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Network Analysis of Ecologocal Footprint & CO2 Emission based on Input-Output Table for East Asia

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*Abstract***:** We study the Input-Output table for East Asia as complex networks. The 50%~95% of sum of the off-diagonal elements is included in several percent of the big off-diagonal elements of the Input-Output table. This makes the network representation useful. We make the extracted networks with these big off-diagonal elements. The distributions of these off-diagonal elements (edge values) are power law shape with exponents of 2.56(money base), 2.07(EF base) and 2.00(CO2 emission base) on the average. EF base and CO2 base inter-dependences between industry sections are more unequal than money base, so from environmental point of view, a fewer inter-dependences are important. We can see the differences of the maximum 'degree', 'closeness' and 'the sum of elements (edge values)' in developed nations and in developing nations.
Keywords: Ecological Footprint, CO2 Emission, Input-Output table, Induced analysis, Complex Networks

I. INTRODUCTION

How production in each industry causes environmental impacts becomes more important for reducing these impacts and sustaining the earth for future. One of the methods to research this problem is to use environmental extension of Input-Output table. For decades, Input-Output table has been studied for analyzing the nation or regional economy on the basis of the inter-industry relations of how much production in one section is induced by the production in other sections. Generally, inter-industry relations are complicated, so it is not easy to extract the useful information to appeal to intuition. On the other hand, lots of studies on the topic of complex networks have been done recently and applied to various fields. Network representation is suitable to appeal to intuition and various analytical methods in this area help our deep understanding of the problems. And the Input-Output table can be thought as network matrix, but few studies of the complex networks have been applied to Input-Output table. [1][2][3] Moreover it is interesting to compare the economy (money) base inter-industry relations and the environmental impact base ones.

There are a lot of representations of environmental impact. One of them is Ecological Footprint (**EF**)[4] and other is CO2 emission. EF is one of the sustainable indexes, which converts nation's or regional basic consumption to the nation's or regional virtual area which is necessary to produce it. For example, we consume agricultural products to keep our life. These consumptions are converted to cropland area. Finally the virtual area caused by our total consumption is compared to bio capacity of the earth. The CO2 emission is most severe environmental impact which has to be reduced.

So in this paper, we compare inter-industry relations of money base , EF base and CO2 emission base.

II. INDUCED ANALYSIS OF ENVIRONMENTAL IMPACT

EF is represented by total area of six land types, "Cropland", "Forest", "Grazing land", "Fishing ground" , "Carbon uptake land" and "Built-up land". Each area is calculated to reproduce our final consumption as necessity area for "the supplies of crop", "the supplies of wood", "the supplies of livestock feed", "the supplies of fish", "absorption of CO2 emission" and "house, factory, road etc.". And it is compared to the real area (bio capacity) on the earth. Actually Japan needs 2.5 times as much area as real Japan area to keep our lifestyle. Whole world people need more area than whole area of the earth.

EF is calculated for an area on the basis of consumption in the area. That is, EF of the imported product does not belong to the nation in which the product is produced but it belongs to the nation in which the product is consumed.

$$EF_N = \sum_{\alpha,i,j\ldots k,\Omega} \frac{1}{y_{N,\alpha}} \varepsilon_{l(\alpha)} \psi_{N,l(\alpha)} \chi_{\alpha i} \chi_{ij} \cdots\cdot \chi_{k\Omega} C_\Omega \qquad (1)$$

Here C_Ω is the weight of the consumed product Ω of which we want to know the effect, χ_{ij} is the weight of the product i to produce unit weight of product j, $\varepsilon_{l(\alpha)}$ is the equivalence factor of land type $l(\alpha)$ for the product α *, $\psi_{N,l(\alpha)}$ is yield factor of nation N and land type $l(\alpha)$, $y_{N,\alpha}$ is the average weight of the product from unit area in the nation N. And the sums are executed in all paths from product Ω to product α through intermediate products *i*, *j*... Using the matrix representation, $\{1+\chi+\chi\chi+\chi\chi\chi+ \quad\} = [1-\chi]^{-1}$, and

$$EF = \vec{\lambda}[\mathbf{1}-\boldsymbol{\chi}]^{-1}\vec{C} \qquad (2)$$

here $\vec{\lambda}$, $\vec{C}$ is vector representation of $\varepsilon_{l(\alpha)}\psi_{N,l(\alpha)}/y_{N,\alpha}$ and C_{Ω}, $\boldsymbol{\chi}$ is the matrix representation of χ_{ij} and $\mathbf{1}$ is unit matrix and we omit the nation's suffix N in *EF* and $\vec{\lambda}$. But usually it is difficult to know χ_{ij} of all products' pairs [*i*, *j*] without double counting. Sometimes we want to measure the effect of consumption toward other industrial sectors or toward other nations, not only on economic impact but also on environmental impact. Input-Output table enables us to calculate such impacts by induced analysis.

$$EF = \vec{\lambda}[\mathbf{1}-\boldsymbol{\chi}]^{-1}\vec{C}+\vec{\lambda}^{fuel}\vec{C} \qquad (3)$$

In eq.(3), $\vec{C}$ is a demand vector of sectors expressed by amount of money, $\boldsymbol{\chi}$ is the coefficient matrix and $[\mathbf{1}-\boldsymbol{\chi}]^{-1}$ is the Leontief Inverse Matrix of the Input-Output table. $\vec{\lambda}$ is a kind of induced value added vector which shows environmental impacts. Additional term $\vec{\lambda}^{fuel}\vec{C}$ represents CO2 emission from the direct fuel use of final consumption. For example, in case of agriculture sector, $y_{N,\alpha}$ is the total amount of agricultural product divided by the total area of the Cropland of the considering region N. $\varepsilon_{l(\alpha)}$ is the equivalence factor of Cropland, $\psi_{N,l(\alpha)}$ is yield factor of the region N and Cropland .

There is another method to calculate the vector $\vec{\lambda}$. Global Footprint Network (GFN) calculates nation's EF_l of each land type l every year and these EF_l s represent the area after considering the productivity.

If EF_l s were distributed to each sector α (They are called direct EFs), $\vec{\lambda}$ is able to replace by them. The merit of this method is that induced EFs are able to compare to other nations' EFs through EFs calculated by GFN.

III. NETWORK REPRESENTATION

Our purpose of this paper is to study inter-industry relation on the economy (money) base and environmental impact base by network representation. So we rewrite the vectors $\vec{\lambda}$ and $\vec{C}$ to the diagonal matrix $\boldsymbol{\lambda}$ and $\mathbf{C}$. Then we get the basic matrix.

$$\mathbf{W} = [\mathbf{1}-\boldsymbol{\chi}]^{-1}\mathbf{C} \qquad (4)$$

$$\mathbf{EF} = \boldsymbol{\lambda}[\mathbf{1}-\boldsymbol{\chi}]^{-1}\mathbf{C}+\boldsymbol{\lambda}^{fuel}\mathbf{C} \qquad (5)$$

$$\mathbf{EF}_C = \boldsymbol{\lambda}_C[\mathbf{1}-\boldsymbol{\chi}]^{-1}\mathbf{C}+\boldsymbol{\lambda}_C^{fuel}\mathbf{C} \qquad (6)$$

Here eq.(4), eq.(5) and eq.(6) are the matrix representations of normal induced analysis, of EF base (eq(3)) and of CO2 emission EF base. $\boldsymbol{\lambda}_C$ is one part of $\boldsymbol{\lambda}$ calculated by EF of Carbon uptake land.

$\mathbf{W}$, $\mathbf{EF}$ and $\mathbf{EF}_C$ are no symmetric matrix with diagonal elements, so they can be thought as the adjacency matrix of the directed multi-weighted networks.

IV. Input-Output Table for East Asia

We use "Input-Output table for East Asia" of 2000 [5]. This Input-Output table includes the data of 8 nations in East Asia (China, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Thailand) and the data of USA. In this paper, we split this table into each nation's table with 76 industry sections.

1. To calculate the matrix $\boldsymbol{\lambda}, \boldsymbol{\lambda}^{fuel}, \boldsymbol{\lambda}_C, \boldsymbol{\lambda}_C^{fuel}$, we allocate the EF calculated by GFN to each sector of each nation. EFs are allocated in proportion to the total of each sector according to the Table 1. We reallocate the CO2 emission data provided by International Energy Agency(IEA) into the 76 sectors of Input-Output table. Next we allocate the Carbon uptake land EF into 76 sectors in proportion to these CO2 emission data.

Table 1. Land types and corresponding sectors

1	EF of Cropland	Agriculture sectors
2	EF of Forest	Forestry sectors
3	EF of Grazing land	Agriculture sectors
4	EF of Fishing ground	Fishery sectors
5	EF of Carbon uptake land	All sectors Final consumption
6	EF of Built-up land	All sectors

2. Using the Input-Output table, we calculate eq.(4), eq.(5) and eq.(6).
3. The networks represented by the adjacency matrixes $\mathbf{W}$, $\mathbf{EF}$ and $\mathbf{EF}_C$ are directed multi-weighted networks. But the analytical tools for directed multi-weighted networks have not been developed well, so in this paper we extract directed un-weighted networks as follows.

Extraction of the network
1. We make complete network of all industry sections as nodes being connected each other by edges.
2. We remove edges from the complete network in order from the smaller corresponding matrix elements until the number of nodes of largest connected network becomes 38(half of the number of all nodes).

V. RESULT

Figure 1 shows extracted network of **EF** in Japan, which includes 38 nodes. Figure 2 shows the distribution of off-diagonal elements (edge values) of the matrix **EF** of Japan. The edges (log(edge values) >

31, right side of the dotted line) remain in extracted network. Log-log plot of the cumulative distribution of extracted network is shown in Figure 3. It shows power law with exponent -2.12+1. For example in Japan, Table 2 shows that only 2.13%(money base), 1.83%(EF base) and 2.17%(CO2 base) of all edges remain in extracted network, but the sum of these edge values reaches 51.9% , 77.2% and 80.8% of the sum of all edge values. In EF base network, the smaller number of edges have more edge values than money base network. In CO2 base network, the smaller number of edges have more edge values than EF base network. The power law exponents in 27 extracted networks are summarized in Table 3. In Japan, power law exponents are 2.79, 2.12 and 2.08 on money, EF and CO2 base. Table 4 shows industry sections (nodes) of maximum degree, of maximum closeness and of maximum sum of elements (edge values), being calculated by out-edge and in-edge separately. In developed nations (USA, Japan, Korea, Singapore), on money base, Building construction sector has maximum connection and gives large influence to other sectors. On EF base and CO2 emission base, Wholesale and retail trade sector has maximum connection to inward direction. On money, EF and CO2 emission base, Other services sector has maximum connections to inward direction and gets large influence from other sections.
In developing nations (China, Malaysia, Philipines, Thailand, Indonesia), on money base, Wholesale and retail trade sector has maximum connection to inward direction from other sections. On EF base, Livestock and poultry/ Fishery/ Food crops have maximum connection to the outward direction to other sections. But on CO2 emission base, Wholesale and retail trade sector has maximum connection to the outward direction to other sections.

V. CONCLUSION

We study the Input-Output table for East Asia as complex networks. We show that 'the complex networks' is suitable method for these studies. We find the basic characteristics of the inter-connection between industry sections. Although we have not studied the international relations, it is expected that these studies will be able to make clear the way on which nations have developed with inter-nations connection if we study the Input-Output table of other years.

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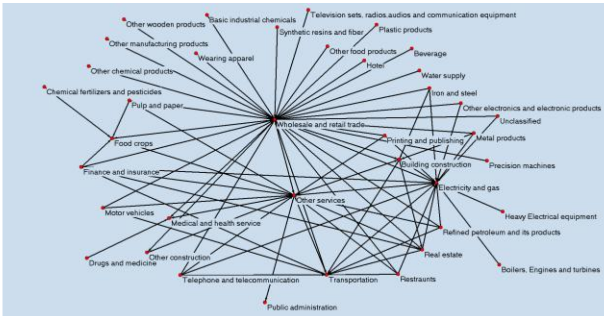

Fig. 1 Extracted network made by matrix **EF** in Japan, which includes 38 edges.

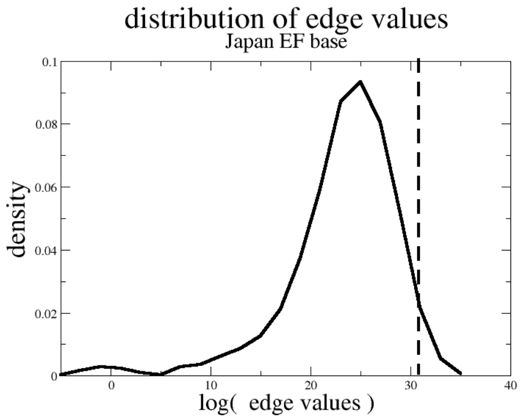

Fig. 2 Distribution of off-diagonal elements (edge values) of the matrix **EF** of Japan. The edges, log(edge values) > 31, remain in extracted network.

Table 4 Industry sections (nodes) of maximum degree, of maximum closeness and of maximum sum of elements (edge values), being calculated by out-edge and in-edge separately.

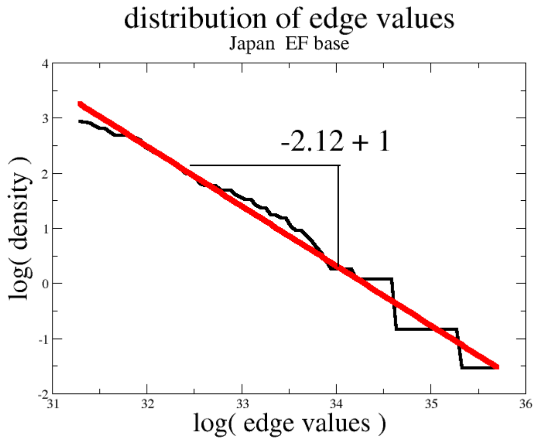

Fig. 3 Log-log plot of cumulative distribution of off-diagonal elements (edge values) of remaining in extracted network. Straight line is the least-squares approximation of the distribution. It shows power law with exponent -2.12+1.

Table 2 Percentage of the number of edges included in extracted network per the number of edges in complete network. And percentage of the sum of edge values included in extracted network per the sum of edge values in complete network.

	money		EF		CO2	
matrixes	**W**		**EF**		**EF_C**	
Indonesia	1.28	54.90	2.22	81.90	1.48	82.30
Malaysia	1.85	59.30	2.30	81.60	6.98	91.00
Philippines	3.02	80.10	2.44	89.50	2.21	93.20
Singapore	5.13	83.20	2.21	97.60	23.90	99.00
Thailand	1.42	55.80	1.79	81.00	2.00	85.80
China	1.29	38.20	2.68	71.60	1.47	58.00
Korea	2.2	51.10	2.47	71.60	2.37	76.00
Japan	2.13	51.90	1.83	77.20	2.17	80.80
USA	2.2	60.40	1.29	86.10	1.43	88.80
average	2.28	59.43	2.14	82.01	4.89	83.88

Table 3 Power law exponents of distribution of off-diagonal elements in 27 extracted networks

	money	EF	CO2
matrixes	**W**	**EF**	**EF_C**
Indonesia	2.69	2.17	2.03
Malaysia	2.69	2.10	1.99
Philippines	2.33	1.94	1.80
Singapore	2.14	1.70	1.65
Thailand	2.60	2.06	1.88
China	2.65	2.38	2.52
Korea	2.59	2.16	2.06
Japan	2.79	2.12	2.08
USA	2.56	1.97	1.96
average	2.56	2.07	2.00

BC Building construction
OS Other services
WR Wholesale and retail trade

Table 4

money base			USA		Japan		Korea		Singapore		China		Malaysia		Philipines		Thailand		Indonesia	
out	hub		BC	[19,2]	BC	[16,3]	BC	[16,1]	BC	[24,2]	BC	[23,0]	BC	[18,0]	Other food products	[16,7]	Public administration Restraunts	[11,0]		
	closeness		Public administration	0.50	BC	0.46	BC	0.44	BC	0.69	BC	0.63	BC	0.51	Public administration	0.52	Public administration	0.34	Other construction	0.35
	sum of edge [US$1000]		Public administration	7E+08	BC	3E+08	BC	4E+07	BC	7E+06	BC	3E+08	BC	4E+06	Other food products	4E+06	Public administration	1E+07	Other construction	1E+07
in	authority		OS	[7,16]	OS	[9,16]	OS	[7,11]	OS	[13,22]	WR	[0,5]	WR	[0,10]	WR	[8,18]	WR	[8,11]	WR	[2,16]
	closeness		OS	0.45	OS	0.45	OS	0.32	WR	0.74	WR	0.18	WR	0.37	WR	0.5	WR	0.32	WR	0.45
	sum of edge [US$1000]		OS	1E+09	OS	4E+08	OS	3E+07	OS	6E+06	Iron and steel	8E+07	WR	2E+06	OS	3E+06	WR	7E+06	WR	1E+07

EF base			USA		Japan		Korea		Singapore		China		Malaysia		Philipines		Thailand		Indonesia	
out	hub		WR	[34,2]	WR	[29,7]	WR	[22,6]	WR	[35,4]	Livestock and poultry	[29,0]	Fishery	[17,0]	Fishery	[20,0]	WR	[28,5]	Food crops	[22,3]
	closeness		WR	0.92	WR	0.79	WR	0.62	WR	0.95	Livestock and poultry	0.79	Fishery	0.55	Fishery	0.61	WR	0.78	Food crops	0.68
	sum of edge [gha][US$1000]		WR	2E+17	WR	1E+16	WR	3E+14	WR	7E+12	Livestock and poultry	1E+16	Fishery	5E+12	WR	1E+13	WR	5E+13	Food crops	6E+13
in	authority		OS	[4,8]	OS	[12,10]	OS	[10,11]	OS Finance and insurance	[0,5]	Chemical fertilizers and pesticides	[0,6]	WR	[12,9]	OS	[0,11]	Refined petroleum and its products	[1,5]	OS	[0,8]
	closeness		OS	0.24	OS	0.29	OS	0.32	Finance and insurance	0.16	Refined petroleum and its products	0.26	OS	0.27	OS	0.32	Crude petroleum and natural gas	0.16	WR	0.32
	sum of edge [gha][US$1000]		OS	1E+17	OS	5E+15	Refined petroleum and its products	8E+13	OS	2E+12	Chemical fertilizers and pesticides	4E+15	Refined petroleum and its products	4E+12	Refined petroleum and its products	8E+12	Refined petroleum and its products	2E+13	WR	3E+13

CO2 base			USA		Japan		Korea		Singapore		China		Malaysia		Philipines		Thailand		Indonesia	
out	hub		WR	[35,2]	WR	[30,6]	WR	[30,5]	WR	[37,2]	WR	[22,3]	Electricity and gas	[24,7]	WR	[28,7]	WR	[33,3]	WR	[28,7]
	closeness		WR	0.95	WR	0.82	WR	0.82	WR	1	WR	0.63	WR	0.76	WR	0.79	WR	0.902	WR	0.77
	sum of edge [gha][US$1000]		WR	2E+17	WR	1E+16	WR	3E+14	WR	7E+12	Electricity and gas	3E+15	Electricity and gas	3E+12	WR	1E+13	WR	4E+13	WR	3E+13
in	authority		OS	[4,7]	OS	[12,9]	OS	[10,7]	OS Finance and insurance	[0,3]	Crude petroleum and natural gas Refined petroleum and its products	[0,4]	Crude petroleum and natural gas	[1,5]	Refined petroleum and its products	[3,6]	Refined petroleum and its products	[1,3]	Crude petroleum and natural gas	[0,4]
	closeness		OS	0.21	OS	0.26	Iron and steel	0.23	Refined petroleum and its products	0.11	Crude petroleum and natural gas	0.14	OS	0.24	OS	0.24	Crude petroleum and natural gas	0.13	WR	0.21
	sum of edge [gha][US$1000]		OS	1E+17	OS	5E+15	Refined petroleum and its products	7E+13	OS	2E+12	Refined petroleum and its products	8E+14	Crude petroleum and natural gas	2E+12	Refined petroleum and its products	4E+12	Refined petroleum and its products	1E+13	Crude petroleum and natural gas	1E+13

[7,16] = [7 out edges, 16 in-edges]