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Prototype of private enterprise capital stock model by industry for predicting economic damage caused by earthquakes and tsunamis

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Abstract

In Cross-ministerial Strategic Innovation Promotion Program (SIP), NIED is developing an economic damage prediction system for the purpose of supporting early economic recovery after the Nankai Trough earthquake. This system predicts economic damage (direct damage and indirect damage) due to earthquakes and tsunamis based on real-time hazard information of ground motions and tsunamis. In order to predict economic damage, it is necessary to calculate the amount of damage to capital stock due to seismic motion and tsunami inundation depth. There is a problem that the previous stock model does not have sufficient spatial resolution for damage prediction reflecting earthquake and tsunami hazard information. Therefore, in this study, a prototype of private enterprise capital stock model by industry in mesh units is developed. We estimate private enterprise capital stock by prefecture in 2014 based on the value published by the Cabinet Office. We subdivide the spatial resolution from municipalities to smaller regional units based on the estimated values for each prefecture. Finally, the capital stock model of private enterprises with 250m mesh size for inland areas and 50m mesh size for coastal areas is developed. We plan to estimate the seismic intensity-exposed capital stock and economic damage caused by actual earthquakes using this model.

Keywords: private enterprise capital stock model, Nankai Trough earthquake, economic damage

1. Introduction

The National Research Institute for Earth Science and Disaster Resilience (NIED) is developing an economic damage prediction system that provides an overview of a wide area. The objective is to support early recovery of the economy after the Nankai Trough megathrust earthquake, and this effort is part of the Cross-ministerial Strategic Innovation Promotion Program (SIP) project “Enhancement of Societal Resiliency against Natural Disaster” that is funded by the Council for Science, Technology and Innovation [1]. The system predicts direct and indirect economic damage due to earthquakes and tsunamis in all of Japan based on seismic motion and tsunami hazard information, which are estimated from real time observation data from ground motion monitoring networks (K-NET and KiK-net) as well as the tsunami monitoring network. The damage to capital stock caused by seismic motion and tsunami inundation must be calculated to predict economic damage. However, the gross capital stock data of private enterprises by industry, which is used as the exposure data, is only published at the prefectural level [2]. Therefore, it lacks the spatial resolution necessary for sufficient damage prediction reflecting earthquake and tsunami hazard information.

Therefore, in this study, we prepared a mesh-level capital stock model of private enterprises by industry of the whole country. The gross capital stock data of private enterprises (national accounts) [3] published by the Cabinet Office was used as the foundation. The estimation method used for capital stock of private enterprises by prefecture, which is published up to fiscal year (FY) 2009, was applied to estimate the capital stock of private enterprises by prefecture for FY 2014. The spatial resolution was granulized to the city/town/village (hereafter collectively "city") level, "cho" / "cho"/ "moku" / "oaza" (hereafter "district") level, and then mesh level. The final capital stock model of private enterprises was obtained for each mesh with 250 m and 50 m sizes for inland and coastal areas, respectively. Fig. 1 shows the workflow to generate data.

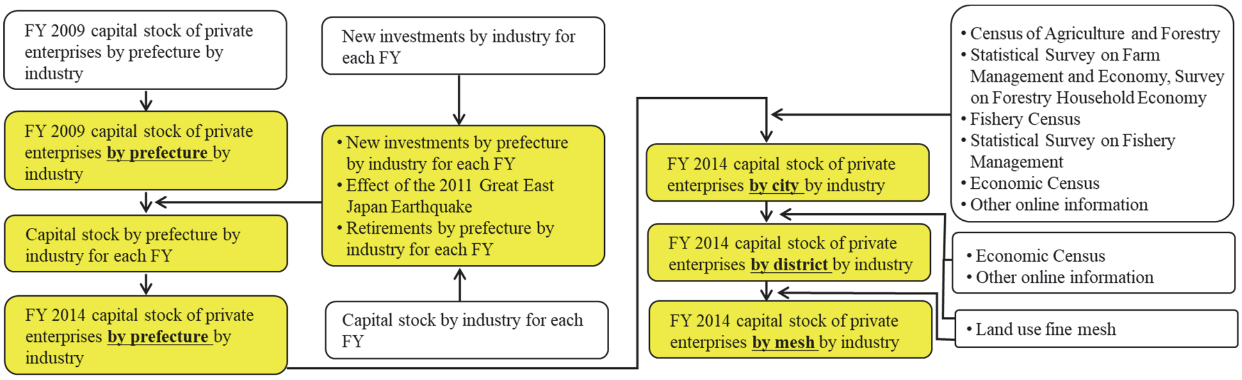

Fig. 1 Workflow to generate capital stock model of private enterprises at the mesh level.
(Yellow boxes in the figure indicate generated data.)

2. Specifications of the capital stock model of private enterprises

The capital stock model is designed to predict economic damage due to seismic motion and tsunami inundation hazard information; thus, it must be consistent somewhat with the spatial resolution of two-dimensional hazard information. Therefore, a 250 m mesh (one-quarter mesh) was used for inland areas with reference to Fujiwara *et al.* (2019) [4]. A 50 m mesh, in which each one-quarter mesh was split into 25 (5x5) portions, was used for coastal areas that might be inundated with a tsunami in a manner similar to Fujiwara *et al.* (2015) [5]. Fig. 2 shows where the 50 m and 250 m meshes were employed in Japan. An industrial classification of capital stock data into 32 categories (shown in Table 1), based on the categorization of gross capital stock data of private enterprises published from the Cabinet Office [2,3], was used. The capital stock in this study is based on progress-based gross capital stock and the prices are for calendar year (CY) 2005 [3].

Table 1 The industrial classification of the capital stock model

Agriculture	Pulp and paper	General-purpose machinery	Retail trade	Construction	Ceramic, stone and clay
Forestry	Printing and publishing	Electrical machinery	Finance and insurance	Other transportation equipment	Information and communications
Fisheries	Chemical products	Motor vehicles	Real estate	Food	Iron and steel
Mining	Petroleum and coal	Motor vehicle parts	Transportation	Precision machinery	Electricity
Beverages and tobacco	Non-ferrous metals	Other manufacturing	Gas and water	Wholesale trade	Services
Textiles	Metal products				

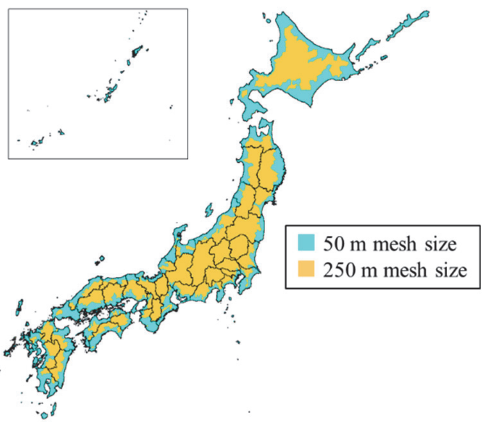

Fig.2 Areas of 50 m and 250 m mesh size

3. Gross capital stock model of private enterprises by prefecture.

3.1 Method

The capital stock data of private enterprises by prefecture was estimated using the benchmark method [2]. The FY 2009 gross capital stock data of private enterprises by prefecture [2], which is the latest published data by prefecture, was used as the reference data. The FY 2014 value was estimated by considering estimated new investments and retirements for each FY to this reference data. The capital stock for each FY was obtained using Eq. (1).

$$K_{i,p,t} = K_{i,p,t-1} + I_{i,p,t} - R_{i,p,t} \tag{1}$$

Here, K is capital stock, I is the amount of new investments, R is the amount of net retirements, i is the industrial classification, p is the prefecture, and t is the year, respectively. The amount of net retirements in equation (1), R, was obtained using Eq. (2) and Eq. (3).

$$\text{FY 2010} \qquad R_{i,p,t} = K_{i,p,t-1} \times r_{i,t} + E_{i,p,t} \tag{2}$$

$$\text{FY 2011-14} \qquad R_{i,p,t} = K_{i,p,t-1} \times r_{i,t} \tag{3}$$

Here, r is the net retirement rate and E is the capital loss from the 2011 Great East Japan Earthquake. The net retirement rate except from the capital loss from the 2011 Earthquake is a constant value over all prefectures, and the capital stock loss of private enterprises by prefecture by industry from the 2011 Earthquake was estimated using the procedure in Section 3.4. The net retirement rate was obtained using Eq. (4) and Eq. (5) and the national accounts of the gross capital stock by industry and new investments published by the Cabinet Office [3] as well as the national account of capital loss from the 2011 Earthquake. The following explains the estimation methods and results of the baseline data, which is the FY 2009 capital stock data of private enterprises by prefecture, the amount of new investments and net retirements in FY 2010-2014, and the capital loss from the 2011 Earthquake.

$$\text{FY 2010} \qquad r_{i,t} = \frac{(K_{i,t-1}+I_{i,t}-K_{i,t})-E_{i,t}}{K_{i,t-1}} \tag{4}$$

$$\text{FY 2011-14} \qquad r_{i,t} = \frac{(K_{i,t-1}+I_{i,t}-K_{i,t})}{K_{i,t-1}} \tag{5}$$

3.2 Estimation of the FY 2009 capital stock data of private enterprises by prefecture

The FY 2009 capital stock data of private enterprises by prefecture that was used as the baseline data is based on CY 2000 prices, thus the ratio of CY 2005 [3] and CY 2000 [2] prices of the FY 2009 capital stock data of private enterprises (national accounts) were applied to convert prices to CY 2005 standards. The industrial classification in reference [2], which was used as the reference data, has 22 categories. “Agriculture, forestry, and fisheries,” “food,” “primary metals,” “transportation equipment,” “other manufacturing,” “wholesale and retail trade,” “transportation and communications,” and “electricity, gas, and water” categories needed to be refined to correspond to the 32 categories in Table 1. Refinement was conducted based on reference [2]. As an example, the following is the procedure to refine “transportation equipment” to “motor vehicles,” “motor vehicle parts,” and “other transportation equipment.”

Refinement of “transportation equipment” to “motor vehicles,” “motor vehicle parts,” and “other transportation equipment” requires the use of the industry categories in the Census of Manufactures [6]; however, the amount of tangible fixed assets by industry by prefecture is not available in this Census. Therefore, the industry statistical tables (national accounts) of the Census of Manufactures were used to obtain the year-end tangible fixed asset balance per worker for the three categories (Table 2). This was multiplied by the number of workers in each of the three categories by prefecture in the Census of Manufactures to estimate the fixed assets by prefecture of each category. The constitution ratio of these three categories was used as the split metric for each prefecture. This was applied to “transportation equipment” in the FY 2009 gross capital stock data of private enterprises by prefecture (reference data) to estimate the fixed assets in the three categories by prefecture (primary estimation). The capital stock data of private enterprises by prefecture obtained by primary estimation was aggregated over the whole country by category, and a fixed correction factor that is uniform over all prefectures was applied to each category such that the constitution ratio of the three categories in the national account becomes the same as that of the tangible fixed asset balance shown in Table 2 (secondary estimate). A uniform correction factor over all prefectures was subsequently applied such that the sum of the secondary estimate of the three categories in each prefecture matches the value of the "transportation equipment" in the FY 2009 gross capital stock data of private enterprises by prefecture which was mentioned earlier (tertiary estimate). The secondary and tertiary estimate processes were iterated. The final capital stock of the three categories satisfies both (i) that the constitution ratio of "motor vehicles," "motor vehicle parts," and "other transportation equipment" of the whole country is the same as the ratio of tangible fixed asset balances in Table 2 and that (ii) the total amount of the sum of the three categories is within 99-101 % of the "transportation equipment" value in the FY 2009 gross capital stock data of private enterprises by prefecture.

Table 2 The number of workers and tangible fixed asset balances used to refine the "transportation equipment"

Item	Unit	Motor vehicles	Motor vehicle parts	Other transportation equipment
Number of workers	People	179998	541435	131686
Year-end tangible fixed assets	Million yen	2873656	6361795	1658817
Year-end tangible fixed assets per worker	Million yen	15.965	11.75	12.597
Constitution ratio in all of transportation equipment	-	0.264	0.584	0.152

3.3 Estimation of new investments in each FY

The capital stock data of private enterprises by prefecture is estimated in each FY. The national accounts of new investments by industry for FY 2010-2014 [3] are already published. Therefore, a split metric (distribution ratio by prefecture) by industry was obtained based on the estimation method for intermediate years [2], and this was applied to the national account to estimate the new investments by industry by prefecture. The following shows how the split metric for each industry was obtained.

3.3.1 Manufacturing industries

The split metric of manufacturing industries was obtained based on the net investment on tangible fixed assets by prefecture by industry in the Census of Manufactures [6] of each year. However, the net investment in tangible fixed assets in the Census of Manufactures is from workplaces with 30 or more workers. Therefore, the net investment in tangible fixed assets by industry by prefecture including workplaces with less than 30 workers was estimated using data on manufactured goods shipments, and this was used in the split metric (Eq. (8)). The net investment on tangible fixed assets including workplaces with less than 30 workers was estimated using the ratio of manufactured goods shipment amounts between workplaces with 30 or more workers and those with less than 30 workers (Eq. (6), Eq. (7)).

$$A_{i,p,t} = A30_{i,p,t} \times \left(1 + R_{i,p,t}\right) \tag{6}$$

$$R_{i,p,t} = \left(S3_{i,p,t} + S29_{i,p,t}\right)/S30_{i,p,t} \tag{7}$$

$$S_{i,p,t} = A_{i,p,t}/\sum_p A_{i,p,t} \tag{8}$$

Here, $A_{i,p,t}$ is the net investment on tangible fixed assets of all workplaces, $A30_{i,p,t}$ is the net investment on tangible fixed assets of workplaces with 30 or more workers, $S30_{i,p,t}$ is the manufactured goods shipments of workplaces with 30 or more workers, $S3_{i,p,t}$ is the manufactured goods shipments of workplaces with less than three workers, $S29_{i,p,t}$ is the manufactured goods shipments of workplaces with four to 29 workers, $R_{i,p,t}$ is the ratio of manufactured goods shipments between workplaces with 30 or more workers and less than 30 workers, $S_{i,p,t}$ is the split metric, *i* is the industry, *p* is the prefecture, and *t* is the year. For prefectures where the manufactured goods shipments are not disclosed, the total investments of the prefecture estimated from the number of workers in the prefecture was used.

3.3.2 Non-manufacturing industries

The spatial distribution of agriculture, forestry, and fisheries is expected to be different, thus the national account of new investments of "agriculture, forestry, and fisheries" was individually separated using the agriculture: forestry: fisheries ratio of capital consumption allowance in the Input-Output Tables for Japan [7] as in reference [2]. The national accounts of agriculture, forestry, and fisheries were divided proportionately to each prefecture by summing the amount of fixed assets by industry by prefecture, which was estimated by Eq. (9), over the whole country and then using the constitution ratio of prefectures in Japan (Eq. (10)).

$$A_{i,p,t} = UA_{i,r,t} \times N_{i,p,t} \tag{9}$$

$$S_{i,p,t} = A_{i,p,t}/\left(\sum_p A_{i,p,t}\right) \tag{10}$$

Here, $A_{i,p,t}$ is the fixed assets in agriculture, forestry, and fisheries, $UA_{i,r,t}$ is the fixed assets investment per management body, $S_{i,p,t}$ is the split metric, $N_{i,p,t}$ is the number of management bodies, r is the region, p is the prefecture, t is the year, and i is the industry. The fixed assets investment per management body was derived using the gross fixed asset investment (individual management) or investment during period (not individual management) in the Statistical Survey on Farm Management and Economy for agriculture, the current value of the depreciable assets at the start of term in the Survey on Forestry Household Economy for forestry, and the invested capital for fisheries in the Statistical Survey on Fishery Management for fisheries. The number of management bodies was obtained using the Census of Agriculture and Forestry and the Fishery Census. The split metrics in Table 3 were used for non-manufacturing industries other than agriculture, forestry, and fisheries.

Table 3 The split metrics of new investments in non-manufacturing industries

Industrial classification	Split metric
Mining	Gross prefectural domestic product of mining in the Prefectural Accounts
Construction	Amounts of construction completed (prime contract) by construction site by prefecture in the Construction Work Survey
Wholesale trade	Gross prefectural domestic product of wholesale trade in the Prefectural Accounts
Retail trade	Gross prefectural domestic product of retail trade in the Prefectural Accounts
Finance and insurance	Gross prefectural domestic product of finance and insurance in the Prefectural Accounts
Transportation	Gross prefectural domestic product of transportation in the Prefectural Accounts

Industrial classification	Split metric
Real estate	The sum of workers in "real estate agencies" and "real estate lessors and managers" in the Economic Census for Business Frame
Information and communications	Gross prefectural domestic product of information and communications in the Prefectural Accounts
Electricity	Electric power consumption (electricity for light) in the Handbook of Electric Power Industry
Gas and water	Sales of gas by prefecture in the Gas Industry Handbook
Services	Gross prefectural domestic product of services in the Prefectural Accounts

3.4 The effect of the 2011 Great East Japan Earthquake

To estimate the capital stock data of private enterprises by prefecture after FY 2010, the effect of the 2011 Great East Japan Earthquake must be taken into consideration. The amount of loss of capital stock from the 2011 Earthquake by prefecture by industrial classification was derived based on the calculation procedure of damage from the Great Hanshin-Awaji Earthquake [2]. Namely, the amount of damage from the 2011 Earthquake by prefecture according to the Board of Audit of Japan [8] was refined. The "land, buildings, and machinery equipment of private enterprises" was divided into "related to industry," "fishery processing," and "related to commerce" based on earthquake disaster summaries of various prefectures [9, 10, 11, 12, 13, 14], the FY 2011 White Paper on Small and Medium Enterprises in Japan, the FY 2011 Annual Report on the

Developments in Japan's Fisheries, and securities reports of Tohoku Electric Power and Tokyo Electric Power. The amount of damage related to lifelines and agriculture, forestry, and fisheries were corrected and the amount of damage by damage category by prefecture was adjusted. In this study, the relation between damage categories and the industrial classifications of capital stock of private enterprises was set as in Table 4. The composition ratio of capital stock of various industries in the damage category was used to obtain the amount of damage by industry by prefecture from the amount of damage by damage category by prefecture, and the result was employed as the amount of damage from the 2011 Earthquake (Table 5).

The loss of capital stock of private enterprises from the 2011 Earthquake was estimated at about 5.3 trillion yen. By the industrial classification of capital stock, electricity, agriculture, transportation, and fisheries are about 1.1 trillion yen (20%), 0.78 trillion yen (15%), 0.58 trillion yen (11%), and 0.36 trillion yen (7%), respectively. The loss of these four industries makes up more than half of the total. By prefecture, Miyagi and Fukushima incurred large losses at about 1.9 trillion yen (37%) and 1.5 trillion yen (29%), respectively. More than half of the loss of capital stock of private enterprises came from electricity in Fukushima Prefecture, indicating the large effect of the Fukushima Daiichi nuclear disaster. Our results roughly agree with the figure of approximately 5.6 trillion yen for damage to capital stock of “manufacturing industries” and “others,” excluding housing and social capital, that the Development Bank of Japan [15] made public in April 2011.

Table 4 Relation between the industrial classifications of capital stock and damage classifications from the Great East Japan Earthquake

		Buildings, etc.					Lifelines			Related to agriculture, forestry, and fisheries		
	Industrial classification	Land, buildings, machinery, equipment, etc. of private enterprises	Related to industry	Fishery processing	Related to commerce	Other (motor vehicles, vessels, etc.)	Gas	Electricity	Communications and broadcast facilities	Agricultural land, facilities for agriculture, etc.	Facilities for forestry, etc.	Facilities for fisheries, etc.
Public	Agriculture, forestry, and fisheries (agriculture)									○		
	Agriculture, forestry, and fisheries (forestry)										○	
Private	Agriculture									○		
	Forestry										○	
	Fisheries											○
	Food	○	○	○								
	Mining, construction, beverages and tobacco, textiles, pulp and paper, chemical products, petroleum and coal, ceramic, stone and clay, iron and steel, non-ferrous metals, metal products, general-purpose machinery, electrical machinery, motor vehicles, motor vehicle parts, other transportation equipment, precision machinery, other manufacturing, printing and publishing	○	○									
	Wholesale trade, retail trade, finance and insurance, real estate, services	○			○							
	Transportation	○			○	○						
	Information and communications	○			○				○			
	Electricity				○			○				
	Gas and water				○		○					

Table 5 Estimated loss in capital stock of private enterprises from the Great East Japan Earthquake by industry by prefecture [Unit: 1 billion yen]

Prefecture	Agriculture	Forestry	Fisheries	Mining	Construction	Manufacturing	Wholesale trade	Retail trade	Finance and insurance	Real estate	Transportation	Information and communications	Electricity	Gas and water	Services	Total
Aomori	2.2	2.3	14.8	0.4	3.2	20.8	0.9	6.4	1.0	2.1	7.0	1.7	0.0	0.0	14.1	77.0
Iwate	58.4	13.9	98.2	0.9	10.9	116.3	1.9	12.4	2.7	4.5	91.3	6.5	4.7	2.1	32.7	457.4
Miyagi	474.6	9.8	210.5	1.9	75.8	619.9	8.3	23.7	4.0	12.5	283.0	71.2	70.8	27.6	55.7	1949.3
Fukushima	193.9	10.3	20.2	1.1	17.8	207.7	2.7	20.1	4.6	8.6	80.4	7.6	893.4	1.1	62.4	1532.1
Ibaraki	32.6	3.1	12.9	1.3	23.0	448.3	5.0	34.3	7.9	15.7	67.3	16.8	50.4	0.6	103.4	822.6
Tochigi	3.9	0.0	0.0	1.2	9.6	164.1	3.0	17.1	3.4	7.8	16.6	5.3	7.7	0.0	47.0	287.0
Chiba	16.7	0.5	2.5	0.2	3.2	32.5	0.2	1.5	0.3	1.1	30.5	1.5	29.2	1.1	4.5	125.6
Others	0.3	0.0	0.0	0.1	0.8	7.0	0.2	1.1	0.3	0.5	1.4	0.5	0.0	0.0	3.4	15.6
Total	782.7	40.0	359.2	7.2	144.5	1616.7	22.3	116.6	24.2	52.9	577.5	111.1	1056.2	32.5	323.1	5266.6

3.5 Estimation of the FY 2014 capital stock data of private enterprises by prefecture

The FY 2014 capital stock data of private enterprises by industry by prefecture was estimated using Eq. (1) - Eq. (5) and the results in Sections 3.2-3.4. The national account of capital stock used in the estimation was the data by industry obtained in Section 3.2 summed over all of Japan for FY 2009 and the capital stock data of private enterprises published by the Cabinet Office [3] for FY 2010-2014. However, the industrial classification in reference [3] is different from that in this study; hence the method in Table 6 was used to refine "agriculture, forestry and fisheries," "food," "transportation equipment," and "transportation and telecommunications." Most of the capital stock data of private enterprises in the "gas and water" industries belongs to the gas industries, but data of the water industry in the input-output tables appear to include public transactions. Therefore, with the prediction of future economic damage in mind, the gross stock of the water industry in the social capital stock estimate [16] was added to the "gas and water" industry capital stock in this research. As examples of the ultimately obtained FY 2014 capital stock data of private enterprises by prefecture, Fig. 3 shows the capital stock of "steel and iron," "motor vehicles," and the total of all 32 classifications.

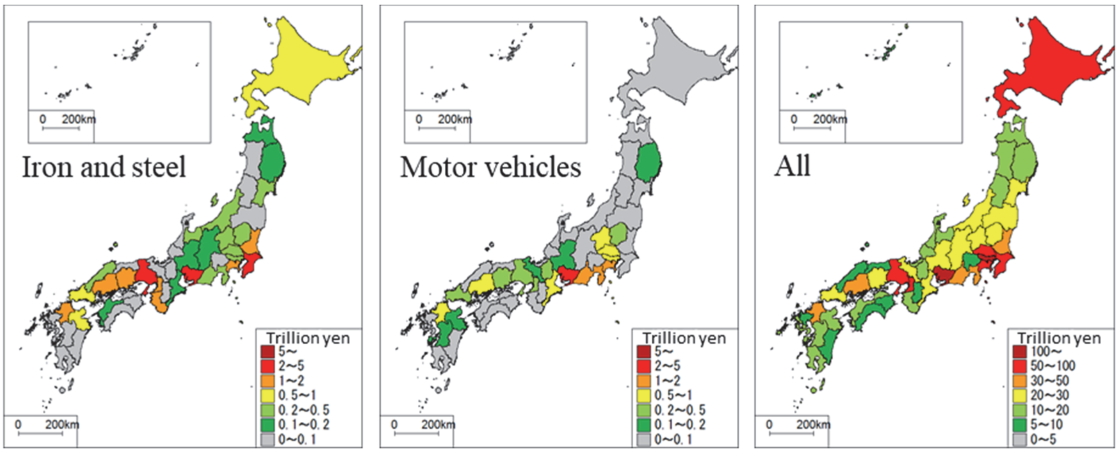

Fig. 3 Capital stock data of private enterprises by industry by prefecture (FY 2014)

Table 6 How to refine industrial classifications from the national account of capital stock data of private enterprises published by the Cabinet Office in 2009

Industrial classification		Refinement method
Original	Refined	
Agriculture, forestry, and fisheries	Agriculture, forestry, fisheries	Used the agriculture: forestry : and fisheries ratio of the capital formation amount in the fixed capital formation matrix in the Input-Output Tables.
Food	Food, beverages and tobacco	Used the food: beverages and tobacco ratio of the year-end tangible fixed asset balance as estimated from the Census of Manufactures.
Transportation equipment	Motor vehicles, motor vehicle parts, other transportation equipment	The motor vehicles: motor vehicle parts : other transportation equipment ratio of the year-end tangible fixed asset balances was used, which was derived by summing data for industries over each classification. Data was obtained from the Census of Manufactures (national accounts) of each year. Namely, the year-end tangible fixed asset balances in the 2010 Census of Manufactures was used as the baseline. The tangible fixed asset balances without considering depreciation was calculated. This constitution ratio was used to distribute capital stock of "transportation equipment (national accounts) to "motor vehicles," "motor vehicle parts," and "other transportation equipment".
Transportation and communications	Transportation, communications	Refined using the constitution ratio of "transportation" to "communications" in the FY 2009 capital stock data of private enterprises by prefecture obtained in this research (62.6%:37.4%).

4. Estimation of the capital stock data of private enterprises by city and by district

The capital stock data of private enterprises by city was derived from the FY 2014 capital stock data of private enterprises by industry by prefecture shown in Section 3.5 and the split metric shown in Table 7. The capital stock data of private enterprises by district was further obtained by using the split metric in Table 8.

Table 7 Split metric from prefecture to city

Industrial classification	Split metric or distribution method
Agriculture	Fixed assets by city estimated from the product of fixed assets per management body in the Statistical Survey on Farm Management and Economy and the number of management bodies (agriculture) by city in the Census of Agriculture and Forestry
Forestry	Number of management bodies (forestry) by city in the Census of Agriculture and Forestry
Fisheries	Fixed assets by city estimated from the product of end-of-term fixed assets per management body in the Statistical Survey on Fishery Management and the number of management bodies by city in the Fishery Census
Motor vehicles, motor vehicle parts	The addresses of manufacturing bases of "motor vehicles, including motorcycles" and "motor vehicles bodies and trailers" were searched online. If there is a motor vehicle manufacturing base in the prefecture but not in the city, all workers were considered to work in motor vehicle parts manufacturing. If there is a base, the number of "motor vehicle" workers by prefecture that was obtained by adding up industries in the Census of Manufactures was distributed to match the number of workers by prefecture obtained in this research, and the remains were considered workers in motor vehicle parts manufacturing. For prefectures that do not have a motor vehicle manufacturing base as judged from online information, the workers for motor vehicles and motor vehicle parts were estimated by splitting the number of workers in "motor vehicles and accessories manufacturing" according to the economic census of each city by the "motor vehicles" : "motor vehicle accessories" industry ratio in the Census of Manufactures.
Others	Number of workers by city in the Economic Census for Business Frame

Table 8 Split metric from city to district

Industrial classification	Split metric or distribution method
Agriculture, forestry	The urban land use fine mesh (land use fine mesh if not available) in the National Land Numerical Information was used. The weights of "paddy field" and "other agricultural land" for agriculture and "forest" for forestry, were used as the split metric from city to district.
Motor vehicles	If there is a motor vehicle manufacturing base in the city based on online information, the number of workers at the base was used as the split metric. If there is a base but the number of workers could not be identified based on online information, employees were distributed using the ratio of total floor space or building area of the manufacturing plant. If neither total floor space nor building area were available, employees were then uniformly distributed in districts where the bases exist in the city. When there is no manufacturing base that was found in online information, the number of workers by district in the Economic Census for Business Frame was used as the split metric.
Others	Number of workers by district in the Economic Census for Business Frame

5. Estimation of the capital stock data of private enterprises by mesh

As shown in Table 8, the number of workers by district in the Economic Census for Business Frame was used when obtaining the capital stock data of private enterprises by district from the capital stock data of private enterprises by city. The latter data shows the spatial distribution of industries at the most granulized level and there are no mesh-level data. Therefore, data on land use was used to distribute capital stock to individual meshes in all industrial classifications. The urban land use fine mesh (land use fine mesh if not available) in the National Land Numerical Information [17] was used as data on land use. This data uses a 100 m mesh and the mesh boundary is not consistent with 50 m and 250 m meshes. Therefore, the district that the mesh center lies on is identified for each 50 m mesh; the land use type of the land use fine mesh that the mesh center included was selected as the land use type of this particular mesh center. For areas covered by a 250 m mesh, these land use data were summed over a 250m mesh and then used as a split metric, and the land use data was simply used as the split metric for areas covered by a 50m mesh.

The relation between land use and industrial classification was based on the definition of land use in the (urban) land use fine mesh. For manufacturing industries, two sites were chosen per industrial classification. The land use type in the urban land use fine mesh and factory location situation inferred from aerial photographs for these sites were checked, and the land use type to be used as the split metric per industry was set as in Table 9. Splitting of capital stock data by district to capital stock by mesh was conducted by uniformly distributing to meshes with the first candidate group in each industry in Table 9. However, for industries where the target is “mesh with buildings,” capital stock was distributed to meshes with buildings only in the 250 m building data by mesh [18] to avoid distribution of capital stock to meshes without buildings. If there was no first candidate group land use in the target district, the second candidate group was used. If this was not possible, the third candidate group was chosen, and if this was also not possible, capital stock was equally distributed to all meshes in the district. Fig. 4 shows a distribution map for each mesh that totals the capital stock of all industries

Table 9 Relation between industrial classification and land use that was used in distribution to meshes

No	Industrial classification		1st candidate land use	2nd candidate land use	3rd candidate land use	Target
1	Agriculture		Paddy field, other agricultural land	Wasteland	Forest, unused land, park and greenery	All meshes
2	Forestry		Forest	Other agricultural land, wasteland, unused land, park and greenery	None	All meshes
3	Fisheries		Land for building, low-rise building, low-rise building (dense), other land, land for public use, rivers and lakes	Unused land, park and greenery, beach	None	Meshes with buildings
4	Mining		Wasteland, land for building, factory, unused land	Low-rise building, low-rise building (dense)	Other land, land for public use	All meshes
5	Construction		Land for building, low-rise building, low-rise building (dense)	Factory	Other land, land for public use, unused land	Meshes with buildings
6	Manufacturing	Food, beverages and tobacco, textiles, printing and publishing, ceramic, stone and clay, non-ferrous metals, metal products, general-purpose machinery, electrical machinery, motor vehicles, motor vehicle parts, other transportation equipment, precision machinery, other manufacturing	Land for building, factory	Low-rise building, low-rise building (dense)	Other land, land for public use	Meshes with buildings
7		Pulp and paper	Land for building, factory, unused land	Low-rise building, low-rise building (dense)	Other land, land for public use	All meshes
8		Chemical products, petroleum and coal	Land for building, factory, land for public use	Low-rise building, low-rise building (dense)	Other land	All meshes
9		Iron and steel	Land for building, factory, land for public use, unused land	Low-rise building, low-rise building (dense)	Other land	All meshes
10	Wholesale trade, retail trade, finance and insurance, real estate, information and communications		Land for building, high-rise building, low-rise building, low-rise building (dense)	Factory	Road, railroad, other land, land for public use	Meshes with buildings
11	Transportation		Land for building, high-rise building, low-rise building, low-rise building (dense), road, railroad, other land, land for public use	Factory	None	All meshes
12	Electricity, gas and water		Land for building, high-rise building, factory, land for public use	Low-rise building, low-rise building (dense)	Other land	All meshes
13	Services		Land for building, high-rise building, low-rise building, low-rise building (dense), other land, land for public use, golf course	Factory, road, railroad	Park and greenery	Meshes with buildings

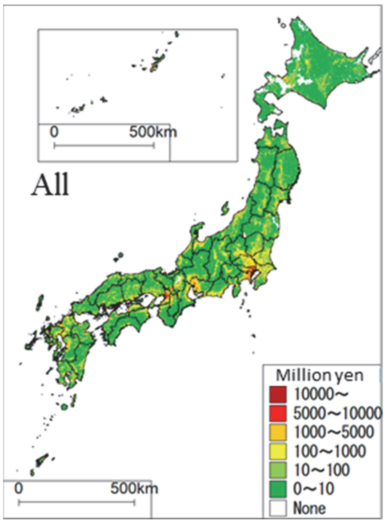

Fig. 4 Gross capital stock of private enterprises by mesh.

6. Summary

We developed the capital stock model of private enterprises by industry (water industry includes social capital stock) that is consistent with the spatial resolution used in seismic motion and tsunami inundation depth (250 m and 50 m meshes in inland and coastal areas, respectively) to serve as fundamental data for economic damage prediction from earthquakes and tsunamis. The total capital stock data of private enterprises in Japan is about 1,370 trillion yen in 2005 prices according to our model. The total of Tokyo Metropolis and Aichi Prefecture both exceed 100 trillion yen. Regarding the industrial classifications, the service industry was the largest at about 264 trillion yen, followed by electricity at about 117 trillion yen. The mesh-level data covers all of Japan. There are about 56 million and 3 million meshes at the 50 m and 250 m levels, respectively, to which capital stock is assigned. This allows economic damage analysis and risk evaluation using the production function method and general equilibrium model using the spatial resolution of various earthquake and tsunami hazard information. Fragility evaluation based on our capital stock model is necessary to further establish prediction methods of economic damage due to earthquakes and tsunamis.

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