Sectoral and Regional Interdependency of Japanese Firms under the Influence of Information Security Risks

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Outline

- Introduction
- Methodology
- Sectoral and Regional Interdependency and the results from the main empirical study
- The impact of the Great East Japan Earthquake (as an extended study)
- Conclusion

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Economic analysis of a supply chain: Inter-industry linkage

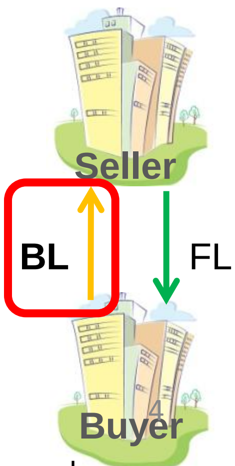
- A well-known assessment methodology from demand-side and supply-side perspectives [DL97].

Backward linkage (BL)

- Reflect a sector's dependence on inputs that are sold to the sector within the production process.
- **Demand-side** perspective.

Forward linkage (FL)

- Reflect a sector's dependence on other sectors to which the sector's outputs are sold to.
- Supply-side perspective.



Sale (Output) \ Purchase (Input)	Agriculture	Mining	• • •
Agriculture	2,101	309	• • •
Mining	870	9,877	• • •
⋮	⋮	⋮	⋮

Suppose a column is completely damaged.

Assess the output reduction of each sector.

Sale (Output) \ Purchase (Input)	Agriculture	Mining	• • •
Agriculture	2,101	0	• • •
Mining	870	0	• • •
⋮	⋮	⋮	⋮

Interdependency under the influence of information security risks

- Tanaka introduced the concept of ISBL (Information Security Backward Linkage) [T09].
- He also assessed the influence of business location on IS efforts in [T07].
- However, he did not analyzed regional interdependency in his ISBL.

Sale (Output) \ Purchase (Input)	Agriculture	Mining	• • •
Agriculture	2,101	309	• • •
Mining	870	9,877	• • •
⋮	⋮	⋮	⋮

Suppose the damages depend on IS risk levels of the sectors.

→

Assess the output reduction of each sector.

Sale (Output) \ Purchase (Input)	Agriculture	Mining	• • •
Agriculture	2,101	**10**	• • •
Mining	870	**303**	• • •
⋮	⋮	⋮	⋮

Objective of our work

- Broadens the concept of the measurement methodology of interdependency.
  - Consider both sectoral and regional interdependencies under the influence of IS risks.
- Show an extended analysis which suggests the usefulness of the methodology.
  - Estimate reductions in the interdependency when we suppose the economic damages by the Great East Japan Earthquake depend on IS investments.

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Two-step approach

- Step 1 : Basic economic analysis
  - Analysis of cross-sectoral/regional interdependency.
  - Suppose a complete damage in a particular column of the inter-regional input-output table.
- Step 2 : Analysis of the interdependency under the influence of IS risks.
  - Suppose that the damages depend on IS risk levels which are estimated based on the levels of IT dependency and the levels of IS efforts.

Inter-regional Input-Output table

Economic Transaction

Purchase value by
  Companies of sector *j* in region *r* (column index)
from
  Companies of sector *i* in region *q* (row index)

Final Demand

Value which is used to determine input and output of the sector

Import

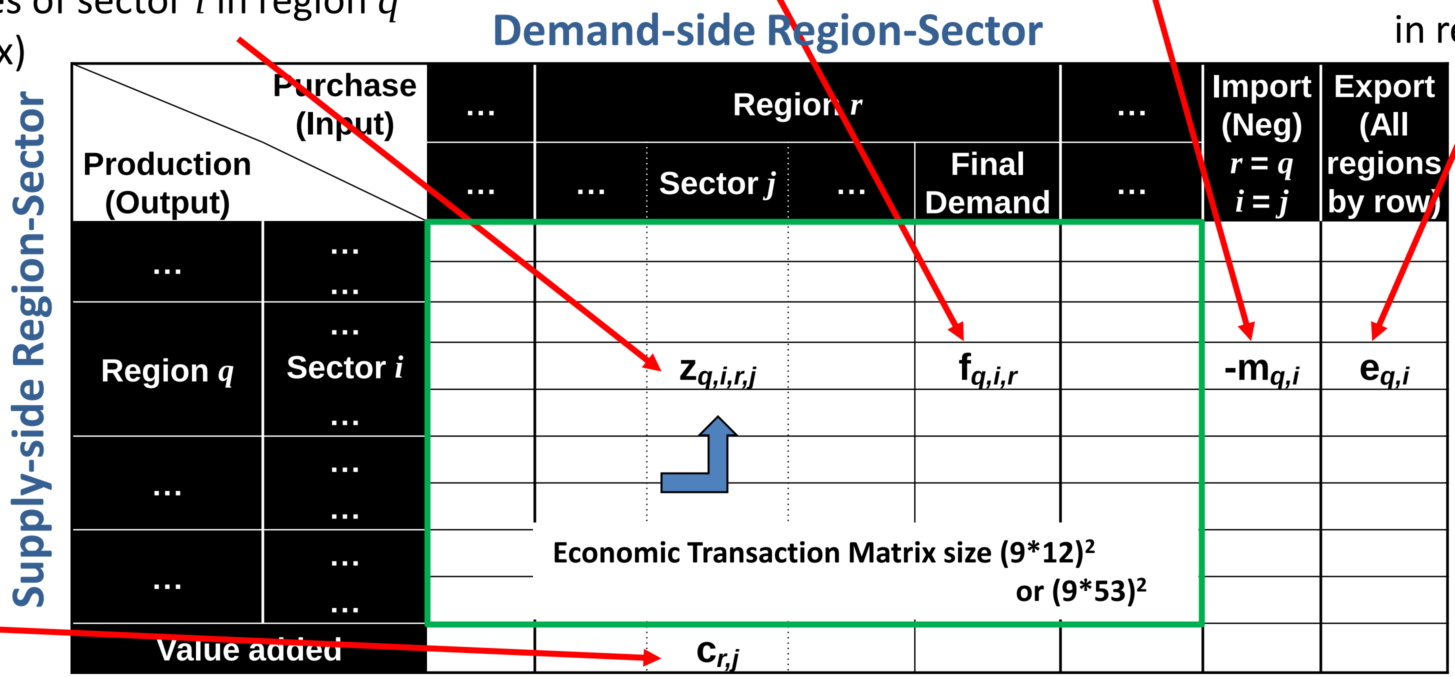
Value of import in sector *j* in region *q*.

Export

Value of export in sector *j* in region *q*.

Value added

(Tax)



Step1: Backward Dependency (BD)

- BD of demand-side group is computed as a normalized value of an output reduction

$$u_{q,i,\bar{r},\bar{j}} \equiv 100 \frac{h_{q,i} - \bar{h}_{q,i}(\bar{r},\bar{j})}{g_{\bar{r},\bar{j}}}$$

$u_{q,i,r,j}$ = Backward dependency of sector *j* in region *r* on production-side group.

$h_{q,i}$ = Value of output when sector *j* in region *r* fully depend on production side.
Calculated from $z_{q,i,r,j}$

$\bar{h}_{q,i}(\bar{r},\bar{j})$ = Value of output when sector *j* in region *r* no longer depend on production side.
Calculated from

$$\bar{z}_{q,i,r,j}(\bar{r},\bar{j}) = \begin{cases} 0 & \text{if } r = \bar{r} \text{ and } j = \bar{j} \\ z_{q,i,r,j} & \text{otherwise} \end{cases}$$

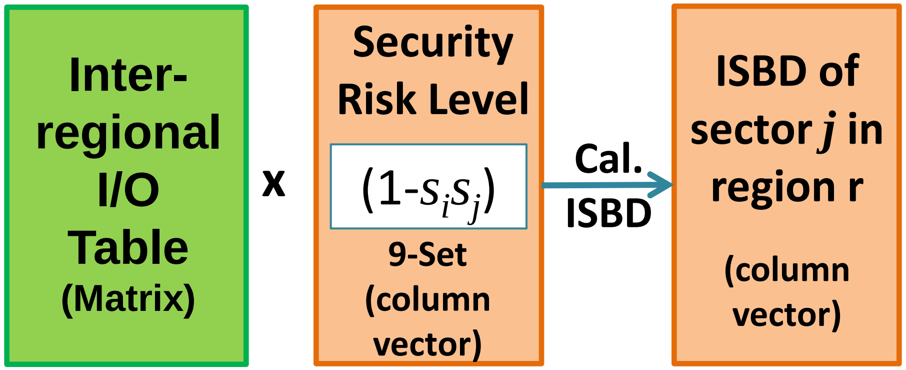
$g^{\bar{r},\bar{j}}$ = Gross output of each input-side sector *j* in region *r*.

Demand-side Region-Sector

Supply-side Region-Sector

Production (Output) \ Purchase (Input)		…	Region *r*				…	Import (Neg) $r = q$ $i = j$	Export (All regions by row)
		…	…	Sector *j*	…	Final Demand	…		
…	…				0				
	…				0				
Region *q*	…				0				
	Sector *i*			$z_{q,i,r,j}$	0	$f_{q,i,r}$		$-m_{q,i}$	$e_{q,i}$
	…				0				
…	…				0				
	…				0				
Value added				$c_{r,j}$					

Information Security Backward Dependency (ISBD)



- Instead of 0, compute a particular column by

  $$(1-s_i s_j) z_{q,i,r,j}$$

- Reduction is based on Security Risk Levels.

1. **Level of IT dependency (of sector *i*)**

   Proxy of system vulnerability

   $$IT_i/(IT_i+nIT_i)$$

   where

   IT_i = IT capital stock of sector *i*

   nIT_i =non-IT capital stock of sector *i*

2. **IS Multiplier (of sector *i*)**

   Reflects IS efforts (investments)

   $$\frac{\text{Avg. no. of IS measures in all sectors}}{\text{Avg. no. of IS measures in sector } i}$$

3. **Security Risk Level**

   S_i = (1) x (2)

Collecting results (1/4)

- If ISBD>=a heuristic threshold(= 0.01%※) → We say "**dependent**"
- Count the number of dependent pairs.

Demand-side sector name (ID)	Sector ID of supply-side sector (Sector ID)											
	01	02	03	04	05	06	07	08	09	10	11	12
Agriculture (01)												
Mining (02)												
Manufacturing-Food &beverage (03)												
Manufacturing-Metal (04)												
Manufacturing-Machinery (05)												
Manufacturing-Other (06)	0	2	0	8	0	56	2	9	28	11	10	22
Construction (07)												
Utilities (08)												
Commerce&Logistic (09)												
Financial, indurance, and real estate (10)												
ICT (11)												
Services (12)												

If there are 9 regions, each intersection has 81 pairs. Suppose 10 out of the 81 pairs are dependent at this intersection. Then we say "the level of interdependency between demand-side sector Manufacturing-other (06) and supply-side sector ICT (11) is 10."

※ From average mean value & the standard deviation.

Collecting results (2/4)

Demand-side sector name (ID)	Sector ID of supply-side sector (Sector ID)											
	01	02	03	04	05	06	07	08	09	10	11	12
Agriculture (01)												
Mining (02)												
Manufacturing-Food &beverage (03)												
Manufacturing-Metal (04)												
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Manufacturing-Other (06)	0	2	0	8	0	56	2	9	28	11	10	22
Construction (07)												
Utilities (08)												
Commerce&Logistic (09)												
Financial, indurance, and real estate (10)												
ICT (11)												
Services (12)												

The largest element in this row.

Collecting results (3/4)

Demand-side sector name (ID)	Sector ID of supply-side sector (Sector ID)											
	01	02	03	04	05	06	07	08	09	10	11	12
Agriculture (01)												
Mining (02)												
Manufacturing-Food &beverage (03)												
Manufacturing-Metal (04)												
Manufacturing-Machinery (05)												
Manufacturing-Other (06)	0/56	2/56	0/56	8/56	0/56	56/56	2/56	9/56	28/56	11/56	10/56	22/56
Construction (07)												
Utilities (08)												
Commerce&Logistic (09)												
Financial, indurance, and real estate (10)												
ICT (11)												
Services (12)												

Compute the ratio of the “value of each element of this row” to the largest value in the row.

Collecting results (4/4)

Demand-side sector name (ID)	Sector ID of supply-side sector (Sector ID)											
	01	02	03	04	05	06	07	08	09	10	11	12
Agriculture (01)												
Mining (02)												
Manufacturing-Food &beverage (03)												
Manufacturing-Metal (04)												
Manufacturing-Machinery (05)												
Manufacturing-Other (06)	–	●	–	○	–	○○	●	○	○○	○	○	○
Construction (07)												
Utilities (08)												
Commerce&Logistic (09)												
Financial, indurance, and real estate (10)												
ICT (11)												
Services (12)												

Replace the ratios by signs.

○○ = Ratio is larger than or equals to 50%
○ = Ratio is between 10% and 50%
● = Ratio is non-zero but less than 10%
- = Ratio is zero

The above is to examine sectoral interdependencies.
In order to examine regional interdependencies,
we do the same for the region-by-region table.

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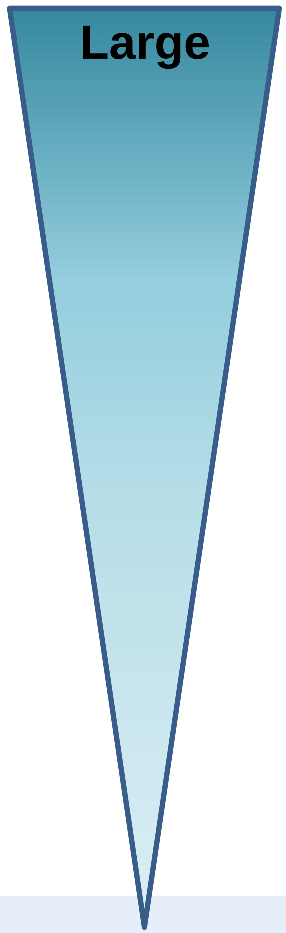
Fundamental official datasets

1. **Inter-regional Input-Output Table 2005**[METI05]
   – Economic transaction values (12 (and 53) sectors, 9 regions).
2. **2006 Survey of Information Technology** [METI07]
   – 3,647 firms.
   – We obtain average number of information security (IS) measures.
   – Number of IS measure is collected according to 4 main categories of measures.
3. **Japan Industrial Productivity Database 2008**[REITI08]
   – Use the data of IT capital stock and non-IT capital stock for year 2005 (107 sectors)

Regional & sectoral economic scales

By Region
(9 regions)

- Kanto
- Kinki
- Chubu
- Kyushu
- Chugoku
- Tohoku
- Hokkaido
- Shikoku
- Okinawa



By Sector
(12 Industrial Sectors)

- Services
- Commerce & Logistic
- Machinery
- Financial, Insurance, & Real Estate
- Other Manufacturing
- Construction
- ICT
- Metal
- Food & Beverage
- Utilities
- Agriculture
- Mining

Source: Inter-Regional Input-Output table for 2005

Results regarding sectoral interdependency

We found critical and non-critical sectors

- Let us say “critical sectors” if they are very influential.
  - Critical sectors: Supply-side sectors which are highly depended by demand-side sectors.
  - We found three critical sectors
    - Manufacturing – other
    - Commerce & Logistic
    - Services
  - Demand-side sectors have high opportunities to be affected by incidents in critical sectors.
- Other sectors are called non-critical sectors.

Characteristics of demand-side sectors: 5 main classes of industrial sectors (1/3)

Class 1 : Sectors which show high interdependency ***when and only when*** tested with the critical sectors

– Mining, Utilities

Class 2 : Sectors which show high interdependency when tested with its own sector and ***all*** of the critical sectors.

– Manufacturing – Food & beverage, Manufacturing – Machinery, Commerce & logistic, ICT, Services

Characteristics of Demand-side Sectors: 5 Main Classes of Industrial Sectors (2/3)

Class 3 :Sectors which show high interdependency when tested with its own sector and ***not all but some*** of the critical sectors.

- Manufacturing – Metal, Manufacturing – Other

Class 4 :Sectors which show ***little*** interdependency when tested with supply-side sectors.

- Financial, insurance, and real estate
- However, our detailed analysis by using 53-sector dataset shows that the sub-sector of Financial and insurance shows characteristics similar to Class 3.

Characteristics of Demand-side Sectors: 5 Main Classes of Industrial Sectors (3/3)

Class 5: The rest of the demand-side sectors.

- Agriculture, Construction
- These two sectors show no self-interdependency when tested with supply-side sectors.

Summary of sectoral interdependency

- Majority of demand-side sectors belong to Class 2 and 3.
  - Sectors with high self-dependency.
  - Do not show high interdependency with non-critical sectors.
  - Analysis of regional interdependency is needed for getting more implications.

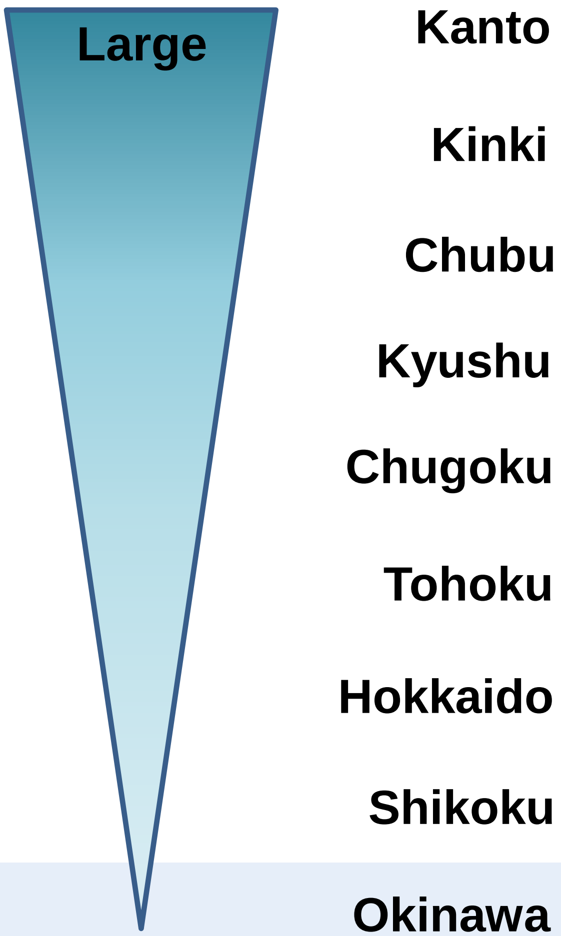
- Economically large size demand-side sectors (Machinery and Services) are the most influenced sectors.

Results regarding regional interdependency

Influential regions
(Supply-side region)

- Economic scale of a region has a great influence.
- Economically largest region (Kanto) is the most influential.
- Economically smallest region (Okinawa) is the least influential.
- Economically larger regions tend to be more influential.

Economic scale by region (9 regions)



Influenced regions (Demand-side region)

- Highly influenced regions likely have smaller economic scales.
  - Shikoku, Okinawa
  - By contrast, in the case of sectoral interdependency, economically larger sectors tend to be more influenced.
- The economically largest region, Kanto, is the least influenced.
- A remarkable point:
  - Tohoku (economically middle sized region, and the most damaged region by the quake) has similar features to those of Kanto.

Influenced level

Most	Shikoku
	Okinawa
	Chugoku
	Chubu
	Kyushu
	Kinki
	Hokkaido
	Tohoku
Least	Kanto

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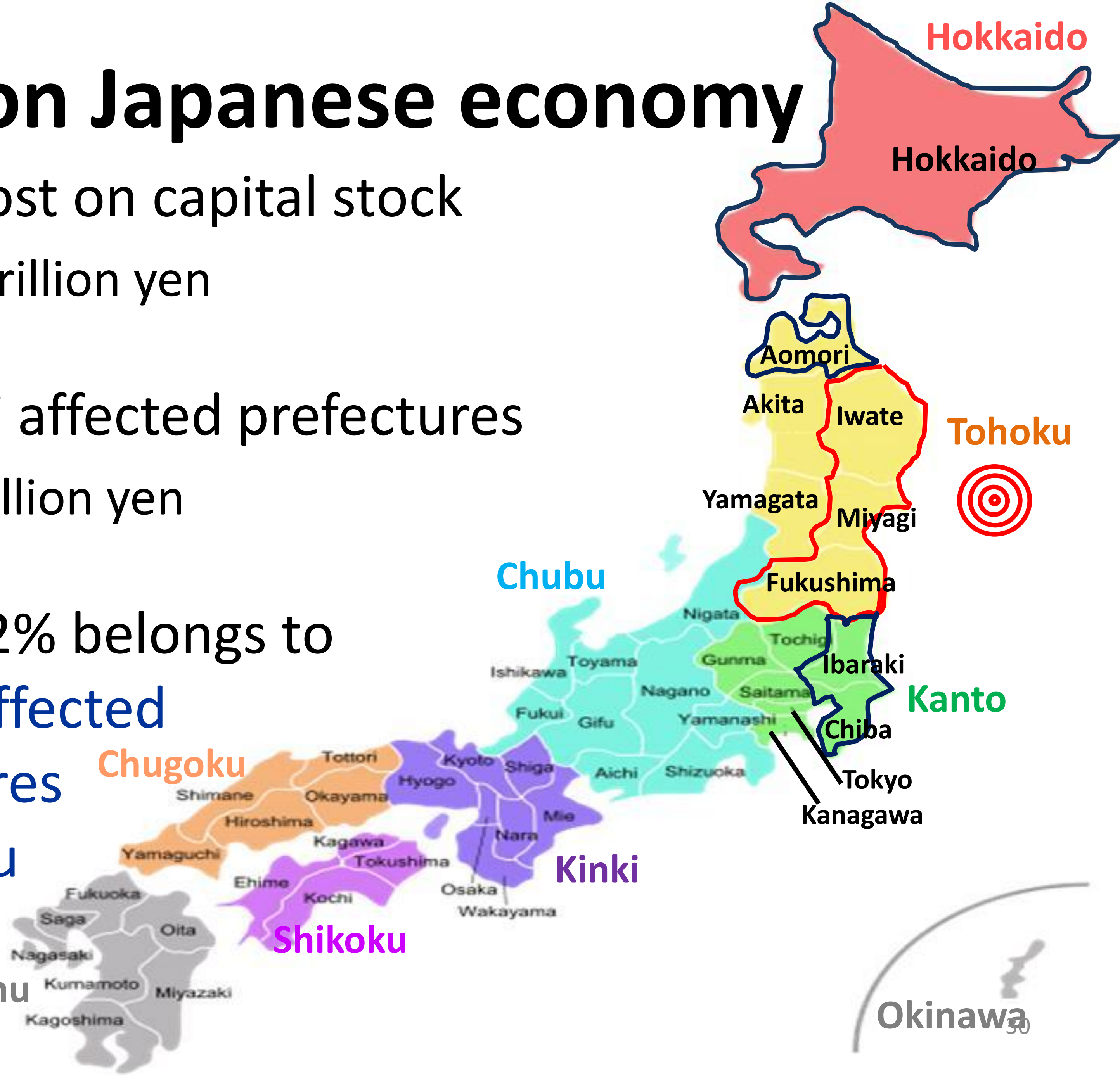
The Great East Japan Earthquake

- March 11, 2011 – 2:46 pm.
- 7 prefectures are announced as affected areas.
  - Defined by the Cabinet Office, Government of Japan [ESRI11]
- Two types of impacts
  - Earthquake only
  - Earthquake and Tsunami

Effects on Japanese economy

- Overall lost on capital stock
  - 16-25 trillion yen
- Lost on 7 affected prefectures
  - 9-16 trillion yen
- 87.5%-92% belongs to 3 main affected prefectures in Tohoku



Datasets

1. **Material of economic report due to the earthquake**[ESRI11]
   - **Value of overall damage on capital stock due to the earthquake.**
   - By cabinet office, government of Japan. March 23, 2011
2. **Japan Nationwide Capital Stock**[ESRI09]
   - **Overall values of capital stock** for Japan
   - By cabinet office, government of Japan 2009

Additional Datasets

3. **Japan Industrial Productivity Database 2008**[REITI08]
   - Use data of **IT capital stock** for year 2005 (107 sectors)
   - By Research Institute of Economy, Trade, and Industry (REITI)
4. **Inter-regional Input-Output Table 2005**[METI05]
   - Economic transaction values (**12 industrial sectors, 9 regions)**
   - By Ministry of Economic, Trade, and Industrial (METI)

Regional proxies and Damages on IT system

Analysis regarding the structural interdependency

We use

$$\bar{z}_{q,i,r,j} = \begin{cases} (1-R_r)z_{q,i,r,j} & \text{if } r=\text{Tohoku} \\ z_{q,i,r,j} & \text{otherwise} \end{cases}$$

R_r = a "**regional ratio of damage**" of region r defined by

$$R_r = \frac{D^{all}}{C_r}$$

where

D^{all} = overall damage on capital stock due to the earthquake

C_r = capital stock of region r

Analysis regarding ISBD

Reduction is based on Damage on IT systems

$$D^{IT} = D^{all} \times t_{Total}$$

t_{Total} is the ratio of IT capital stock given by

$$\frac{IT_{total}}{(IT_{total} + nIT_{total})}$$

where

IT_{total} = All IT-related capital stock

nIT_{total} = All non IT-related capital stock

Inter-regional Input-Output table which reflects the damages by the quake

(Value related to damage)

$1 - \text{Regional ratio of damage}$

Economic Transaction

Let *r* be affected region

Production (Output) \ Purchase (Input)		…	Region *r*				…	Import (Neg) $r = q$ $i = j$	Export (All regions by row)
		…	…	Sector *j*	…	Final Demand	…		
…	…								
	…								
Region *q*	…								
	Sector *i*			$z_{q,i,r,j}$		$f_{q,i,r}$		$-m_{q,i}$	$e_{q,i}$
	…								
…	…								
	…								
…	…								
	…								
Value added				$c_{r,j}$					

Recall the result-collection process

- If ISBD>=a heuristic threshold(= 0.01%※) → We say "dependent"
- Count the number of dependent pairs.

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Dependent pairs could be reduced by the quake. If a former dependent pair is no longer dependent after the quake, we say this pair is ***missing***.

If there are 9 regions, each intersection has 81 pairs. Suppose 10 out of the 81 pairs are dependent at this intersection. Then we say "the level of interdependency between demand-side sector Manufacturing-other (06) and supply-side sector of ICT (11) is 10."

※ From average mean value & the standard deviation.

We examine the impact of the quake by counting the missing pairs.

- We set the following 2 testing scenarios
  - Damage from the earthquake
    - 9 trillion yen (117 billion US$)
  - Damage from the earthquake and Tsunami
    - 16 trillion yen (208 billion US$)

- Estimate an effect from investment in IS
  - Assume that the pre-disaster investment in information security can reduce the damage by 10%.

Results regarding sectoral interdependency

- The reduction of interdependency occurs more likely with the following sectors:
  - Financial, insurance, and real estate
  - Manufacturing – other
  - Commerce and logistic

  (Manufacturing – other; Commerce and logistic) Critical sectors

- There is no change by security investment.

Results regarding regional interdependency

- Two patterns of the reduction of interdependency
  - Reduction of interdependency between sectors inside Tohoku.
    - Impact on the most damaged region.
  - Reduction of interdependency between sectors in Tohoku and those in Kanto.
    - Impact on the economically largest region.

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Conclusion

- The *economic scale of a region has a great influence* on the characteristics of the interdependency.
- Demand-side sectors can be classified into 5 classes based on the characteristics.
- The sectors with *high self-dependency get more benefits* from understanding of regional characteristics.
- The interdependency characteristics of the *most damaged region* and *economically largest region* are impacted by the earthquake.

Thank you