THE DECOMPOSITION FOR THE SOURCES OF CHANGES IN CARBON EMISSION INTENSITIES: A CASE STUDY OF CARBON EMISSION FROM ROAD CONSTRUCTION WORK IN JAPAN DURING 1975-1990

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Abstract: This study aimed to estimate the amount of life cycle emission change of selected road construction works in Japan during 1975-1990. Input-output model was utilized as an inventory model to estimate the embedded emission from construction works. We could clarify the structure of emission and the change of emission breakdown by primary emission sources and input sources. The result revealed considerable reduction about 40% of the emission per one unit of construction for all the categories during the period of study. Thereafter, structural decomposition analysis was utilized to reveal the main force driving behind the emission change. The direct emission at construction site is very little compared with indirect emission. The result from decomposition analysis revealed that the major factor driving behind the change was different by road construction category.

1. INTRODUCTION

To achieve the goal of sustainable transport, the analysis of emission from a transport project is necessary. Global warming is one of environmental problems caused by the emission from transport. By the concept of sustainable transport, the system must not create the externalities that affect the future generation. In addition, the global warming is caused by the accumulation of carbon dioxide in long run. Thus, the concept of life cycle emission should be applied to the analysis. This study mainly focused on the analysis carbon emission from road construction works. The life cycle emission from road construction included both direct and indirect emission. Direct emission is the emission that actually occurred at the construction site while indirect emission embedded in resources input that the emission occurred elsewhere. To account for both direct and indirect emission in systematic way, input-output model was applied in this study. The model was described and discussed in chapter 2. The model can be used to estimate the amount of emission at any base year technology assumption. The emission per unit cost of selected road construction types could be estimated in this stage. The comparative analysis was carried out to perceive the structure of emission change by primary emission sources and resource inputs. To recognize the factors driving behind this change, the Structural Decomposition Analysis (SDA) was applied in chapter 3. In this study, we selected 6 types of road construction works in Japan and made an analysis of technical change that effects the emission change in road construction during 1975-1990. The data sources and accounting concept was described in chapter 4. In chapter 5, the result of the analysis was presented. Finally, the conclusion drawn from the study was summarized in chapter 6.

2. ENVIRONMENTAL INPUT-OUTPUT ANALYSIS

Input-output analysis is an economic model that is particularly suitable for the analysis of life cycle emission because of the availability of the data and the capability of the model to capture the interaction effects of the complex production chain within the economy. The model can be described as following.

Any sector's output is equal to its intermediate consumption required by other industries plus its net final consumption. The balance equation of any industry can be described as

$$X_i = \sum_j T_{ij} + Y_i \tag{1}$$

Where X_i is industrial output, T_{ij} is intermediate input from sector i required by sector j, and Y_i is the net final demand for sector i.

Input-output model makes an assumption that the intermediate input required is proportional to the output of that industry. This statement can be expressed by

$$T_{ij} = a_{ij} X_j \tag{2}$$

Where a_{ij} is a constant called technical coefficient.

Combining equation (1) and (2) gives

$$X_i = \sum_j a_{ij} X_j + Y_i \tag{3}$$

For the economy containing n industrial sectors, we can write a set of equations in the matrix form of

$$X = AX + Y \tag{4}$$

Where X =	vector of industry output	(nx1)
A =	technical coefficient matrix	(nxn)
Y =	vector of net final demand	(nx1)

Solving for a set of output (X) required to satisfy an exogenous given set of final demand (Y) gives

$$X = (I - A)^{-1} Y \tag{5}$$

From equation 5, we can estimate the output needed to satisfy any set of final demand. Although the model is derived in physical term, input-output relationship is usually expressed in monetary term for the sake of convenience. From now on, we shall define matrix $B = (I - A)^{-1}$.

To obtain the amount of emission, one may simply apply the conventional model by multiplying the emission per one unit of output of the energy sectors to their associating output in monetary term (direct impact coefficient method). However, it was found that the energy prices are different across sectors and the set of final demand, Y^*, (construction input coefficient) applied for the study is also substantially different from the final demand of the base year, Y, used to derive the model. Thus, the direct emission intensity derived from the original data in the base year and the direct emission intensity derived from any case study would not necessary to be the same; because the induced emission per induced output from a different set of final demand would be different, as illustrated in equation 6.

$$\frac{\left(\sum_{i \ni E} B_{ij}\right) Y_j^*}{\sum_k B_{jk} Y_k^*} = \frac{\sum_i E_{ij}^*}{X_j^*} \neq \frac{\sum_i E_{ij}}{X_j} = \frac{\left(\sum_i B_{ij}\right) Y_j}{\sum_k B_{jk} Y_k} \tag{6}$$

Note: Induced emission and induced output are superscript by asterisk (*). $i \ni E$ means for all energy sector i

Therefore, in this study, we applied the hybrid model, that the money terms in primary energy sectors were replaced by the associated emission in physical term, to obtain the accurate result of the total amount emission and its distribution among sectors. The broad discussion can be found in Miller and Blair (1985).

Normally, the net final demand vector (Y) includes final consumption, gross domestic fixed capital formation, exports, stocks, and minus import. In this study, since the carbon emission is accumulated in long run and the environmental problem considered is global, we neglected change in stocks and included import into Y. By this formulation, we included the emission from import upstream products assuming that import products has the same input structure and the same emission structure as the domestic product.

3. STRUCTURAL DECOMPOSITION ANALYSIS

To discover the driving force lying behind the change of emission, Input-Output (IO) Structural Decomposition Analysis (SDA) is one of appropriate approaches to decompose the source of change. By the abundance of studies, the approach has developed into a major analytical tool and has received increasing attention during recent years. SDA is a pragmatic alternative of econometric estimation (Rose & Casler, 1995). In this study, only input-output tables of initial year and terminal year are needed to perform the basic decomposition analysis. Nonetheless, the extension of SDA can be done by including the neoclassical production function into a basic IO framework, for example, Rose and Chen (1991).

Equations 7-11 shows some possible decomposition schemes that are different by the choice of base year weight.

$$\Delta X = B_0 \Delta Y + \Delta B Y_t \tag{7}$$

$$\Delta X = B_t \Delta Y + \Delta B Y_0 \tag{8}$$

$$\Delta X = B_0 \Delta Y + \Delta B Y_0 + \Delta B \Delta Y \tag{9}$$

$$\Delta X = B_t \Delta Y + \Delta B Y_t - \Delta B \Delta Y \tag{10}$$

$$\Delta X = \left(\frac{B_0 + B_t}{2}\right) \Delta Y + \Delta B \left(\frac{Y_0 + Y_t}{2}\right) \tag{11}$$

$$dX = (B)(dY) + (dB)(Y) \tag{12}$$

In a discrete time analysis, the interaction terms always present and the choice of base year weight is arbitrary. This scheme applied the average approach, proposed by Betts (1989), to eliminate the problem of arbitrary weight and interaction terms. This method takes an average for the polar weights between the period of study. For example, taking an average of equation 7 and 8, or taking an average of equation 9 and 10 would give the same result of the average scheme (5) as shown in equation 11.

We shall show an example by applying a set of the country's final demand in 1975 and 1990 to estimate emission change. The result of decomposition by various schemes is shown in Table 1.

Table 1. Result of a decomposition of national emission change during 1975-1990 (Mt-C)

Scheme	Final Demand	Technology	Interaction	Total change
1	273.7	-257.4	0.0	16.3
2	111.6	-95.3	0.0	16.3
3	273.7	-95.3	-162.2	16.3
4	111.6	-257.4	162.2	16.3
5	192.7	-176.4	0.0	16.3

Note: Total amount of emission in 1975 and 1990 were estimated as 283.7 Mt-C and 300 Mt-C respectively.

During the period, technology change could reduce the amount of carbon emission considerably (minus sign). However, the effect of final demand change overshadowed the change in technology, therefore, resulted in net increase in carbon emission.

Using different weights would produce different results of effect in each factor as illustrate in an example. This problem is called an index number problem. Dietzenbacher and Los (1998) discussed in detail about this problem. In their study, more than two variables were included. They investigated all possible combination of the choices of weight scheme. In their study, they found that the average method that takes an average of the polar weights gives very close result to the average of the results from all possible combinations.

Equation 12 shows the decomposition in differential form when small change occurs during the short time period. In this case, interaction term does not exist. From this study, it was found empirically that the result from average method is exactly the same as the result from the assumption that the coefficients change linearly in time. If we subdivide the study period into many sub-periods, and calculate small changes during each sub-period, the error term (interaction term) will be reduced by n times when n is the number of sub-periods. If we assume that the coefficients change continuously in time, n approaches infinity, the summation of error terms will converge to zero as shown in table 2.

Table 2. Empirical result from the assumption of linearly coefficients change in time.

	Final Demand	Technology	Interaction	Total change
n=1	273.7	-95.3	-162.2	16.3
n=2	235.1	-137.7	-81.1	16.3
n=4	215.3	-158.5	-40.5	16.3
n=8	205.3	-168.7	-20.3	16.3
n->infinity	192.7	-176.4	0.0	16.3

If we assume technical coefficients (A) and final demand (Y) change linearly during the period, summing up all changes of sub-periods would yield the total change during that period and the error term would be distributed equally to final demand and technology in exactly the same manner as the result from the average method (scheme 5) as presented in table 1.

After an investigation, from the many supporting reasons mentioned above, in this study, we selected the average method to make further analysis of factors that caused total emission changes in road construction works in Japan during 1975-1990.

Proposed by Betts (1989), equation 13 to 15 are the generalization of the average method when the variable of interest (X) is the product of variables (F_i), ($n \geq 2$).

$$X = \prod_{i=1}^{n} (F_i) \tag{13}$$

$$X^t - X^0 = \Delta X = \prod_{i=1}^{n} (F_i^t) - \prod_{i=1}^{n} (F_i^0) \tag{14}$$

$$\Delta X = 0.5 \sum_{k=1}^{n} \left\{ \prod_{j<k} F_j^0 \Delta F_k \prod_{l>k} F_l^t \right\} + 0.5 \sum_{k=1}^{n} \left\{ \prod_{j<k} F_j^t \Delta F_k \prod_{l>k} F_l^0 \right\} \tag{15}$$

It's obvious that equation 11 is a just case of equation 15 with n=2. This formulation can be used to carry out the detailed analysis when more than two variables effect the final demand and technical matrix change.

4. DATA

4.1 Input-output Tables

Japan's input-output table of 1975 and 1990 is utilized in this study. Since input-output tables are recorded in current price, they can not be compared without proper calibration. Thus, the data was calibrated using 1985 as a base year price yardstick. In addition, 1975 and 1990 input-output were aggregated into 325x325 sectors.

4.2 Energy Consumed by sectors

The data of energy consumed by sectors was compiled using the data supported from CGER-report (1997). The data included the energy of various types consumed by sector in physical unit.

4.3 Input coefficient for road construction works

The coefficient is the resources input needed by sector for any kind of construction work, usually expressed in monetary term. In this study, the coefficients were derived from input tables for construction work for the year 1975 and 1990 that were recorded in current price. To make a comparative analysis, the input coefficients of both years were converted using 1985 as the base year price.

4.4 Accounting of emission

To avoid double counting problem, we should account the emission only from primary energy sectors. Some sectors are just an input source for another form of energy, for example, crude oil mining and petroleum refinery products. For this kind of sector, we accounted only the emission occurred during its process. For instance, in crude oil mining sector, we accounted only partial emission called 'off-gas' while the rest of emission was accounted in petroleum refinery product that the fuel is really burnt. Such kind of sectors included crude oil mining (petroleum refinery products), coal mining (coal products), part of natural gas sector (gas supply). In the conventional analysis, all emission would ultimately fall into the original sources of emission, for example, petroleum refinery products, coal products, natural gas, etc. In order to analyze the structure of emission embedded in resource input, the emission was assigned to the final user instead of the source of emission. The reallocation of emission was done using the expression on the left-hand side of equation 6. By doing this, we would be able to recognize what resource inputs contribute high emission and would be able to make the choice of less environmental damaging resource inputs for the project.

5. RESULTS

5.1 The Structure of Carbon Emission from Road Construction Works

First of all, the total amount of life cycle emission from six selected road construction categories were estimated as shown in table 3 and table 4. Using the conventional hybrid model, the result in the table shows the emission by primary sectors that actually released the emission. The change in carbon emission in each category was summarized in table 5.

Table 3. Carbon emission for 1975 technology assumption (kg-C per one million yen of construction cost in 1985)

Emission source	Improvement	Pavement	Bridge	Repair	Earthwork	Others
Lime stone	325	91	208	183	308	212
Raw Coal	1	1	1	1	1	1
Coal products	250	176	1095	201	190	422
Crude Oil	85	92	118	99	65	81
Petroleum	767	926	626	880	767	694
Natural gas	11	11	17	12	8	11
Gas supply	11	12	9	13	11	14
Subtotal : emission at site	73	72	23	81	62	51
Subtotal : indirect emission	1378	1237	2052	1308	1290	1383
Total	1450	1309	2075	1389	1351	1434

Note: Dark shaded area shows the major sectors contributing to the emission

Table 4. Carbon emission for 1990 technology assumption (kg-C per one million yen of construction cost in 1985)

Emission source	Improvement	Pavement	Bridge	Repair	Earthwork	Others
Lime stone	229	109	280	218	175	147
Raw Coal	22	17	45	18	13	24
Coal products	325	245	549	302	246	326
Crude Oil	26	32	30	32	30	32
Petroleum	191	287	181	247	204	233
Natural gas	36	44	45	45	44	49
Gas supply	3	4	4	4	3	4
Subtotal : emission at site	67	96	34	60	41	60
Subtotal : indirect emission	765	642	1100	806	674	753
Total	832	738	1134	865	715	814

Note: Dark shaded area shows the major sectors contributing to the emission

Table 5. Change in carbon emission between 1975 and 1990 technology assumption (kg-C per one million yen of construction cost in 1985)

	Improvement	Pavement	Bridge	Repair	Earthwork	Others
Emission Change	-618	-571	-941	-524	-636	-621
%Change	-43%	-44%	-45%	-38%	-47%	-43%

In each type of road construction work, instead of allocating emission to the primary sources, we apply equation 15 to recognize what kind of raw material or service embedded high level of emission.

$$E_j = \left(\sum_{i \ni E} B_{ij}\right) Y_j \qquad (16)$$

Using equation 16, table 6 and 7 show the results aggregated into 12 major sectors contributing the emission from road construction.

Table 6. Carbon emission embedded in raw material and services input for several categories of road construction works, 1975 technology assumption (kg-C per one million yen of construction cost in 1985)

	Improvement	Pavement	Bridge	Repair	Earthwork	Other Works
Gravel and crushed stone	89	151	11	62	50	50
Paving material	12	**433**	4	**323**	1	1
Cement and cement products	**709**	**198**	312	**364**	**708**	**440**
Iron and steel	**187**	69	**865**	95	93	**328**
Metal and metal products	34	30	**569**	59	70	194
Other products	98	103	41	126	106	115
Machinery	9	1	2	3	12	41
Electric power and self-power generation	110	121	157	143	28	54
Gas Supply	10	11	8	13	11	13
Transportation	136	129	62	139	**219**	141
Other sevices	56	59	42	61	51	56
Other acitivities	3	3	2	3	2	2
Total	1451	1309	2076	1389	1351	1435

Note: Dark shaded area shows the major sectors contributing to the emission

Table 7. Carbon emission embedded in raw material and services input for several categories of road construction works, 1990 technology assumption (kg-C per one million yen of construction cost in 1985)

	Improvement	Pavement	Bridge	Repair	Earthwork	Other Works
Gravel and crushed stone	10	24	1	10	43	13
Paving material	3	88	1	80	3	6
Cement and cement products	**381**	**179**	**420**	**338**	**294**	**236**
Iron and steel	**190**	112	253	**123**	59	114
Metal and metal products	46	68	**299**	81	64	**159**
Other products	85	**122**	61	85	**104**	125
Machinery	5	8	5	8	10	14
Electric power and self-power generation	34	37	26	37	34	31
Gas Supply	1	1	1	1	1	1
Transportation	18	29	19	29	28	21
Other sevices	50	59	41	64	63	81
Other acitivities	10	11	7	11	13	12
Total	832	738	1134	865	715	814

Note: Dark shaded area shows the major sectors contributing to the emission

Tables 6-7 show the structure of carbon emission embedded in final product required for road construction. For example, using products from iron and steel sector may induce considerably carbon emission share. The result shows the carbon emission from the viewpoint of final use of material and service in construction work. Table 8 shows the carbon emission change during the period.

Table 8. Carbon emission change during 1975-1990 by several categories of road construction works (kg-C per one million yen of construction cost in 1985)

	Improvement	Pavement	Bridge	Repair	Earth Work	Other Works
Gravel and crushed stone	-79	-127	-11	-52	-8	-37
Paving material	-9	-345	-3	-243	2	5
Cement and cement products	-328	-19	108	-26	-414	-204
Iron and steel	4	43	-612	28	-34	-214
Metal and metal products	12	38	-270	22	-6	-35
Other products	-13	19	20	-41	-3	10
Machinery	-3	7	2	5	-2	-26
Electric power and self-power generation	-76	-84	-130	-106	6	-23
Gas Supply	-9	-10	-7	-12	-10	-13
Transportation	-118	-101	-43	-111	-191	-120
Other sevices	-6	0	-1	3	12	25
Other acitivities	7	8	6	8	11	10
Total	-619	-571	-942	-524	-636	-621

Note: Dark shaded area shows the major reduction of emission, light shaded area shows the major increase in emission share.

5.2 Sources of Changes in Carbon Emission Intensities of Road Construction Work

In this study, major sources of carbon emission were classified as

5.1.1 Construction Technology Effect

This source of change is caused by change in construction technology. The technology change in road construction can be expressed by the change in resource input needed for the construction. In input-output framework, the change reflects by the change in the final demand vector of the construction input coefficients.

5.1.2 Economy's Technology Effect

This source of change is other sources of change due to technology change in other sectors. The change can be expressed as a change in the hybrid input-output technical coefficient matrix.

The decomposition was carried out by utilizing the equation 11 of average method as discussed earlier. The result of decomposition is shown in Table 9 and Fig. 1. The emission change caused by construction technology change was disaggregated further into change of direct emission at construction site and indirect emission change caused by input selection change, using equation 17 and 18.

$$E_d = \Delta Y \tag{17}$$

$$E_{ind} = \left\{ \left(\frac{B_1 + B_2}{2} \right) - I \right\} \Delta Y \tag{18}$$

Table 9. Decomposition of emission change due to road construction technology change and change caused by the economy's technology change (kg-C per one million yen of construction cost in 1985)

		Improvement	Pavement	Bridge	Repair	Earthwork	Other Works
Construction technology change	Direct emission at site change	-6	24	11	-21	-21	9
	Indirect change in final demand	-462	-128	-406	-72	-520	-367
	Subtotal	-468	-105	-395	-93	-541	-358
Other changes (Economy change)	Subtotal	-150	-467	-547	-431	-96	-263
Total change		-618	-571	-941	-524	-636	-621

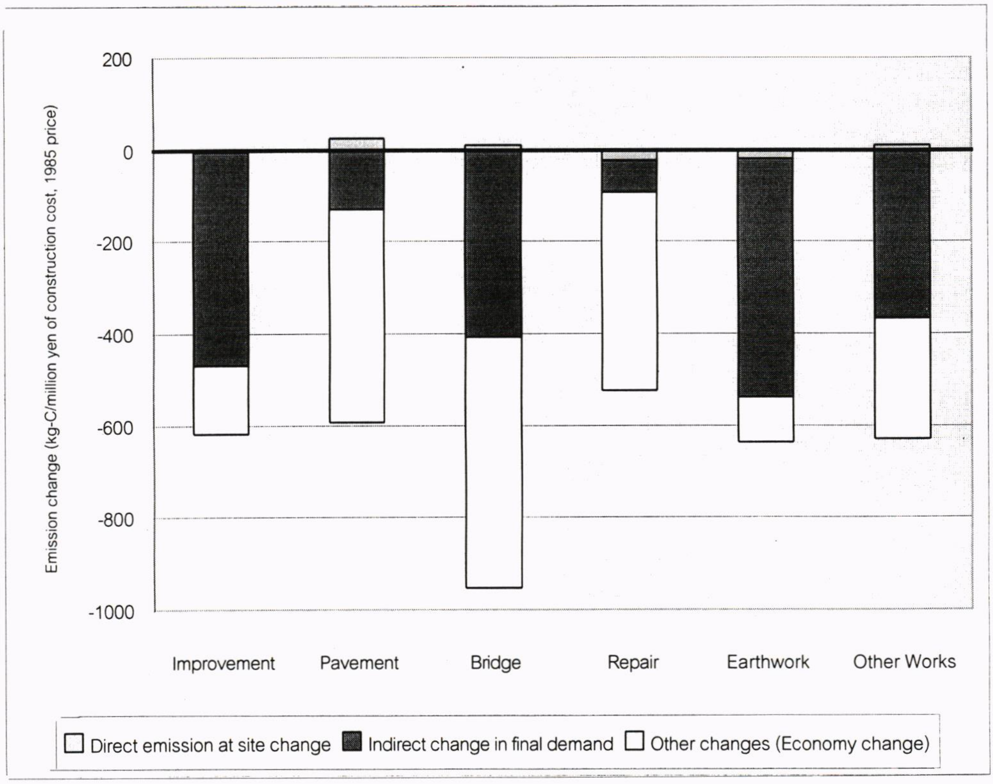

Fig. 1 Decomposition of emission change due to road construction technology change and change caused by the economy's technology change

6. SUMMARY

In this study, we could estimate the amount of life cycle emission from various road construction works in Japan by applying hybrid input-output model with technology assumption. All selected construction works revealed considerable reduction in carbon emission per one unit of construction. One major finding is that, from 1975 to 1990, the amount of carbon emission per one unit of road construction works in Japan was reduced about 40 percent (Table 5). From the primary energy view point, in 1975 most of emission ultimately came from burning of petroleum refinery products (Table 3). However, in 1990, the emission from coal products prevailed (Table 4). This result reflected more or less the increase in price of petroleum products during that period. From the resource-input viewpoint, most of emission came from using cement, cement products, iron, and steel (Table 6-7). Each construction categories presented the unique emission structure, for example, emission from pavement construction mostly embedded in paving material and cement while emission from the bridge construction mostly embedded in cement and steel. It was also interesting that transportation sector also contribute much reduction during the period (Table 8).

The structural decomposition analysis was carried out to reveal the major force driving behind the emission change. It was found that the major driving force behind the emission change in each road construction category is different (Fig. 1). Emission at construction site is very little comparing with indirect emission (Table 3, 4) and contribute very small share in emission change (Fig. 1). Road improvement, earthwork, and other construction works showed emission change mainly from final demand change while pavement construction, bridge construction, and road repair shows major change resulted from economy change.

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