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The Complex Network Study of Money and CO2 Emission Flows between Industrial Sectors in Asian Countries using Input-Output Table

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Abstract: In 2011, earthquakes in Japan and flood in Thailand revealed the serious risks that local break downs of Motor vehicle sector and Electronic computing sector cause the cascade breakdown of world economy. To estimate such risks, it seems that the connections between international industrial sectors are important and recently developed complex networks method is suitable for this study. We use the data of the Input-Output table of Asian countries and USA made by JETRO in 2000[1]. We regard the table as network matrix and make various directed weighted networks. In these networks, the nodes correspond to each industry sector in a country and the weight of the link corresponds to the amount of the money which uses the product of an industry sector as material to produce the product of another industry sector. We think cascade failure of the industry sector has deep connection with not only quantitative weights of the links but also network structure. So we calculate betweenness centrality of nodes using Dijkstra algorithm [2,3,4], which describes basically the number of paths through the node. We found the betweenness centrality is high in Motor vehicle sector, Electronic computing sector and Semiconductors and integrated circuits sector. Next we use CO2 emission data made by IEA [5] and make environmental extension of Input-Output table. Our results warn that CO2 emission of developing countries is also important problem..

Keywords: Complex Networks, CO2 Emission, Asian Countries, Input-Output Table.

1 INTRODUCTION

The connections among various economic factors or economic units have become complicated more and more according to developing economy and society in each country. We have to pay attention to the risk that a small negative effect is amplified by these complicated connections. In other words, economic factors or economic units with various connections make complex networks and the risk of big economic failure lies behind the structure of these networks. In wide variety of research fields including economy, the complex networks[6,7,8] have been studied earnestly in these 10 years. A lot of analytical methods have been developed and applied to various data. They have contributed to solve the various problems in real world.

Industry-industry connections are described by Input-Output table[9], which has been widely applied in the economic analysis for the past 50 years. In many countries, governments and local states or prefectures make Input-Output tables for analysis of domestic economy in every year. And the environmental extension of the Input-Output table has been used energetically in various environmental problems in these 20 years[10]. This analytic method is one of the most systematic and practical tool for environmental problems. Though Input-Output table includes lots of information, it does not seem that traditional analysis is enough to extract such information and show us understandable way. Connections between nodes are main interest in complex networks study, but only a few complex networks studies have been done using Input-Output table[12-19]. Because Input-Output table corresponds to the complete network with directed weighted links including self loops, the analysis of such networks is not so simple as networks which mainly have been studied in the past. We think the recent development of the various analytical methods enables us to extract new results from different point of view.

2 DATA

We use "Input-Output table for East Asia" in 2000. They are made by JETRO (Japan External Trade Organization) by combining 10 countries tables, 9 Asian countries (China, Taiwan, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Thailand) and USA, and include 76 industrial sectors per a country. One of the aims of this paper is to track CO2 emission from the production of an industry sector in a country until the final consumption of the products of other industry sector in other country. IEA(International Energy Agency) issues the data about CO2 emission of each industry sector in each country except Taiwan, so we remove Taiwan's data from the table and analyze 9 countries data. So the inter-industry sectors part of the table is a square matrix of the size of 684(2000). The classification of industry sectors is different between "Input-Output table for East Asia" and "IEA CO2 emission data". So we redistributed CO2 emission data to sectors in Input-Output table after referring to these papers[].

3 METHOD

3.1 Network Matrix

In this paper, we study the connections between the production in an industry sector in a country and the final consumption of the products in an industry sector in a country. To get network matrix for this study, we start from the traditional induced analysis. In case of Non-Competitive Import Type Input-Output table, induced production vector Y is described by

$$Y = [\mathbf{I} - \mathbf{A}]^{-1} C \quad (1)$$

Here, $[\mathbf{I} - \mathbf{A}]^{-1}$ is the Leontief inverse and C is final consumption vector. Induced CO2 emission EI is de scribed by,

$$EI = \lambda [\mathbf{I} - \mathbf{A}]^{-1} C \quad (2)$$

Here, λ is the diagonal matrix whose diagonal elemen ts are direct CO2 emission in each industry sector.

To get the information about which sector's final cons umption induces which sector's production, we use di agonal final consumption matrix $\mathbf{C}$ whose diagonal e lements are the elements of final consumption vector C.

$$\mathbf{Y} = [\mathbf{I} - \mathbf{A}]^{-1} \mathbf{C} \quad (3)$$

$$\mathbf{EI} = \lambda [\mathbf{I} - \mathbf{A}]^{-1} \mathbf{C} \quad (4)$$

The induced production matrix $\mathbf{Y}$ represents which secto r's final consumption induces which sector's production and the induced CO2 emission matrix $\mathbf{EI}$ represents which sector's final consumption induces which sector' s CO2 emission. We consider the matrix $\mathbf{Y}$ and $\mathbf{EI}$ as network matrixes. So the network created by networ k matrix $\mathbf{Y}$ is constructed by nodes which represent e ach industry section and constructed by links which re present product flows from productions to consumption s. And the network created by network matrix $\mathbf{EI}$ is constructed by nodes which represent each industry sec tion and constructed by links which represent CO2 emi ssion flows with products. In previous paper[20], we a nalyzed networks corresponding to these network matri xes $\mathbf{Y}$ and $\mathbf{EI}$. These results are strongly dominated by big countries (Japan, USA and China) and big ind ustry sections, so we can not see the structure well. S ometimes small industry becomes a key of the econom ic failure.

In this paper, we analyze production ratio not producti on. That is, we analyze matrix $\mathbf{L}$ and $\mathbf{EL}$ which ar e described by

$$\mathbf{L} = [\mathbf{I} - \mathbf{A}]^{-1} \quad (5)$$

$$\mathbf{EL} = \lambda [\mathbf{I} - \mathbf{A}]^{-1} \quad (6)$$

3.2. Betweenness centrality

Considering a cascade failure of the economy resulting from a breakdown of small industry, we think the ne ck of the paths in the network relates to the cascade. Betweenness centrality describes the importance of the node under the meaning of path going through it. The definition of Betweenness centrality of node v in sim ple (undirected unweighted) network is,

$$c_{\mathrm{B}}(v) = \sum_{s \neq v, t \neq v} \frac{\sigma_{s,t}(v)}{\sigma_{s,t}} \quad (7)$$

Here, $\sigma_{s,t}(v)$ is the number of shortest paths from no de s to node t going through node v and $\sigma_{s,t}$ is the number of shortest paths from node s to node t. The extended definition of Betweenness centrality for direct ed weighted network is counting shortest cost paths wi th link direction instead of shortest paths. In our netw ork, the costs are the inverses of the network matrix e lements. This centrality can be calculated using Dijkstr a algorithm for shortest cost paths.

4 RESULT

Table 1 shows top ten sectors (nodes) of total produ ction (total weight of links) in production ratio base n etwork $\mathbf{L}$ In total outward weight, USA and Japan "Ot her services sector" and "Wholesale and retail trade se ctor" have heavy weight. In total inward weight, indust ry sectors do not have so much different weights. The y have the same weight on the average.

Table 2 shows top ten sectors (nodes) of betweennes s centrality in production ratio base network $\mathbf{L}$. Motor vehicles sector in Japan has high betweenness centrali ty. This means if breakdown of this sector happens, a lot of paths of the products are destroyed and affects world economy. And it is not proportion to its amount of money. This is really the fact that happened after earthquake in local area of Japan in 2011. Electronic c omputing equipment sector in Singapore, Semiconductor s sector in Malaysia and Philippines have high betwee nness centrality either. They are not Thailand but we c an guess the situations are similar in Thailand.

Table 1. top ten sectors (nodes) of total production ratio (total weight of links)

	Inward Weight (production ratio base network **L**)	
	Total weight	Industry section
1	3.18	Japan Cement and cement products
2	2.67	Korea Cement and cement products
3	2.10	Japan Non-metallic ore and quarrying
4	2.09	Japan Motor cycles
5	2.04	China Electronic products
6	1.97	Korea Slaughtering, meat products
7	1.91	USA Slaughtering, meat products
8	1.90	China Lighting fixtures
9	1.89	China Wooden furniture
10	1.87	China Metal products

	Outward Weight (production ratio base network **L**)	
	Total weight	Industry section
1	15.23	USA Other services
2	12.75	Japan Wholesale and retail trade
3	11.80	Japan Other services
4	9.58	USA Wholesale and retail trade
5	9.56	Japan Iron and steel
6	8.71	Japan Basic industrial chemicals
7	8.59	Singapore Wholesale and retail trade
8	8.25	China Electricity and gas
9	7.44	China Wholesale and retail trade
10	7.39	Thailand Wholesale and retail trade

Table 1 shows top ten sectors (nodes) of total producti on (total weight of links) in production ratio base net work **L** In total outward weight, USA and Japan "Oth er services sector" and "Wholesale and retail trade sect or" have heavy weight.

Table 2. top ten sectors (nodes) of betweenness centrality

	Betweenness (Money base network **L**)	
	betweenn es	*Industry section*
1	48945	**Japan Motor vehicles**
2	38390	Singapore Wholesale and retail trade
3	37084	USA Transportation
4	36047	**Singapore Electronic computing equi.**
5	36036	**Malaysia Semiconductors**
6	35318	China Wholesale and retail trade
7	33162	Japan Electricity and gas
8	31357	**Philippines Semiconductor**
9	31312	Thailand Wholesale and retail trade
10	29815	China Other services

Table 2 shows top ten sectors (nodes) of betweenness centrality in production ratio base network **L** .motor vehicles sector in japan has high betweenness centrality.

Table 3. top ten sectors (nodes) of total production (total weight of links)

	Inward Weight (CO2 emission base network **EL**)	
	Total weight	Industry section
1	1.21	China Water supply
2	1.14	China Unclassified
3	1.05	China Metal products
4	1.04	China Iron ore
5	1.04	China Cement and cement products
6	0.93	China Chemical fertilizers and pesticides
7	0.93	China Basic industrial chemicals
8	0.93	China Non-ferrous metal
9	0.92	China Other metallic ore
10	0.84	China Other transport equipment

	Outward Weight (CO2 emission base network **EL**)	
	Total weight	Industry section
1	25.66	China Electricity and gas
2	8.29	Malaysia Electricity and gas
3	7.91	Thailand Electricity and gas
4	7.03	Indonesia Electricity and gas
5	6.91	Korea Electricity and gas
6	6.10	Philippines Electricity and gas
7	5.86	USA Electricity and gas
8	5.24	China Iron and steel
9	4.70	Singapore Electricity and gas
10	4.24	Japan Electricity and gas

Table 3 shows top ten sectors (nodes) of total producti on (total weight of links) in CO2 emission base netwo rk **EL** . In total outward weight, "Electricity and gas s ector" in rather developing countries are dominant.In t otal inward weight, all top ten sectors are China.

Table 4. top ten sectors (nodes) of betweenness centrality

	Betweenness (**CO2** emission base network **EL**)	
	betweenn es	*Industry section*
1	85563	China Iron and steel
2	84824	China Electricity and gas
3	82406	Malaysia Crude petroleum & natural gas
4	69520	Malaysia Electricity and gas
5	59840	Singapore Refined petroleum
6	51189	Japan Electricity and gas
7	50831	Malaysia Precision machines
8	49816	Korea Iron and steel
9	44718	Malaysia Transportation
10	41394	Japan Iron and steel

Table 4 shows top ten sectors (nodes) of betweenness centrality in CO2 emission base network **EL** "Iron and steel" and "Refined petroleum" appears. They can be i mported and exported between countries, and conseque ntly carry heavy CO2 emission.

Table 3 shows top ten sectors (nodes) of total production (total weight of links) in CO2 emission base network **EL**. In total outward weight, "Electricity and gas sector" in rather developing countries are dominant.In total inward weight, all top ten sectors are China. It can be thought that the results are caused from the inefficient industrial machines or system in the case of ratio.

Table 4 shows top ten sectors (nodes) of betweenness centrality in CO2 emission base network **EL** "Iron and steel" and "Refined petroleum" appears. They can be imported and exported between countries, and consequently carry heavy CO2 emission.

Figure 1 show the networks constructed by network matrix **L**. To visualize, only 1000 links are left, after cutting small links whose weights are under minimum weight. The directions of links show product flow (counter direction of money flow). "Motor vehicles sector" and "Electronic computing equipment sector" are in the middle part between countries. Coincide These results coincide with the results of betweenness centrality. The nodes connecting different country's industry sectors are neck of the paths and have hight betweenness centralities.These are considered also necks of the world economy.

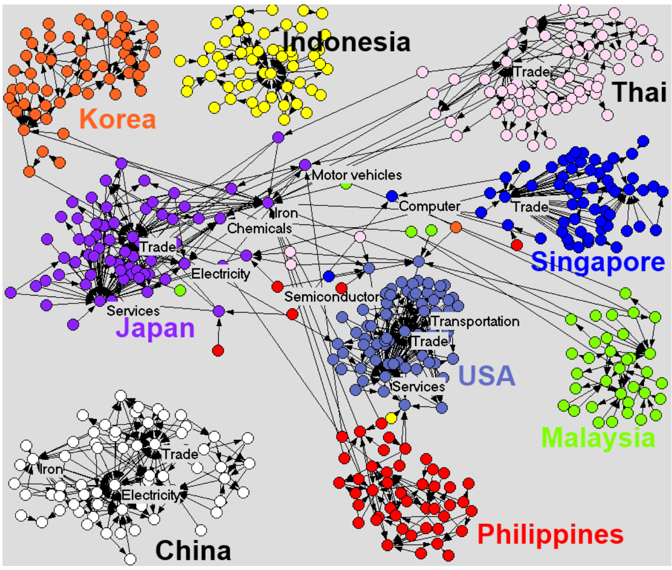

Figure 1 Production ratio base network **L**

5 CONCLUSION

We show the possibility of the cascade failure of the world economy caused by the breakdown of some local industry sectors. The complex networks analysis of the data is consistent with the facts in local breakdowns of Motor vehicle sector in Japan and of Electronic computing sector in Thailand. We have to find the risks of the cascade failure of the world economy from various directions. And also our results warn that CO2 emission of developing countries is also important problem..

We think the complex networks analysis gives us the really useful tools and this paper will be a hint of the research from this direction.

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