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Evaluation of CO_2 Emission Reduction in Japan Utilizing the Interregional Repercussion Model on Freight Transportation

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ABSTRACT. This study proposes a novel method of input-output analysis for physical distribution, with applications in the evaluation of potential reductions in CO_2 emissions. Using the "Physical Distribution Census" published by the National Land and Transportation Ministry in Japan, methods of calculating physical distribution induced by a unit of final demand and physical distribution derived by a unit of production are developed. Induced and/or derived CO_2 emissions are directly calculated from the induced and/or derived physical distribution. This allows analysis of the interregional relationship that combines physical distribution with either industrial production or household consumption. A case study of derived physical distribution shows that a ton of final demand of farm and marine products in Tokyo and Hokkaido generates CO_2 emissions of 62 kg and 31 kg, respectively. As an application of this method, potential for CO_2 reduction was evaluated by considering a modal shift from truck transportation to rail and marine transportation. A 50 % modal shift was found to achieve a 990 Mt reduction in CO_2 emissions. In a case study for the induced physical distribution method, a ton of farm and marine products produced in Hokkaido was found to generate 2.5 tons of interregional physical distribution. This method was applied by evaluating the potential increase in CO_2 emissions that would be caused by an improvement in the rate of food self-sufficiency. The results indicate that more than one million tons of CO_2 could be further emitted due to a five-percentage point improvement in Japan's self-sufficiency rate.

Keywords: induced physical distribution, derived physical distribution, CO_2 emissions, freight transportation, self-sufficiency rate, modal shift

1. Introduction

A novel method of estimating interregional physical distribution is proposed by focusing on physical distribution caused by production repercussions. The flow of physical distribution starts when raw material is acquired and ends when the commodities are consumed as final demand. The activity of physical distribution is measured in weight or the product of weight and distance. Utilizing data from the National Physical Distribution Census (Ministry of Land, Infrastructure and Transport of Japan, 2002), physical distribution is viewed in this study from two perspectives. One is "derived physical distribution", which considers commodity flow from downstream to upstream. The quantity of derived physical distribution is calculated as the sum of the interregional physical distribution that is derived for a unit of commodity as a final demand and accumulates every time products are processed and transported. The other is "induced physical distribution", which considers commodity flow from upstream to downstream. The quantity of induced physical distribution is calculated as the sum of the interregional physical distribution that is generated by a unit of raw material acquired from the earth and accumulates every time products are processed and transported.The total quantities of derived and induced physical distribution are equal to each other. This framework can be considered as an input-output analysis of physical distribution, which combines physical distribution with either industrial production or household consumption.

Conventional input-output analysis is often applied in the energy-environmental field because both the direct and indirect environmental repercussions can be explored. Input-output analysis enables evaluation of the relationship between final demand and production in different industries (Lenzen, 1998; Yoshida et al., 2002). Lee and Mokhtarian (2008) investigates the correlation between industrial demand and transportation using input-output analysis. Facanha and Horvath (2006) provides a life-cycle inventory of air emissions associated with the transporttation of goods by road, rail and air in the U.S.A.. These studies temporally or spatially evaluate environmental effects derived from transportation using input-output analysis, but do not analyze interregional transportation. Regional input-output tables can be used to generate interregional analysis (Yi et al., 2006; Yi et al., 2007). However, it is difficult to analyze the relationship between transportation and industrial production. The difference between conventional input-output analy-

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sis and the present study is that the amounts of interregional transporttation are summed for all steps where products are processed and transported. Without calculating the Leontief inverse matrix used in conventional input-output analysis, accumulation calculation is necessary to obtain the total interregional transporttation derived from industrial production.

Except for these previous studies utilizing input-output tables, interregional transportation is usually analyzed by utilizing person-trip data (U.S. Department of Transportation, 2004) or freight transport data (Ministry of Land, Infrastructure and Transport of Japan, 2002). Kudoh et al. (2001) developed a dynamic traffic-flow model of the Tokyo metropolitan area based on person-trip data and evaluated the environmental effect of introducing electric vehicles. Shimazaki (2008) analyzed the material flow in a region in Japan using physical distribution data.

However, using physical distribution data for freight transport makes it difficult to evaluate the relation between transportation and production in different industries. This study highlights the analysis that combines the national freight circulation data in Japan with input-output tables. A new method of combining the interregional transport analysis with input-output analysis is also presented. The method by which physical distribution is derived from final demand and relevant case studies are given in the following sections.

Murakoshi et al. (1988) proposed a similar framework in a theoretical study considering the difference in industrial structure between regions. However, they did not calculate results due to the restraints of data accessibility of input-output tables in each region. In this study, the industrial structure is not assumed to be different between regions. Although this is a strong restriction, it is accepted in order to give greater importance to the difference in interregional transport using actual data on freight transport and to obtain practical results as well as a theoretical framework. The validity of the assumption of the mono-structure of industry is also examined in this study.

In application, we calculated CO_2 emission reduction potential in the transportation sector in Japan. Many studies have been conducted for evaluating CO_2 emission reduction in Japan using input-output analysis. Yabe (2004) examined the factors that have an effect on CO_2 emissions produced by Japanese industries between 1985 and 1995 by using input-output tables. Takase et al. (2005) developed the waste input-output model to analyze households' sustainable consumption patterns. This study has an original approach based on the new input-output analysis for evaluating physical distribution, although the focus of modal shift from truck transportation to rail or marine transportation has been treated in the previous studies.

2. Calculation Method

2.1. Derived Physical Distribution

Input-output analysis calculates the amount of derived production from a unit of final demand. In the case of derived physical distribution, the commodity flow from downstream to upstream is considered. The derived physical distribution is calculated as the sum of the interregional physical distribution that is derived from a unit of commodity as final demand and accumulates every time products are processed and transported. The derived physical distribution is summed until the material or product is produced from raw materials or imported from abroad. The terms and method for calculating the derived physical distribution are given below:

(1) Derived physical distribution matrix $\mathbf{X}_c^{(k)}$: The element *ij* of this matrix is the input of a commodity *c* from region *i* to region *j*. Superscript *k* gives the number of production repercussions. For example, the number *k* equals one when the deriveed physical distribution is generated from the production to satisfy final demands. The total derived physical distribution for commodity *c* by summing these matrices over *k*.

(2) Derived demand matrix $\mathbf{D}_c^{(k)}$: The i^{th} element in the principal diagonal of this diagonal matrix gives the demand of commodity *c* in region *i* derived from the k^{th} production repercussion.

(3) B table **B**: This matrix gives the input structure across all industries. The element *ij* of this matrix shows the percentage of commodity *i* used when industry *j* receives a unit of input. Hence, the sum of each column equals one. This matrix is calculated from the National Physical Distribution Census (Ministry of Land, Infrastructure and Transport of Japan, 2002).

(4) D table **D**: This matrix gives the output structure for the range of commodities. The element *ij* of this matrix gives the percentage of commodity *j* shipped from each industry *i* when a unit of commodity *j* is shipped in total. Hence, the sum of each column equals one. This matrix is calculated from the National Physical Distribution Census.

(5) Input-output rate matrix **E**: The i^{th} element in the principal diagonal of this diagonal matrix gives the weight ratio of inputs to outputs in industry *i*. The input does not include imports, but the output does include exports. Imports are excluded because this matrix is used for calculating the amount of inputs corresponding to only domestic physical distribution. This matrix is calculated from the National Physical Distribution Census.

(6) Input coefficient matrix **A**: The element *ij* of this matrix is the amount of output of commodity *i* for a unit of input of the commodity *j*. This matrix is given by $\mathbf{BED}$.

(7) Regional input matrix $\mathbf{N}^{(k)}$: The element *ij* of this matrix is the amount of input of commodity *i* to region *j* in the k^{th} production repercussion.

(8) Regional output matrix $\mathbf{S}^{(k)}$: The element *ij* of this matrix is the amount of output of commodity *i* from region *j* in the k^{th} production repercussion.

(9) Interregional transport matrix $\mathbf{R}_c$: The element *ij* of this matrix is the weight percentage of transport required to transport commodity *c* from region *i* to region *j* when a unit of commodity *c* is produced in region *j*. Hence, the sum of each column equals one. This matrix is calculated from the National Physical Distribution Census.

The derived physical distribution is then calculated from these matrices. In the k^{th} production repercussion, the demand of commodity c is given as $\mathbf{D}_c^{(k)}$. The derived physical distribution matrix $\mathbf{X}_c^{(k)}$ is calculated by:

$$\mathbf{X}_c^{(k)} = \mathbf{R}_c \mathbf{D}_c^{(k)} \tag{1}$$

The necessary output of commodity c required to satisfy demand is obtained by summing each row, so that the regional output matrix $\mathbf{S}^{(k)}$ is given by:

$$\mathbf{S}^{(k)} = \left(\mathbf{s}_1^{(k)} \quad \cdots \quad \mathbf{s}_C^{(k)}\right)^t \tag{2}$$

where $\mathbf{s}_c^{(k)} = \mathbf{X}_c^{(k)}\mathbf{e}$, and $\mathbf{e}$ is a column vector with all elements equal to 1, and C is the number of commodities. Then, the regional input matrix $\mathbf{N}^{(k)}$ is given by:

$$\mathbf{N}^{(k)} = \mathbf{A}\mathbf{S}^{(k)} \tag{3}$$

where $\mathbf{A}$ is the input coefficient matrix. $\mathbf{N}^{(k)}$ is expressed as:

$$\mathbf{N}^{(k)} = \left(\mathbf{n}_1^{(k)} \quad \cdots \quad \mathbf{n}_C^{(k)}\right)^t \tag{4}$$

where $\mathbf{n}_c^{(k)}$ is the c^{th} column of matrix $\mathbf{N}^{(k)}$. The demand for commodity c given as $\mathbf{D}_c^{(k+1)}$ in the $(k + 1)^{\text{th}}$ production repercussion is the diagonal matrix whose i^{th} element in the principal diagonal is given by the i^{th} element of vector $\mathbf{n}_c^{(k)}$.

2.2. Induced Physical Distribution

Induced physical distribution is the sum of the interregional physical distribution that is generated by a unit of raw material acquired from the earth and accumulates every time products are processed and transported. The induced physical distribution is summed until the material or the product is consumed as final demand. The terms and method used for calculating the induced physical distribution are given below:

(1) Induced physical distribution matrix $\mathbf{X}_c^{(k)}$: The element ij of this matrix is the output of commodity c from region i to region j. Superscript k indicates the number of production repercussions. k equals one when the induced physical distribution starts from the acquisition of raw material. The total induced physical distribution for commodity c is obtained by summing these matrices over k.

(2) Induced final demand matrix $\mathbf{D}_c^{(k)}$: The i^{th} element in the principal diagonal of this diagonal matrix gives the final demand of commodity c induced in region i.

(3) Intermediate demand rate matrix $\mathbf{F}_c$: The i^{th} element in the principal diagonal of this diagonal matrix gives the rate of intermediate demand as part of the total demand of commodity c. This rate is obtained from input-output tables (Ministry of Economy, Trade and Industry of Japan, 2002).

(4) U table $\mathbf{U}$: This matrix is called the "use table" in the framework for input-output tables in the System of National Account (SNA) (OECD, 2000). The element ij of this matrix gives the percentage of commodity j used in industry i when a unit of commodity j is supplied in total. Hence, the sum of each column equals one. This matrix is calculated from the National Physical Distribution Census.

(5) V table $\mathbf{V}$: This matrix is called the "supply table" in the SNA framework. The element ij of this matrix gives the percentage of commodity i in each unit of output of industry j. Hence, the sum of each column equals one. This matrix is calculated from the National Physical Distribution Census.

(6) Yield rate matrix $\mathbf{E}$: The i^{th} element in the principal diagonal of this diagonal matrix gives the weight ratio of outputs to inputs in the industry i. This matrix is calculated from the National Physical Distribution Census.

(7) Output coefficient matrix $\mathbf{A}$: The element ij of this matrix is the output of commodity i per unit of input of commodity j. This matrix is given by $\mathbf{VEU}$.

(8) Regional input matrix $\mathbf{N}^{(k)}$: The element ij of this matrix is the input of commodity i to region j in the k^{th} production repercussion.

(9) Regional output matrix $\mathbf{S}^{(k)}$: The element ij of this matrix is the output of commodity i from region j in the k^{th} production repercussion.

(10) Interregional transport matrix $\mathbf{R}_c$: The element ij of this matrix is the weight percentage of transport required to transport commodity c from region i to region j when a unit of commodity c is produced in region i. Hence, the sum of each row equals one. This matrix is calculated from the National Physical Distribution Census. This is the transpose of the matrix $\mathbf{R}_c$ used for calculating derived physical distribution.

The induced physical distribution is then calculated from these matrices. $\mathbf{X}_c^{(k)}$ is the physical distribution matrix of the commodity c in the k^{th} production repercussion. In the k^{th} production repercussion, the physical distribution for the final demand is given by:

$$\mathbf{D}_c^{(k)} = \mathbf{X}_x^{(k)}(\mathbf{I} - \mathbf{F}_c) \tag{5}$$

The physical distribution $\mathbf{X}_x^{(k)}\mathbf{F}_c$, which is found by subtracting $\mathbf{D}_c^{(k)}$ from $\mathbf{X}_c^{(k)}$, is that consumed in each industry as the intermediate demand. The regional input matrix $\mathbf{N}^{(k)}$ is given by:

$$\mathbf{N}^{(k)} = \left(\mathbf{n}_1^{(k)} \quad \cdots \quad \mathbf{n}_C^{(k)}\right)^t \tag{6}$$

where the vector $\mathbf{n}_c^{(k)}$ is given by:

$$\mathbf{n}_c^{(k)} = \mathbf{e}\mathbf{X}_c^{(k)}\mathbf{F}_c \tag{7}$$

and $\mathbf{e}$ is a row vector whose all elements equal to one, and $\boldsymbol{C}$ is the number of commodities. Using the output coefficient matrix $\mathbf{A}$, the regional output matrix $\mathbf{S}^{(k)}$ is given by:

$$\mathbf{S}^{(k)} = \mathbf{A}\mathbf{N}^{(k)} \tag{8}$$

$\mathbf{S}^{(k)}$ can be expressed as:

$$\mathbf{S}^{(k)} = \left(\mathbf{s}_1^{(k)} \quad \cdots \quad \mathbf{s}_C^{(k)}\right)^t \tag{9}$$

and $\widehat{\mathbf{S}}_c^{(k)}$ is defined as the diagonal matrix whose diagonal elements are the elements of the vector $\mathbf{s}_c^{(k)}$. Then, the induced physical distribution in the $(k + 1)^{\text{th}}$ production repercussion is given by:

$$\mathbf{X}_c^{(k+1)} = \widehat{\mathbf{S}}_c^{(k)} \mathbf{R}_c \tag{10}$$

where $\mathbf{R}_c$ is the interregional transport matrix.

The physical distribution matrix $\mathbf{X}_c^{(k)}$ is sequentially obtained by this method. The initial value of induced physical distribution is calculated as:

$$\mathbf{X}_c^{(1)} = \widehat{\mathbf{S}}_c^{(0)} \mathbf{R}_c \tag{11}$$

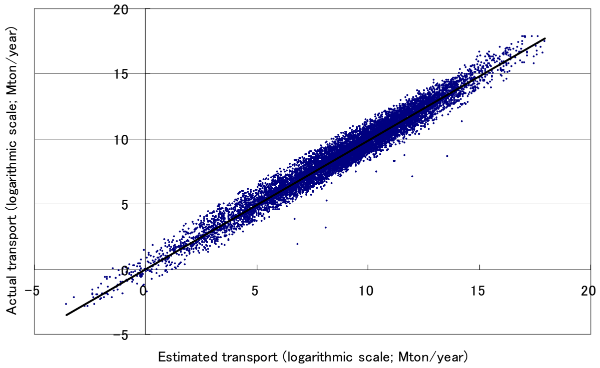

Figure 1. Comparison between actual transport and estimated transport on a logarithmic scale. Each plot corresponds to amount of transport between 49 prefectures in Japan over a year.

Assuming that a unit of commodity c is produced in region j, the regional output matrix $\mathbf{S}^{(0)}$ is initially defined as a matrix whose elements are zero except for the element in the c^{th} row and j^{th} column which is equal to one. Then, $\mathbf{X}_c^{(2)}$, $\mathbf{X}_c^{(3)}$ … are sequentially calculated. The induced physical distribution is summed until commodity c is consumed as the final demand after processing and transporting. The total induced physical distribution is given by:

$$\mathbf{X}_c = \sum_{k=0}^{\infty} \mathbf{X}_c^{(k)} \tag{12}$$

By using this calculation for all combinations of commodities and regions, the physical distribution induced by a unit of production of each commodity in each region is obtained. The induced physical distribution can also be attributed to the final demand by:

$$\mathbf{D}_c^{(k)} = \sum_{k=0}^{\infty} \mathbf{X}_c^{(k)} (\mathbf{I} - \mathbf{F}_c) \tag{13}$$

3. Application

3.1. Validation of the Estimation

Based on the method of derived physical distribution, we compare the estimated and actual amount of interregional transport between 49 prefectures in Japan over a year. The result is shown in Figure 1. In this figure, the amount of transport is shown on a logarithmic scale. Estimated transports fit well to actual transport since the correlation coefficient is 0.99. The coefficient of correlation is 0.81 if the logarithmic scale is not adopted. We can validate our method in each case.

3.2. Calculation of CO_2 Emissions

CO_2 emissions are estimated as the product of quantity of commodity distributed (kg), distance of transportation (km) and the emission coefficient (kg-CO_2·kg^{-1}·km^{-1}). The emission coefficients for different means of transportation are shown in Table 1.

Table 1. CO_2 Emission Coefficients Classified by Means of Transportation (Government of Japan, 2005)

Means of transportation	CO_2 emission coefficient (kg-CO_2 kg^{-1} km^{-1})
Business-use truck	161
Personal-use truck	971
Rail	22
Domestic marine	38
Air	1500

Table 2. Product Classification in the National Physical Distribution Census in Japan

No.	Product
I	Farm and marine product
II	Forest product
III	Mineral product
IV	Metal and machinery product
V	Chemical product
VI	Light industry product
VII	Miscellaneous industry product
VIII	Specialty product

3.3. A Case Study for Derived Physical Distribution

The National Physical Distribution Census classifies products into eight categories, shown in Table 2. The industrial classification is shown in Table 3, which is based on the Japan standardized industrial classification. The data used for derived physical distribution is calculated from data of the National Physical Distribution Census as follows. Table 4 shows a part

Table 3. Industrial Classification in the National Physical Distribution Census in Japan

No.	Industry	
1	Mining	Metal
2		Coal and lignite
3		Crude petroleum and natural gas production
4		Other nonmetal
5	Manufacturing	Food
6		Beverages, tobacco and feed
7		Textile mill products, except apparel and other finished products made from fabrics and similar materials
8		Apparel and other finished products made from fabrics and similar materials
9		Lumber and wood products- except furniture
10		Furniture and fixtures
11		Pulp, paper and paper products
12		Printing and allied industries
13		Chemical and allied products
14		Petroleum and coal products
15		Plastic products
16		Rubber products
17		Leather tanning, leather products and fur skins
18		Ceramic, stone and clay products
19		Iron and steel
20		Non-ferrous metals and products
21		Fabricated metal products
22		General machinery
23		Electrical machinery, equipment and supplies
24		Transportation equipment
25		Precision instruments and machinery
26		Miscellaneous manufacturing industries
27	Wholesale trade	General merchandise
28		Textile and apparel
29		Apparel, apparel accessories and notions
30		Agricultural, animal and poultry farm and aquatic products
31		Food and beverages
32		Building materials
33		Chemicals and related products
34		Minerals and metals
35		Recycled material
36		Machinery and equipment
37		Furniture, fixtures and house furnishings
38		Drugs and toiletries
39		Other products
40	Warehousing	Building
41		Field heaping
42		Silo
43		Building (dangerous material)
44		Tank (dangerous material)
45		Water surface
46		Refrigeration

of *B* table for 8 products by 46 industries, whose element *ij* is calculated as the input of product *i* to industry *j* divided by the total input in industry *j*. Table 5 shows a part of *D* table for 46 industries by 8 products, whose element *ij* is calculated as the output of product *j* from industry *i* divided by the total output of product *j*. Table 6 shows the diagonal elements of input-output rate matrix *E*, which is calculated as output divided by input in each industry. Input coefficient matrix *A* is given by *BED*, which is the product of the above three matrices. Table 7 shows a part of the interregional transport matrix R_c for farm and marine products. The element *ij* of this matrix is given by the amount of transport of farm and marine products from prefecture *i* to prefecture *j* divided by the total transport of farm and marine product to prefecture *j*. *Rc* matrices are also constructed

Table 4. B Table for 8 Products by 46 Industries (Products I to VIII; Industries 1 to 46)

	1	2	3	..	44	45	46
I	0.00	0.00	0.00	..	0.00	0.00	0.82
II	0.00	0.09	0.00	..	0.00	1.00	0.00
III	1.00	0.85	0.60	..	0.20	0.00	0.00
IV	0.00	0.05	0.00	..	0.00	0.00	0.00
V	0.00	0.00	0.40	..	0.80	0.00	0.01
VI	0.00	0.00	0.00	..	0.00	0.00	0.17
VII	0.00	0.02	0.00	..	0.00	0.00	0.00
VIII	0.00	0.00	0.00	..	0.00	0.00	0.00

Table 5. D Table for 46 Industries by 8 Products (Products I to VIII; Industries 1 to 46)

	I	II	III	IV	V	VI	VII	VIII
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.54	0.00	0.01	0.00	0.00	0.00
:	:	:	:	:	:	:	:	:
42	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.02
43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
45	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
46	0.10	0.00	0.00	0.00	0.00	0.01	0.00	0.00

Table 6. Input-Output Rate in Each Industry

Industry	1	2	3	4	5	6	7	8
IO* rate	1.00	1.00	1.00	1.00	1.00	0.76	0.82	0.79
Industry	9	10	11	12	13	14	15	16
IO rate	0.89	0.64	0.94	0.58	0.95	0.73	0.56	0.94
Industry	17	18	19	20	21	22	23	24
IO rate	0.88	0.79	0.93	0.46	0.70	0.96	1.00	1.00
Industry	25	26	27	28	29	30	31	32
IO rate	1.00	0.97	0.95	0.92	0.75	0.85	0.92	1.00
Industry	33	34	35	36	37	38	39	40
IO rate	0.99	0.98	0.98	0.97	0.87	1.00	0.81	0.88
Industry	41	42	43	44	45	46		
IO rate	1.00	1.00	0.97	1.00	1.00	1.00		

*IO: Input-output.

for the seven other products.

We assume a case where 1,000 kg of farm and marine products are demanded in Hokkaido and Tokyo, respectively.The diagonal element corresponding to Hokkaido or Tokyo in the derived demand matrix $D_c^{(0)}$ is 1,000 (kg), where c indicates farm and marine products. The derived physical distribution matrix $X_c^{(0)}$ is calculated by Equation (1). The next repercussion demand $D_c^{(1)}$ is given by Equations (2) to (4). Then next $X_c^{(1)}$ is again given by Equation (1). The total derived physical distribution of farm and marine products can be convergently given by $\sum_k X_c^{(k)}$. The total derived physical distribution is transformed to CO_2 emissions using Table 1 and the rate

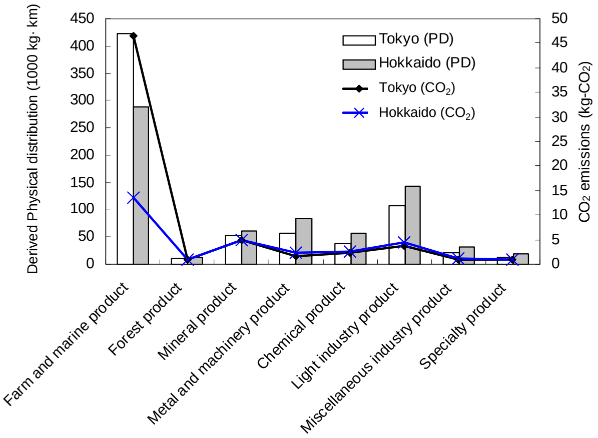

Figure 2. Derived physical distribution and CO_2 emissions calculated when 1,000 kg of farm and marine products are demanded in Hokkaido and Tokyo, respectively.

of transportation between prefectures.

The derived physical distribution and CO_2 emissions calculated are shown in Figure 2. In the production repercussions, many different categories of products, for example light industry product, are produced in order to meet the final demand of farm and marine products. The derived physical distribution and CO_2 emissions are classified for each product. In total, CO_2 emissions from the activity of physical distribution derived from 1,000 kg of farm and marine products demanded in Tokyo and Hokkaido are 62 and 31 kg, respectively. Despite the same amount of final demand, the derived physical distribution and CO_2 emissions are different between regions. Tokyo has greater derived physical distribution and CO_2 emissions than Hokkaido since Tokyo is located farther from the producing areas for farm and marine products than Hokkaido. The other products, such as light industry products, contribute less activity of physical distribution and CO_2 emissions for Tokyo than Hokkaido. The difference between regions can be seen in the next example on induced physical distribution.

3.4. A Case Study for Induced Physical Distribution

Table 8 shows the intermediate demand rate for each product, which are given by the total intermediate demand divided by total demand shown in an input-output table for Japan. Diagonal elements of intermediate demand rate matrix F_c (c = I, II, ... , VIII) are given by the values of this table. All of the diagonal elements in F_c are assumed to be equal, which indicates the intermediate demand rates are same between regions. Other data used for induced physical distribution are also given from the National Physical Distribution Census as follows. Table 9 shows part of a U table for 46 industries for eight products, whose element ij is calculated as the input of product j to industry i divided by the total production of product j. Table 10 shows part of a V table for eight products in 46 industries, whose element ij is calculated as the output of product i in in-

Table 7. Interregional Transport Matrix R_c for Farm and Marine Product

		Arrival region								
		Hokkaido	Aomori	Iwate	Miyagi		Oita	Miyazaki	Kagoshima	Okinawa
Departure region	Hokkaido	0.91	0.02	0.02	0.02	..	0.04	0.00	0.05	0.00
	Aomori	0.03	0.90	0.18	0.01	..	0.00	0.00	0.00	0.00
	Iwate	0.00	0.00	0.66	0.17	..	0.00	0.00	0.00	0.00
	Miyagi	0.01	0.04	0.08	0.64	..	0.00	0.00	0.00	0.00
	:	:	:	:	:		:	:	:	:
	Oita	0.00	0.00	0.00	0.00	..	0.58	0.00	0.00	0.00
	Miyazaki	0.00	0.00	0.00	0.00	..	0.00	0.62	0.01	0.01
	Kagoshima	0.00	0.00	0.00	0.00	..	0.11	0.21	0.89	0.07
	Okinawa	0.00	0.00	0.00	0.00	..	0.00	0.00	0.00	0.65

Table 8. Intermediate Demand Rate for 8 Products

I	II	III	IV	V	VI	VII	VIII
0.72	0.50	1.00	0.56	0.78	0.43	0.68	0.87

Table 9. U Table for 46 Industries by 8 Products

	I	II	III	IV	V	VI	VII	VIII
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.07	0.00	0.01	0.00	0.00	0.01
5	0.25	0.00	0.00	0.00	0.01	0.16	0.03	0.01
6	0.14	0.00	0.00	0.00	0.01	0.10	0.00	0.06
:	:	:	:	:	:	:	:	:
45	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
46	0.07	0.00	0.00	0.00	0.00	0.01	0.00	0.00

Table 10. V Table for 8 Products by 46 Industries

	1	2	3	4	5	6		45	46
I	0.00	0.00	0.00	0.00	0.19	0.02	..	0.00	0.82
II	0.00	0.00	0.00	0.00	0.00	0.00	..	1.00	0.00
III	1.00	1.00	1.00	0.97	0.00	0.00	..	0.00	0.00
IV	0.00	0.00	0.00	0.00	0.00	0.00	..	0.00	0.00
V	0.00	0.00	0.00	0.02	0.08	0.01	..	0.00	0.01
VI	0.00	0.00	0.00	0.00	0.67	0.64	..	0.00	0.17
VII	0.00	0.00	0.00	0.00	0.00	0.00	..	0.00	0.00
VIII	0.00	0.00	0.00	0.00	0.07	0.33	..	0.00	0.00

dustry *j* divided by the total output in industry *j*. Table 11 shows the yield rate for 46 industries. The diagonal elements of yield rate matrix *E* are shown in this table.

Induced physical distribution was calculated for the case where 1,000 kg of farm and marine products are produced in Hokkaido. Table 12 shows the resulting induced physical distribution classified by product type. The physical distribution induced by the production of farm and marine products induces transport of not only the farm and marine products, but also other products. In total, 2.54 times the physical distribution is induced. The second largest product induced is light-industry products, which include food products transformed from farm and marine products. The transport of chemical products and metal and machinery products is induced by the transport of fuel and machinery that is used in the production process for the food products.

Table 11. Yield Rate for 46 Industries

IND	1	2	3	4	5	6	7	8
YR*	7.14	53.74	56.37	4.08	0.93	0.98	0.86	0.95
IND	9	10	11	12	13	14	15	16
YR	0.76	0.98	0.72	0.96	0.83	0.92	0.94	0.90
IND	17	18	19	20	21	22	23	24
YR	0.83	0.97	0.62	0.89	0.96	0.95	0.96	0.90
IND	25	26	27	28	29	30	31	32
YR	0.93	1.00	0.95	0.88	0.98	0.96	1.00	1.00
IND	33	34	35	36	37	38	39	40
YR	0.98	0.98	0.97	0.87	1.14	0.81	0.93	1.01
IND	41	42	43	44	45	46		
YR	1.00	0.96	1.02	0.99	1.05	0.99		

*YR: Yield rate; IND: Industry.

Table 12. Quantity of Physical Distribution Induced by the Production of 1,000 kg of Farm and Marine Products in Hokkaido

Product	Induced physical distribution (kg)
Farm and marine product	1554
Forest product	9
Mineral product	43
Metal and machinery product	129
Chemical product	179
Light industry product	456
Miscellaneous industry product	44
Specialty product	126
Total	2540

Figure 3 shows the main interregional physical distributions that are induced by the production of 1,000 kg of farm and marine products in Hokkaido. For instance, 209 kg of farm and marine products are transported from Hokkaido to Kanto. Farm and marine products are mainly transported to Kanto and Kansai, which have many final consumers.

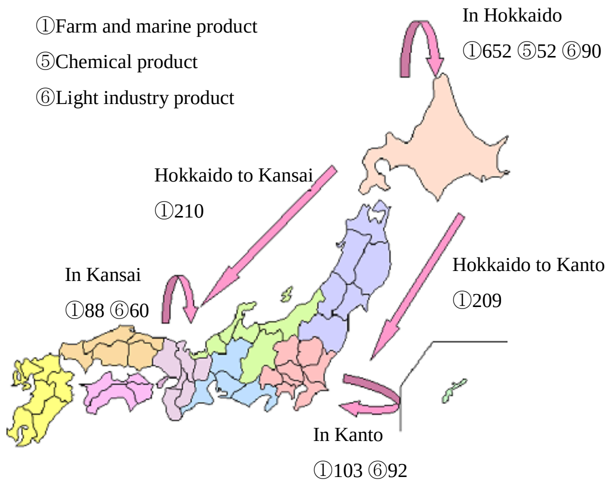

Figure 3. Interregional physical distribution induced by the production of 1000 kg of farm and marine products in Hokkaido (unit: kg).

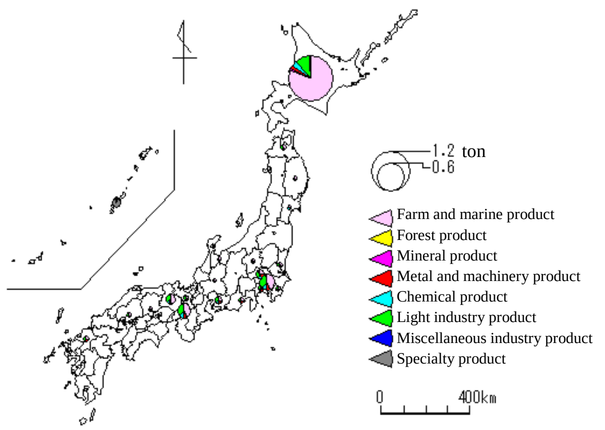

Figure 4. Output weight by product and by prefecture when 1000 kg of farm and marine product is produced in Hokkaido.

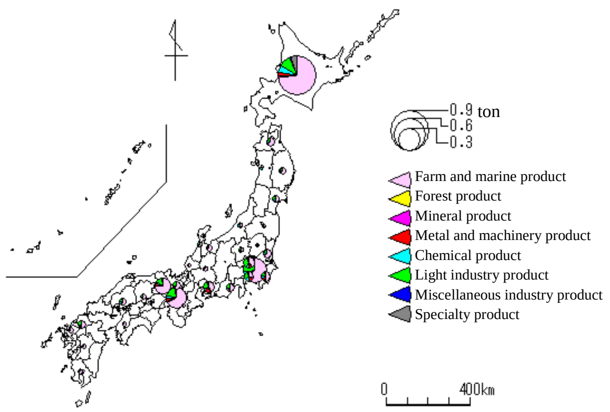

Figure 5. Input weight by product and by prefecture when 1000 kg of farm and marine product is produced in Hokkaido.

Figures 4 and 5 depict the output weight and input weight by product and by prefecture when 1,000 kg of farm and marine product is produced in Hokkaido. Both figures show that transport from Hokkaido generates the greatest physical distribution and that commodities are delivered to large consuming regions such as Tokyo, Osaka and Aichi.

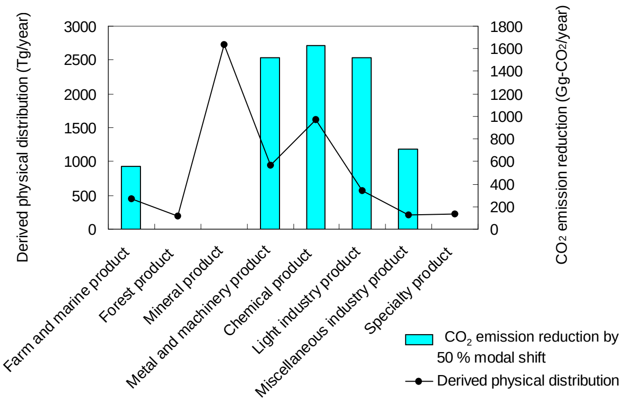

Figure 6. CO_2 emission reduction for the case where the modal shift rate is 50 percent (products classified by the category of final demand; the amount of physical distribution in a year classified by the type of transported product is also shown).

3.5. Simulation of Traffic Modal Shift as the Application of Derived Physical Distribution

Modal shift from truck to rail or marine transportation is a promising CO_2 reduction measure in the freight sector. The Japanese government has set a goal aiming for a modal shift rate of 50% by 2010 (Ministry of Land, Infrastructure and Transport of Japan et al., 2005). The modal shift rate is defined as the physical distribution of greater than 500 km by rail and marine transportation divided by the total physical distribution of greater than 500 km. The difficulty in achieving modal shift is that cargo owners have the initiative to determine the means of transportation. Hence, the effect of modal shift is evaluated for eight types of final products by summing the derived physical distribution in the production process of each product. It is assumed that truck transport is shifted to rail and marine transport in a ratio of 15 : 85. The potential for modal shift is not considered for the transport of farm and marine products since freshness is important for these products. Figure 6 shows the CO_2 emission reduction for the case where the modal shift rate is 50%. Chemical products hold the largest reduction potential. This result means that the modal shift in the production process of chemical products has the large amount of derived physical distribution. Although modal shift was not considered for the transport of farm and marine products, the CO_2 emission reduction from farm and marine product is not zero because the final demand of farm and marine product makes a lot of physical distribution for other products in production repercussions. The reduction of CO_2 from forest, mineral and specialty products is zero since there was no final demand. Figure 6 also depicts the amount of physical distribution for each product category over a year. Mineral products have the greatest physical distribution, since they are consumed for many purposes in many production processes, and therefore a large amount is derived from final demand. In total, a CO_2 reduction of 9907 Gg can be achieved by a 50% modal shift, which accounts for 7% of all the GHG emissions in Japan in 2005.

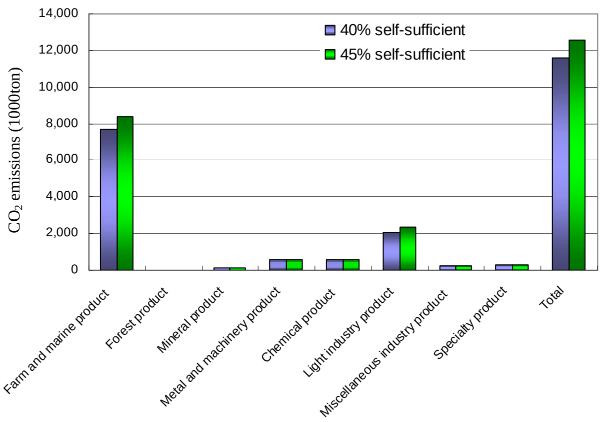

Figure 7. CO_2 emissions for food self-sufficiency rates of 40 and 45 % emitted from the physical distribution induced by the production of farm and marine products.

3.6. Simulation of Food Self-Sufficiency Rate as the Application of Induced Physical Distribution

The food self-sufficiency rate in Japan was approximately 40% in 2003, which is much lower than in other nations. The Ministry of Agriculture and Fisheries of Japan has set a goal aiming for an increase in the food self-sufficiency rate to 45% by 2015 (Ministry of Agriculture, 2005). Increasing the food self-sufficiency rate will require growth in the domestic production of farm and marine products. Such production increase will have repercussions for physical distribution. Since automobile transportation is often used for food transport, the potential increase in CO_2 emissions may be substantial.

The increase in domestic production of farm and marine products is estimated in the case where the food self-sufficiency goal is achieved in 2015. Assuming a reduction in food waste in the future, food supply per capita is expected to decrease to 2480 kcal from the present value of 2558 kcal (The Ministry of Agriculture and Fisheries of Japan, 2005). Therefore, domestic production will increase to 1.08 ($= 2480/2558 \times 45/40$) times its present amount by 2015.

The additional physical distribution generated by an increase in the food self-sufficiency rate is calculated utilizing the induced physical distribution method (Figure 7). After calculating the additional physical distribution, increases in CO_2 emissions are evaluated using data for present traffic volumes and CO_2 emission coefficient of transportation modes given by the National Physical Distribution Census (Table 1).

Figure 7 depicts the CO_2 emissions calculated from the physical distribution induced by production of farm and marine products for food self-sufficiency rates of 40% and 45%. The present CO_2 emissions induced by the production of farm and marine products is 12 million tons, which is more than 10% of the total emissions in the freight industry. Improvement in the food self-sufficiency rate has the potential to increase domestic CO_2 emissions by a further one million tons. This result indicates the importance of introducing lower-impact means of freight transportation to domestic physical distribution.

4. Conclusions

This study highlights the analysis that combines the national freight circulation data in Japan with the input-output tables that show the industrial structure in Japan. For this purpose, a novel method of estimating interregional physical distributions focusing on repercussions is proposed in this study. Physical distribution is viewed from two perspectives: derived and induced physical distribution. These concepts enable the evaluation of the relationship between industrial structure and physical distribution. We validated our method by verifying that estimated transports fit well to actual transport. Utilizing the data obtained by the National Physical Distribution Census, a example of derived physical distribution was given. In total, CO_2 emissions from the activity of physical distribution derived from 1,000 kg of farm and marine products demanded in Tokyo and Hokkaido were found to be 62 kg and 31 kg, respectively. Despite the same amount of final demand, the derived physical distribution and CO_2 emissions differs between regions. An example of induced physical distribution was calculated for the case where 1,000 kg of farm and marine products are produced in Hokkaido. In total, 2,540 kg of commodity were found to be produced and distributed to various regions. Also, the potential change in CO_2 emissions by a modal shift from truck to rail and marine transportation is simulated as an application for derived physical distribution. The potential change in CO_2 emissions caused by future improvement in the food self-sufficiency rate is also estimated as an application for induced physical distribution.

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