A STUDY ON ENVIRONMENTAL EFFECTS DUE TO HISTORICAL CHANGES IN TECHNOLOGY

Gloria P. GERILLA
Doctoral student
International and Intermodal Laboratory
Graduate School of Information Sciences, Tohoku University, JAPAN.
Email: glotek_2000@yahoo.com. For comments, please contact this author.

Shigemi KAGAWA
Doctoral student
International and Intermodal Laboratory
Graduate School of Information Sciences, Tohoku University, JAPAN.
Email: kagawa@plan.civil.tohoku.ac.jp

Hajime INAMURA
Professor
Graduate School of Information Sciences, Tohoku University, JAPAN
Email: inamura@plan.civil.tohoku.ac.jp

Selected Proceedings of
9 th World Conference on Transport Research, Seoul, Korea, July 22-27, 2001

1 INTRODUCTION

Pollution is a global concern as it affects all sectors of the society. Transport systems have been pinpointed as one of the major causes of pollutant emission, which affect the environment. Road construction is part of the transport systems that we need to study for sustainability. To be able to assess the future requirements of society in terms of infrastructure facilities and its sustainability, a study on the historical changes of carbon emissions and the relationship of material requirements to emissions are necessary. This paper tries to study the changes of carbon emissions induced by road construction for a 20 year time period. The relationship between the assessment of environment loads and the economic system is modeled through the use of the Input-Output Methodology. The conventional Input-Output model has been employed to estimate environmental loads due to the production processes of the entire economic system. Leontief (1970), Hayami, *et al.* (1993), Gale (1995), Weir (1998), Gerilla and Inamura (2000) employed the static input-output model to estimate environmental loads in relation to some aspect of the economy. These studies failed to consider the changing energy prices in the world, which more or less affects the values of the estimated emissions. Furthermore, the studies using the commodity by commodity framework have inherent problems due to the assumption of product mix and because the problem of secondary production is not considered. Bullard and Herendeen (1975), Piantanakulchai, *et al.* (1999), resolved the problem of changing energy prices by the use of physical units for energy sectors. However, the studies are limited to the calculation of the environmental impacts of a given final demand.

The complex interactions and interdependencies of the industries and sectors in the economy contribute to the changes in emissions. Sonis and Hewings (1990), Weber and Schnabl (1998) showed a method to display the paths of direct and indirect dependencies in the economy by partitioning or decomposing the economic structure. Fritz, et al. (1998) applied the method in partitioning the input-output matrix into polluting and non-polluting industries. Kagawa and Inamura (2000), meanwhile, applied the hierarchical decomposition techniques to the hybrid rectangular input-output model (HRIO) to analyze the energy requirements of non-energy sectors. The proposed HRIO reduced the problems inherent to the commodity by commodity framework. However, Kagawa and Inamura (2000), in their model, were not able to decompose the final demand into several types.

The comparison of changes in structure can be modeled through the structural decomposition analysis (SDA). It represents a way of distinguishing major sources of change in an economy. Several researches had been made in this area using the SDA methodology like Carter (1970); Rose & Chen (1991); Fujimagari (1989); Skolka (1989); Gale (1995); Weir (1998) and others. Dietzenbacher and Los (1998), moreover, showed a detailed sensitivity analyses of the decomposition.

The present paper shows a connection between the internal decomposition, wherein the direct and indirect dependencies in the economy are explicitly exhibited, and the external decomposition known as SDA. The sources of changes in carbon emission intensities induced by road construction in Japan are studied from 1975 to 1995. The different construction technologies in road construction and their sources of changes are also identified and analyzed. The paper is organized as follows: the following section discusses the framework of the study. The decomposition of structural changes is done in Section 3. Following it is the empirical application of the model using the rectangular IO tables of Japan. Concluding comments closes the paper in Section 5.

2 FRAMEWORK OF THE MODEL

The model uses a rectangular hybrid model introduced by Kagawa and Inamura (2000) and further extended by Gerilla, *et al*. (2000). The analytical framework is the commodity by industry framework, which can differentiate between industry and commodity accounts. The strengths of the model are that it can address the problem of secondary production of industries and it can also identify the interdependencies of decomposed economic subsystems whether it is forward, or backward linkages. The model also connects the internal and external decompositions of the rectangular system.

2.1 Rectangular Input Output Model

The rectangular Input-Output table exhibits a fundamental distinction between industries and commodities as shown in Table 1.

Table 1. Schematic diagram of the Rectangular Input-Output Table

	Commodity	Industry			
Commodity		**U**	**f**	**e**	**q**
Industry	**V**				**g**
		w			
	q	**g**			

Source: Miller & Blair (1995)

where:
V = make matrix; a typical element represents the amount of commodity produced by industry;
U = use matrix; a typical element represents the amount of commodity used up by industry;
f = vector of commodity deliveries to final demand;
e = net national exports;
q = vector of commodity gross output;
w = vector of value added;
g = vector of industry total outputs;

The commodity based technology assumption is utilized to formulate the model. Here, we assume that each industry produces commodities in its own fixed proportion. In the assumption, we have:

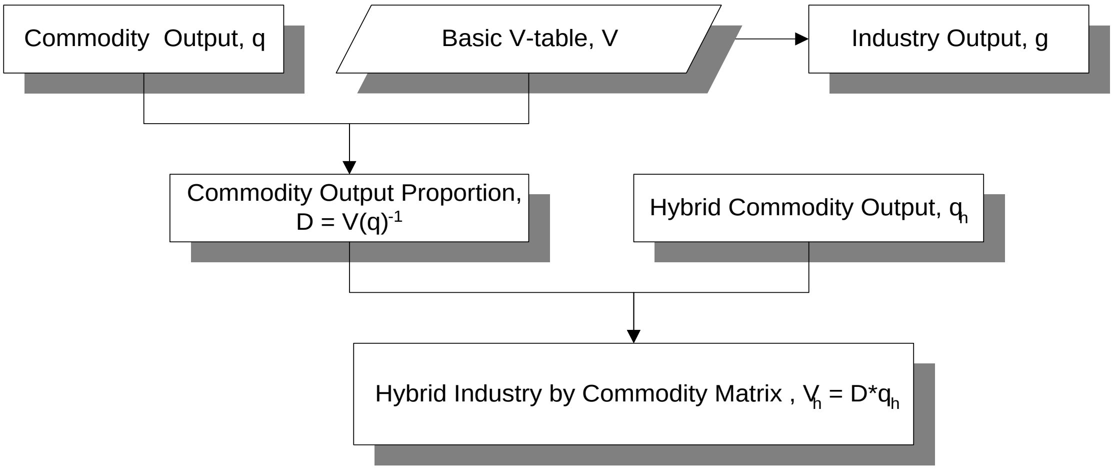
$$q = (I - BC^{-1})^{-1} f \quad (1)$$

$$g = (I - C^{-1}B)^{-1} C^{-1} f \quad (2)$$

where:
q = vector of commodity gross output;
g = vector of industry total outputs;
C = industry output coefficient matrix;
B = direct requirements matrix;
I = n x n unit matrix;
f = final demand;

Each sector in the direct requirements matrix, B and the output coefficient matrix, C are sorted and grouped into the carbon-producing sector (es), the non-construction sector (nc) and the construction sector (cs). The carbon-producing sector is defined as the sector of primary sources of carbon emission. The non-construction sector, on the other hand, is determined to be the sectors that are not included in the construction and carbon-producing sectors. The carbon-producing sectors' unit has been changed to ton-carbon (ton-C) instead of monetary terms while the non-construction and construction sectors retained their units which are in million yen (MY). This is done to be able to curtail the over or under estimation of carbon emission intensities due to changes in energy prices. Therefore, matrices B and C were converted to B_h and C_h indicating the use of hybrid units. The V matrix was also converted into hybrid units using the procedure shown in Figure 1. To be able to invert the industry output coefficient matrix from C_h to C_h^{-1}, the assumption that the number of industries and the number of commodities are equal is made. C_h^{-1} represents the market share structure using the commodity based technology assumption.

Figure 1 Transformation of the V matrix into a hybrid V matrix



Source: Authors' Chart

2.2 Hierarchical Decomposition

The economy in this model is subdivided into 3 subsystems namely: the carbon producing industries (es), the non-construction industries (nc) and the construction industries, (cs). The different interactions and hierarchy between these subsystems are presented in this section. The comparison of the emission structure among carbon-producing industries, non-construction industries and construction industries can be explained using the decomposition of the matrices. The subdivision of block matrices B_h and C_h^{-1} are shown in the figures below.

$$\underbrace{\begin{array}{c|ccc} & es & nc & cs \\ \hline es & B_{11} & B_{12} & B_{13} \\ nc & B_{21} & B_{22} & B_{23} \\ cs & B_{31} & B_{32} & B_{33} \end{array}}_{B_h} = \underbrace{\begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & O & O \\ B_{31} & O & O \end{bmatrix}}_{B_{es}} + \underbrace{\begin{bmatrix} O & O & O \\ O & B_{22} & B_{23} \\ O & B_{32} & O \end{bmatrix}}_{B_{nc}} + \underbrace{\begin{bmatrix} O & O & O \\ O & O & O \\ O & O & B_{33} \end{bmatrix}}_{Bcs} \qquad (3)$$

$$\underbrace{\begin{array}{c} \\ es \\ nc \\ cs \end{array}\begin{array}{c} \begin{array}{ccc} es & nc & cs \end{array} \\ \left[\begin{array}{c|c|c} C_{11}^{-1} & C_{12}^{-1} & C_{13}^{-1} \\ \hline C_{21}^{-1} & C_{22}^{-1} & C_{23}^{-1} \\ \hline C_{31}^{-1} & C_{32}^{-1} & C_{33}^{-1} \end{array}\right]\end{array}}_{C_h^{-1}} = \begin{array}{c} es \\ nc \\ cs \end{array}\underbrace{\left[\begin{array}{c|c|c} C_{11}^{-1} & C_{12}^{-1} & C_{13}^{-1} \\ \hline C_{21}^{-1} & O & O \\ \hline C_{31}^{-1} & O & O \end{array}\right]}_{C_{es}^{-1}} + \begin{array}{c} es \\ nc \\ cs \end{array}\underbrace{\left[\begin{array}{c|c|c} O & O & O \\ \hline O & C_{22}^{-1} & C_{23}^{-1} \\ \hline O & C_{32}^{-1} & O \end{array}\right]}_{C_{nc}^{-1}} + \begin{array}{c} es \\ nc \\ cs \end{array}\underbrace{\left[\begin{array}{c|c|c} O & O & O \\ \hline O & O & O \\ \hline O & O & C_{33}^{-1} \end{array}\right]}_{C_{cs}^{-1}} \quad (4)$$

where:

B_{11} = input coefficient sub-matrix of carbon producing commodities required by carbon producing industries (ton-C/ton-C);
B_{12} = input coefficient sub-matrix of carbon producing commodities required by non-construction industries (ton-C/MY);
B_{13} = input coefficient sub-matrix of carbon producing commodities required by construction industries (ton-C/MY);
B_{21} = input coefficient sub-matrix of non-construction commodities required by carbon producing industries (MY/ton-C);
B_{22} = input coefficient sub-matrix of non-construction commodities required by non-construction industries (MY/MY);
B_{23} = input coefficient sub-matrix of non-construction commodities required by construction industries (MY/MY);
B_{31} = input coefficient sub-matrix of construction commodities required by carbon producing industries (MY/ton-C);
B_{32} = input coefficient sub-matrix of construction commodities required by non-construction industries (MY/MY);
B_{33} = input coefficient sub-matrix of construction commodities required by construction industries (MY/MY);

C_{11}^{-1} = market share sub-matrix of carbon-producing commodities produced by the carbon producing industries;
C_{12}^{-1} = market share sub-matrix of non-construction commodities produced by the carbon producing industries;
C_{13}^{-1} = market share sub-matrix of construction commodities produced by the carbon producing industries;
C_{21}^{-1} = market share sub-matrix of the carbon producing commodities produced by the non-construction industries;
C_{22}^{-1} = market share sub-matrix of non-construction commodities produced by the non-construction industries;
C_{23}^{-1} = market share sub-matrix of construction commodities produced by the non-construction industries;
C_{31}^{-1} = market share sub-matrix of the carbon producing commodities produced by the construction industries;
C_{32}^{-1} = market share sub-matrix of non-construction commodities produced by the construction industries;
C_{33}^{-1} = market share sub-matrix of construction commodities produced by the construction industries;

The subdivision of the matrices is also done to be able show the hierarchy of forward linkages, backward linkages versus the isolated sub-system which in this case is the construction industry.

The production function for commodity (1) and industry (2) were decomposed according to the structure of the B_h and C_h^{-1} matrices in (3) and (4). This decomposition shows the strengths of the linkages between the non-construction sector, nc, the construction sector, cs and the carbon producing industries, es, which induces the amount of emissions from the construction sector. It also aids in the understanding of the relationships in the large economic system. The decomposed production function is shown:

$$q_1 = (I + L_0 B_{es} C_h^{-1})(I + L_2 B_{cs} C_a^{-1})(I + L_3 B_{nc} C_{cs}^{-1})(I - B_{nc} C_{nc}^{-1})^{-1} f \quad (5)$$

$$g_1 = (C_h^{-1} + C_h^{-1} L_0 B_{es} C_h^{-1})(I + L_2 B_{cs} C_a^{-1})(I + L_3 B_{nc} C_{cs}^{-1})(I - B_{nc} C_{nc}^{-1})^{-1} f \quad (6)$$

where:

$L_0 = (I - B_h C_h^{-1})^{-1}$ $\quad$ $L_3 = (I - B_{nc} C_a^{-1})^{-1}$ $\quad$ $B_a = B_{nc} + B_{cs}$

$L_2 = (I - B_a C_a^{-1})^{-1}$ $\quad$ $C^{-1}{}_a = C^{-1}{}_{nc} + C^{-1}{}_{cs}$

From equation (6), we have E_g as the matrix of total carbon emission coefficient of industries induced by the non-construction sector for the production of final demand. This represents the emission structure of carbon producing industries. It represents the interconnections of the carbon-producing industry, the non-construction industry and the construction industry, which contributes to the carbon emissions.

$$E_g = \left(C_h^{-1} + C_h^{-1} L_0 B_{es} C_h^{-1}\right)\left(I + L_2 B_{cs} C_a^{-1}\right)\left(I + L_3 B_{nc} C_{cs}^{-1}\right) \quad (7)$$

Equation (7) can be presented in matrix form as follow:

$$E_g = \begin{bmatrix} E_{g11} & E_{g12} & E_{g13} \\ E_{g21} & E_{g22} & E_{g23} \\ E_{g31} & E_{g32} & E_{g33} \end{bmatrix} \quad (8)$$

where:

E_{g11} = carbon producing industry output submatrix of carbon producing industries induced by the final demand of the carbon-producing sector;

E_{g12} = carbon producing industry output submatrix of carbon producing industries induced by the final demand of the non-construction sector;

E_{g13} = carbon producing industry output submatrix of carbon producing industries induced by the final demand of the construction sector;

E_{g21} = non-construction output submatrix of carbon producing industries induced by the final demand of the carbon-producing sector;

E_{g22} = non-construction output submatrix of carbon producing industries induced by the final demand of the non-construction sector;

E_{g23} = non-construction output submatrix of carbon producing industries induced by the final demand of the construction sector;

E_{g31} = construction output submatrix of carbon producing industries induced by the final demand of the carbon-producing sector;

E_{g32} = construction output submatrix of carbon producing industries induced by the final demand of the non-construction sector;
E_{g33} = construction output submatrix of carbon producing industries induced by the final demand of the construction sector;
The carbon emission coefficient vector of carbon producing industries is given in the matrix below:

$$E_{ge} = \left[E_{g11} \mid E_{g12} \mid E_{g13} \right] \quad (9)$$

E_{ge} is defined as the direct and indirect emission output acquired as a result of the production processes of the carbon producing sectors, non-construction and the construction sectors. To be able to get the direct and indirect emission output discharged in the processes of the non-construction industry, we can decompose equation (9) to equation (10) as shown below:

$$E_{gnc} = \left[\; O \; \mid E_{g12} \mid \; O \; \right] \quad (10)$$

2.3 Final Demand

The road construction commodity used as final demand in this paper is composed of all construction connected with road construction such as pavement (local and national), bridge (local and national), improvement, repair, and local road. The final demand used for the production of a road construction commodity is a final demand converter. A final demand converter is used because no detailed construction category is given in the basic I-O table. This converter is taken from the input transactions of the construction sector. The final demand converter, f_i^c, is defined as the input coefficient for construction as shown in equation 11.

$$f_i^c = \frac{p_i^c}{\sum_i P_i^c} \quad (11)$$

where:
p_i^c = input coefficient from the industrial sector i for the road construction category c;
P_i^c = cost of inputs from the industrial sector i for the construction category c

The final demand for a road construction commodity can be converted into the hybrid system as given in the vector:

$$f_i^c = \left[f_{es}^c \mid f_{nc}^c \mid f_{cs}^c \right]^t \quad (12)$$

where:
f_i^c = final demand converter for every construction commodity c;
f^c_{es} = Final demand of the carbon producing industry requirements of a construction commodity;
f^c_{nc} = Final demand of the non-construction industry requirements of a construction commodity;
f^c_{cs} = Final demand of the construction industry requirements of a construction commodity;

Note that the symbol (^{t}) means the transpose of the vector. The final demand converter used is the non-construction-input requirements of a road construction commodity. The final demand converter can also be subdivided into each road construction category. The equation below shows the final demand converter used for every construction category.

$$f^{c}_{nc} = f^{p}_{nc} + f^{b}_{nc} + f^{r}_{nc} + f^{i}_{nc} + \ldots \qquad (13)$$

The production-based carbon emission function can be formulated from equations (6), (10) and (13), the total carbon emission intensity from the carbon producing industries induced by the non-construction sector for the production of a construction commodity is given by:

$$CO_{es} = E_{gnc} * \left(I - B_{nc}C^{-1}_{nc}\right)^{-1} * f^{c}_{nc} \qquad (14)$$

where:

CO_{es} =Total carbon emission intensity of a construction commodity induced by processes in the non-construction industry (ton-C/MY);
E_{gnc}= Carbon emission coefficient vector of carbon producing industries;
$(I - B_{nc}C^{-1}{}_{nc})^{-1}$= Total requirements matrix induced by the non-construction sector;
$f^{c}{}_{nc}$ = Final demand of the non-construction requirements of a construction commodity;

3 STRUCTURAL DECOMPOSITION ANALYSIS

The sources of changes in carbon emission intensity are studied using SDA. The total change in carbon emissions intensities is decomposed into effects caused by the changes in the emission structure of carbon producing sectors, E_{gnc}, changes in non-construction technology, $(I – B_{nc}C_{nc}{}^{-1})^{-1}$ as well as changes in the construction technology of the road construction. Using equation (14), we can carry out its decomposition over time by

$$\Delta CO_{es} = \left\{E_{gnc}\left(I - B_{nc}C^{-1}_{nc}\right)^{-1} f^{c}_{nc}\right\}_{1} - \left\{E_{gnc}\left(I - B_{nc}C^{-1}_{nc}\right)^{-1} f^{c}_{nc}\right\}_{0} \qquad (15)$$

The subscripts 1 and 0 denote the future year t1 and base year t0, respectively. If we let $L_{nc}= (I – B_{nc}C_{nc}{}^{-1})^{-1}$, we have:

$$\Delta CO_{es} = E_{gnc1}L_{nc1}f^{c}_{nc1} - E_{gnc0}L_{nc0}f^{c}_{nc0} \qquad (16)$$

Equation (16) can be transformed into six different types of decomposition forms, which are shown in equation (17).

$$\begin{aligned}
\Delta CO_{es} &= \Delta E_{gnc}L_{nc1}f^{c}_{nc1} + E_{gnc0}\Delta L_{nc}f^{c}_{nc1} + E_{gnc0}L_{nc0}\Delta f^{c}_{nc} \\
&= \Delta E_{gnc}L_{nc0}f^{c}_{nc0} + E_{gnc1}\Delta L_{nc}f^{c}_{nc0} + E_{gnc1}L_{nc1}\Delta f^{c}_{nc} \\
&= \Delta E_{gnc}L_{nc1}f^{c}_{nc0} + E_{gnc0}\Delta L_{nc}f^{c}_{nc0} + E_{gnc1}L_{nc1}\Delta f^{c}_{nc} \\
&= \Delta E_{gnc}L_{nc0}f^{c}_{nc0} + E_{gnc1}\Delta L_{nc}f^{c}_{nc1} + E_{gnc1}L_{nc0}\Delta f^{c}_{nc} \qquad (17) \\
&= \Delta E_{gnc}L_{nc0}f^{c}_{nc1} + E_{gnc1}\Delta L_{nc}f^{c}_{nc1} + E_{gnc0}L_{nc0}\Delta f^{c}_{nc} \\
&= \Delta E_{gnc}L_{nc1}f^{c}_{nc1} + E_{gnc0}\Delta L_{nc}f^{c}_{nc0} + E_{gnc0}L_{nc1}\Delta f^{c}_{nc}
\end{aligned}$$

ΔE_{gnc} represents the changes in the emission structure of the carbon producing industries, while ΔL_{nc} represents the changes in the non-construction technology and Δf^{c}_{nc} denotes the final demand changes of the non-construction requirements of a road construction commodity. Dietzenbacher and Los (1998) suggested that the average of polar decompositions be computed for cases with more than two determinants. So the average effects of the determinants are computed. The average effects of the emission structure changes of the carbon producing industries, ΔE_{gnc}, can be calculated by the formula:

$$(1/6)\cdot\left[2\cdot\left(\Delta E_{gnc}L_{nc1}f^{c}_{nc1}\right)+2\cdot\left(\Delta E_{gnc}L_{nc0}f^{c}_{nc0}\right)+\Delta E_{gnc}L_{nc1}f^{c}_{nc0}+\Delta E_{gnc}L_{nc0}f^{c}_{nc1})\right] \quad (18)$$

Equation (19) estimates the average effects of changes in construction technology.

$$(1/6)\cdot\left\{2\left(E_{gnc0}L_{nc0}\Delta f^{c}_{nc}\right)+2\left(E_{gnc1}L_{nc1}\Delta f^{c}_{nc}\right)+E_{gnc1}L_{nc0}\Delta f^{c}_{nc}+E_{gnc0}L_{nc1}\Delta f^{c}_{nc}\right\} \quad (19)$$

It should be noted that the final demand used in the study is a final demand converter, which consists of the input coefficients of each road construction category, in effect, Δf^{c}_{nc} can be called the changes in the construction technology for each road construction category.

The average effects of the changes in non-construction technology are manifested in equation (20).

$$(1/6)\cdot\left[2\cdot\left(E_{gnc0}\Delta L_{nc}f^{c}_{nc0}\right)+2\cdot\left(E_{gnc1}\Delta L_{nc}f^{c}_{nc1}\right)+E_{gnc0}\Delta L_{nc}f^{c}_{nc1}+E_{gnc1}\Delta L_{nc}f^{c}_{nc0}\right] \quad (20)$$

Moreover, the effects of changes in the non-construction technology, ΔL_{nc}, can be further subdivided into the effects of changes in the input structure in the non-construction industry, ΔB_{nc} and into the effects of the changes in the product mix of the non-construction industry, ΔC^{-1}_{nc}.

$$\begin{aligned}\Delta L_{nc} &= \left[\left(I-B_{nc}C^{-1}_{nc}\right)^{-1}\right]_1-\left[\left(I-B_{nc}C^{-1}_{nc}\right)^{-1}\right]_0\\ &= L_{nc0}\Delta B_{nc}C^{-1}_{nc0}L_{nc1}+L_{nc0}B_{nc1}\Delta C^{-1}_{nc}L_{nc1}\\ &= L_{nc0}B_{nc1}\Delta C^{-1}_{nc0}L_{nc1}+L_{nc0}\Delta B_{nc1}C^{-1}_{nc1}L_{nc1}\end{aligned} \quad (21)$$

Substituting equation (21) into equation (20), we can obtain the average effects of changes in the input structure of the non-construction industry as shown in equation (22).

$$\begin{aligned}&(1/12)\cdot\{2\cdot\left(E_{gnc0}L_{nc0}\Delta B_{nc}C_{nc0}L_{nc1}f^{c}_{nc1}\right)+2\cdot\left(E_{gnc0}L_{nc0}\Delta B_{nc}C_{nc1}L_{nc1}f^{c}_{nc1}\right)+\\ &2\cdot\left(E_{gnc1}L_{nc0}\Delta B_{nc}C_{nc0}L_{nc1}f^{c}_{nc1}\right)+2\cdot\left(E_{gnc1}L_{nc0}\Delta B_{nc}C_{nc1}L_{nc1}f^{c}_{nc1}\right)+\\ &E_{gnc1}L_{nc0}\Delta B_{nc}C_{nc1}L_{nc1}f^{c}_{nc0}+E_{gnc1}L_{nc0}\Delta B_{nc}C_{nc0}L_{nc1}f^{c}_{nc0}+\\ &E_{gnc0}L_{nc0}\Delta B_{nc}C_{nc0}L_{nc1}f^{c}_{nc0}+E_{gnc0}L_{nc0}\Delta B_{nc}C_{nc1}L_{nc1}f^{c}_{nc0}\}\end{aligned} \quad (22)$$

Similarly, the average effects of changes in the product mix are obtained in equation (23).

$$(1/12)\cdot\{2\cdot\left(E_{gnc0}L_{nc0}B_{nc1}\Delta C^{-1}_{nc}L_{nc1}f^{c}_{nc1}\right)+2\cdot\left(E_{gnc0}L_{nc0}B_{nc0}\Delta C^{-1}_{nc}L_{nc1}f^{c}_{nc1}\right)+$$

$$2\cdot\left(E_{gnc1}L_{nc0}B_{nc1}\Delta C_{nc}^{-1}L_{nc1}f_{nc1}^{c}\right)+2\cdot\left(E_{gnc1}L_{nc0}B_{nc0}\Delta C_{nc}^{-1}L_{nc1}f_{nc1}^{c}\right)+$$
$$E_{gnc1}L_{nc0}B_{nc1}\Delta C_{nc}^{-1}L_{nc1}f_{nc0}^{c}+E_{gnc1}L_{nc0}B_{nc0}\Delta C_{nc}^{-1}L_{nc1}f_{nc0}^{c}+$$
$$E_{gnc0}L_{nc0}B_{nc1}\Delta C_{nc}^{-1}L_{nc1}f_{nc0}^{c}+E_{gnc0}L_{nc0}B_{nc0}\Delta C_{nc}^{-1}L_{nc1}f_{nc0}^{c}\Big\} \qquad (23)$$

The carbon emissions from industries are affected by the changes in the variables mentioned above. The empirical application of the decomposition equations is shown in the next section.

4 EMPIRICAL APPLICATION

The decomposition equations presented in section 3 are applied to the analysis of the changes in the carbon emission intensities of road construction from 1975 to 1995. These periods were chosen to be able to trace the historical changes of carbon emissions in Japan induced by road construction.

4.1 Basic Data

The data used in the study were the basic commodity by commodity input-output tables; the industry by commodity tables (V matrices); the table of by-products; the carbon dioxide emission intensity based on the input-output analysis and the input tables for construction work. All the above mentioned data were collected for the years 1975,1980,1985,1990 and 1995.

The sectors in the V matrices for different years do not correspond to the sector classification of the commodity x commodity tables therefore all the tables were aggregated into a 60 x 60 matrix for each analysis year. The aggregation was done to be able to make all the sectors uniform and manageable. Moreover, all monetary terms were converted to 1985 prices to facilitate comparison and to exclude price components from the analysis of structural change. The sectors were rearranged according to the carbon-producing sectors, non-construction industry sector and the construction sector. There are 7 sectors in the carbon producing sector (es) which is composed of Coal mining, Crude petroleum and Natural gas, Limestone, Petroleum refinery products, coal products, electricity and power generation and gas supply and steam. Two sectors are from the construction industry (cs) namely: the residential and non-residential construction sector and civil engineering construction sector, and lastly, the other 51 sectors are the non-construction (nc) sectors.

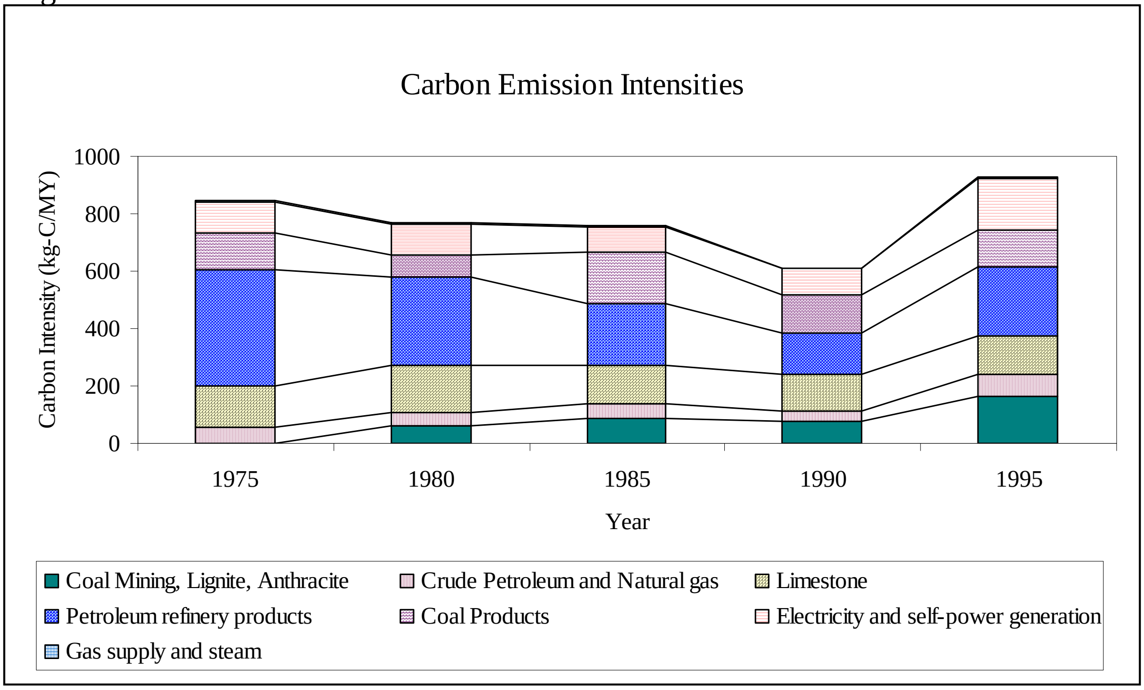
4.2 Results and Discussion

The result of the calculations and analysis is presented in this section. The survey of carbon emissions is introduced in the next part. The application of the decomposition equations is shown in the following sections both for road construction and its commodities.

4.2.1 Survey of Carbon Emissions

Figure 2 presents the levels of carbon emissions induced by the carbon producing industry for road construction in 1975 to 1995. These intensities are based on 1985 constant prices. The trend of carbon emissions can be seen from 1975 to 1995. During 1975-1995, carbon emissions increased by 10%. The emission level decreased by 20% from 1985 to 1990 which is the biggest decrease during the 20-year interval.

Figure 2 Carbon Emission Intensities of Road Construction Industries for 2 decades



Source: Authors' Calculation

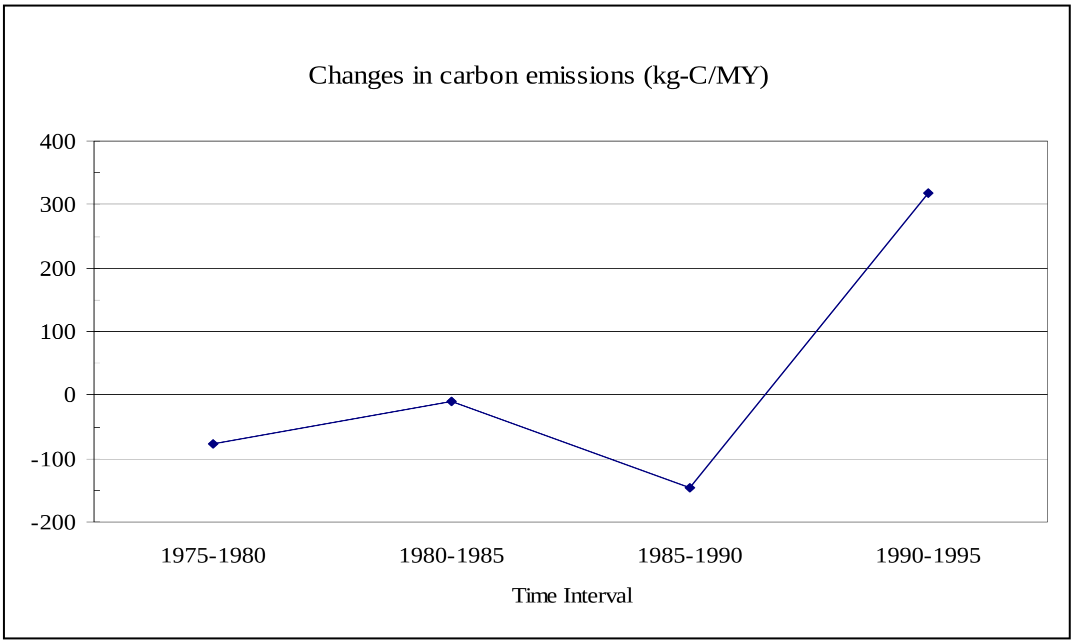
Looking into the carbon producing industry usage, we see that the emission from the coal mining industry gradually increased from 1975 to 1995 with the biggest emission in 1995 which is about 166 kg-C/MY. It is also interesting to note that the period from 1985 to 1990 posted a 19% decrease in emission intensity due to decreased usage of coal products and petroleum refinery products. The carbon emissions from petroleum refinery products gradually decreased with a 32% decrease in 1985-1990. Eventhough carbon emissions from petroleum refinery products decreased by 39% from 1975-1995, the emissions from the electricity and coal mining industries increased during the period. Further explanation of the changes in emissions is given in the following sections.

4.2.2 Decomposition Results induced by Road Construction

The results of the decomposition analysis of the structural changes in the carbon intensities induced by road construction are shown in the tables and figures presented in this section. The road construction final demand in this section does not include earthwork and other construction works unless otherwise specified.

Figure 3 shows the trend in the changes in carbon emissions from 1975 to 1995. Considering the absolute changes in the carbon emissions induced by road construction, the carbon emissions slightly went up from 1980-1985 compared to 1975-1980. Moreover, it can be seen that the greatest decrease in carbon emissions happened within the period of 1985-1990. The overall change in carbon emissions from 1975 to 1990 shows a slight increase in carbon emissions though the carbon emission during 1985-1990 showed the greatest decrease. It might be due to the very distinct increase of carbon emission change from 1990-1995. There was a 52% increase in carbon emissions from 1990-1995.

Figure 3 Changes in Carbon Intensities for Road Construction



Source: Authors' calculation

The reasons for the fluctuation in the carbon emission intensities induced by the input requirements of road construction are shown in Table 2. The table presents the estimates of the decomposition equations used.

Table 2. Decomposition analysis of changes in carbon emission intensity for road construction (kg-C/MY)

Period	ΔE_{gnc}	ΔB_{nc}	ΔC^{-1}_{nc}	Δf^{c}_{nc}	Total Δ
1975-1980	-158.3	34.0	22.8	35.1	-66.3
1980-1985	-59.4	66.7	-78.4	61.2	-10.0
1985-1990	-52.0	-60.9	-4.3	-28.2	-145.6
1990-1995	70.9	-111.4	60.5	296.9	316.9
1975-1995	-389.8	-109.0	62.4	521.7	85.3

Source: Authors' calculation

The total changes in carbon emissions (Total Δ) for a certain time interval can be decomposed into changes in emission structure, ΔE_{gnc}, changes in the non-construction input structure, ΔB_{nc}, changes in non-construction product mix, ΔC^{-1}_{nc} and changes in the input coefficients of road construction, Δf^{c}_{nc}. Emission structure changes are sets of reciprocal action of the subsystems that induce carbon emissions. Input structural changes and product mix changes are non-construction technological changes in the economy that affect carbon emissions. Changes in input coefficients of road construction are basically the changes in road construction technology.

The increase in carbon emissions from 1975-1995 is largely a result of the apparent increase in the non-construction inputs to road construction (0.5217 ton-C/MY). The increase in the final demand effect can also be seen during the period of 1990-1995. The reason for this increase in construction technology can be explained in the following tables. The second most important effect is the carbon-producing industry's emission structure, which accounted for a decrease of 0.3898 ton-C/MY. A negative emission structure shows that these industries shift from being carbon intensive to being less carbon intensive. This can be seen in Figure 2 wherein carbon emissions from petroleum refinery products have decreased and changed to 'less carbon intensive' industries. Changes in non-construction industry input structure from 1975-1995 also show a significant effect to the change in carbon intensity. This explains the improvement in the overall non-construction technology at this time period.

The period in 1975-1980 indicates that the decrease in the emission is mainly due to the change in the carbon-producing industries' emission structure. This reveals that the dependence on energy intensive industries has waned and shifted to less energy intensive industries, which contributed to the decrease in carbon emissions. Another reason for the shift maybe a result of the oil crisis which affected the world in 1973.

From 1980-1985, the change in product mix and decrease in emission structure influenced the decrease in emission. Since non-construction input technology increased compared to the previous period, the decrease in carbon emissions was smaller compared to the previous one. The negative effect of product mix may be related to the savings in energy consumption thereby decreasing carbon emission. It also reflects the importance of technology in the decrease in carbon emissions.

The period of 1985-1990 showed the biggest dip in the emission change as a result of combined improvement in emission structure, non-construction technology and construction technology. This reflects increased industrial efficiency and productivity in construction design and methods.

For 1990-1995, a drastic increase in carbon emission intensity occurred as compared to the previous period. This is due to the increase in the change in final demand as well as increased change in the emission structure although the non-construction technology improved in this period it was offset by increase in other variables.

Table 3 shows the top 3 intermediate input requirement of road construction, which contributed, to the major increase in carbon intensity. Table 4 presents the major decrease in carbon intensity as embedded in the intermediate inputs of road construction. These two tables can enlighten us on the fluctuation of the construction technology during the study period. We see from Tables 3 and 4 that carbon emission embedded in steel and steel products as well as cement and cement products contributed to a large effect in the fluctuation in emission levels.

During 1975-1980, services accounted for a major effect in the increase in emissions levels but the steel technology at that time also aided in the decrease in the emission levels. For 1980-1985, carbon emission embedded in steel and steel products contributed to the increase in emission level while cement and cement products induced the decrease.

Transportation services' also contributed to the increase in carbon emissions during this period

Table 3 also shows that carbon emission embedded in cement and cement products for 1990-1995 contributed to the marked increase in carbon emission even if carbon emission embedded in steel (Table 4) contributed to a decrease. The carbon emission intensity embedded in the cement and cement products roughly composes about 49% of the total change in carbon emissions. This may be due to the increased public investment in the construction of concrete roads as against asphalt based pavements. In 1985-1990, the carbon emissions embedded in cement and cement products, steel and steel products as well as industrial machinery all decreased. This reflects the improvement in these technologies. It also infers that simultaneous improvement in the technologies of steel and cement will lead to a tremendous decrease in carbon emissions for road construction.

Table 3 Effects that contributed to a major increase in carbon intensity for each time period (kg-C/MY)

Period	Industry	ΔE_{gnc}	ΔB_{nc}	ΔC^{-1}_{nc}	Δf^{c}_{nc}	Total
1990-1995	Cement and cement products	-104.1	-21.9	10.0	273.0	157.0
	Metal products for construction	34.4	-37.0	24.2	108.2	129.9
	Transportation, packing and its services	10.7	-2.6	1.2	24.8	34.0
1985-1990	Transport vehicles and its repair	-0.9	-2.7	-9E-3	18.1	14.5
	Non-ferrous metals and products	-2.2	0.3	-0.1	12.9	11.0
	Organic and inorganic chemicals	-1.6	0.3	-0.1	6.0	4.6
1980-1985	Steels and steel products	80.7	5.3	-24.4	15.5	77.2
	Transportation, packing and its services	-8.7	11.5	8.8	19.2	30.9
	Transport vehicles and its repair	-1.8	15.5	-0.5	11.2	24.4
1975-1980	Activities not elsewhere classified	-7.3	5.8	0.8	32.5	31.7
	Advertising, information and other business services	0.1	-1.3	5E-2	13.4	12.3
	Non-ferrous metals and products	-0.6	0.8	1E-2	9.1	9.3

Source: Authors' calculation

Table 4 Industries that contributed to a major decrease in carbon intensity for each time period (kg-C/MY)

Period	Industry	ΔE_{gnc}	ΔB_{nc}	ΔC^{-1}_{nc}	Δf^{c}_{nc}	Total
1990-1995	Steels and steel products	41.5	-22.9	17.5	-95.6	-59.5
	Activities not elsewhere classified	-1.0	-3.7	0.2	-6.2	-10.7
	Transport vehicles and its repair	24.1	-1.6	0.5	-35.3	-12.3
1985-1990	Steels and steel products	-21.9	-34.2	-2.0	-11.3	-69.3
	Cement and cement products	-19.4	-4.8	-0.8	-8.7	-33.7
	Industrial machinery	-3.3	-1.5	-0.4	-28.5	-33.6
1980-1985	Cement and cement products	-130.9	2.7	-0.7	6.5	-122.4
	Activities not elsewhere classified	1.8	-6.7	-1.7	-14.2	-20.8
	Wholesale and retail trade	-7.0	-1.5	2.1	-3.8	-10.2

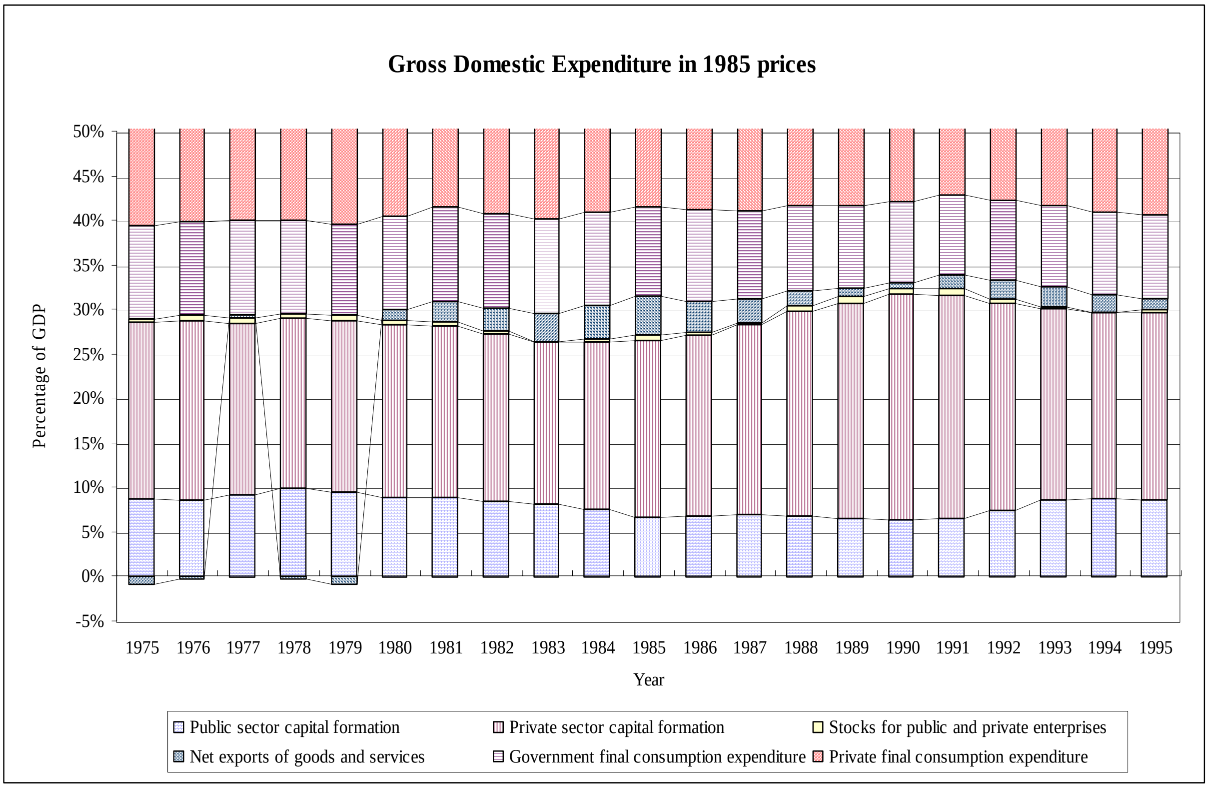
Period	Industry	ΔE_{gnc}	ΔB_{nc}	ΔC^{-1}_{nc}	Δf^{c}_{nc}	Total
1975-1980	Steels and steel products	-101.6	52.0	13.9	10.8	-24.9
	Transport vehicles and its repair	12.4	-37.0	1.7	-14.2	-37.1
	Transportation, packing and its services	2.8	-31.1	1.4	-33.4	-60.2

Source: Authors' calculation

Now, let's see the investment in infrastructure facilities from the public sectors as a part of the gross domestic product. Figure 4 shows the gross domestic expenditure in Japan from 1975-1995. It can be seen that household consumption has the biggest share in the GDP followed by private sector investment in infrastructure and equipment. The period from 1985-1990 saw an increased investment in facilities especially from the private sector, this investment led to the improvement of steel and other technologies, in turn decreasing carbon emissions during this period. This period was also the so-called bubble economy wherein the stock markets boomed and land prices increased (Wood, 1992) and manufacturing technology also heightened. The bubble was burst in 1991 where many large companies became bankrupt. This led to a slow growth in Japan from 1990 as seen in the figure. Eventhough, the public sector investment averages about 8% in the total GDP we can see that through the period of drastic increase in carbon emissions (1990-1995), the public sector investment in infrastructure facilities increased by 50% which accounts for about the same increase in carbon emission. A simple regression analysis was done between the carbon dioxide change and the change in public investment. Results show that with a r^2 of 0.42 and F-statistic of 1.46, there is a correlation between change in public investment and carbon emissions induced by road construction. This period also shows a slow growth in the economy as seen in the decreased investment of the private sector in infrastructure and the decreased household consumption during the period. This slow growth from the private sector's side has prompted the government to invest heavily on public infrastructure hence the increase in carbon emissions especially from cement and cement products.

The 20-year period of analysis showed that technologies in steel or cement contributed to either an increase or decrease in carbon emissions and in the period of 1985-1990, both technologies improved thereby reducing carbon emissions drastically.

Figure 4 Gross Domestic Expenditure in Japan from 1975-1995



Source: Authors' Calculation

4.2.3 Decomposition results from each Construction Category

In this section, the carbon emission changes for each road construction category are analyzed. The sources of change of carbon emissions with respect to each construction category are also decomposed in terms of carbon emission structure, non-construction technology input structure, non-construction technology output structure and construction technology. Table 5 exhibits the major sources of change of carbon emission for each construction category during 1975 to 1995. The shaded cells in the table show the highest absolute decrease or increase in carbon emissions.

For the period of 1975-1980, carbon emissions decreased for bridge construction, improvement, pavement works and earthworks. Among them bridge construction reflected the highest absolute decrease in carbon emissions mainly due to changes in the emission structure and improvement of construction technology. Other works, on the other hand, showed an increase in carbon emissions mainly due to increase in the final use of materials. For the next period of 1980-1985, carbon emissions due to bridge construction increased due to an increase in final demand while other works reflected a decrease in carbon emissions due to a decrease in the construction final demand and a decrease in the non-construction product mix. For 1985 to 1990, carbon emissions due to bridge construction decreased because of improvement in non-construction and construction technology. It is also noted that during this period, all but one registered a decrease in carbon emissions. Pavement works, however, yielded a slight increase in carbon emissions. During 1990–1995, carbon emissions due to all the road construction categories increased. The reason is mainly due to the increase in the input coefficients.

Table 5 Decomposition Analysis for each road construction category (kg-C/MY)

Period		Improvement	Bridge	Pavement	Repair	Earthwork	Other Works

Period		Improvement	Bridge	Pavement	Repair	Earthwork	Other Works
1975-1980	ΔE_{gnc}	-130.0	-464.2	-84.5	-132.4	-212.4	-445.6
	ΔB_{nc}	23.1	216.1	-14.1	23.2	74.4	220.0
	ΔC^{-1}_{nc}	19.4	55.6	13.5	19.7	21.9	14.7
	Δf^{c}_{nc}	-16.9	-.05	213.17999		711.05E3.8404001	711.080265

Period	Industry	Emission Source	ΔE_{gnc}	ΔB_{nc}	ΔC^{-1}_{nc}	Δf^{c}_{nc}	Total Δ
1985-1990	Metal products for construction	Coal Mining	3.8	-2.9	-0.1	9.8	10.6
		Crude Petroleum	-7.3	-2.7	-0.1	12.2	2.1
		Limestone	1.7	-1.9	-0.1	4.5	4.1
		Petroleum products	-71.6	-20.5	-1.1	54.5	-38.8
		Coal Products	46.6	-17.7	-1.0	46.2	74.0
		Electricity	0.0	-4.2	-0.2	24.9	20.4
		Gas supply	0.5	-0.1	0.0	0.9	1.3
		Total	-26.3	-50.0	-2.7	152.9	73.9
1990-1995	Metal products for construction	Coal Mining	41.1	-15.5	9.7	25.6	61.0
		Crude Petroleum	9.8	-5.1	2.7	15.0	22.3
		Limestone	3.6	-4.9	3.3	7.1	9.1
		Petroleum products	6.5	-5.9	3.0	34.5	38.1
		Coal Products	20.9	-58.2	36.8	81.2	80.7
		Electricity	16.0	-12.5	6.7	37.5	47.7
		Gas supply	1.8	-0.4	0.2	2.0	3.6
		Total	99.7	-102.4	62.3	202.8	262.4
1975-1995	Metal products for construction	Coal Mining	61.6	-4.8	5.9	16.6	79.2
		Crude Petroleum	-12.0	-1.5	2.1	18.9	7.5
		Limestone	6.0	-2.2	2.5	5.5	11.8
		Petroleum products	-141.8	-3.1	7.8	70.5	-66.6
		Coal Products	-36.4	-27.7	30.4	85.6	52.0
		Electricity	-29.1	0.7	4.9	44.4	20.9
		Gas supply	3.2	0.1	0.2	1.4	4.8
		Total	-148.5	-38.5	53.8	242.9	109.7

Source: Authors' calculation

The non-construction industry resource inputs were ranked in descending order to know their positive and negative contributions to the increase or decrease in carbon emissions for bridge construction. Table 6 presents the carbon emission embedded into the main resource input that contributed to the increase in the emissions. It can be seen from the table that the increased usage of steel and steel products in 1980-1985 contributed to the slight increase in carbon emissions during this period. An increase in the crude petroleum and natural gas industry compared to the previous period also induced the change.

Table 7 Effects that contributed to a major decrease in carbon intensity for bridge construction (kg-C/MY)

Period	Industry	Emission Source	ΔE_{gnc}	ΔB_{nc}	ΔC^{-1}_{nc}	Δf^{c}_{nc}	Total Δ
1975-1980	Steels and steel Products	Coal Mining	10.2	1.9	0.5	-2.6	10.1
		Crude Petroleum	-7.6	5.3	1.8	-9.3	-9.8
		Limestone	-1.6	6.6	1.4	-4.9	1.5
		Petroleum products	-45.3	16.7	7.0	-40.6	-62.2
		Coal Products	-206.3	79.3	18.0	-82.6	-191.5
		Electricity	-10.3	15.3	4.7	-22.8	-13.1
		Gas supply	0.5	0.2	0.1	-0.4	0.4
		Total	-260.3	125.4	33.5	-163.1	-264.6
1980-1985	Metal products for construction	Coal Mining	2.4	0.8	-1.7	-6.7	-5.2
		Crude Petroleum	4.4	1.6	-3.0	-12.2	-9.2
		Limestone	0.2	-0.1	-1.3	-3.9	-5.1
		Petroleum products	52.8	2.5	-18.3	-66.3	-29.2
		Coal Products	-8.2	2.6	-6.5	-27.7	-39.9
		Electricity	-11.6	4.2	-5.9	-25.4	-38.8
		Gas supply	-0.2	0.1	-0.1	-0.6	-0.9
		Total	39.7	11.6	-36.9	-142.7	-128.3

Period	Industry	Emission Source	ΔE_{gnc}	ΔB_{nc}	ΔC^{-1}_{nc}	Δf^{c}_{nc}	Total Δ
1985-1990	Steels and steel Products	Coal Mining	13.0	-3.7	-0.2	-13.0	-3.9
		Crude Petroleum	-13.8	-3.4	-0.2	-14.5	-31.9
		Limestone	3.3	-2.3	-0.2	-7.9	-7.1
		Petroleum products	-211.0	-26.9	-1.6	-93.8	-333.3
		Coal Products	160.2	-23.2	-1.3	-76.3	59.3
		Electricity	1.3	-5.3	-0.3	-23.9	-28.1
		Gas supply	0.5	-0.1	0.0	-0.5	-0.1
		Total	-46.5	-64.9	-3.7	-229.9	-345.0
1990-1995	Steels and steel Products	Coal Mining	24.3	-6.2	5.2	-12.8	10.5
		Crude Petroleum	5.4	-1.4	1.0	-5.0	0.1
		Limestone	3.2	-2.2	1.9	-4.0	-1.1
		Petroleum products	5.8	-0.9	1.1	-8.4	-2.5
		Coal Products	16.3	-26.0	21.8	-50.6	-38.5
		Electricity	11.6	-3.5	2.7	-12.0	-1.2
		Gas supply	0.9	-0.1	0.0	-0.5	0.4
		Total	67.4	-40.2	33.8	-93.3	-32.2
1975-1995	Steels and steel Products	Coal Mining	55.0	-1.0	4.0	-32.9	25.0
		Crude Petroleum	1.8	0.3	1.1	-20.5	-17.2
		Limestone	7.7	-0.5	2.0	-11.6	-2.5
		Petroleum products	-53.8	3.5	2.6	-64.1	-111.8
		Coal Products	-20.7	-10.0	26.1	-193.9	-198.6
		Electricity	6.3	1.1	2.9	-46.9	-36.5
		Gas supply	1.8	0.1	0.0	-1.5	0.4
		Total	-1.9	-6.4	38.7	-371.4	-341.1

Source: Authors' calculation

Table 7, on the other hand, exhibits the main resource input that contributed to the decrease in carbon emissions for bridge construction. The technology change and emission structure change and construction technology change for steel and its products aided in the decrease of emissions due to bridge construction in 1975-1980, 1985-1990. It can also be inferred that the shifts from petroleum refinery products and the crude petroleum and natural gas industry reflected the decrease in emissions. Bridge construction technology has improved from 1975-1995, which is reflected in the decrease in total carbon emissions for this type of road construction.

5 CONCLUSION

The structural decomposition analysis (SDA) developed using the hybrid rectangular model framework has shown the important sources of change in carbon emissions induced by road construction. The changes in emission structure, non-construction input structure, non-construction product-mix and road construction technology has been clearly defined in the model. Another feature of the study is the identification of different road construction technologies, which affect the carbon emission intensities.

During the 1975-1995, carbon emission intensities have increased due to a shift to cement based road construction technology. But it is worthy to note that within this 20-year period, technological changes in non-construction input structure, emission structure, non-construction product mix changes and construction technology have contributed to the fluctuation in carbon intensities. The greatest improvement in construction technology can be seen in the period of 1985-1990 where the greatest decrease in emissions can be seen.

This improvement led to a decrease in emission levels. The shifts in energy usage for road construction also contributed to a decrease in the emission. The shift in the dependence on crude petroleum and petroleum products and coal products showed a marked decrease in emission levels. Moreover, improvement in bridge construction technology over the years was seen as a major contribution to the decrease in carbon emissions. The improvement in steel technology was the main proponent in the decrease in emissions for bridge. However, pavement construction technology is the reverse. This may be due to the fact of increasing usage of cement and cement products.

Overall, technological advances and improvement during the 20-year period for some types of construction technology have led to the decrease in emission levels. The improvement of steel and steel products in combination with cement and cement products led to a drastic decrease in carbon emissions induced from road construction. However, increased public investment in road and road construction offsets technological improvements in terms of carbon emissions as seen in during 1990-1995. This knowledge of the structural changes is very important to bring about the decrease in overall carbon emissions from road construction.

REFERENCES

Bullard, C. and Herendeen, R. A., 1975. The energy cost of goods and services, Energy Policy, 268-278.

Environmental Agency of Japan, 1997. Carbon dioxide emission intensity based on the Input-Output Analysis. CGER-report no. CGER-D016-97, Japan.

Fujimagari, D., 1989. The Sources of Change in Canadian Industry Output, Economic Systems Research 1 (2), 187-201.

Fritz, O., Sonis, M., Hewings, G.J.D., 1998. A Miyazawa analysis of interactions between polluting and non-polluting sectors, Structural Change and Economic Dynamics 9, 289-305.

Gale, L., IV, 1995. Trade Liberalization and Pollution: An Input-Output Study of Carbon Dioxide Emissions in Mexico, Economic Systems Research 7 (3), 309-320.

Gerilla, G, Inamura, H., Takeyama, Y., 2000. Environmental Impacts of the Building and Road Construction Industry in Japan. Proceedings of the International Symposium on Lowland Technology, Saga, Japan, pp. 457-464.

Kagawa, S. and H. Inamura, 2000. The Structural Decomposition of Energy Consumption Based on a Hybrid Rectangular Input-Output Framework – Japan's Case –, Presented in the 13th International Input-Output Conference, Macerata, Italy.

Leontief, W., 1970. Environmental repercussions and the economic structure: An input-output approach, The Review of Economics and Statistics 52, 3.

Miller, R. E. and Blair, P.D., 1985. Input-Output Analysis, Prentice Hall, Inc, Englewood Cliffs, New Jersey.

Piantanakulchai, M., Inamura, H., Takeyama, Y., 1999. A Life Cycle Inventory Analysis of Carbon-Dioxide for a Highway Construction Project Using Input-Output Scheme: A Case Study of the Tohoku Expressway Construction Works, Journal of Infrastructure Planning and Management of Japan Society of Civil Engineers (16), 411-418.

Piantanakulchai, M., and Inamura, H., 1999. The Decomposition for the Sources of Changes in Carbon Emission Intensities: A Case Study of Carbon Emissions from

Road Construction Work in Japan during 1975-1990, Journal of the East Asia Society for Transportation Studies 3 (1) 9-18.
Rose, A. and Chen, C.Y., 1991. Sources of change in energy use in the U.S. economy, 1972-1982 A structural decomposition analysis, Resources and Energy 13, 1-21.
Sonis, M. and Hewings, G.J.D., 1990. The 'Matrioshka Principle' in the Hierarchical Decomposition of Multi-Regional Social Accounting Systems, In: New Directions in Regional Analysis: Integrated and Multi-regional Approaches, L. Anselin & M. Madden (eds) (London, Pinter), pp. 101-111.
Sonis, M, et al, 1993, Spatial Economic Structure And Structural Changes in the EC: Feedback Loop Input-Output Analysis, Economic Systems Research 5 (2), 173-184.
Sonis, M., et al, 1995. The Asian Economy: Trade Structure Interpreted by Feedback Loop Analysis, Journal of Applied Input-Output Analysis 2 (2), 24 - 40.
Skolka, J., 1989. Input-Output Structural Decomposition Analysis for Austria. Journal of Policy Modeling 11 (1), 45-66.
Weber, C. and Schnabl, H., 1998. Environmentally Important Intersectoral Flows: Insights from Main Contributions Identification and Minimal Flow Analysis, Economic Systems Research 10 (4), 337-356.
Wier, M., 1998. Sources of Changes in Emissions from Energy: A Structural Decomposition Analysis, Economic Systems Research 10 (2) 99-111.
Wood, C., 1992. THE BUBBLE ECONOMY. The Japanese economic collapse. Charles E. Tuttle Co.,Inc., Tokyo.