Impact assessment and a fiscal recovery policy for tsunami risk: GIS and the general equilibrium approach in Hakodate City, Japan

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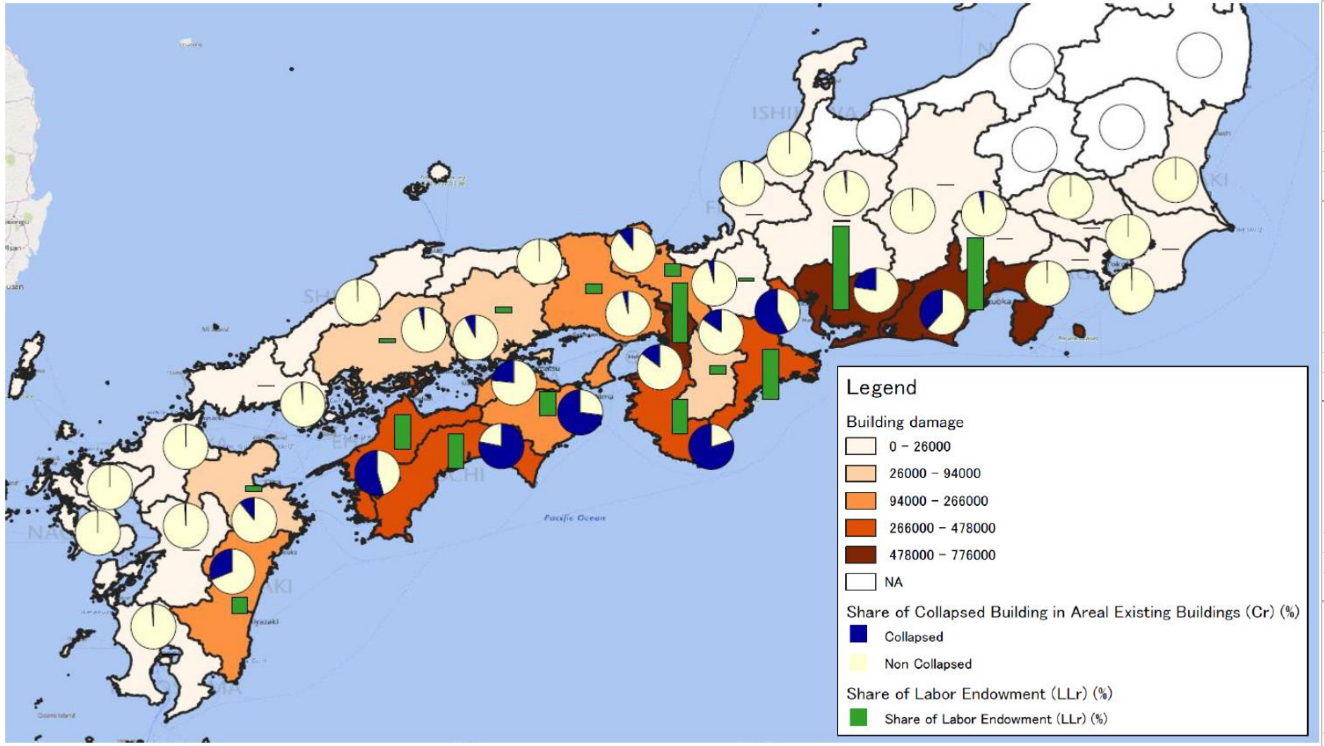
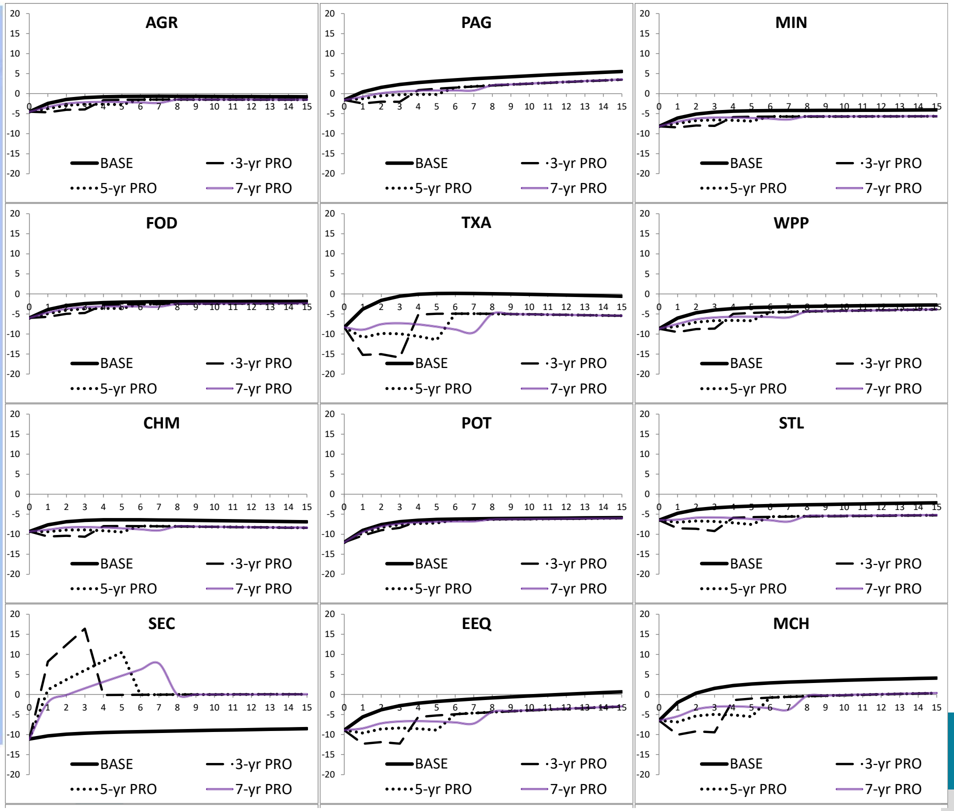
Outlines

- **Motivation**
  - ➢ Research area
- **Methodology**
  - ➢ Damage estimate: GIS, Census data, Hazard map
  - ➢ Recursive CGE model
- **Simulation results**
  - ➢ Identify the sectoral vulnerabilities
  - ➢ Estimate the costs required for recovery and social welfare analysis
- **Concluding remarks**

Motivations

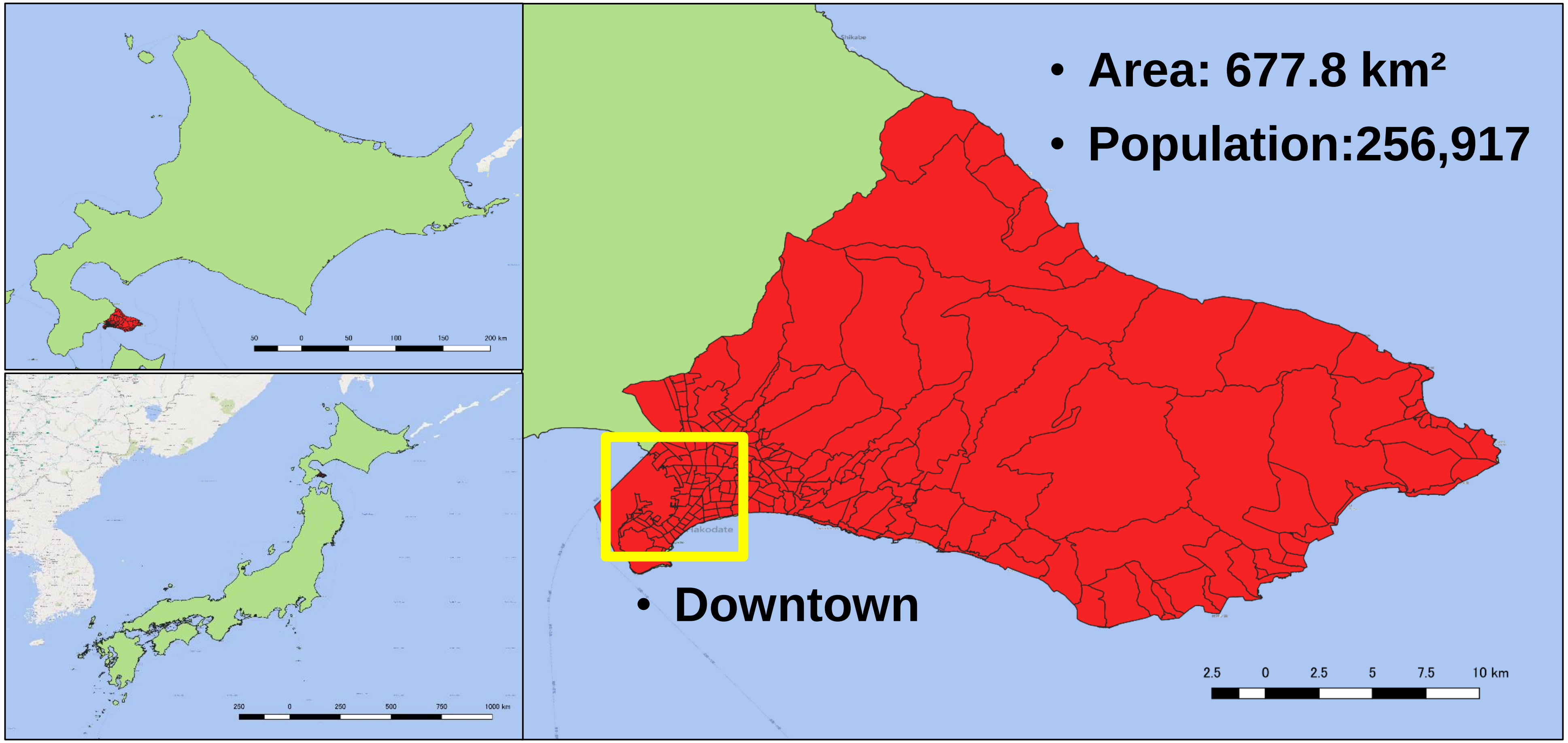
- Ocean related natural disasters, such as Tsunami should be tackled with cautions, the effective plan for resilience investment is desirable.
- Evidence-based and visualized approach for recovery would assist policy makers to allocate resources or call for financing options.





Source: Developed by authors based on Cabinet Office of Japan (2017)

Research area: South of Hokkaido - Hakodate City



- Major city in Southern Hokkaido.
- Famous for Kelp, Squid and Tourism.
- The most attractive city in Japan (2018).

Flood damage of Tsunami in Hakodate-city

Morning market in Hakodate

The Great East Japan Earthquake and Tsunami (2011)

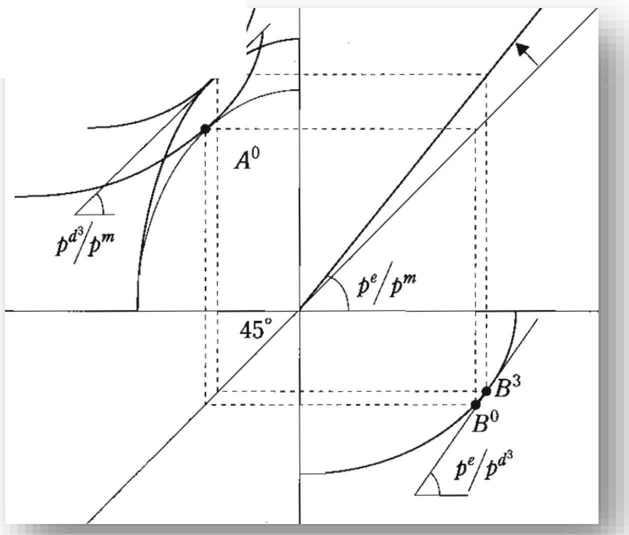
- Hakodate City is highly exposed to Tsunamis (eg. 1960, 1968, 2011).
- 12 million USD losses in 2011 by Tsunami.
- The large-scale earthquake or tsunami can happen within 30 years with relatively high probability nearside Hakodate City.
- Effective disaster risk reduction policy desirable.

Analytical flow

Supply of Output

Input for a specific product

	Wheat	Wheat Flour	Bread	Con-sumption	Total Products
Wheat	0	10	0	0	10
Wheat Flour	0	0	25	0	25
Bread	0	0	0	40	40
Salary & Profit	10	15	15		
Total Products	10	25	40		



1. Input-output Table

- 36 sectors
- Social accounting matrix
- Economic structure

2. GIS Analysis

- 13,795 offices (97 sectors)
- Tsunami Hazard Map
- Damage estimate

3.CGE modeling

- Aggregate into 16 sectors
- **Impact assessment**
- **Recovery process**

Summary of data in use

No.	Name of Data	Source	Spatial Scale	Year
1	Tsunami Hazard Map	Hokkaido Bosai Information	10m	2012
2	Land Usage Map	Geospatial Information Authority	100m	2012
3	Office Data	Economic Census	Street, District	2016
4	Building Types	Hakodate City	City	2016
5	Damage Definition	Hakodate City	Japan	2012
6	Input-Output Table	Asakawa et al. 2006	City	2005

Process to estimate capital and labor losses

① **The number of offices and employees by street or district (Census)**

② **Tsunami hazard map:** The average height of flooding area

③ **The land usage map:** Identify the geographical location of offices.

④ **The rate of building area covered by Tsunami (②＋③):**
To estimate the ratio of office area covered by Tsunami.

⑤ **The ratio of buildings(wooden or non-wooden) in Hakodate city:**
To categorize damages by type of buildings

⑥ **Tsunami damage classifications:**
To categorize damages by height and types of buildings

① The information of the number of offices and employees by street or district.

- Each point (211) has the number of offices and labor of 97 industries in each district in 2016.

② Tsunami hazard map

- An assumed Mw 9.1 earthquake occurred in southeast of Hokkaido Pacific rim (approx. 350 km from Hakodate City).
- 189,660 samples ($10m^2$)
- Min: 0.01m
- Max:15.75m
- Ave: 3.1m

③ The land usage map

- Building area defined by satellite image can be assumed to contain all offices.

④ Building area covered by Tsunami (merge of ② and ③)

- Calculate the average coverage rate of Tsunami in buildings area in each district.
- By multiplying with ①, the estimate number of offices damaged by Tsunami can be estimated.

⑤ The ratio of buildings in Hakodate city (wooden or non-wooden)

- Damage to buildings differs by the type of buildings.
- The ratio applies to all Hakodate city as estimation rate.

The ratio of buildings in Hakodate city (2014)

	Number of existing buildings	Percentage
Wooden	98,925	79.2%
Non-Wooden	25,960	20.8%

Authors calculated from the summary of tax revenue in Hakodate city(2014)

⑥ Tsunami damage classifications

Damage classifications

Damage Category	Flooded Height(H)	
	Wooden Buildings	Non-Wooden Buildings
Fully collapse	2.0m≦H	n.a.
Half collapse	1.0m≦H<2.0m	n.a.
High flooding	0.5m≦H<1.0m	0.5m≤H
Low flooding	0.0m<H<0.5m	0.0m<H<0.5m

Source: Hakodate City (2012)

Damage classifications*

Damage Category	Flooded Height(H)	
	Wooden Buildings	Non-Wooden Buildings
100%	2.0m≦H	4.0m≦H
50%	1.0m≦H<2.0m	2.0m≦H<4.0m
25%	0.5m≦H<1.0m	0.5m≦H<2.0m
0%	0.0m<H<0.5m	0.0m<H<0.5m

*Estimated by authors

Data for policy simulations

Abbreviation	Sector
AGR	Agriculture, Forest and mining
SWD*	**Kelp**
NEF*	**Fixed Net-fishery**
SQI*	**Squid**
FIS*	**Other fishery**
PRO*	**Food processing**
TEX	Texitle
PET	Petroleum & chemical
MAE	Metal & machinery
MDU	Education & medical service
CON	Construction
ELY	Electricity
COM	Commerce & financing
TRS	Transportation & communication
SRV	Public service
REC*	**Recreation (Restaurant & hotel)**
Labor	**Labor endowment**

*Ocean-related sectors

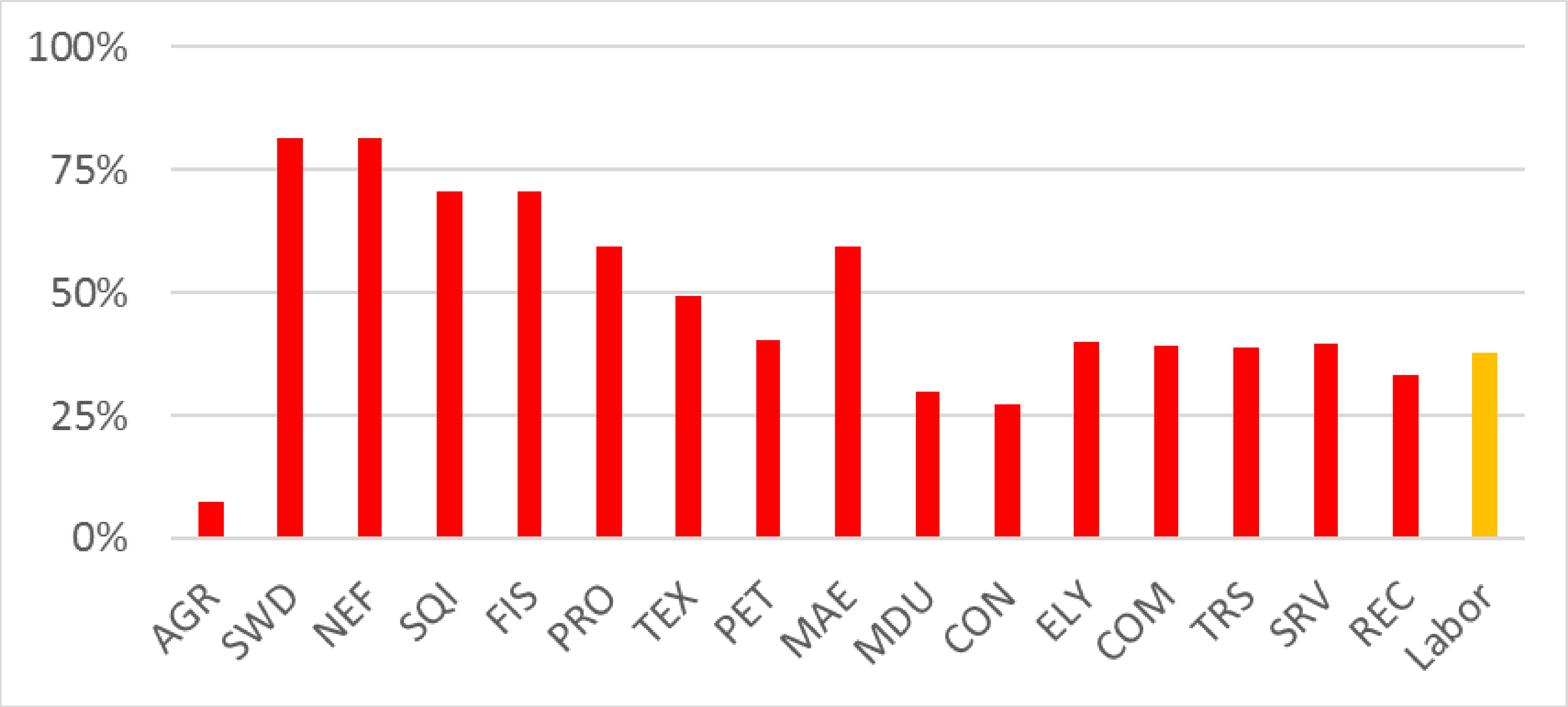
- **The 2005 input-output table** of Hakodate City (specific categories for fishery and recreation sectors)
- Estimated the loss of offices & employees in 97 industries by the tsunami by the max height assumption in each district

The sectoral impact of the tsunami under the flooded area

Sector	Wooden building				Non-wooden building				Total stock	**Total impact**
	0-0.5 m	0.5-1 m	1-2 m	> 2 m	0.5-2 m	2-4 m	4-6 m	> 6 m		
	(-0%)	(-25%)	(-50%)	(-100%)	(-0%)	(-25%)	(-50%)	(-100%)		
AGR	0.1	0	0	1.7	0	0	0.2	0.3	27	**-7.6%**
SWD	0	0	0	1.9	0	0	0	0.5	3	**-81.3%**
NEF	0	0	0	1.9	0	0	0	0.5	3	**-81.3%**
SQI	0	0	0.5	9.1	0	0.3	0	2.5	17	**-70.7%**
FIS	0	0	0.5	9.1	0	0.3	0	2.5	17	**-70.7%**
PRO	0.1	0.4	0.1	103	0	0.3	2.4	26.3	220	**-59.4%**
TEX	0	0.4	0.8	79.2	0	0.7	5.2	16.9	202	**-49.2%**
PET	0	0	0	5	0	0	0.7	0.7	15	**-40.2%**
MAE	0	0.4	0.6	82.4	0	0.5	4.1	18.8	175	**-59.3%**
MDU	1	3.2	9.1	362.4	0.3	7.2	19.6	81.4	1,538	**-30.0%**
CON	0.4	2.8	6.3	260.5	0.1	5.2	10.3	62.3	1,224	**-27.2%**
ELY	0	0	0	5.4	0	0	0.2	1.3	17	**-40.1%**
COM	2.4	14.5	23.6	1,491.8	0.7	21.9	72.5	343.3	4,844	**-39.1%**
TRS	0.1	0.4	0.4	115.1	0	0.4	2.8	29.3	375	**-39.0%**
SRV	0.8	1.5	8.2	476.6	0.2	5.6	24.3	108.6	1,522	**-39.6%**
REC	1.8	9	16	938.1	0.5	14.4	30.7	230.8	3,616	**-33.1%**
Labor	69	280	535	37,070	19	227	1410	8,924	124,215	**-37.9%**

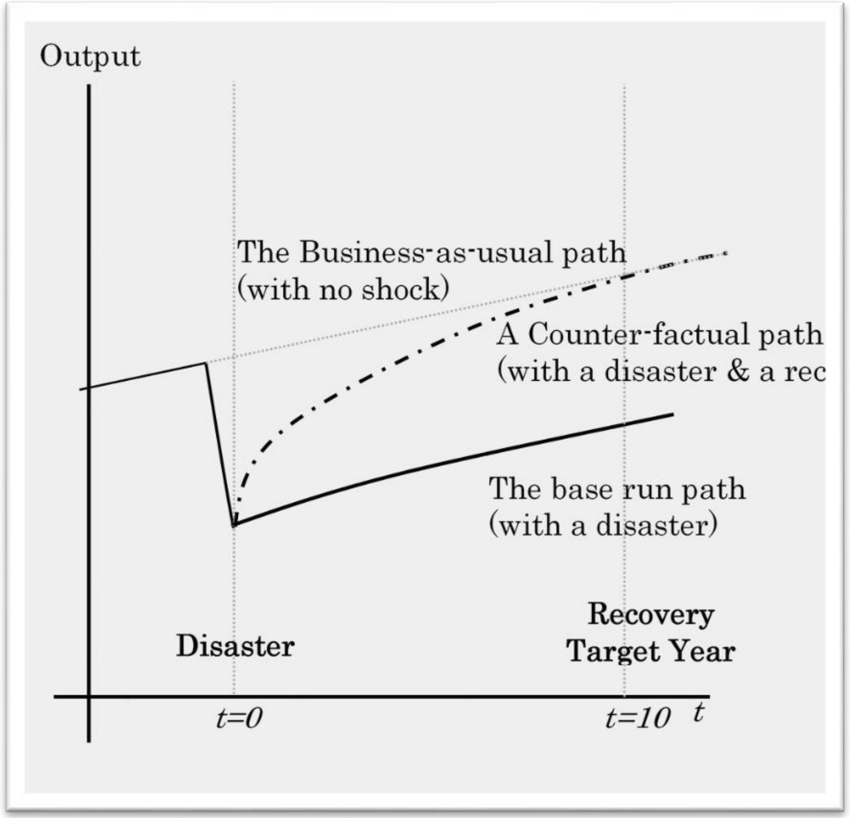
Source: Calculated by the authors.

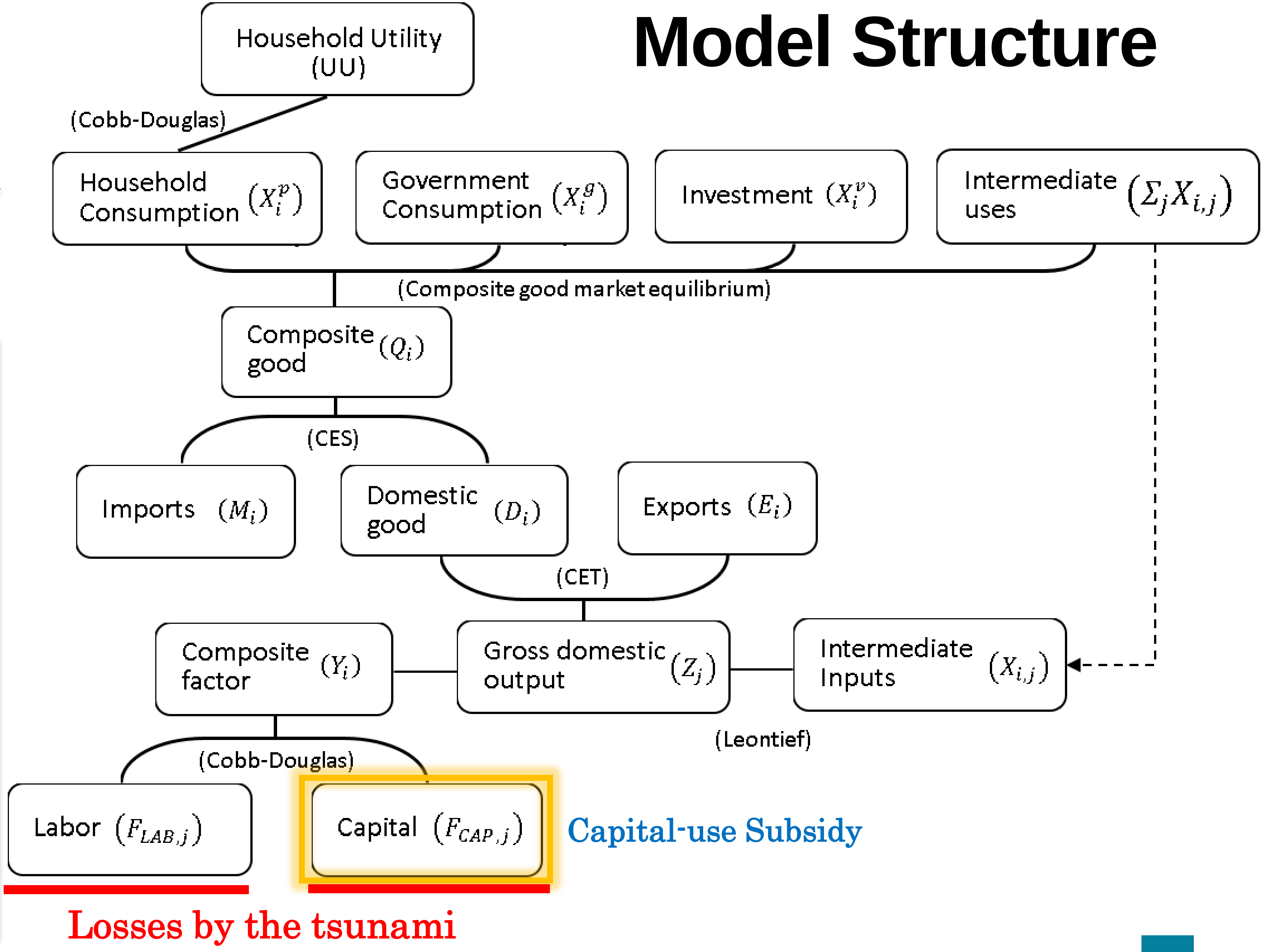
Assumed sectoral damage by tsunami



*Due to data limitation, the damage on NEF and FIS are assumed equivalent with SWD and SQI respectively

Model Structure





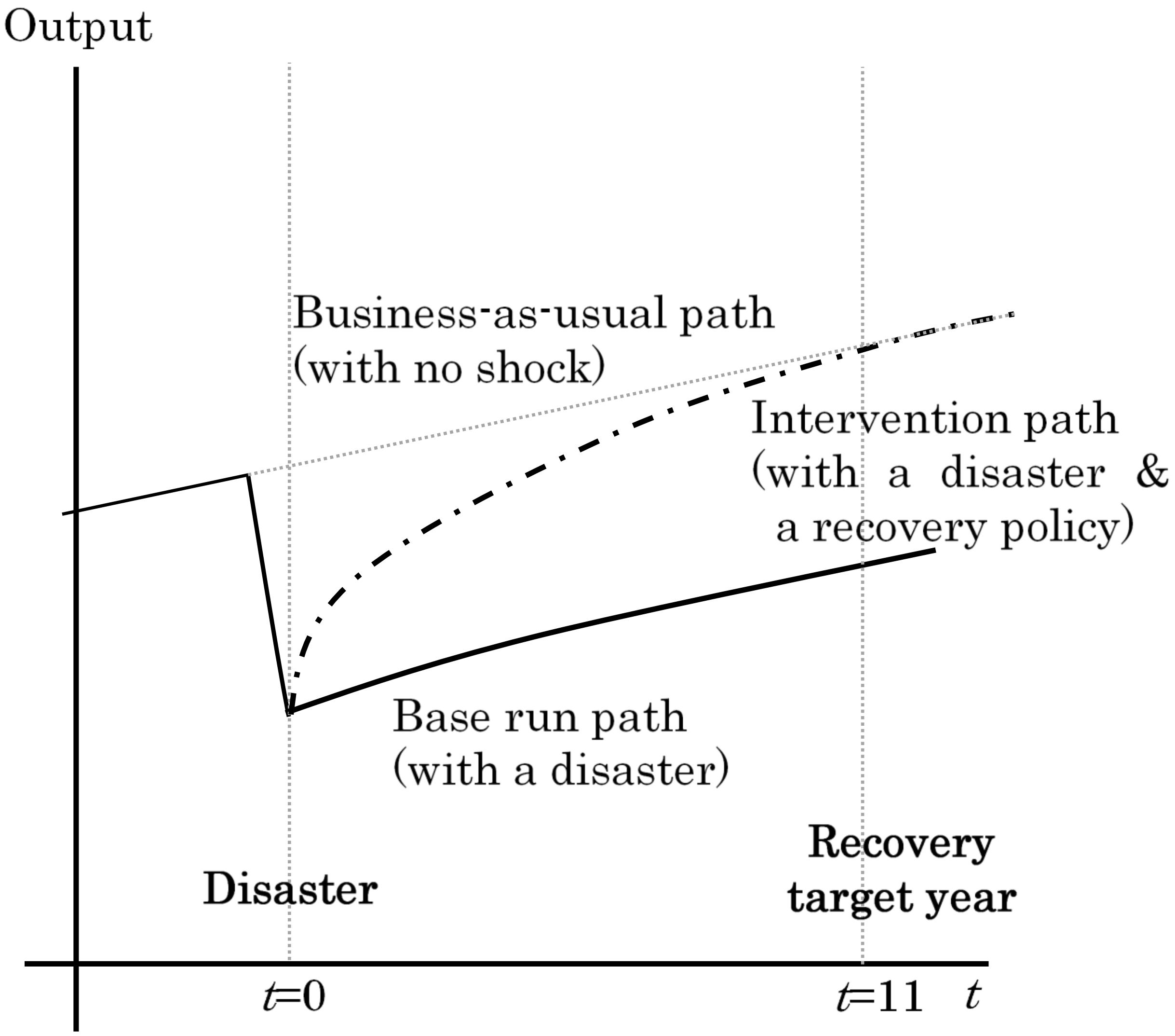
Source: Revised by authors based on Huang & Hosoe (2016, 2017)

Scenarios for policy simulations

- **10-year recovery policy for ocean-related sectors:**
  - SWD (Kelp), NEF (Fixed Net-fishery),
  - SQI (Squid), FIS (other fishery),
  - PRO (food processing [agriculture & fishery]),
  - REC (recreation [restaurant & hotel])
- **Recursive modelling assumptions:**
  - Capital factor: ***immobile*** [could only be increased by investment]
  - Labor factor: ***mobile***, could recover 75% every year, fully recover in 5-th year.

Recovery policy:

- Capital-use subsidy:
  To add back the damaged capital stock
- Target year:
  To resume the output level as ***pre-disaster*** in the **11th year**.



- Gross domestic output transformation function:

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

where Z_i = sectoral output; ξ = share parameter; E_i = export good;
D_i = domestic good, e_i = exchange rate; ϕ_i = trans. elasticity parameter

- The welfare function is determined by:

$$ep(p^q, UU) = \min_{XP}\{p^q \cdot | UU(X^p) = UU\}$$
$$EV = ep(p^q, UU^1) - ep(p^q, UU^0)$$

where $ep(\cdot)$: expenditure function; X^p: consumption vector, p^q: price vector;
UU: utility level (given); $UU(\cdot)$: utility function

Model scope: Inter-temporal Model Structure

$$p_{i,t}^{q} II_{i,t} = \frac{{p_{CAP,i,t+1}^{f}}^{\zeta} F_{CAP,i,t+1}}{\sum_j {p_{CAP,j,t+1}^{f}}^{\zeta} F_{CAP,j,t+1}} \left(S_t^p + \varepsilon_t S_t^f \right)$$

$p_{i,t}^{q}$ price of Armington composite goods $II_{i,t}$ sectoral investment in the *i*-th sector

$p_{CAP,i,t+1}^{f}$ $F_{CAP,i,t+1}$ price and the amount of capital service in the *i-th* sector in the next period

S_t^p private savings, which are generated with a constant saving propensity

S_t^f foreign savings in the foreign currency converted with an exchange rate ε_t are spent in purchasing investment goods

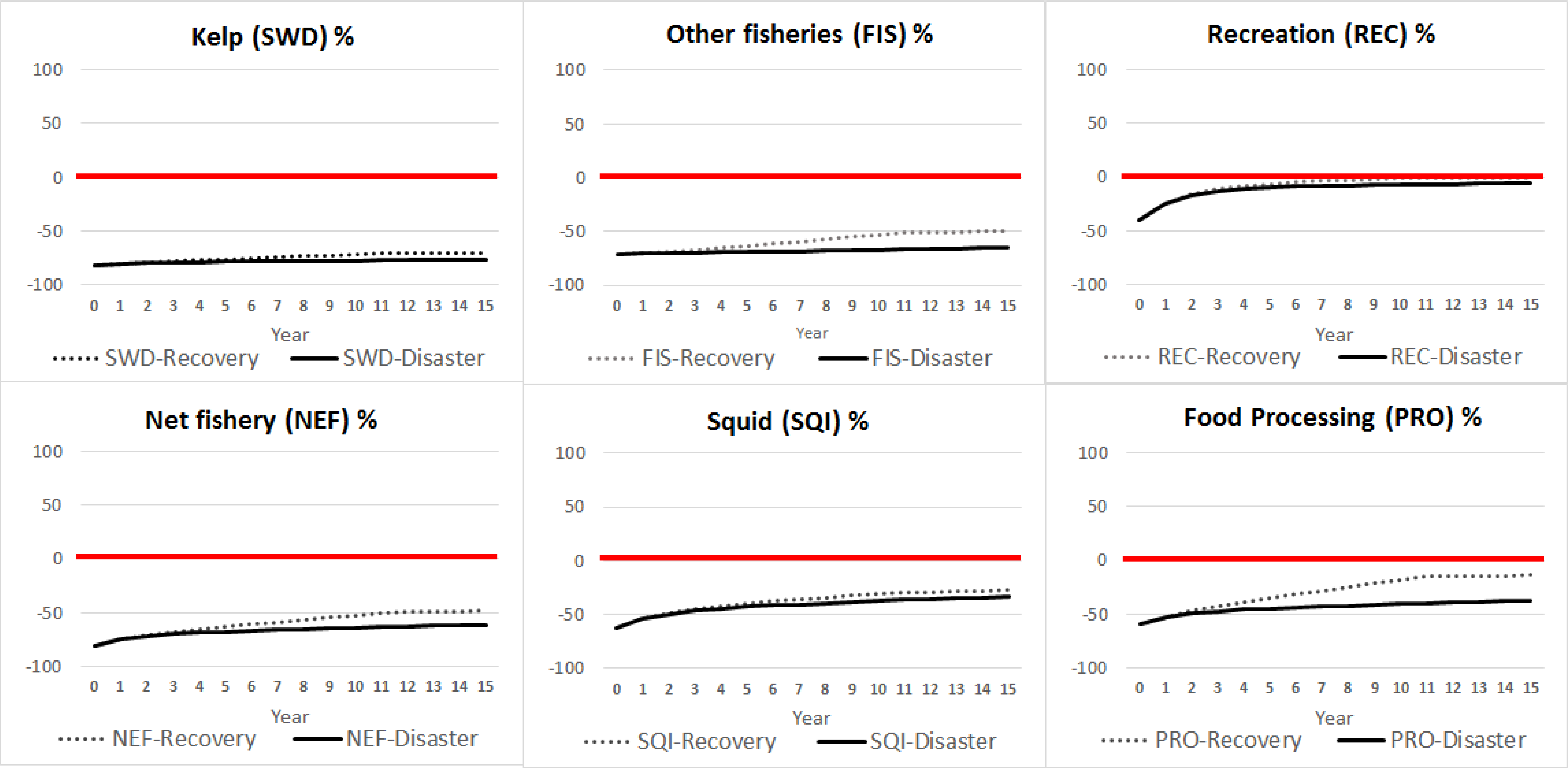
n population growth rate

ζ elasticity parameter that determines sensitivity of sectoral investment allocation to a gap of sectoral rate of returns

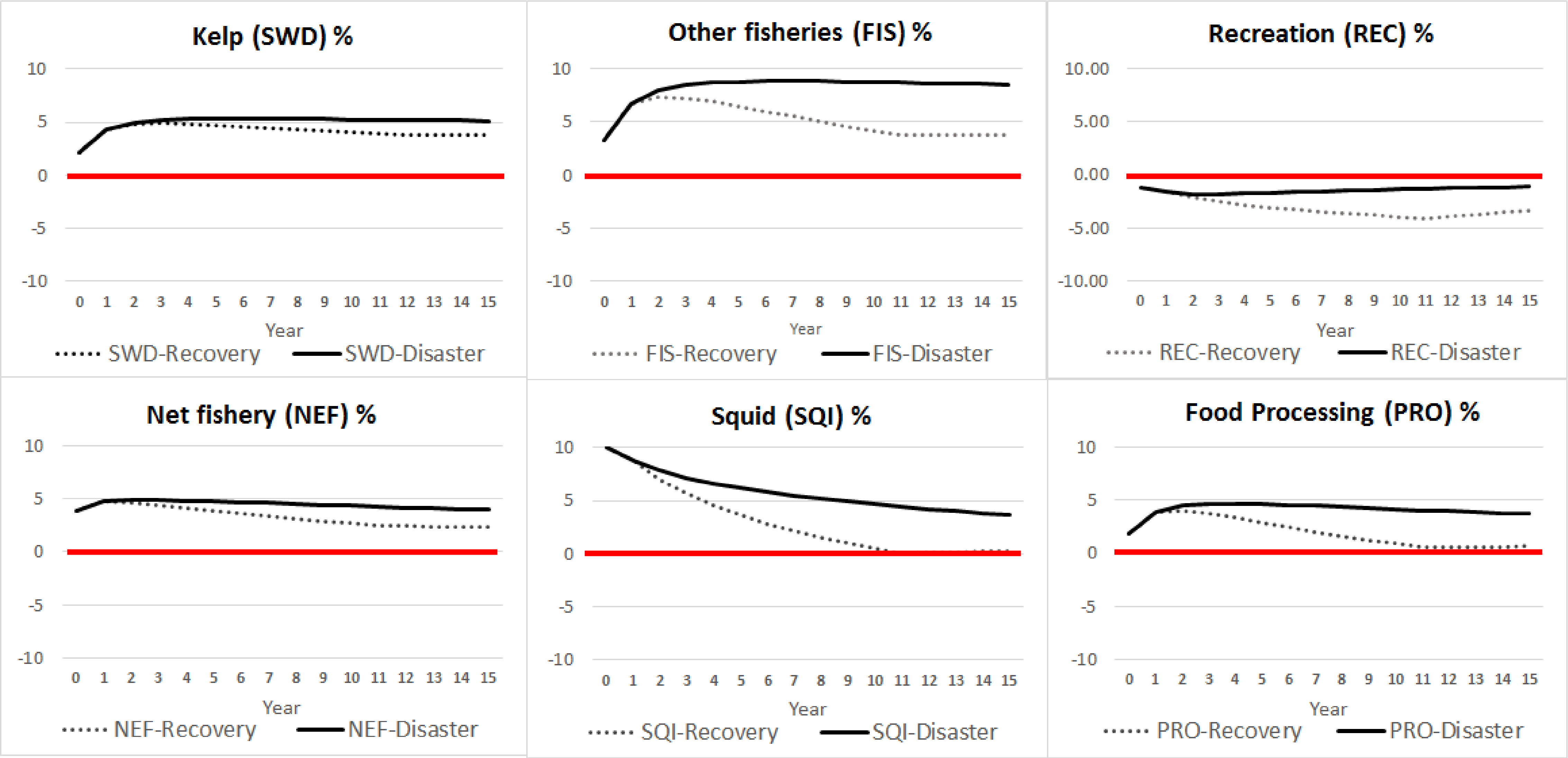
The capital-use subsidy rate for a 10-year recovery policy

	SWD	SQI	NEF	FIS	PRO	REC
Subsidy rates	31%	30%	34%	42%	47%	34%
Recovery to BAU	No	No	No	No	Almost	Yes

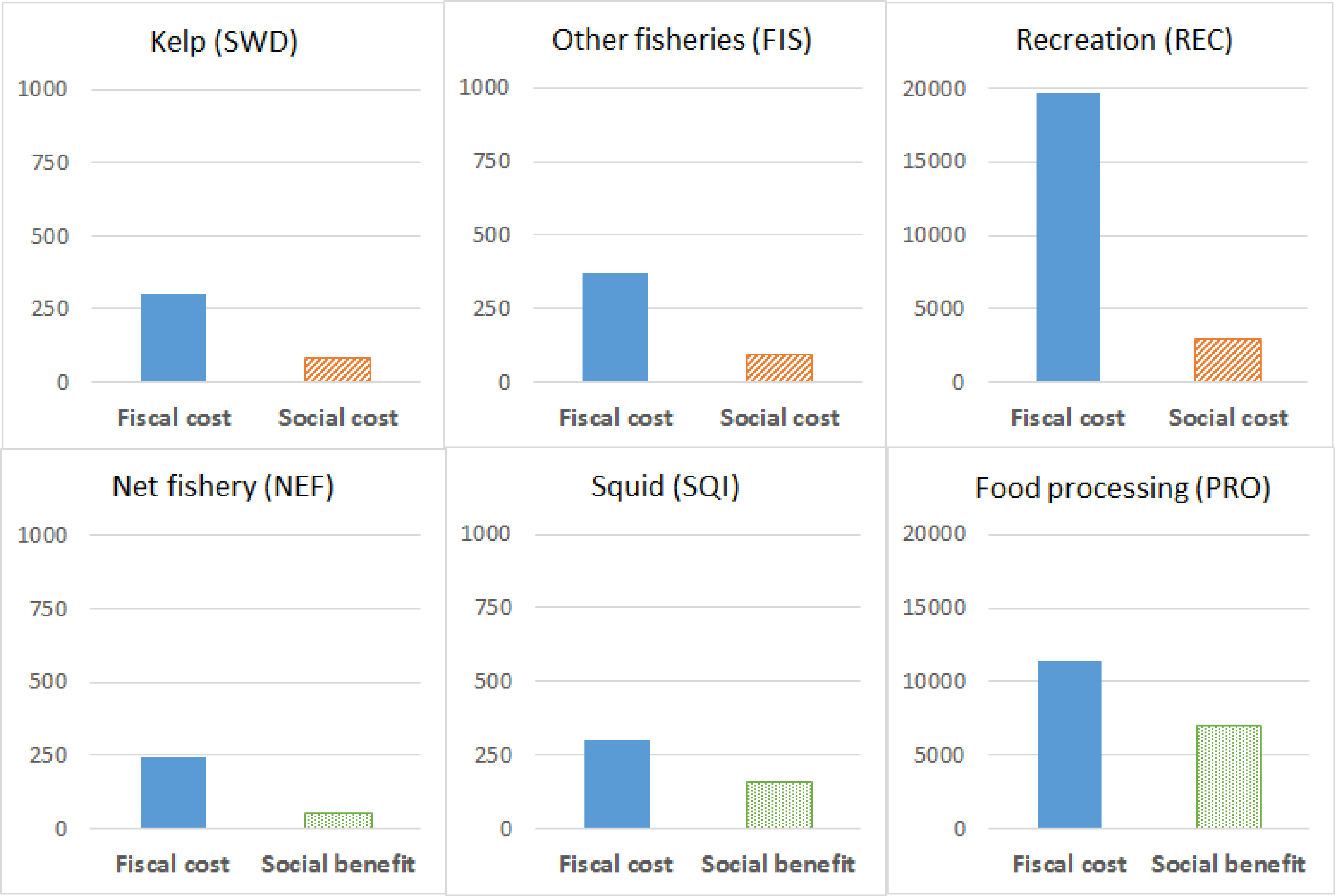
The recovery paths (output change)



The recovery paths (output price change)



Fiscal cost and social cost/benefit (unit: mil. JPY)



Concluding remarks & Policy Implications

- The ***CGE model***, together with ***hazard map*** and ***industry census*** could visualize and quantify the disaster impact with DRR recommendations.
- The aquaculture sectors: **Fishery (FIS), Squid (SQI) Kelp (SWD)** and **Fixed-net Fishery (NEF)** are ***extremely vulnerable*** and could not recover within the Hakodate's capacity, ***require special measures/mechanism*** to reduce disaster risk.
- **Food processing sector (PRO)** requires huge support to recover, but could generate notable social benefits (with increase of **(SQI)**), such sector **should be promoted**.

Policy implications

- More scenarios of **DRR measures** (eg. **Dyke construction, building reinforcement**) should be made available, awareness and DRR could be quantified.
- ***Investing in resilience could ensure prosperous economy:*** The simulation results could also provide city with development potential.

Limitation and future perspectives

- The assumption of building category and factor endowment could be oversimplified (which is already the best level we could grant)
- The research could be expanded for larger scale, such as county (prefecture), or the vulnerability and resilience index could be defined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