sector with *pop*=0.02 (unit: billion TWD)

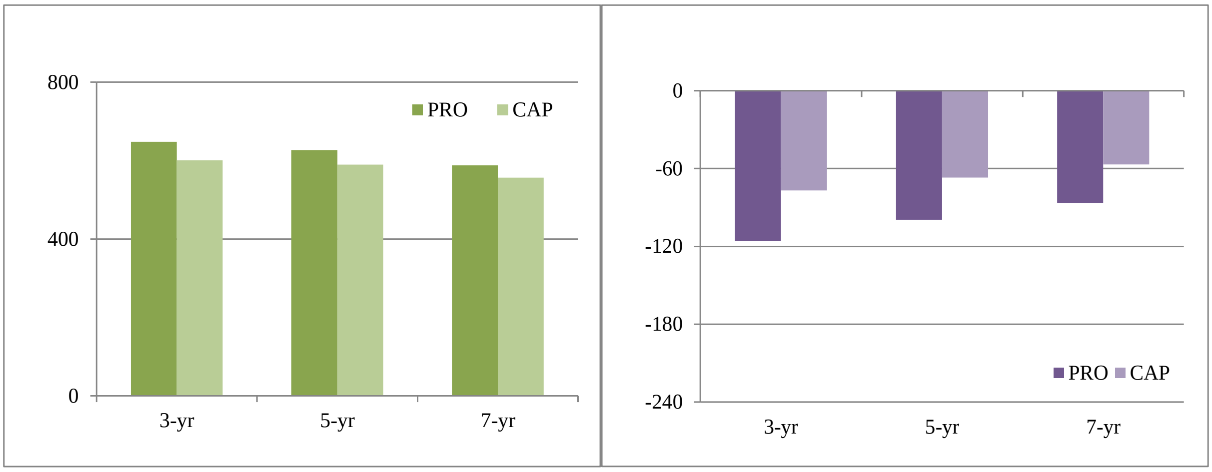

Figure 4.A.4: Fiscal (Left Panel) and Social Costs (Right Panel) of Recovery Programs for Semiconductor Sector with $\zeta = 2$ (unit: billion TWD)

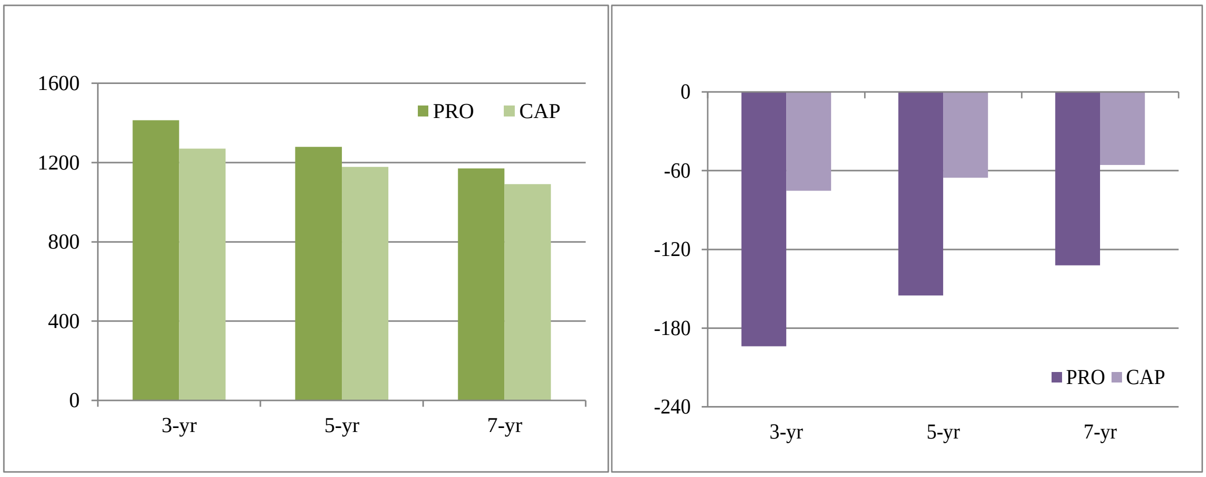

Figure 4.A.5: Fiscal (Left Panel) and Social Costs (Right Panel) of Recovery Programs for Semiconductor Sector with $\sigma^e = 2$ (unit: billion TWD)

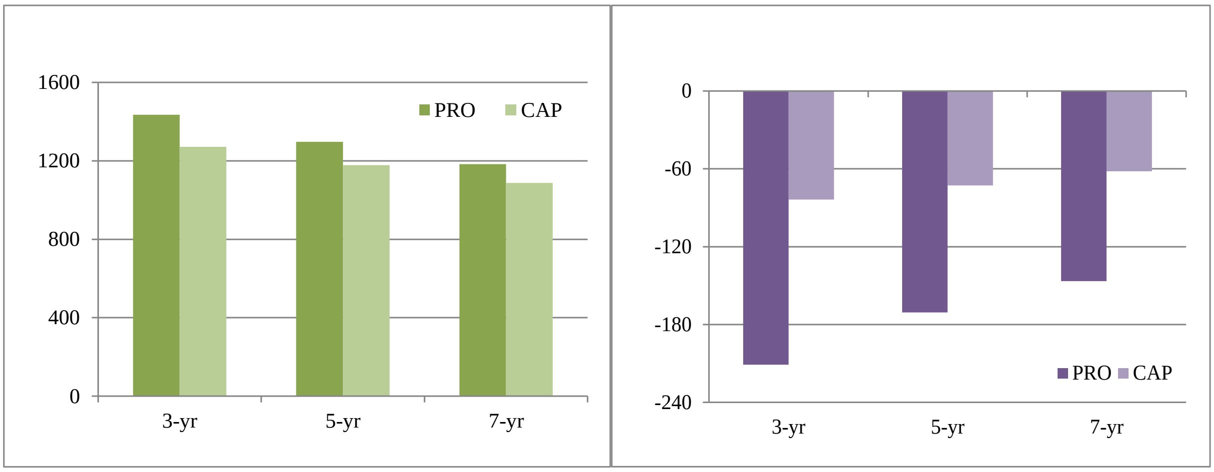

Figure 4.A.6: Fiscal (Left Panel) and Social Costs (Right Panel) of Recovery Programs for Semiconductor Sector with 30% smaller σ_i/ψ_i (unit: billion TWD)

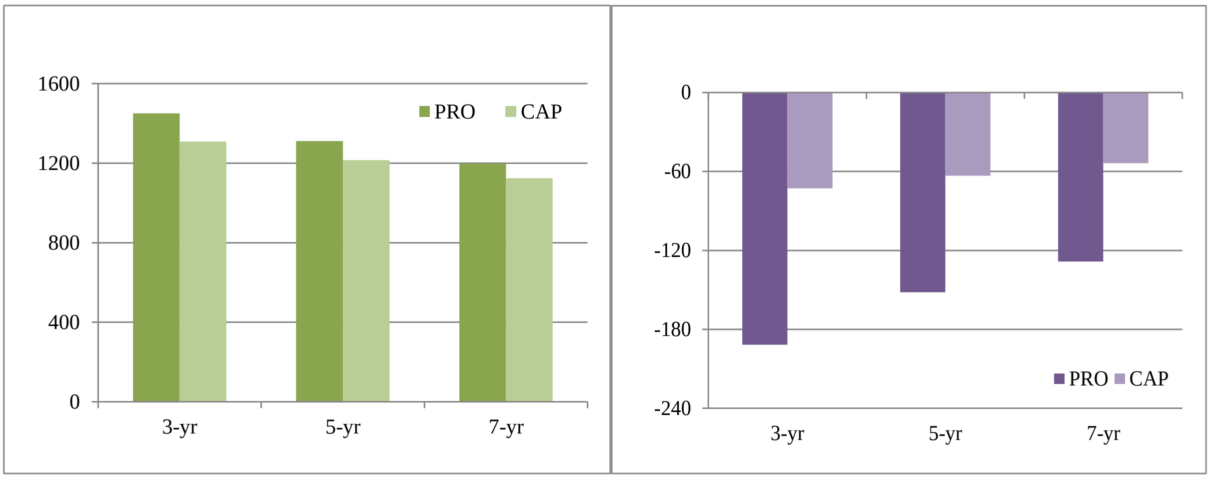

Figure 4.A.7: Fiscal (Left Panel) and Social Costs (Right Panel) of Recovery Programs for Semiconductor Sector with 30% larger σ_i/ψ_i (unit: billion TWD)

CHAPTER 5

Conclusions and Policy Implications

5.1 Summary of Simulation Results

The study used a computable general equilibrium (CGE) model with estimated losses generated by the Taiwan Earthquake Loss Estimation System (TELES) to create a compound disaster scenario for impact assessment and recovery policy simulations. Using a static model, Chapter 3 conducted a disaster sectoral impact assessment. A dynamic model was used in Chapter 4 to examine the effectiveness of the recovery policy and the length of the policy duration. The simulation results provided quantitative implications for both short-run and long-run disaster impacts with the sensitivity tests on each assumed parameter for robustness.

5.1.1 Disaster Impact Assessment

In Chapter 3, a static single-country CGE model was applied to simulate a compound disaster of an earthquake and a power crisis occurring in Taiwan's capital city. The study used the building collapse rates estimated by TELES to assume capital losses and nationwide labor unavailability. The power crisis would result in an 18.4% gap of nuclear power supply to be substituted by other power generation methods with other energy sources. Four scenarios were created for specifying the disaster impact from different shocks.

The simulation results showed that sectors with high factor intensity would be damaged most severely. In the compound disaster scenario, Taiwan's key sectors, semiconductors and chemicals, would suffer the most. In terms of price changes of sectoral output, the most notable finding is a 27% rise of output prices in the electricity sector, as well as a 1–2% rise of prices in all sectors. Moreover, the massive increase of imports by five energy sectors in the power crisis scenario indicated greater fuel demand for power generation. In addition, Taiwan's key sectors, such as semiconductors, electronic equipment, and machinery, generated slight increases in exports, implying their strength in global markets. The compound disaster would yield approximately 17% additional damage compared with the earthquake disaster case and each household would bear 75,590 TWD in the compound disaster scenario.

5.1.2 Investigating Fiscal and Social Costs of Recovery Policy

In Chapter 4, we used a dynamic CGE model to simulate recovery policy on the compound disaster scenario assumed in Chapter 3. We conducted dynamic simulations and examined production and capital-use subsidy policies on the semiconductor, electronic equipment, chemical, and electric power sectors in a compound disaster scenario while setting the program duration for 3, 5, and 7 years. The simulation results show that the semiconductor and electronic equipment sectors could recover with the recovery program while the chemical and electric power sectors could not. By comparing fiscal and social costs, the capital-use subsidy policy and longer policy duration were found to be less costly than the production subsidy policy. On the other hand, for the semiconductor sector, the annual cost of the recovery program was equivalent to about 30% of Taiwanese government expenditure while creating an additional 7% of social costs. The chemical sector could not achieve a recovery, partially owing to its heavy dependence on petroleum inputs, which are used intensively for power generation because of the shutdown of nuclear power plants. The electric power sector could not achieve a recovery, not even with massive subsidies. Moreover, other industries would be sacrificed in the implementation of the recovery policy program. The 7% social losses when pursuing the recovery of the semiconductor sector is as high as 37,411 TWD per household or 3.4% of its income. The study could provide policymakers with advice to develop recovery policies and plans for disaster risk management.

5.2 Policy Implications

The economic impact of a compound disaster has been discussed rarely owing to its complexity and lack of a practical empirical framework for Taiwan. After the 921 Earthquake in Taiwan and the GEJE in Japan, the importance of the indispensability of understanding compound disasters has increased. The macroeconomic framework developed in this dissertation has enabled us to combine the findings and estimates of the direct physical impact of a disaster from an engineering viewpoint with an economic model, which describes how disaster shocks are propagated in an economy and how much indirect losses are generated. Several policy implications are derived in the following subsections.

5.2.1 Disaster Preparedness and Policy Design

By applying the macroeconomic framework, we visualized the consequences of a disaster event. For example, we could quantitatively show the economic impact of loss estimates from many aspects, such as production, energy use, external trade, and social welfare. While mainstream disaster studies focus on the resilience of building losses and infrastructure, this dissertation developed and used a general equilibrium approach to analyze the macroeconomic impact of disaster and construct a disaster risk management framework for both impact assessment and recovery policy planning. Insights obtained by this framework will enable not only the Taiwanese government to improve its preparedness against disasters and capacity for disaster risk management, but also the governments of other countries.

In addition, we could use this framework to design types of policies other than the ones we analyzed. While we examined the effects of government interventions with subsidies from the expenditure side, we could also examine them from the revenue side, following Okiyama, Tokunaga, and Akune (2014). As it takes many years for an economy to recover, we need to find sustainable and politically-feasible revenue sources. The lump-sum direct tax that we assumed could be replaced with more sophisticated taxes so that we could take account of well-balanced tax burden allocations among households with different attributes, such as those by income, region, employment, and demography. By using this framework, the government could manage disaster risk better by preparing policy packages that are targeted at vulnerable sectors.

5.2.2 Up-to-date Disaster Database and Survey

While this dissertation demonstrated the economic impact resulting from one particular compound disaster of an earthquake and power crisis, the scope of this framework could be applied to other types of disasters, for example, mudflows, gas line explosions, and air crashes. Once the framework is developed, we could apply it quickly with new input data of direct disaster shocks to examine new disaster cases, as demonstrated in this dissertation. The government should systematically and regularly undertake the development of a framework for disaster risk analysis. In addition, the disaster data and model framework should be kept up-to-date.

Finally, while the framework in this dissertation adopts a macroeconomic approach, policy analysis and planning would need greater details *within* the macroeconomy. A micro level survey would be useful and complement the macro scope. Detailed information about product transactions in major industries would contribute to the study of supply chains; surveys on foreign direct investment would assist to investigate their interdependence. This effort would bring more accurate and richer information that would enable the government to achieve more efficient and effective resource allocation to those most needed.

5.3 Research Limitations

The current model has limitations in understanding the interdependence of global supply chains and the economic impact of a compound disaster in northern Taiwan from a wider international scope. However, this problem could be resolved by using the Global Trade Analysis Project (GTAP) world trade model in the scope of multicountry or multi-region determined by the level of trade volume with Taiwan, such as Japan, China, the US, and ASEAN nations. In addition, the concept of foreign direct investment could be applied to illustrate the implications for global investment flows.

With such a wider scope, global supply chain risks could be identified. The ex ante risk countermeasure for production allocation could be made more comprehensively. By contrast, for such a global modeling extension, the model could be elaborated through the use of SCGE models so that disaster impact could be scrutinized at a subnational level.

References

Adam, C. 2013. "Coping with Adversity: The Macroeconomic Management of Natural Disasters," *Environmental Science & Policy*, 27S: S99–S111.

ADB 2013. *Investing in Resilience: Ensuring a Disaster-Resistant Future*, Asian Development Bank, Manila.

Akune, Y., M. Okiyama, and S. Tokunaga. 2013. "Evaluation of the Recovery Policy for the Fishery Industry after the Great East Japan Earthquake: A Dynamic CGE Model Approach," *RIETI Policy Discussion Paper Series 13-P-022*. (http://www.rieti.go.jp/jp/publications/pdp/13p022.pdf) [in Japanese]

Armington, P. 1969. "A Theory of Demand for Products Distinguished by Place of Production," *International Monetary Fund Staff Papers*, 16: 159–178.

Bissell, R. 2013. *Preparedness and Response for Catastrophic Disasters*. Taylor & Francis, New York.

Board of Audit of Japan. 2013. *Audit Report for the Recovery Projects and their Implementations for the Great East Japan Earthquake*, Government of Japan, Tokyo. (http://report.jbaudit.go.jp/org/pdf/251031_zenbun_1.pdf) [in Japanese].

Chan, C. and Y. Chen. 2011. "A Fukushima-Like Nuclear Crisis in Taiwan or a Nonnuclear Taiwan?" *East Asian Science, Technology and Society: An International Journal*, 5(3): 403–407.

Chen, Y. 2013. "Non-Nuclear, Low-Carbon, or Both? The Case of Taiwan," *Energy Economics*, 39: 53–65.

Chen, S. 2002. "Global Production Networks and Information Technology: The Case of Taiwan," *Industry and Innovation*, 9(3): 249–265.

Chiu, D. 2013. "Advancing the Production Networks in East Asia," *Modern Management Science & Engineering*, 1(1): 79–99.

Davis, I. (ed.). 2014. *Disaster Risk Management in Asia and the Pacific*. Routledge, London, UK.

Directorate-General of Budget, Accounting and Statistics (DGBAS). 2011a. 2006 I/O Table of Taiwan, Executive Yuan, Taiwan. (http://eng.stat.gov.tw/lp.asp?ctNode=1650&CtUnit=799&BaseDSD=7&MP=5)

Directorate-General of Budget, Accounting and Statistics, (DGBAS). 2011b. Agriculture, Forestry, Fishery and Animal Husbandry Census, Taiwan. (http://eng.stat.gov.tw/lp.asp?CtNode=1634&CtUnit=784&BaseDSD=7&mp=5)

Directorate-General of Budget, Accounting and Statistics, (DGBAS). 2007. Labor Force Statistics by County and Municipality, Taiwan.

(http://win.dgbas.gov.tw/dgbas04/bc4/timeser/shien_f.asp). [in Chinese].

Eiser, R., A. Bostrom, I. Burton, D. Johnston, J. McClure, D. Paton, J. Pligt, and M. White. 2012. "Risk Interpretation and Action: A Conceptual Framework for Responses to Natural Hazards," *International Journal of Disaster Risk Reduction*, 1: 5–16.

Eisner, R. 2014. "Managing the Risk of Compound Disaster," in I. Davis (ed.). *Disaster Risk Management in Asia and the Pacific*, Routledge, London, pp. 137–167.

Executive Yuan. 2006. *Experiences on Post-disaster Reconstruction for the 921 Earthquake*, Taiwan Historica, Taipei.

Fukushige, M. and Yamawaki, H. 2015. "The Relationship between an Electricity Supply Ceiling and Economic Growth: An Application of Disequilibrium Modeling to Taiwan," *Journal of Asian Economics*, 36: 14–23.

Hallegatte, S. 2014. "Economic Resilience: Definition and Measurement," *Policy Research Working Paper 6852*, World Bank, Washington DC.

Henriet, F., S. Hallegatte, and L. Tabourier. 2012. "Firm-Network Characteristics and Economic Robustness to Natural Disasters," *Journal of Economic Dynamics & Control*, 36: 150–167.

Hertel, T. (ed.) 1997. *Global Trade Analysis*, Cambridge, New York.

Hsinchu Science Park. 2011. *The Special Edition for the 30th Anniversary of Hsinchu Science Park*, Science Park Administration. (http://www.sipa.gov.tw/file/20101216143851.pdf) [in Chinese]

Hosoe, N. 2014. "Japanese Manufacturing Facing Post-Fukushima Power Crisis: A Dynamic Computable General Equilibrium Analysis with Foreign Direct Investment," *Applied Economics*, 46(17): 2010–2020.

Hosoe, N. 2006. "The Deregulation of Japan's Electricity Industry," *Japan and the World Economy*, 18(2): 230–246.

Hosoe, N., K. Gasawa, and H. Hashimoto. 2010. *Textbook of Computable General Equilibrium Modelling*, Palgrave Macmillan, London.

Huang, J. and J. Min. 2002. "Earthquake Devastation and Recovery in Tourism: The Taiwan Case," *Tourism Management*, 23: 145–154.

Huang, M., and N. Hosoe 2014. "A General Equilibrium Assessment on a Compound Disaster in Northern Taiwan," *GRIPS Discussion Paper 14-06*. (http://www.grips.ac.jp/r-center/wp-content/uploads/14-06.pdf)

IC Insights. 2014. "Leading-Edge IC Foundry Market Forecast," *Research Bulletin,* September 2014, IC INSIGHTS, INC. (http://www.icinsights.com/data/articles/documents/724.pdf)

Itakura, K. 2012. "The Economic Consequences of Shifting Away from Nuclear Energy," *ERIA*

Policy Brief No. 2011 04, Economic Research Institute for ASEAN and East Asia, Jakarta.

Kajitani, Y., S. Chang, and H. Tatano. 2013. "Economic Impacts of the 2011 Tohoku–Oki Earthquake and Tsunami," *Earthquake Spectra*, 29(S1): S457–S478.

Kajitani, Y. and H. Tatano. 2014. "Estimation of Production Capacity Loss Rate after the Great East Japan Earthquake and Tsunami in 2011," *Economic Systems Research*, 26(1): 13–38.

Kajitani, Y. and H. Tatano. 2009. "Estimation of Lifeline Resilience Factors Based on Surveys of Japanese Industries," *Earthquake Spectra*, 25(4): 755–776.

Kawata, Y. 2011. "Downfall of Tokyo due to Devastating Compound Disaster," *Journal of Disaster Research*, 6(2): 176–184.

Kim, H., M. Chen, and S. Jang. 2006. "Tourism Expansion and Economic Development: The Case of Taiwan," *Tourism Management*, 27: 925–933.

Koike, A., L. Tavasszy, L., K. Sato, and T. Monma. 2012. "Spatial Incidence of Economic Benefit of Road-Network Investments: Case Studies under the Usual and Disaster Scenarios," *Journal of Infrastructure Systems*, 18(4): 252–260.

Lai, M. and Y. Chen. 2000. "The Review of Post-earthquake Residential Reconstruction Policy," in *Chinese Society of Housing Studies 2000 Annual Conference Selected Papers*, pp. 269-278. [in Chinese]. Chinese Society of Housing Studies, Taipei.

Lee, C. and M. Chien. 2008. "Structural Breaks, Tourism Development, and Economic Growth: Evidence from Taiwan," *Mathematics and Computers in Simulation*, 77: 358–368.

Liang, Q., S. Tsuchiya, H. Tatano, N. Okada, and Y. Wei. 2008. "An Application of SCGE Model to Assess the Labour and Capital Related Economic Loss in Nankai Earthquake," *International Journal of Risk Assessment and Management*, 8(4): 412-423.

Lin, H., Y. Kuo, D. Shaw, M. Chang, and T. Kao. 2012. "Regional Economic Impact Analysis of Earthquakes in Northern Taiwan and its Implications for Disaster Reduction Policies," *Natural Hazards*, 61(2): 603–620.

Liu, K., Y. Tsai, and K. Chen. 2013. "Estimation of Seismic Hazard Potential in Taiwan based on ShakeMaps," *Natural Hazards*, 69(3): 2233–2262.

Mai, C., Z. Yu, K. Sun, A. Lin, C. Wang, C. Chen, L. Shue, K. Ma, C. Chong, C. Du, Y. Du, C. Chou, and C. Hsu. 1999. *The Estimation of the 921 Earthquake on Taiwan's Economy,* Chung-Hua Institution for Economic Research, Taipei. [in Chinese]

Narayan, P. 2003. "Macroeconomic Impact of Natural Disasters on a Small Island Economy: Evidence from a CGE model," *Applied Economics Letters*, 10(11): 721–723.

McEntire, D. 2006. *Disaster Response and Recovery*, Wiley, New York.

Nakano, K. and H. Tatano. 2008. "Economic Restoration Process after Natural Disasters under

Mutual Relationships between Industrial Sectors," *Systems, Man and Cybernetics 2008*: 2895–2900.

Noy, I. 2009. "The Macroeconomic Consequences of Disasters," *Journal of Development Economics*, 88: 221–231.

Okiyama, M., S. Tokunaga, and Y. Akune. 2014. "Analysis of Effective Revenue Source to Reconstruct the Disaster-Affected Region of the Great East Japan Earthquake: Utilizing a Two-Regional CGE Model," *Journal of Applied Regional Science*, 18: 1–16. [in Japanese]

Okuyama, Y. 2004. "Modeling Spatial Economic Impacts of an Earthquake: Input–Output Approaches," *Disaster Prevention and Management*, 13(4): 297–306.

Okuyama, Y. and S. Sahin. 2009. "Impact Estimation of Disasters: A Global Aggregate for 1960 to 2007," *Policy Research Working Paper 4963*, World Bank, Washington DC.

Park, Y., P. Hong, and J. Roh. 2013. "Supply Chain Lessons from the Catastrophic Natural Disaster in Japan," *Business Horizons*, 56: 75–85.

Perrow, C. 1999. *Normal Accident: Living with High-Risk Technologies*, 2nd edition, Princeton University Press, New Jersey.

Prater, C. and J. Wu. 2002. "The Politics of Emergency Response and Recovery: Preliminary Observations on Taiwan's 921 Earthquake," *Australian Journal of Emergency Management*, 17: 48–59.

Rodríguez-Vidal, J., J. Rodríguez-Llanes, and D. Guha-Sapir. 2012. "Civil Nuclear Power at Risk of Tsunamis," *Natural Hazards*, 63(2): 1273–1278.

Rose, A. 2011. "Resilience and Sustainability in the Face of Disasters," *Environmental Innovation and Societal Transitions*, 1: 96–100.

Rose, A. 2007. "Economic Resilience to Natural and Man-made Disasters: Multidisciplinary Origins and Contextual Dimensions," *Environmental Hazards*, 7(4): 383–398.

Rose, A. and G. Guha. 2004. "Computable General Equilibrium Modeling of Electric Utility Lifeline Losses from Earthquakes," in Y. Okuyama and S. Chang (eds.) *Modeling Spatial and Economic Impacts of Disasters*, Springer, Heidelberg, pp. 119–141.

Rose, A. and S. Liao. 2005. "Modeling Regional Economic Resilience to Disasters: A Computable General Equilibrium Analysis of Water Service Disruptions," *Journal of Regional Science*, 45(1): 75–112.

SEMI. 2013. *The Power of Taiwan: Taiwan Semiconductor/LED/PV Market*, SEMI Industry Research & Statistics, SEMI Taiwan, Taipei.

Shieh, J. 2004. "Analysis of 921 Post-Earthquake Housing Reconstruction Policies," in *International Conference in Commemoration of 5th Anniversary of the 1999 Chi-Chi*

Earthquake Proceedings, Taipei: National Science Council.

Sue Wing, I. 2011. "Computable General Equilibrium Models for the Analysis of Economy-Environment Interactions," in A. Batabyal and P. Nijkamp (eds.) *Research Tools in Natural Resource and Environmental Economics*, World Scientific, Hackensack, New Jersey, pp. 255–305.

Tatano, H. and S. Tsuchiya. 2008. "A Framework of Economic Seismic Loss Estimation for Transportation Network Disruption," *Journal of Natural Hazards*, 44: 253–265.

Tsai, C. and C. Chen. 2011. "The Establishment of a Rapid Natural Disaster Risk Assessment Model for the Tourism Industry," *Tourism Management*, 32: 158–171.

Tsuchiya, S., H. Tatano, and N. Okada. 2007. "Economic Loss Assessment due to Railroad and Highway Disruptions," *Economic Systems Research*, 19(2): 147–162.

UNISDR. 2009. *2009 UNISDR Terminology on Disaster Risk Reduction*, UNISDR, Geneva.

Vivoda, V. 2014a. "Japan's Energy Security Predicament Post Fukushima," *Energy Policy*, 46: 135–143.

Vivoda, V. 2014b. "LNG Import Diversification in Asia," *Energy Strategy Reviews*, 2: 289–297.

World Bank and Global Facility for Disaster Reduction and Recovery (GFDRR). 2012. *The Sendai Report: Managing Disaster Risk for a Resilient Future*, World Bank, Washington DC.

World Bank. 2010. *Natural Hazards, UnNatural Disasters: The Economics of Effective Prevention*, World Bank, Washington DC.

World Bank. 2005. *Natural Disaster Hotspots: A Global Risk Analysis*, World Bank, Washington DC.

Xie, W., N. Li, J. Wu, and X. Hao. 2014. "Modeling the Economic Costs of Disasters and Recovery: Analysis Using a Dynamic Computable General Equilibrium Model," *Natural Hazards Earth System Science*, 14: 757–772.

Yamazaki, M. and S. Takeda. 2013. "An Assessment of a Nuclear Power Shutdown in Japan Using the Computable General Equilibrium Model," *Journal of Integrated Disaster Risk Management*, 3(1). (http://idrimjournal.com/index.php/idrim/article/viewFile/55/pdf_21)

Yeh, C., C. Loh, and K. Tsai. 2006. "Overview of Taiwan Earthquake Loss Estimation System," *Natural Hazards*, 37(1–2): 23–37.

Zobel, C. and L. Khansa. 2014. "Characterizing Multi-Event Disaster Resilience," *Computers & Operations Research*, 42: 83–94.

Annex: Details of the Model

The model system and formula used in the dissertation are stated in the following section. For the dynamic model, the time suffix t is not shown for simplicity unless needed.

Type of goods and factors, etc., in suffix	Symbol	Abbreviations
Sectors	i, j	AGR, PAG, MIN, COA, FOD, TXA, WPP, PET, CHM, CHM, POT, STL, MET, SEC, EEQ, MCH, TEQ, MAN, ELY, TWG, CON, TRS, SRV
Energy goods	ei, ej	PAG, PET, COA, ELY, TWG
Nonenergy goods for the industries	ni, nj	$\{ i \} \setminus \{ ei \}$
Energy goods for households	$ei2$, $ej2$	PAG, PET, ELY, TWG
Nonenergy goods for the household	$ni2$, $nj2$	$\{ i \} \setminus \{ ei2 \}$
Nonelectricity goods	ne	$\{ i \}\setminus$ELY
Factor	h, k	CAP, LAB
Mobile factor	h_mob	LAB
Time period	t	0, 1, 2, …, 30

Endogenous variables

Y_j	Composite factor used by the j-th sector
$F_{h,j}$	The h-th factor input by the j-th sector
$X_{i,j}$	Intermediate input of the i-th good by the j-th sector
Z_j	Output of the j-th good
X_i^p	Household consumption of the i-th good
X_i^g	Government consumption
X_i^v	Input for composite investment good production
X_i^e	Energy composite used by the i-th sector
X^{pe}	Energy composite used by the household
E_i	Exports of the i-th good
M_i	Imports of the i-th good
Q_i	Armington's composite good
D_i	Domestic good
$p_{h,j}^f$	Price of $F_{h,j}$
p_j^y	Price of Y_j
p_i^e	Export price (in local currency)
p_i^m	Import price (in local currency)
p_i^d	Price of D_i
p_{ne}^{xe}	Price of X_{ne}^e
p^{xpe}	Price of X^{pe}
p_i^q	Price of Q_i
p_j^y	Price of Y_j
p_j^z	Price of Z_j
p_i^k	Price of the composite investment good, III
ε	Exchange rate
T^d	Direct tax revenue
T_j^z	Production tax revenue from the j-th sector

T_i^m Import tariff revenue from the i-th good imports

$T_{h,j}^f$ Factor tax revenue from the uses of the h-th factor by the j-th sector

UU Utility

ep Scale utility

II_i Sectoral investment in the i-th sector

III Composite investment good

S^p Private saving

KK_i Capital stock in the i-th sector

CC Composite consumption or felicity

Exogenous variables

τ_i^z	Production tax rate
τ_i^m	Import tariff rate
$\tau_{h,j}^f$	Factor tax rate for the h-th factor use by the j-th sector
$FF_{h,j}$	Factor endowment of the h-th factor in the j-th sector
S^f	Foreign saving (in US dollars)
p_i^{We}	World export price (in US dollars)
p_i^{Wm}	World import price (in US dollars)

Parameters

σ_i	Armington's elasticity of substitution between imports and domestic goods
σ^e	Elasticity of substitution among energy sources
ψ_i	Elasticity of transformation between exports and domestic goods
η_i	Substitution elasticity parameter (= $(\sigma_i - 1)/\sigma_i$)
ϕ_i	Transformation elasticity parameter (= $(\psi_i + 1)/\psi_i$)
χ	Substitution elasticity of energy goods (=$(\sigma^e - 1)/\sigma^e$)
pop	Population growth rate
ror	Rate of return of capital
dep	Depreciation rate
ς	Elasticity parameter for sectoral investment allocation

[Domestic production]

Composite factor production function (Cobb–Douglas)

$$Y_j = b_j \prod_h F_{h,j}{}^{\beta_{h,j}} \qquad \forall j$$

Factor demand function (Cobb–Douglas)

$$F_{h,j} = \frac{\beta_{h,j} p_j^y}{\left(1 + \tau_{h,j}^f\right) p_{h,j}^f} Y_j \qquad \forall h,j$$

Intermediate good demand function for nonelectricity sectors

$$X_{ni,ne} = ax_{ni,ne} Z_{ne} \quad \forall ni, ne$$

The energy composite good demand function for nonelectricity sectors

$$X_{ne}^{e} = ax_{ne}^{e} Z_{ne} \quad \forall ne$$

Intermediate good demand function for the electricity sector (ELY)

$$X_{i,ELY} = ax_{i,ELY} Z_{ELY} \quad \forall i$$

The unit cost function for nonelectricity sectors

$$p_{ne}^{z} = ay_{ne} p_{ne}^{y} + \sum_{ni} ax_{ni,ne} p_{ne}^{q} + ax_{ne}^{e} p_{ne}^{xe} \quad \forall ne$$

The unit cost function for the electricity sector (ELY)

$$p_{ELY}^{z} = ay_{ELY} p_{ELY}^{y} + \sum_{i} ax_{i,ELY} p_{i}^{q}$$

[Household consumption]

Household demand for nonenergy goods

$$X_{ni2}^{p} = \frac{\alpha_{ni2}}{p_{ni2}^{q}} \left(\sum_{h,j} p_{h,j}^{f} FF_{h,j} - S^{p} - T^{d} \right) \quad \forall ni2$$

Household demand for the energy composite good

$$X^{pe} = \alpha^{e} \left(\sum_{h,j} p_{h,j}^{f} FF_{h,j} - S - T^{d} \right) / p^{xpe}$$

[Felicity/Composite consumption good production function]

$$CC = a \left(\prod_{i} X_{i}^{p^{\alpha_i}} \right) \left(X^{pe^{\alpha^{e}}} \right)$$

[Energy Composite Aggregation]

The energy composite aggregation function for nonelectricity sectors

$$X_{ne}^{e} = o_{ne}\left(\sum_{ei} \kappa_{ei,ne} {X_{ei,ne}}^{\chi}\right)^{1/\chi} \qquad \forall ne$$

The energy good demand function for nonelectricity sectors

$$X_{ei,ne} = \left(\frac{{o_{ne}}^{\chi} \kappa_{ei,ne} p_{ne}^{xe}}{p_{ei}^{g}}\right)^{1/(1-\chi)} X_{ne}^{e} \qquad \forall ei, ne$$

The energy composite aggregation function for the household

$$X^{pe} = o^{p}\left(\sum_{ei2} \kappa_{ei2}^{p} X_{ei2}^{p\chi}\right)^{1/\chi}$$

The energy goods demand for the household

$$X_{ei2}^{p} = \left(\frac{{o^{p}}^{\chi} \kappa_{ei2}^{p} p^{xpe}}{p_{ei2}^{q}}\right)^{1/(1-\chi)} X^{pe} \qquad \forall ei2$$

[Government behavior]

Factor tax revenue

$$T_{h,j}^{f} = \tau_{h,j}^{f} p_{h,j}^{f} F_{h,j} \qquad \forall h, j$$

Lump-sum direct tax revenue

$$T^{d} = \sum\nolimits_{i} p_{i}^{q} X_{i}^{g} + S^{g} - \left(\sum\nolimits_{i} T_{i}^{m} + \sum\nolimits_{i} T_{i}^{z} + \sum\nolimits_{h,j} T_{h,j}^{f}\right)$$

Import tariff revenue

$$T_{i}^{m} = \tau_{i}^{m} p_{i}^{m} M_{i} \qquad \forall i$$

Indirect tax revenue

$$T_{j}^{z} = \tau_{j}^{z} p_{j}^{z} Z_{j} \qquad \forall j$$

[International Trade]

Export and import prices and the exchange rate

$$p_i^e = \varepsilon p_i^{We} \quad \forall i$$

$$p_i^m = \varepsilon p_i^{Wm} \quad \forall i$$

Balance-of-payments constraint

$$\sum_i p_i^{We} E_i + S^f = \sum_i p_i^{Wm} M$$

Armington composite good production function

$$Q_i = \gamma_i (\delta m_i M_i{}^{\eta_i} + \delta d_i D_i{}^{\eta_i})^{1/\eta_i} \quad \forall i$$

Import demand function

$$M_i = \left(\frac{\gamma_i{}^{\eta_i} \delta m_i p_i^q}{(1 + \tau_i^m) p_i^m} \right)^{1/(1-\eta_i)} Q_i \quad \forall i$$

Domestic good demand function

$$D_i = \left(\frac{\gamma_i{}^{\eta_i} \delta d_i p_i^q}{p_i^d} \right)^{1/(1-\eta_i)} Q_i \quad \forall i$$

Gross domestic output transformation function

$$Z_i = \theta_i \left(\xi e_i E_i{}^{\phi_i} + \xi d_i D_i{}^{\phi_i} \right)^{1/\phi_i} \quad \forall i$$

Export supply function

$$E_i = \left(\frac{\theta_i{}^{\phi_i} \xi e_i (1 + \tau_i^z) p_i^z}{p_i^e} \right)^{1/(1-\phi_i)} Z_i \quad \forall i$$

Domestic good supply function

$$D_i = \left(\frac{\theta_i{}^{\phi_i} \xi d_i (1 + \tau_i^z) p_i^z}{p_i^d} \right)^{1/(1-\phi_i)} Z_i \quad \forall i$$

[Dynamic Equations]

Composite investment good production function

$$III = \iota \prod_i X_i^{v\lambda_i}$$

Sectoral investment allocation for the j-th sector

$$p^k II_j = \frac{p_{CAP,j}^{f}{}^{\zeta} F_{CAP,j}}{\sum_i p_{CAP,i}^{f}{}^{\zeta} F_{CAP,i}} (S^p + \varepsilon S^f) \quad \forall j$$

Capital accumulation

$$KK_{j,t+1} = (1 - dep)KK_{j,t} + II_{j,t} \quad \forall j, t$$

[Market-clearing condition]

Armington's composite good market-clearing condition

$$Q_i = X_i^p + X_i^g + X_i^v + \sum_j X_{i,j} \quad \forall i$$

Capital service market-clearing condition

$$F_{CAP,j} = rorKK_j \quad \forall j$$

Labor market-clearing condition

$$\sum_j F_{h\_mob,j} = \sum_j FF_{h\_mob,j} \quad \forall h\_mob, j$$

$$p_{h\_mob,j}^f = p_{h\_mob,i}^f \quad \forall i, j$$

Investment good market-clearing condition

$$\sum_j II_j = III$$

Utility function (static model)

$$UU = \left(\prod_i X_i^{p\alpha_i}\right)\left(x^{pe\alpha^e}\right)$$

Felicity/composite consumption good production function (dynamic model)

$$CC = a\left(\prod_i X_i^{p\alpha_i}\right) * \left(X^{pe^{\alpha^e}}\right)$$