The Structural Decomposition of Energy Consumption Based on a Hybrid Rectangular Input-Output Framework – Japan's Case –

By
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Abstract

This paper proposes a hybrid model, based on a rectangular input-output framework, to evaluate the effects of the changes in the energy demand structure, the non-energy input-output structure, and the non-energy final demand on energy intensities and total energy requirements. The demand structure of input-output system is decomposed into the structure of energy sectors and other sectors. The effects of change in the structures are analyzed by industry side and commodity side. A hybrid rectangular input-output framework expressed in both monetary terms and physical terms (terra calorie) is introduced to relax the effects of dynamic change of energy prices on the input structure in physical terms. The hybrid model was applied to estimate the energy intensities and the total energy requirements contributed by energy-supply industries. Moreover, the sources of changes in the energy intensities and the total energy requirements between 1985 and 1990 are analyzed by applying structural decomposition analysis to the hybrid model. Major findings are as follows; The total energy requirement in Japan has increased mainly because of the changes in non-energy final demand, the second, the changes in energy demand structure and the third, the changes in non-energy input structure, while the product-mix changes have reverse effects, that is, saving of energy. The results also proved a practical use of the proposed method.

Keywords: hybrid rectangular IO framework, structural decomposition analysis

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1. Introduction

The Life Cycle Assessment (LCA) for production, consumption, and waste disposal has been discussed in both social and political aspects. Only qualitative and subjective discussion has been made because of lack of quantitative and objective information on the life cycle flow from the cradle to the grave.

The conventional input-output model is often employed for LCA to estimate energy requirements and loads on environment brought from production processes throughout the entire economic system. The structural decomposition analysis (SDA) has been rapidly developed for impact analysis of LCA and applied to the real world. Rose and Chen (1991) greatly contributed to the theoretical expansion of SDA, and showed an application.

Lin and Polenske (1995) analyzed the effects of the final demand shifts and production technology changes on the China's energy use structure. They evaluated the effects of energy and non-energy input changes on the intermediate energy requirements connecting the hybrid IO method (see Bullard & Herendeen, 1975) with SDA. Weber and Schnabl (1998) proposed a mathematical formulation to decompose the economic system into energy and non-energy demand structure by applying the hierarchy system with feedback loops for non-energy sectors to the hybrid IO model.

Bullard et al., Rose et al., Lin et al., and Weber et al. greatly extended the conventional IO analysis for the environmental evaluation, however most studies with commodity-by-commodity framework have essential problems due to the assumption of product-mix. First, it is very difficult to analyze the effects of product-mix changes on energy consumption and emission from production activities (Afrasiabi & Casler, 1991). If the share of primary and secondary products of an industry changes, its input structure should change through the production processes. It also affects the energy requirements and environmental loads. Second, since the market price of by-products, recycle materials, and/or waste disposal is unstable and sometimes does not exist, it is difficult to analyze the effects of the material flow changes on the energy requirements and environmental loads (Inamura & Kagawa, 1998).

The problems mentioned above are kept in mind, the purposes of this paper are as follows;

(1) To propose the hybrid rectangular IO model (HRIO) expressed in both monetary term and physical term.
(2) To conduct the sensitivity analysis to estimate the effects of the changes in energy demand structure, non-energy input structure, non-energy product-mix, and non-energy final demand by applying the hierarchy system to the hybrid model.
(3) To analyze Japan's energy consumption structural changes between 1985 and 1990.

2. Formulation of the Basic Framework

The rectangular Input-Output framework (SNA type) is used to solve the problems described before. The basic framework of the model is shown in Table 1.

Table 1. Basic Framework of the Model

	Commodities.	Industries.	F. D.	T. D.
Commodities.		$\mathbf{U_{ij}}$	$\mathbf{f_i}$	$\mathbf{q_i}$
Industries.	$\mathbf{V_{ij}}$			$\mathbf{g_i}$
V. A.		$\mathbf{y_j}$		
T. S.	$\mathbf{q_j}$	$\mathbf{g_j}$		

Where

$\mathbf{V_{ij}}$ = output (make) matrix of industries i producing commodities j
$\mathbf{U_{ij}}$ = input (use) matrix of commodities i required by industries j
$\mathbf{q_i}$ = column vector of domestic output of commodities i
$\mathbf{g_i}$ = column vector of domestic output of industries i
$\mathbf{f_i}$ = column vector of final demand of commodities i
$\mathbf{y_j}$ = row vector of value added of industries j
T.D. = total demand
(i, j = 1,2,3, . . ., n)
F.D. = final demand
T.S. = total supply
V.A. = value added
n = number of industry sectors and/or commodity sectors

The model is formulated under the assumption of a commodity technology. First, the technological coefficient matrix **A** is defined based on the conventional commodity-by-commodity table.

$$\mathbf{A = a_{ij} = x_{ij} / q_j}$$

(1)

Where $\mathbf{x_{ij}}$ denotes an intermediate input requirement of commodities i required in order to produce commodities j. $\mathbf{q_j}$ is a domestic output of commodities j. The output coefficient matrix, **C** is stated as eq. (2).

$$\mathbf{C^t = c_{ij} = v_{ij} / g_i}$$

(2)

Where **t** is transposition. **B**, which expresses the input structure in the rectangular

IO system, is given by using eq. (1) and (2) under the assumption of a commodity technology: $\mathbf{A} = \mathbf{B}\mathbf{C}^{-1}$, that is,

$$\mathbf{B} = \mathbf{A}\mathbf{C}$$

(3)

The input matrix **U** can be easily calculated from equation (4).

$$\mathbf{U} = \mathbf{B}\hat{\mathbf{g}}$$

(4)

Where $\hat{\mathbf{g}}$ is the diagonal matrix with the elements of domestic output vector **g.** Next, considering the balance between the inputs and the outputs in the rectangular framework, the following relationships are reduced.

$$\mathbf{q} = \mathbf{B}\mathbf{g} + \mathbf{f} = \mathbf{B}\mathbf{C}^{-1}\mathbf{q} + \mathbf{f} = (\mathbf{I} - \mathbf{B}\mathbf{C}^{-1})^{-1}\mathbf{f}$$

(5)

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

(6)

Where $\mathbf{I}$ denotes a $n \times n$ unit matrix. From eq. (5) and (6), the domestic output of each commodity and/or industry induced by the final demand can be estimated respectively. Eq. (5) and (6) are well known as a production formula in the static rectangular IO system.

3. Formulation of Hybrid Rectangular Framework

A hybrid rectangular input-output framework expressed in both a monetary term and a physical term, is used to escape from the effects of the dynamic changes of energy prices on the input structure in physical term. Industry sector and commodity sector of the framework shown in Table 1 are decomposed into an energy sector ($\mathbf{e}$) and a non-energy sector ($\mathbf{ne}$), respectively. The energy sector has a unit of million yen ($\mathbf{MY}$) and those of non-energy sector is terra calorie ($\mathbf{TC}$). The input coefficient matrix $\mathbf{B}$ and the output coefficient matrix $\mathbf{C}$ can be formulated as follows.

$$\mathbf{B} = \begin{array}{c} \\ \mathbf{e} \\ \mathbf{ne} \end{array} \begin{array}{c} \begin{array}{cc} \mathbf{e} & \mathbf{ne} \end{array} \\ \left[\begin{array}{c:c} \mathbf{B}_{11}(\mathbf{TC}/\mathbf{TC}) & \mathbf{B}_{12}(\mathbf{TC}/\mathbf{MY}) \\ \hdashline \mathbf{B}_{21}(\mathbf{MY}/\mathbf{TC}) & \mathbf{B}_{22}(\mathbf{MY}/\mathbf{MY}) \end{array}\right] \end{array} \qquad (7)$$

$$\mathbf{C}^{t} = \begin{array}{c} \\ \mathbf{e} \\ \mathbf{ne} \end{array} \begin{array}{c} \begin{array}{cc} \mathbf{e} & \mathbf{ne} \end{array} \\ \left[\begin{array}{c:c} \mathbf{C}_{11}(\mathbf{TC}/\mathbf{TC}) & \mathbf{C}_{12}(\mathbf{MY}/\mathbf{TC}) \\ \hdashline \mathbf{C}_{21}(\mathbf{TC}/\mathbf{MY}) & \mathbf{C}_{22}(\mathbf{MY}/\mathbf{MY}) \end{array}\right] \end{array}$$

(8)

$\mathbf{B}_{11}$ = input coefficient sub-matrix of energy commodities required by energy-supply industries

$\mathbf{B}_{12}$ = input coefficient sub-matrix of energy commodities required by other industries

$\mathbf{B}_{21}$ = input coefficient sub-matrix of non-energy commodities required by energy- supply industries

$\mathbf{B}_{22}$ = input coefficient sub-matrix of non-energy commodities required by other industries

$\mathbf{C}_{11}$ = output coefficient sub-matrix of energy-supply industries producing energy commodities

$\mathbf{C}_{12}$ = output coefficient sub-matrix of energy-supply industries producing non-energy commodities

$\mathbf{C}_{21}$ = output coefficient sub-matrix of other industries producing energy commodities

$\mathbf{C}_{22}$ = output coefficient sub-matrix of other industries producing non-energy commodities

$\mathbf{B}$ and $\mathbf{C}$ have to follow the assumption of a commodity technology: $\mathbf{A} = \mathbf{B}\mathbf{C}^{-1}$. Here, $\mathbf{A}$ is the hybrid technological coefficient matrix as suggested by Beutel et al. (1984). By substituting eq. (7) and (8) into eq. (5) and (6), the total input requirements by commodity ($\mathbf{q}$) and industry ($\mathbf{g}$) can be estimated respectively. It is difficult to identify the differences between the energy requirements produced by the energy-supply industries and the other industries under the conventional IO system, while the rectangular IO system can easily identify from eq. (5) and (6).

In order to compare the demand structure of energy sectors and non-energy sectors, the well-known Matiroshka principle is applied to the rectangular IO system. The demand structure of input-output system is decomposed into the demand structure of energy sectors and non-energy sectors.

First, $\mathbf{B}$ and $\mathbf{C}^{-1}$ given by eq. (7) and (8) are decomposed as:

$$\underbrace{\begin{bmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} \\ \mathbf{B}_{21} & \mathbf{B}_{22} \end{bmatrix}}_{\mathbf{B}} = \underbrace{\begin{bmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} \\ \mathbf{B}_{21} & \mathbf{0} \end{bmatrix}}_{\mathbf{B}_{\mathbf{e}}} + \underbrace{\begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{B}_{22} \end{bmatrix}}_{\mathbf{B}_{\mathbf{ne}}} \qquad (9)$$

$$\underbrace{\begin{bmatrix} [\mathbf{C}^{-1}]_{11} & [\mathbf{C}^{-1}]_{12} \\ [\mathbf{C}^{-1}]_{21} & [\mathbf{C}^{-1}]_{22} \end{bmatrix}}_{\mathbf{C}^{-1}} = \underbrace{\begin{bmatrix} [\mathbf{C}^{-1}]_{11} & [\mathbf{C}^{-1}]_{12} \\ [\mathbf{C}^{-1}]_{21} & \mathbf{0} \end{bmatrix}}_{[\mathbf{C}^{-1}]_{\mathbf{e}}} + \underbrace{\begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & [\mathbf{C}^{-1}]_{22} \end{bmatrix}}_{[\mathbf{C}^{-1}]_{\mathbf{ne}}} \qquad (10)$$

Here $\mathbf{C}^{-1}$ represents a market share structure under the assumption of a commodity technology. Also $\mathbf{C}^{-1}$ can be expressed by the following sub-matrices.

$[\mathbf{C}^{-1}]_{11}$ = market share sub-matrix of energy commodities produced by energy-supply industries

$[\mathbf{C}^{-1}]_{12}$ = market share sub-matrix of non-energy commodities produced by energy-supply industries

$[\mathbf{C}^{-1}]_{21}$ = market share sub-matrix of energy commodities produced by other industries

$[\mathbf{C}^{-1}]_{22}$ = market share sub-matrix of non-energy commodities produced by other industries

Eq. (9) and (10) are substituted into (5) and (6) respectively and Matiroshka principle is applied, then the following system is formulated.

$$\mathbf{q} = (\mathbf{I} - \mathbf{B}\mathbf{C}^{-1})^{-1}\mathbf{f} = (\mathbf{L_0}\mathbf{B}[\mathbf{C}^{-1}]_{\mathbf{e}} + \mathbf{I})(\mathbf{L_1}\mathbf{B_e}[\mathbf{C}^{-1}]_{\mathbf{ne}} + \mathbf{I})(\mathbf{I} - \mathbf{B_{ne}}[\mathbf{C}^{-1}]_{\mathbf{ne}})^{-1}\mathbf{f}$$

(11)

$$\mathbf{g} = (\mathbf{L_2}\mathbf{B}[\mathbf{C}^{-1}]_{\mathbf{e}} + \mathbf{C}^{-1})(\mathbf{L_1}\mathbf{B_e}[\mathbf{C}^{-1}]_{\mathbf{ne}} + \mathbf{I})(\mathbf{I} - \mathbf{B_{ne}}[\mathbf{C}^{-1}]_{\mathbf{ne}})^{-1}\mathbf{f}$$

(12)

$$\mathbf{L_0} = (\mathbf{I} - \mathbf{B}\mathbf{C}^{-1})^{-1}$$

(13)

$$\mathbf{L_1} = (\mathbf{I} - \mathbf{B}[\mathbf{C}^{-1}]_{\mathbf{ne}})^{-1}$$

(14)

$$\mathbf{L_2} = (\mathbf{I} - \mathbf{C}^{-1}\mathbf{B})^{-1}\mathbf{C}^{-1}$$

(15)

From eq. (11) and (12), the total energy requirements induced by inter-industry transactions among non-energy sectors can be estimated. Moreover, it is possible to evaluate quantitatively the differences between the demand structure of energy sectors and other sectors.

Considering the components of the following matrix from eq. (12),

$$\mathbf{R_g} = (\mathbf{L_2}\mathbf{B}[\mathbf{C}^{-1}]_{\mathbf{e}} + \mathbf{C}^{-1})(\mathbf{L_1}\mathbf{B_e}[\mathbf{C}^{-1}]_{\mathbf{ne}} + \mathbf{I})$$

(16)

$\mathbf{R_g}$ can further be expressed as eq. (17).

$$\mathbf{R_g} = \left[\begin{array}{c:c} (\mathbf{R_g})_{11} & (\mathbf{R_g})_{12} \\ \hdashline (\mathbf{R_g})_{21} & (\mathbf{R_g})_{22} \end{array}\right]$$

(17)

Where

$(\mathbf{R_g})_{11}$ = energy output sub-matrix of energy-supply industries induced by final demand of energy sectors

$(\mathbf{R_g})_{12}$ = energy output sub-matrix of energy-supply industries induced by transactions among non-energy sectors

$(\mathbf{R_g})_{21}$ = non-energy output sub-matrix of energy-supply industries induced by final demand of energy sectors

$(\mathbf{R_g})_{22}$ = non-energy output sub-matrix of energy-supply industries induced by transactions between non-energy sectors

Here, $\mathbf{W}$ is defined as eq. (18).

$$\mathbf{W} = [\mathbf{0} \ \vdots \ (\mathbf{R_g})_{12}]$$

(18)

The direct and indirect energy inputs $\mathbf{W}$ are required not only to produce the energy goods that are absorbed into the production processes of the non-energy sectors, but also to produce the non-energy goods (services) that are absorbed into the processes of the energy inputs. The energy requirements $\mathbf{E}$ contributed by energy-supply industries (**ESI**) can be formulated from eq. (12) and (18).

$$\mathbf{E}|_{\mathbf{ESI}} = \mathbf{W}(\mathbf{I} - \mathbf{B_{ne}}[\mathbf{C}^{-1}]_{\mathbf{ne}})^{-1}\mathbf{f}$$

(19)

The final demand $\mathbf{f}$ can be standardized as $\mathbf{f^s_{ne}}$ whose element vector of each non-energy commodity is one. By substituting $\mathbf{f^s_{ne}}$ into eq. (19), the energy intensity of each non-energy commodity can be estimated as eq. (20).

$$\mathbf{E^s}|_{\mathbf{ESI}} = \mathbf{W}(\mathbf{I} - \mathbf{B_{ne}}[\mathbf{C}^{-1}]_{\mathbf{ne}})^{-1}\mathbf{f^s_{ne}}$$

(20)

The total energy requirements can be obtained by substituting the current non-energy final demand $\mathbf{f^c_{ne}}$ into eq. (19).

$$\mathbf{E^c}|_{\mathbf{ESI}} = \mathbf{W}(\mathbf{I} - \mathbf{B_{ne}}[\mathbf{C}^{-1}]_{\mathbf{ne}})^{-1}\mathbf{f^c_{ne}}$$

(21)

Eq. (21) is used to estimate the current energy requirements that are direct and indirectly induced by the production processes among non-energy sectors.

In the next chapter, the impacts of changes in the energy demand structure, the non-energy input-output structure, and the non-energy final demand on energy intensities and total energy requirements are discussed. The structural decomposition techniques are derived from eq. (20) and (21).

4. Structural Decomposition of Hybrid Rectangular Model: 1985-1990

4.1. Structural decomposition analysis of energy intensity

In this chapter, the structural decomposition analysis of hybrid rectangular IO model is developed to evaluate the effects of the changes in the energy demand structure $\mathbf{W}$, the non-energy final demand $\mathbf{f_{ne}}$, the non-energy input structure $\mathbf{B_{ne}}$, and the non-energy market share structure $\mathbf{[C^{-1}]_{ne}}$ on the energy intensities and the total energy requirements.

Suppose $\mathbf{[C^{-1}]_{ne}}$ is a unit matrix, the production formula of eq. (20) and (21) can be rewritten as $\mathbf{W(I-B_{ne})^{-1}f_{ne}^{s}}$, $\mathbf{W(I-B_{ne})^{-1}f_{ne}^{c}}$ respectively. Namely, $\mathbf{B_{ne}}$ coincides with a hybrid technological coefficient matrix $\mathbf{A_{ne}}$ in the conventional Leontief system. It means that each industry produces only a primary product, and the industry can be replaced as a product. Here, the product-mix problem does not exist. Suppose $\mathbf{[C^{-1}]_{ne}}$ is not a unit matrix, however, the input structure of an industry should change through the production processes of secondary products. It also affects the energy intensities and the energy requirements. $\mathbf{[C^{-1}]_{ne}}$ represents the degree of non-energy product-mix. The effects of the dynamic product-mix changes on the energy intensities and the energy requirements are analyzed both in 1985 and 1990.

From eq. (20), the energy intensities $\mathbf{E}^s\big|_{\mathbf{ESI}}$ in 1985 and 1990 can be estimated as eq. (22) and (23).

$$\mathbf{E}^s\big|_{\mathbf{ESI}}^{\mathbf{85}} = \mathbf{W^{85}(I-B_{ne}^{85}[C^{-1}]_{ne}^{85})^{-1}f_{ne}^{s}}$$

(22)

$$\mathbf{E}^s\big|_{\mathbf{ESI}}^{\mathbf{90}} = \mathbf{W^{90}(I-B_{ne}^{90}[C^{-1}]_{ne}^{90})^{-1}f_{ne}^{s}}$$

(23)

Where the superscripts $\mathbf{85}$, $\mathbf{90}$ denote the time period. The changes in energy intensities $\mathbf{\Delta E}^s\big|_{\mathbf{ESI}}$ in the five years can be formulated as eq. (24).

$$\mathbf{\Delta E}^s\big|_{\mathbf{ESI}} = \left\{\mathbf{W^{90}(I-B_{ne}^{90}[C^{-1}]_{ne}^{90})^{-1} - W^{85}(I-B_{ne}^{85}[C^{-1}]_{ne}^{85})^{-1}}\right\}\mathbf{f_{ne}^{s}} \quad (24)$$

From the structural decomposition of eq. (24), the two different types of decomposition forms can be written as eq. (25).

$$\mathbf{\Delta E}^s\big|_{\mathbf{ESI}} = \mathbf{\Delta W L_3^{85} + W^{90}\Delta L_3}$$
$$@\ @\ @\ \mathbf{\Delta W L_3^{90} + W^{85}\Delta L_3}$$

(25)

$$\mathbf{L_3^{85} = (I - B_{ne}^{85}[C^{-1}]_{ne}^{85})^{-1}}$$

(26)

$$\mathbf{L_3^{90} = (I - B_{ne}^{90}[C^{-1}]_{ne}^{90})^{-1}}$$

(27)

Where, $\mathit{\Delta}\mathbf{WL_3^{85}}$ and $\mathit{\Delta}\mathbf{WL_3^{90}}$ on the right-hand side of eq. (25) denote the effects of the changes in energy demand structure contributed by energy-supply industries on the energy intensities. Similarly, $\mathbf{W^{90}}\mathit{\Delta}\mathbf{L_3}$ and $\mathbf{W^{85}}\mathit{\Delta}\mathbf{L_3}$ express the effects of the non-energy production technology changes.

Moreover, considering the decomposition techniques of the effects of the technology changes, $\mathbf{\Delta L_3}$ can be decomposed into the effects of the non-energy input structural changes ($\mathbf{\Delta B_{ne}}$) and the non-energy product-mix changes ($\mathbf{\Delta [C^{-1}]_{ne}}$) respectively.

$$\begin{aligned}
\mathit{\Delta}\mathbf{L_3} &= \mathbf{(I - B_{ne}^{90}[C^{-1}]_{ne}^{90})^{-1} - (I - B_{ne}^{85}[C^{-1}]_{ne}^{85})^{-1}} \\
&= \mathbf{L_3^{85} B_{ne}^{85}}\mathit{\Delta}\mathbf{[C^{-1}]_{ne} L_3^{90} + L_3^{85}}\mathit{\Delta}\mathbf{B_{ne}[C^{-1}]_{ne}^{90} L_3^{90}} \\
&= \mathbf{L_3^{85}}\mathit{\Delta}\mathbf{B_{ne}[C^{-1}]_{ne}^{85} L_3^{90} + L_3^{85} B_{ne}^{90}}\mathit{\Delta}\mathbf{[C^{-1}]_{ne} L_3^{90}}
\end{aligned} \qquad (28)$$

Substituting eq. (28) into eq. (25), we can obtain the four different decomposition forms as:

$$\begin{aligned}
\mathit{\Delta}\mathbf{E^s}\big|_{\mathbf{ESI}} &= \mathit{\Delta}\mathbf{WL_3^{85} + W^{90}L_3^{85}}\mathit{\Delta}\mathbf{B_{ne}[C^{-1}]_{ne}^{85}L_3^{90} + W^{90}L_3^{85}B_{ne}^{90}}\mathit{\Delta}\mathbf{[C^{-1}]_{ne}L_3^{90}} \\
&= \mathit{\Delta}\mathbf{WL_3^{85} + W^{90}L_3^{85}B_{ne}^{85}}\mathit{\Delta}\mathbf{[C^{-1}]_{ne}L_3^{90} + W^{90}L_3^{85}}\mathit{\Delta}\mathbf{B_{ne}[C^{-1}]_{ne}^{90}L_3^{90}} \\
&= \mathbf{W^{85}L_3^{85}}\mathit{\Delta}\mathbf{B_{ne}[C^{-1}]_{ne}^{85}L_3^{90} + W^{85}L_3^{85}B_{ne}^{90}}\mathit{\Delta}\mathbf{[C^{-1}]_{ne}L_3^{90}} + \mathit{\Delta}\mathbf{WL_3^{90}} \\
&= \mathbf{W^{85}L_3^{85}B_{ne}^{85}}\mathit{\Delta}\mathbf{[C^{-1}]_{ne}L_3^{90} + W^{85}L_3^{85}}\mathit{\Delta}\mathbf{B_{ne}[C^{-1}]_{ne}^{90}L_3^{90}} + \mathit{\Delta}\mathbf{WL_3^{90}}
\end{aligned}$$

(29)

The average effects $\mathbf{\Delta E^s}\big|_{\overline{\mathbf{ESI}}}$ on the energy intensities can be derived from eq. (29).

$$\begin{aligned}
&\mathit{\Delta}\mathbf{E^s}\big|_{\overline{\mathbf{ESI}}} = \mathbf{1/2}\left\{\mathit{\Delta}\mathbf{WL_3^{85}} + \mathit{\Delta}\mathbf{WL_3^{90}}\right\} \\
&+ \mathbf{1/4}\left\{\mathbf{W^{90}L_3^{85}}\mathit{\Delta}\mathbf{B_{ne} + W^{85}L_3^{85}}\mathit{\Delta}\mathbf{B_{ne}}\right\}\left\{\mathbf{[C^{-1}]_{ne}^{85}L_3^{90} + [C^{-1}]_{ne}^{90}L_3^{90}}\right\} \\
&+ \mathbf{1/4}\left\{\mathbf{W^{90}L_3^{85} + W^{85}L_3^{85}}\right\}\left\{\mathbf{B_{ne}^{90}}\mathit{\Delta}\mathbf{[C^{-1}]_{ne}L_3^{90} + B_{ne}^{85}}\mathit{\Delta}\mathbf{[C^{-1}]_{ne}L_3^{90}}\right\}
\end{aligned} \qquad (30)$$

The first term on the right-hand side of eq. (30) means the average effects of the changes in energy demand structure contributed by energy-supply industries, while the second denotes the average effects of the changes in input structure connected by transaction among non-energy sectors. The third term represents the average effects of the changes in the product-mix structure connected by the transactions among non-energy sectors. If the entry of energy sector is $\mathbf{m}$, each term in equation (30) can be rewritten as the matrix forms.

$$\Delta E^s\Big|_{\overline{ESI}} = \begin{bmatrix} e_{11}^{(\Delta W)} & \cdots & e_{1,n-m}^{(\Delta W)} \\ \vdots & & \vdots \\ e_{m1}^{(\Delta W)} & \cdots & e_{m,n-m}^{(\Delta W)} \end{bmatrix} + \begin{bmatrix} e_{11}^{(\Delta Bne)} & \cdots & e_{1,n-m}^{(\Delta Bne)} \\ \vdots & & \vdots \\ e_{m1}^{(\Delta Bne)} & \cdots & e_{m,n-m}^{(\Delta Bne)} \end{bmatrix} + \begin{bmatrix} e_{11}^{(\Delta [C^{-1}]ne)} & \cdots & e_{1,n-m}^{(\Delta [C^{-1}]ne)} \\ \vdots & & \vdots \\ e_{m1}^{(\Delta [C^{-1}]ne)} & \cdots & e_{m,n-m}^{(\Delta [C^{-1}]ne)} \end{bmatrix} \quad (31)$$

Where $\mathbf{e}_{ij}^{(\Delta W)}$ denotes the average effects of the energy demand structural changes on the energy requirements. The energy requirements are contributed by energy-supply industries i as a result of direct and indirect transaction among other industries induced by the final demand of non-energy commodities j. The $\mathbf{e}_{ij}^{(\Delta Bne)}$ and $\mathbf{e}_{ij}^{(\Delta [C^{-1}]ne)}$ describes the average effects of the non-energy input structural changes and the non-energy product-mix changes respectively. Here, $\hat{\mathbf{W}}$ is defined as the following n×n diagonal matrix.

$$\hat{W} = \left[\begin{array}{ccc:ccc} 0 & \cdots & 0 & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & 0 & \cdots & 0 \\ \hdashline 0 & \cdots & 0 & \sum_{i=1}^{m}\{(R_g)_{12}\}_{i1} & \cdots & 0 \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & 0 & \cdots & \sum_{i=1}^{m}\{(R_g)_{12}\}_{i,n-m} \end{array}\right]$$

(32)

By replacing W in eq. (29) and/or (30) with $\hat{\mathbf{W}}$ in eq. (32), the important transactions among non-energy sectors can be identified as:

$$\Delta E^s\Big|_{\overline{ESI}} = \begin{bmatrix} d_{11}^{(\Delta \hat{W})} & \cdots & d_{1,n-m}^{(\Delta \hat{W})} \\ \vdots & \ddots & \vdots \\ d_{n-m,1}^{(\Delta \hat{W})} & \cdots & d_{n-m,n-m}^{(\Delta \hat{W})} \end{bmatrix} + \begin{bmatrix} d_{11}^{(\Delta B_{ne})} & \cdots & d_{1,n-m}^{(\Delta B_{ne})} \\ \vdots & \ddots & \vdots \\ d_{n-m,1}^{(\Delta B_{ne})} & \cdots & d_{n-m,n-m}^{(\Delta B_{ne})} \end{bmatrix} + \begin{bmatrix} d_{11}^{(\Delta [C^{-1}]_{ne})} & \cdots & d_{1,n-m}^{(\Delta [C^{-1}]_{ne})} \\ \vdots & \ddots & \vdots \\ d_{n-m,1}^{(\Delta [C^{-1}]_{ne})} & \cdots & d_{n-m,n-m}^{(\Delta [C^{-1}]_{ne})} \end{bmatrix} \quad (33)$$

Where $\mathbf{d}_{kl}^{(\Delta \hat{W})}$ denotes the average effects of the energy demand structural changes on the energy requirements absorbed into direct and indirect economic transactions between non-energy commodities k and l. The $\mathbf{d}_{kl}^{(\Delta B_{ne})}$ and $\mathbf{d}_{kl}^{(\Delta [C^{-1}]_{ne})}$ describe the average effects of the non-energy input structural changes and the non-energy product-mix changes on the energy requirements absorbed into economic transactions between non-energy commodities k and l respectively. The total effect of each component $\Delta E^s\big|_{\overline{ESI}}$ is estimated by eq. (34).

$$\Delta E^s\Big|_{\overline{ESI}} = \sum_{j=1}^{n-m}\sum_{i=1}^{m} e_{ij}^{(\Delta W)} + \sum_{j=1}^{n-m}\sum_{i=1}^{m} e_{ij}^{(\Delta B_{ne})} + \sum_{j=1}^{n-m}\sum_{i=1}^{m} e_{ij}^{(\Delta [C^{-1}]_{ne})}$$

$$= \sum_{l=1}^{n-m}\sum_{k=1}^{n-m} d_{kl}^{(\Delta \hat{W})} + \sum_{l=1}^{n-m}\sum_{k=1}^{n-m} d_{kl}^{(\Delta B_{ne})} + \sum_{l=1}^{n-m}\sum_{k=1}^{n-m} d_{kl}^{(\Delta [C^{-1}]_{ne})}$$

(34)

4.2. Structural decomposition analysis of total energy requirement

In addition, the total energy requirements can decompose by extending the formulation of the SDA described before. From eq. (21), (26) and (27), the total energy requirements $\mathbf{E^c}|_{\mathbf{ESI}}$ in 1985 and 1990 can be estimated as eq. (35) and (36).

$$\mathbf{E^c}|^{\mathbf{85}}_{\mathbf{ESI}} = \mathbf{W^{85}L_3^{85}\hat{f}^{85}_{ne}} \quad (35)$$

$$\mathbf{E^c}|^{\mathbf{90}}_{\mathbf{ESI}} = \mathbf{W^{90}L_3^{90}\hat{f}^{90}_{ne}} \quad (36)$$

Where $\mathbf{\hat{f}^{85}_{ne}}$ and $\mathbf{\hat{f}^{90}_{ne}}$ denote the diagonal matrix with the elements of the final demand in 1985 and 1990. The changes in the total energy requirements during the five years can be estimated by eq. (37).

$$\mathbf{\Delta E^c}|_{\mathbf{ESI}} = \mathbf{W^{90}L_3^{90}\hat{f}^{90}_{ne} - W^{85}L_3^{85}\hat{f}^{85}_{ne}} \quad (37)$$

Considering a growth path of the total energy requirements from eq. (37), the six types of different decomposition forms can be written as eq. (38).

$$\begin{aligned}
\mathbf{\Delta E^c}|_{\mathbf{ESI}} &= \mathbf{\Delta W L_3^{85}\hat{f}^{85}_{ne} + W^{90}L_3^{85}\Delta\hat{f}_{ne} + W^{90}\Delta L_3\hat{f}^{90}_{ne}} \\
&= \mathbf{\Delta W L_3^{85}\hat{f}^{85}_{ne} + W^{90}\Delta L_3\hat{f}^{85}_{ne} + W^{90}L_3^{90}\Delta\hat{f}_{ne}} \\
&= \mathbf{W^{85}\Delta L_3\hat{f}^{85}_{ne} + \Delta W L_3^{90}\hat{f}^{85}_{ne} + W^{90}L_3^{90}\Delta\hat{f}_{ne}} \\
&= \mathbf{W^{85}\Delta L_3\hat{f}^{85}_{ne} + W^{85}L_3^{90}\Delta\hat{f}_{ne} + \Delta W L_3^{90}\hat{f}^{90}_{ne}} \\
&= \mathbf{W^{85}L_3^{85}\Delta\hat{f}_{ne} + \Delta W L_3^{85}\hat{f}^{90}_{ne} + W^{90}\Delta L_3\hat{f}^{90}_{ne}} \\
&= \mathbf{W^{85}L_3^{85}\Delta\hat{f}_{ne} + W^{85}\Delta L_3\hat{f}^{90}_{ne} + \Delta W L_3^{90}\hat{f}^{90}_{ne}}
\end{aligned} \quad (38)$$

Where $\mathbf{\Delta\hat{f}_{ne}}$ denotes the changes in the non-energy final demand during the five years. Substituting eq. (28) into eq. (38), we can further obtain the 12 decomposition forms. The average effects of the changes in $\mathbf{\Delta W}$, $\mathbf{\Delta\hat{f}_{ne}}$, $\mathbf{\Delta B_{ne}}$ and $\mathbf{\Delta[C^{-1}]_{ne}}$ on the total energy requirements can be also estimated as the matrix forms.

$$\begin{aligned}
\mathbf{\Delta E^c}|^{-}_{\mathbf{ESI}} = &\begin{bmatrix} \mathbf{e'^{(\Delta W)}_{11}} & \cdots & \mathbf{e'^{(\Delta W)}_{1,n-m}} \\ \vdots & & \vdots \\ \mathbf{e'^{(\Delta W)}_{m1}} & \cdots & \mathbf{e'^{(\Delta W)}_{m,n-m}} \end{bmatrix} + \begin{bmatrix} \mathbf{e'^{(\Delta f_{ne})}_{11}} & \cdots & \mathbf{e'^{(\Delta f_{ne})}_{1,n-m}} \\ \vdots & & \vdots \\ \mathbf{e'^{(\Delta f_{ne})}_{m1}} & \cdots & \mathbf{e'^{(\Delta f_{ne})}_{m,n-m}} \end{bmatrix} \\
\text{@ @ @} &\begin{bmatrix} \mathbf{e'^{(\Delta B_{ne})}_{11}} & \cdots & \mathbf{e'^{(\Delta B_{ne})}_{1,n-m}} \\ \text{@ @} & & \vdots \\ \mathbf{e'^{(\Delta B_{ne})}_{m1}} & \cdots & \mathbf{e'^{(\Delta B_{ne})}_{m,n-m}} \end{bmatrix} + \begin{bmatrix} \mathbf{e'^{(\Delta[C^{-1}]_{ne})}_{11}} & \cdots & \mathbf{e'^{(\Delta[C^{-1}]_{ne})}_{1,n-m}} \\ \vdots & & \vdots \\ \mathbf{e'^{(\Delta[C^{-1}]_{ne})}_{m1}} & \cdots & \mathbf{e'^{(\Delta[C^{-1}]_{ne})}_{m,n-m}} \end{bmatrix}
\end{aligned} \quad (39)$$

Where $\mathbf{e'^{(\Delta W)}_{ij}}$ denotes the average effects of the energy demand structural changes on the total energy requirements. The total energy requirements are contributed by energy-supply industries i as a result of direct and indirect transaction among other industries induced by the final demand of non-energy commodities j. The $\mathbf{e'}_{ij}^{(\Delta f_{ne})}$, $\mathbf{e'}_{ij}^{(\Delta B_{ne})}$ and $\mathbf{e'}_{ij}^{(\Delta [C^{-1}]_{ne})}$ describes the average effects of the non-energy final demand changes, non-energy input structural changes, and the non-energy product-mix changes respectively. By replacing W in eq. (38) with $\hat{\mathbf{W}}$ in eq. (32), the important transactions among non-energy sectors can be identified as:

$$\Delta \mathbf{E}^{c}\big|_{\overline{\mathbf{ESI}}} = \begin{bmatrix} \mathbf{d'}_{11}^{(\Delta \hat{W})} & \cdots & \mathbf{d'}_{1,n-m}^{(\Delta \hat{W})} \\ \vdots & & \vdots \\ \mathbf{d'}_{n-m1}^{(\Delta \hat{W})} & \cdots & \mathbf{d'}_{n-m,n-m}^{(\Delta \hat{W})} \end{bmatrix} + \begin{bmatrix} \mathbf{d'}_{11}^{(\Delta f_{ne})} & \cdots & \mathbf{d'}_{1,n-m}^{(\Delta f_{ne})} \\ \vdots & & \vdots \\ \mathbf{d'}_{n-m1}^{(\Delta f_{ne})} & \cdots & \mathbf{d'}_{n-m,n-m}^{(\Delta f_{ne})} \end{bmatrix}$$
$$+ \begin{bmatrix} \mathbf{d'}_{11}^{(\Delta B_{ne})} & \cdots & \mathbf{d'}_{1,n-m}^{(\Delta B_{ne})} \\ \vdots & & \vdots \\ \mathbf{d'}_{n-m1}^{(\Delta B_{ne})} & \cdots & \mathbf{d'}_{n-m,n-m}^{(\Delta B_{ne})} \end{bmatrix} + \begin{bmatrix} \mathbf{d'}_{11}^{(\Delta [C^{-1}]_{ne})} & \cdots & \mathbf{d'}_{1,n-m}^{(\Delta [C^{-1}]_{ne})} \\ \vdots & & \vdots \\ \mathbf{d'}_{n-m1}^{(\Delta [C^{-1}]_{ne})} & \cdots & \mathbf{d'}_{n-m,n-m}^{(\Delta [C^{-1}]_{ne})} \end{bmatrix} \quad (40)$$

Where $\mathbf{d'}_{kl}^{(\Delta \hat{W})}$ denotes the average effects of the energy demand structural changes on the total energy requirements absorbed into direct and indirect economic transactions between non-energy commodities k and l. The $\mathbf{d'}_{kl}^{(\Delta f_{ne})}$, $\mathbf{d'}_{kl}^{(\Delta B_{ne})}$ and $\mathbf{d'}_{kl}^{(\Delta [C^{-1}]_{ne})}$ describe the average effects of the non-energy final demand changes, non-energy input structural changes, and the non-energy product-mix changes on the total energy requirements absorbed into economic transactions between non-energy commodities k and l respectively. The total effect of each component can be finally written like eq. (34).

$$\Delta \mathbf{E}^{c}\big|_{\overline{\mathbf{ESI}}} = \sum_{j=1}^{n-m}\sum_{i=1}^{m} \mathbf{e'}_{ij}^{(\Delta W)} + \sum_{j=1}^{n-m}\sum_{i=1}^{m} \mathbf{e'}_{ij}^{(\Delta \hat{f}_{ne})} + \sum_{j=1}^{n-m}\sum_{i=1}^{m} \mathbf{e'}_{ij}^{(\Delta B_{ne})} + \sum_{j=1}^{n-m}\sum_{i=1}^{m} \mathbf{e'}_{ij}^{(\Delta [C^{-1}]_{ne})}$$
$$= \sum_{l=1}^{n-m}\sum_{k=1}^{n-m} \mathbf{d'}_{kl}^{(\Delta \hat{W})} + \sum_{l=1}^{n-m}\sum_{k=1}^{n-m} \mathbf{d'}_{kl}^{(\Delta \hat{f}_{ne})} + \sum_{l=1}^{n-m}\sum_{k=1}^{n-m} \mathbf{d'}_{kl}^{(\Delta B_{ne})} + \sum_{l=1}^{n-m}\sum_{k=1}^{n-m} \mathbf{d'}_{kl}^{(\Delta [C^{-1}]_{ne})} \quad (41)$$

In this paper, the hybrid rectangular IO table in 1985 and 1990 was actually estimated by using the basic data, the average effects were analyzed. In the next chapter, the application of basic data is easily explained.

5. Application of Basic Data

Sets of basic data for this analysis are listed below:

(1) Energy intensities based on the Input-Output Analysis in 1985 and 1990 (provided by National Institute for Environmental Studies, Environmental Agency of Japan.)
(2) Output matrices: by industry×commodity (so called V table) in 1985 and 1990
(3) Traditional I-O tables: by commodity×commodity (so called X table) in 1985 and 1990
(4) Output table of by-products in 1985 and 1990

Here, (2), (3), (4) are provided by Management and Coordination Agency of Japan.

First, the inputs of energy goods in X table (column 527×row 411: basic sector classification) were changed from monetary term (million yen) into physical term (terra calorie) by using the amount of energy inputs in physical term estimated by National Institute for Environmental Studies. The amount of imports is included in X table, and therefore it seems that the energy goods like a crude petroleum and so on, which depend on the import in practice, are completely produced in Japan. Furthermore, the outputs and the inputs of by-products were eliminated from X table in order to avoid the inverse flows of productive processes resulting from their negative inputs.

Since the sectors in V table (column 108× row 108) does not correspond to the basic sector classification, the outputs of energy goods of industries cannot be changed from monetary term into physical term in detailed sectors. Therefore, by distributing the domestic energy outputs in physical terms given from the aggregated X table (column 108× row 108) in proportion to the market share in monetary term estimated from V table, the outputs of the energy goods of industries can be estimated in practical. Furthermore, we aggregated both X table and V table from 108 sectors to 94 sectors and the estimated U table by using the basic model under the assumption of a commodity technology. The energy sectors were aggregated from 19 fuels and/or materials in Energy intensities based on the Input-Output Analysis to 6 sectors (Coal mining & lignite, Crude petroleum & natural gas, Petroleum refinery products, Coal products, Electricity, Gas supply & steam & hot water supply) as shown in Table 2. The other 88 sectors were dealt with as the non-energy sectors.

In this study, Both V and U in 1985 and 1990 were converted by using the base year price in 1990. From the estimated V and U, we obtained a hybrid rectangular IO table and analyzed by means of the hybrid methodology discussed in chapter 4.

Table 2. Energy Sector Classification

No. Name of fuel and material	No. Name of energy sector
01. Coking coal 02. Steam coal, Lignite & Anthracite	01. Coal mining & Lignite
03. Crude petroleum 04. Natural gas	02. Crude petroleum & Natural gas
05. Jet fuel oil 06. Gasoline 07. Naphtha 08. Kerosene 09. Light oil 10. Heavy oil A 11. Heavy oil BC 12. LPG	03. Petroleum refinery products
13. Coke 14. Coke oven gas 15. Blast furnace gas	04. Coal products

16. Electricity 17. Self-power generation	05. Electricity
18. Gas supply 19. Steam & Hot water supply	06. Gas supply, Steam & Hot water supply

6. Results

6.1. Structural decomposition of energy intensities: 1985-1990

We analyzed the effects of the changes in economic structure between 1985 and 1990 on the energy intensities by means of the hybrid structural decomposition analysis.

Table 3 shows the effects estimated by using eq. (31). From the results, it was indicated that the energy intensities of each non-energy commodity have fluctuated as a whole due to the changes in non-energy production technology. During this period, especially, the energy intensity of chemical fertilizer (No.30) most greatly increased by 28% (23.473 Gcal). Considering the sources of the change, we can easily comprehend that the large increase is because of the change in the energy demand structure rather than the production technology changes from the chemical fertilizer's row in Table. 3. In the same way, the energy intensities of air transport (No.75) and ocean transport & coastal transport (No.74) greatly increased by 24% (13.893 Gcal) and 13% (9.520 Gcal), respectively because of the changes in the energy demand structure.

Table 4 shows the contributions of energy-supply industries to the effects on the energy intensities of the above-mentioned three non-energy commodities. The column of total change in table 4 indicates that crude petroleum & natural gas industry and petroleum refinery products industry are main contributors of the changes in the energy intensities of these commodities (No.30, No.74, No.75).

On the other hand, as is also seen from Table 3, the energy intensity of non-ferrous metals (No.46) markedly decreased by 46% (41.503 Gcal) mainly because of the changes in energy demand structure. Subsequently, the energy intensities of pig iron & crude steel (No.43) and steels (No.44) greatly decreased by 9% (20.042 Gcal) and 15% (19.346 Gcal), respectively. The large decreases were mainly brought from the non-energy input structural changes. The main reason was that the input structural changes acted in the direction of large reduction in the demand of pig iron & crude steel (No.43) and road transport (No.73) and ocean transport & coastal transport (No.74) as a result.

The total change in Table 5 illustrates that crude petroleum & natural gas industry and electricity industry are main contributors to the decrease in the energy intensity of non-ferrous metals. In the same way, considering the contributions to the decreases in the energy intensities of pig iron & crude steel and steels, the non-energy input structural changes acted in the direction of reduction of the use of coal mining & lignite and coal products.

Although the effects of the non-energy product-mix structural changes were a small value on the whole, it was indicated that the changes decreased the energy intensities on average. Especially, the energy intensity of industrial organic chemicals (No.32) most greatly declined by 2.977 Gcal mainly because of the changes in non-energy product-mix.

Table 3. Structural decomposition analysis of change in energy intensity

(Gcal per million yen)

No.	88-non-energy commodity	Energy intensity 1985	Energy intensity 1990	Effects on energy intensity ▵ W	▵ B_{ne}	▵ $[C^{-1}]_{ne}$	Total
07.	Agriculture	10.859	12.527	1.558	0.036	0.076	1.669
08.	Livestock-raising & Sericulture	15.586	13.206	0.701	-2.628	-0.452	-2.379
09.	Agricultural services	21.418	25.224	4.167	-0.292	-0.070	3.806
10.	Forestry	11.833	15.702	4.636	-0.984	0.217	3.869
11.	Fisheries & Culture	47.668	52.938	6.178	1.654	-2.562	5.270
12.	Metal ores	33.275	29.292	-2.911	-0.810	-0.262	-3.982
13.	Non-ferrous metal ores	12.842	13.810	1.341	-0.489	0.117	0.969
14.	Slaughtering & Meat processing	15.369	12.605	0.336	-2.687	-0.411	-2.762
15.	Livestock-raising foods	19.357	21.043	3.288	-1.540	-0.063	1.685
16.	Sea foods	24.737	31.523	3.848	4.103	-1.165	6.786
17.	Grain milling & Flour	14.080	14.381	1.621	-1.496	0.175	0.300
18.	Preserved agricultural foodstuffs etc	20.943	22.328	2.304	-0.724	-0.195	1.384
19.	Sugar etc & Other foods	17.937	19.190	3.849	-2.646	0.051	1.255
20.	Beverages	18.002	17.664	-0.067	-0.064	-0.207	-0.337
21.	Feeds & Organic fertilizers	22.905	19.991	3.642	-6.451	-0.108	-2.917
22.	Tobacco	5.125	5.574	0.201	0.146	0.103	0.450
23.	Fabricated textile products	37.505	39.766	0.443	2.008	-0.189	2.262
24.	Wearing apparel & Other textile products	22.819	20.550	-1.320	-0.846	-0.102	-2.268
25.	Timber & Wooden products	13.199	16.145	2.875	0.050	0.022	2.946
26.	Furniture & Fixtures	17.305	19.148	0.229	1.847	-0.230	1.846
27.	Pulp & Paper	62.363	67.664	-4.202	9.389	0.116	5.303
28.	Processed paper products	42.522	32.778	-6.445	-3.051	-0.247	-9.743
29.	Printing & Publishing	15.847	18.668	-0.127	2.931	0.017	2.822
30.	Chemical fertilizer	84.040	107.514	34.501	-11.415	0.386	23.473
31.	Industrial inorganic chemicals	103.205	100.705	0.809	-2.522	-0.788	-2.501
32.	Industrial organic chemicals	195.200	194.478	5.953	-3.698	-2.977	-0.722
33.	Resins	134.744	123.613	-4.103	-6.565	-0.463	-11.131
34.	Chemical fibers	101.851	97.827	4.363	-8.335	-0.052	-4.024
35.	Final chemical products	41.600	38.119	-1.638	-0.914	-0.931	-3.482
36.	Plastic products	49.063	52.933	-0.582	4.994	-0.542	3.871
37.	Rubber products	52.145	54.347	2.253	0.373	-0.425	2.201
38.	Leather, Leather products & Fur skins	14.863	16.970	0.672	1.674	-0.239	2.107
39.	Glass & Glass products	47.864	45.574	-2.655	1.342	-0.978	-2.290
40.	Cement & Cement products	39.407	36.747	-2.361	-0.183	-0.113	-2.657
41.	Pottery, China & earthenware	30.598	30.981	0.271	0.420	-0.305	0.385
42.	Miscellaneous ceramic, Stone & Clay products	46.058	43.962	-3.832	2.086	-0.349	-2.096
43.	Pig iron & Crude steel	217.712	197.670	6.644	-27.083	0.398	-20.042
44.	Steels	130.744	111.398	4.165	-22.053	-1.457	-19.346
45.	Steel products	73.129	64.737	-2.389	-5.514	-0.490	-8.393
46.	Non-ferrous metals	90.257	48.755	-36.203	-5.369	0.068	-41.503
47.	Non-ferrous metal products	36.330	30.993	-11.281	5.815	0.130	-5.337
48.	Metal products for construction, architecture	30.848	31.462	-0.743	1.852	-0.496	0.614
49.	Other metal products	37.695	36.304	-0.587	-0.496	-0.308	-1.391
50.	General industrial machinery	24.369	23.725	-0.834	0.290	-0.099	-0.642
51.	Special industrial machinery	21.854	20.743	-1.417	-0.059	0.364	-1.111
52.	Other general machines	20.439	26.859	1.084	5.894	-0.558	6.420
53.	Office machines & Machinery for service industry	23.914	16.998	-1.859	-5.126	0.067	-6.918
54.	Household electric appliance	26.261	20.343	-1.413	-3.234	-1.273	-5.919
55.	Electric & Communication equipment	26.703	16.503	-5.730	-4.467	-0.005	-10.201
56.	Heavy electrical equipment	21.540	20.495	-1.337	0.343	-0.052	-1.046

No.	88-non-energy commodity	Energy intensity		Effects on energy Intensity			
		1985	1990	▵ W	▵ B_{ne}	▵ $[C^{-1}]_{ne}$	Total
57.	Other electrical equipment	20.853	23.355	-1.470	4.469	-0.496	2.503
58.	Motor vehicles	26.007	24.309	-1.543	0.242	-0.397	-1.698
59.	Ships & Its Repair	28.878	28.848	0.256	-0.011	-0.279	-0.033
60.	Other transport equipment & Its Repair	21.751	25.217	0.526	2.822	0.117	3.465
61.	Scientific instruments	16.249	15.409	-0.332	-0.419	-0.092	-0.842
62.	Miscellaneous manufacturing products	23.140	21.114	-0.803	-1.192	-0.032	-2.026
63.	Residential & Non-Residential construction	15.191	15.601	-0.197	0.738	-0.131	0.411
64.	Repair of construction	18.774	20.446	0.568	1.259	-0.154	1.673
65.	Civil engineering	18.305	17.880	0.670	-1.013	-0.082	-0.426
66.	Water supply	33.817	38.007	3.797	0.424	-0.031	4.190
67.	Waste disposal services	9.108	10.680	0.620	0.944	0.009	1.573
68.	Wholesale trade & Retail trade	6.014	7.067	0.567	0.739	-0.253	1.053
69.	Financial service & Insurance	3.404	3.425	0.342	-0.359	0.039	0.022
70.	Real estate rental service	2.874	5.684	2.403	0.411	-0.004	2.810
71.	House rent	1.937	2.338	0.207	0.201	-0.005	0.402
72.	Railway transport	22.590	19.854	-0.956	-2.628	0.849	-2.734
73.	Road transport	24.917	28.269	3.328	-0.196	0.220	3.352
74.	Ocean transport & Coastal transport	72.239	81.759	8.154	1.517	-0.151	9.520
75.	Air transport	56.731	70.622	14.403	-0.519	0.009	13.893
76.	Storage facility service	12.219	13.914	0.994	0.541	0.159	1.694
77.	Services relating to transport	9.197	10.942	0.842	0.914	-0.010	1.745
78.	Telecommunication	5.980	5.418	0.015	-0.590	0.015	-0.561
79.	Broadcasting	8.521	8.937	-0.677	1.098	-0.007	0.415
80.	Education	7.654	7.259	-0.438	0.025	0.018	-0.395
81.	Research	12.563	16.998	1.847	2.568	0.021	4.435
82.	Medical service, Health & Hygiene	15.908	17.649	0.266	1.659	-0.184	1.741
83.	Other public services	5.920	8.197	0.552	1.746	-0.020	2.278
84.	Advertising services	9.964	12.586	-0.043	2.588	0.075	2.621
85.	Information services	5.979	5.895	-0.214	0.120	0.010	-0.084
86.	Goods rental & leasing	2.785	4.814	0.379	1.640	0.008	2.027
87.	Repair of motor vehicles and machine	13.878	14.485	0.584	-0.613	0.637	0.608
88.	Other business services	9.347	6.217	-1.408	-1.749	0.027	-3.130
89.	Amusement and recreation services	11.106	11.593	0.235	0.334	-0.080	0.488
90.	Eating and drinking place	12.525	13.708	0.296	0.988	-0.101	1.183
91.	Hotel and other lodging places	11.944	14.406	1.229	1.323	-0.090	2.461
92.	Other personal services	10.018	11.285	0.398	0.931	-0.060	1.268
93.	Activities not elsewhere classified	33.570	31.812	-2.811	1.162	-0.110	-1.758
94.	Office supplies	8.530	10.208	1.147	0.525	0.007	1.679
95.	Average (＊＊)	32.685	32.258	0.473	-0.703	-0.198	-0.428
96.	Max (＊＊)	217.712	197.670	34.501	9.389	0.849	23.473
97.	Min (＊＊)	1.937	2.338	-36.203	-27.083	-2.977	-41.503

Source: Author's calculations.

Table 4. Contribution of each energy-supply industry to the effect on the energy intensity: typical examples of major increase in energy intensity (Gcal per million yen)

No.	Non-energy commodity	Energy-supply industry	Effects on energy intensity			
			△ W	△ Bne	△ $[C^{-1}]$ne	Total Change
30.	Chemical fertilizer	Coal mining & Lignite:	-0.224	-0.898	-0.034	-1.156
		Crude petroleum & Natural gas:	17.052	-5.197	0.245	12.100
		Petroleum refinery products:	14.546	-3.767	0.231	11.010
		Coal products:	5.979	0.072	0.019	6.070
		Electricity:	-3.137	-1.593	-0.073	-4.803
		Gas supply, Steam & Hot water supply:	0.286	-0.032	-0.002	0.252
		Total:	34.501	-11.415	0.386	23.473
75.	Air transport	Coal mining & Lignite:	-0.054	-0.007	0.001	-0.060
		Crude petroleum & Natural gas:	7.966	-0.207	0.002	7.761
		Petroleum refinery products:	6.023	-0.143	0.000	5.880
		Coal products:	-0.033	0.006	0.000	-0.027
		Electricity:	0.477	-0.158	0.005	0.324
		Gas supply, Steam & Hot water supply:	0.023	-0.009	0.000	0.014
		Total:	14.403	-0.519	0.009	13.893
74.	Ocean transport & Coastal transport	Coal mining & Lignite:	-0.159	0.024	0.023	-0.112
		Crude petroleum & Natural gas:	5.023	0.728	-0.105	5.646
		Petroleum refinery products:	3.431	0.594	-0.098	3.927
		Coal products:	-0.055	-0.003	0.017	-0.041
		Electricity:	-0.110	0.166	0.011	0.067
		Gas supply, Steam & Hot water supply:	0.024	0.008	0.000	0.032
		Total:	8.154	1.517	-0.151	9.520

Source: Author's calculations.

Table 5. Contribution of each energy-supply industry to the effect on the energy intensity: typical examples of major decrease of energy intensity (Gcal per million yen)

No.	Non-energy commodity	Energy-supply industry	Effects on energy intensity			
			△ W	△ Bne	△ $[C^{-1}]$ne	Total Change
46.	Non-ferrous metals	Coal mining & Lignite:	-3.075	0.115	0.067	-2.893
		Crude petroleum & Natural gas:	-10.366	-2.799	0.026	-13.139
		Petroleum refinery products:	-6.904	-2.239	0.035	-9.108
		Coal products:	-1.598	0.221	0.039	-1.338
		Electricity:	-14.260	-0.654	-0.100	-15.014
		Gas supply, Steam & Hot water supply:	-0.001	-0.012	0.001	-0.012
		Total:	-36.203	-5.369	0.068	-41.503
43.	Pig iron & Crude steel	Coal mining & Lignite:	2.161	-9.400	0.128	-7.111
		Crude petroleum & Natural gas:	1.859	-4.454	0.081	-2.514
		Petroleum refinery products:	-0.310	-2.984	0.048	-3.246
		Coal products:	1.969	-7.043	0.092	-4.982
		Electricity:	0.957	-3.169	0.047	-2.165
		Gas supply, Steam & Hot water supply:	0.008	-0.034	0.002	-0.024
		Total:	6.644	-27.083	0.398	-20.042
44.	Steels	Coal mining & Lignite:	0.996	-7.828	-0.658	-7.490
		Crude petroleum & Natural gas:	1.671	-3.477	-0.097	-1.903
		Petroleum refinery products:	-0.375	-2.290	-0.044	-2.709
		Coal products:	0.327	-5.910	-0.504	-6.087
		Electricity:	1.361	-2.511	-0.155	-1.305
		Gas supply, Steam & Hot water supply:	0.185	-0.037	0.000	0.148

	Total:	4.165	-22.053	-1.457	-19.346

Source: Author's calculations.

6.2. Structural decomposition of total energy requirements: 1985-1990

In this secton, we analyzed the effects of the changes in energy demand structure, non-energy final demand, and non-energy production technology on the total energy requirements by using eq. (37) etc. Table 6 shows the effects by non-energy commodities. Table 7 describes the contributions of energy-supply industries to the total effects corresponding to the final row in Table 6. Table 8 and 9 similarly present the contributions to the effects of the typical commodities in which large increase and decrease are shown in Table 6. We further analyzed the effects on the total energy requirements absorbed into the transactions between non-energy sectors. Figures 1, 2, 3 and 4 present the major effects in the transactions between non-energy sectors.

The important findings from the results are explained below.

6.2.1. Total effects of structural changes

First, as is seen from the total effects of the final row in Table 6, the total energy requirements greatly increased by 1,346,819 Tcal mainly because of the changes in non-energy final demands. The final demand changes grealy promoted the contributions of the crude petroleum industry and the electricity industry (see Table 7).

In contrast, the total effect of the changes in non-energy product-mix decreased by 54,490 Tcal and the structural changes led to energy savings between 1985 and 1990. The contributions of crude petroleum & natural gas industry and petroleum refinery product industry especially decreased by 21,674 Tcal and 16,396 Tcal respectively as a result of the product-mix changes (see Table 7).

6.2.2. Sources of significant increase in total energy requirement

Table 6 indicates that the total energy requirement of each commodity has greatly fluctuated in the positive direction or the negative direction during only five years. Especially, the energy requirement of residential & non-residential construction (No.63) greatly increased by 268,669 Tcal because of the changes in non-energy final demand and the non-energy input structure. Subsequently, the energy requirements of civil engineering (No.65) and motor vehicles (No.58) increased by 137,218 Tcal and 120,236 Tcal respectively because of the changes in non-energy final demand. From the total change in Table 8, the rate of the contribution of the crude petroleum & natural gas industry was very high as 30%, 45%, and 37% respectively and the industry was a main contributor of these commodities (No.63, No.65, No.58).

From the 63rd column of left-hand side matrix in Figure 2, we can find that the remarkable increase in the energy requirement of residential & non-residential construction was mainly induced through the direct and indirect transactions of itself, industrial organic chemicals (No.32), cement & cement products (No.40), pig iron & crude steel (No.43), steels (No.44) and road transport (No.73) as a result of the changes in non-energy final demand. Figure 2 similarly illustrates that the large increase of civil engineering was caused by the transactions of itself, cement & cement products (No.40), pig iron & crude steel (No.43) while that of motor vehicles was caused through the transactions of itself, industrial organic chemicals (No.32), pig iron & crude steel (No.43). Taken altogether, Figure 2 illustrates significant increase in the energy inputs required for the intermediate inputs of industrial organic chemicals, pig iron & crude steel that are induced by the change of the final demand of the electric equipment such as household electric appliance (No.54), electric & communication equipment (No.55).

We can, in the same way, obtain more information about key transactions with the major effects of $\boldsymbol{\Delta W}$, $\boldsymbol{\Delta B_{ne}}$, $\boldsymbol{\Delta [C^{-1}]_{ne}}$ on the total energy requirements from the left-hand side matrix in Figures 1, 3, and 4. For example, considering the energy requirements of medical service, health & hygiene (No.82) which showed the largest effect of the changes in non-energy input sturcture ($\boldsymbol{\Delta B_{ne}}$), it turned out that the large increase was caused by the transactions of industrial organic chemicals (No.32) from the left-hand side matrix in Figure 3.

6.2.3. Sources of significant decrease in total energy requirement

In Table 6, the total energy requirement of steels (No.44) greatly decreased by 118,251 because of the changes in non-energy final demand and non-energy input structure. Subsequently, the energy requirements of pulp & paper (No.27) and other electrical equipment (No.57) decreased by 74,924 Tcal and 50,598 Tcal respectively mainly because of the final demand shifts. From total change in Table 9, coal mining & lignaite industry and coal products industry mainly contributed to the significant reduction of the total energy requirement of steels. We can similarly find the major contributors to the total change in the energy requirements of pulp & paper and other electrical equipment.

As is seen from the 44th column of right-hand side in Figures 2 and 3, the large decrease of steels was mainly brought through the transactions of pig iron & crude steel (No.43). Also, the decrease of the total energy requirement of other electrical equipment was mainly caused by the transactions of itself, industrial organic chemicals (No.32), pig iron & crude steel (No.43) and non-ferrous metals (No.46).

6.2.4. Effects of changes in non-energy product-mix

The changes in non-energy product-mix have negative effects, that is, saving of energy in contrast with non-energy input structure and/or non-energy final demand. (see Table 6 and/or Figure 4). The 32nd and 43rd row of the right-hand side in Figure 4 describes that the structural changes especially brought about the reductions in energy inputs required for transactions of industrial organic chemicals (No.32) and pig iron & crude steel (No.43).

Table 6. Structural decomposition analysis of change in total energy requirement (Tcal)

No.	88-non-energy commodity	Effects on total energy requirement				
		▵ W	▵ fne	▵ Bne	▵ $[C^{-1}]$ne	Total Change
07.	Agriculture	1,680	9,439	54	81	11,255
08.	Livestock-raising & Sericulture	254	970	-963	-165	96
09.	Agricultural services	340	657	-24	-6	968
10.	Forestry	-2,328	2,033	490	-109	86
11.	Fisheries & Culture	1,786	8,085	482	-746	9,607
12.	Metal ores	2,991	5,955	835	265	10,046
13.	Non-ferrous metal ores	-334	-964	122	-29	-1,205
14.	Slaughtering & Meat processing	218	-5,528	-1,646	-252	-7,207
15.	Livestock-raising foods	6,386	3,773	-2,995	-123	7,041
16.	Sea foods	13,388	-4,203	14,270	-4,052	19,403
17.	Grain milling & Flour	4,833	-1,082	-4,460	522	-187
18.	Preserved agricultural foodstuffs etc	11,002	40,067	-3,506	-938	46,625
19.	Sugar etc & Other foods	13,481	-39,039	-9,199	183	-34,574
20.	Beverages	-333	20,997	-320	-1,027	19,317
21.	Feeds & Organic fertilizers	184	125	-327	-5	-24
22.	Tobacco	539	-1,095	390	276	111
23.	Fabricated textile products	916	-15,895	4,148	-390	-11,222
24.	Wearing apparel & Other textile products	-6,620	19,798	-4,241	-512	8,425
25.	Timber & Wooden products	-1,626	-4,686	-24	-12	-6,348
26.	Furniture & Fixtures	440	5,372	3,567	-445	8,934
27.	Pulp & Paper	-2,764	-78,681	6,443	78	-74,924
28.	Processed paper products	-1,549	60,663	-672	-65	58,377
29.	Printing & Publishing	-213	-5,893	4,911	29	-1,166
30.	Chemical fertilizer	67	-4,751	-14	2	-4,697
31.	Industrial inorganic chemicals	-23	3,806	68	21	3,872
32.	Industrial organic chemicals	109	12,671	-71	-56	12,654
33.	Resins	-839	10,220	-1,341	-94	7,946
34.	Chemical fibers	828	-6,076	-1,576	-10	-6,835
35.	Final chemical products	-4,386	34,470	-2,442	-2,496	25,146
36.	Plastic products	-398	4,205	3,401	-369	6,839
37.	Rubber products	1,778	388	295	-335	2,126
38.	Leather, Leather products & Fur skins	503	387	1,254	-179	1,965
39.	Glass & Glass products	-417	-3,239	211	-153	-3,598
40.	Cement & Cement products	-86	-1,323	-7	-4	-1,420
41.	Pottery, China & earthenware	75	-1,414	116	-84	-1,306
42.	Miscellaneous ceramic, Stone & Clay products	-1,167	-1,213	637	-106	-1,850
43.	Pig iron & Crude steel	795	91,109	-3,407	49	88,546
44.	Steels	7,246	-85,006	-37,981	-2,511	-118,251
45.	Steel products	-82	-875	-190	-17	-1,164
46.	Non-ferrous metals	47,422	-56,357	7,236	-97	-1,796
47.	Non-ferrous metal products	-6,849	-8,464	3,672	81	-11,560
48.	Metal products for construction, architecture	-152	670	376	-101	793
49.	Other metal products	-861	-5,839	-727	-455	-7,881
50.	General industrial machinery	-4,609	34,709	1,549	-533	31,116
51.	Special industrial machinery	-13,057	52,637	-571	3,348	42,357
52.	Other general machines	2,443	5,446	13,294	-1,258	19,926
53.	Office machines & Machinery for service industry	-4,291	25,304	-11,779	158	9,392
54.	Household electric appliance	-10,512	69,451	-23,896	-9,449	25,595
55.	Electric & Communication equipment	-60,523	219,430	-47,360	-27	111,520
56.	Heavy electrical equipment	-4,902	26,272	1,175	-190	22,355
57.	Other electrical equipment	-3,221	-57,521	11,364	-1,220	-50,598
58.	Motor vehicles	-27,064	150,125	4,102	-6,928	120,236
59.	Ships & Its Repair	449	-11,338	-8	-478	-11,375

No.	88-non-energy commodity	Effects on total energy requirement				
		△ W	△ fne	△ Bne	△ $[C^{-1}]ne$	Total Change
60.	Other transport equipment & Its Repair	630	8,795	3,409	141	12,975
61.	Scientific instruments	-1,006	10,554	-1,269	-276	8,003
62.	Miscellaneous manufacturing products	-2,478	7,178	-3,677	-97	926
63.	Residential, Non-Residential construction	-8,800	251,335	31,823	-5,688	268,669
64.	Repair of construction	15	-777	33	-4	-733
65.	Civil engineering	17,586	149,086	-27,276	-2,178	137,218
66.	Water supply	5,734	13,476	638	-48	19,800
67.	Waste disposal services	763	-1,008	1,161	11	927
68.	Wholesale trade & Retail trade	28,753	35,032	37,418	-12,805	88,397
69.	Financial service & Insurance	2,330	10,036	-2,443	263	10,187
70.	Real estate rental service	1,902	-835	325	-3	1,389
71.	House rent	7,218	16,264	7,002	-180	30,304
72.	Railway transport	-3,075	7,417	-8,451	2,729	-1,380
73.	Road transport	18,790	56,842	-1,113	1,236	75,756
74.	Ocean transport & Coastal transport	17,252	-45,611	3,205	-318	-25,473
75.	Air transport	13,529	25,137	-495	8	38,179
76.	Storage facility service	394	361	215	63	1,033
77.	Services relating to transport	1,149	3,302	1,247	-14	5,685
78.	Telecommunication	41	2,383	-1,629	40	836
79.	Broadcasting	-294	683	477	-3	864
80.	Education	-7,446	22,584	462	302	15,902
81.	Research	982	2,671	1,365	11	5,029
82.	Medical service, Health & Hygiene	6,518	67,372	40,751	-4,529	110,113
83.	Other public services	1,591	1,563	5,036	-57	8,134
84.	Advertising services	9	-481	-517	-15	-1,004
85.	Information services	8	-755	-4	0	-752
86.	Goods rental & leasing	157	2,277	680	3	3,117
87.	Repair of motor vehicles and machine	1,190	7,673	-1,283	1,316	8,897
88.	Other business services	-1,666	12,030	-2,069	31	8,326
89.	Amusement and recreation services	2,750	43,729	3,940	-953	49,466
90.	Eating and drinking place	5,170	20,295	17,284	-1,771	40,978
91.	Hotel and other lodging places	6,483	11,880	6,976	-476	24,864
92.	Other personal services	2,995	4,819	6,998	-454	14,357
93.	Activities not elsewhere classified	594	-32,574	-170	21	-32,128
94.	Office supplies	22,361	11,748	10,230	134	44,473
95.	Average (＊＊)	1,171	14,128	625	-619	15,305
96.	Max (＊＊)	47,422	251,335	40,751	3,348	268,669
97.	Min (＊＊)	-60,523	-85,006	-47,360	-12,805	-118,251
98.	Total (＊＊)	103,078	1,243,239	54,992	-54,490	1,346,819

Source: Author's calculations.

Table 7. Contribution of each energy-supply industry to the total effect on the total energy requirement (Tcal)

		Energy-supply industry	Changes in total energy requirement				
			△ W	△ fne	△ Bne	△ $[C^{-1}]ne$	Total Change
98.	Total (＊＊)	Coal mining & Lignite:	-21,551	176,264	-31,709	-5,976	117,027
		Crude petroleum & Natural gas:	116,657	412,918	46,360	-21,674	554,261
		Petroleum refinery products:	-58,224	285,795	29,128	-16,396	240,303
		Coal products:	-8,415	99,398	-27,428	-3,463	60,092
		Electricity:	74,080	254,805	36,836	-6,685	359,036
		Gas supply, Steam & Hot water supply:	531	14,059	1,806	-295	16,101
		Total:	103,078	1,243,239	54,992	-54,490	1,346,819

Source: Author’s calculations.

Table 8. Contribution of each energy-supply industry to the effect on the total energy requirement: typical examples of major increase in energy requirement (Tcal)

No.	Non-energy commodity	Energy-supply industry	Effects on total energy requirement				
			△ W	△ fne	△ Bne	△ $[C^{-1}]$ne	Total Change
63.	Residential & Non-Residential construction	Coal mining & Lignite:	-3,420	49,855	10,220	-1,900	54,755
		Crude petroleum & Natural gas:	1,761	73,725	4,841	-1,054	79,272
		Petroleum refinery products:	-13,847	50,847	1,713	-752	37,962
		Coal products:	-1,196	29,984	7,863	-1,448	35,202
		Electricity:	9,001	44,024	6,971	-531	59,465
		Gas supply, Steam & Hot water supply:	-1,100	2,900	215	-3	2,013
		Total:	-8,800	251,335	31,823	-5,688	268,670
65.	Civil engineering	Coal mining & Lignite:	-5,916	31,201	-14,608	-807	9,870
		Crude petroleum & Natural gas:	19,498	43,590	-1,251	-349	61,487
		Petroleum refinery products:	8,422	30,140	-961	-249	37,352
		Coal products:	-1,829	15,557	-9,964	-599	3,165
		Electricity:	-2,699	27,926	-557	-177	24,494
		Gas supply, Steam & Hot water supply:	112	672	64	1	849
		Total:	17,586	149,086	-27,276	-2,178	137,218
58.	Motor vehicles	Coal mining & Lignite:	-1,504	23,671	-5,330	-1,920	14,917
		Crude petroleum & Natural gas:	-6,533	46,896	5,567	-1,629	44,300
		Petroleum refinery products:	-14,306	31,587	3,335	-1,139	19,477
		Coal products:	-1,297	15,565	-5,026	-1,406	7,835
		Electricity:	-2,923	31,049	5,252	-817	32,561
		Gas supply, Steam & Hot water supply:	-501	1,358	304	-16	1,145
		Total:	-27,064	150,125	4,102	-6,928	120,235

Source: Author's calculations.

Table 9. Contribution of each energy-supply industry to the effect on the total energy requirement: typical examples of major decrease of energy requirement (Tcal)

No.	Non-energy commodity	Energy-supply industry	Effects on total energy requirement				
			△ W	△ fne	△ Bne	△ $[C^{-1}]$ne	Total Change
44.	Steels	Coal mining & Lignite:	1,727	-32,785	-13,494	-1,134	-45,686
		Crude petroleum & Natural gas:	2,907	-10,505	-5,973	-166	-13,736
		Petroleum refinery products:	-644	-5,738	-3,947	-75	-10,405
		Coal products:	571	-25,098	-10,187	-869	-35,583
		Electricity:	2,365	-10,685	-4,316	-266	-12,902
		Gas supply, Steam & Hot water supply:	321	-195	-63	0	63
		Total:	7,246	-85,006	-37,981	-2,511	-118,252
27.	Pulp & Paper	Coal mining & Lignite:	4	-6,388	524	2	-5,859
		Crude petroleum & Natural gas:	-1,359	-31,803	2,577	43	-30,541
		Petroleum refinery products:	-3,040	-22,376	1,827	33	-23,556
		Coal products:	-143	-1,251	95	-4	-1,303
		Electricity:	1,698	-16,546	1,390	4	-13,454
		Gas supply, Steam & Hot water supply:	75	-317	30	0	-212
		Total:	-2,764	-78,681	6,443	78	-74,924
57.	Other electrical equipment	Coal mining & Lignite:	-324	-7,779	3,033	-182	-5,251
		Crude petroleum & Natural gas:	-493	-18,689	2,087	-436	-17,531
		Petroleum refinery products:	-1,512	-12,352	979	-320	-13,206
		Coal products:	-183	-4,789	2,236	-119	-2,855
		Electricity:	-700	-13,428	3,040	-161	-11,249
		Gas supply, Steam & Hot water supply:	-9	-484	-11	-3	-506
		Total:	-3,221	-57,521	11,364	-1,220	-50,598

Source: Author's calculations.

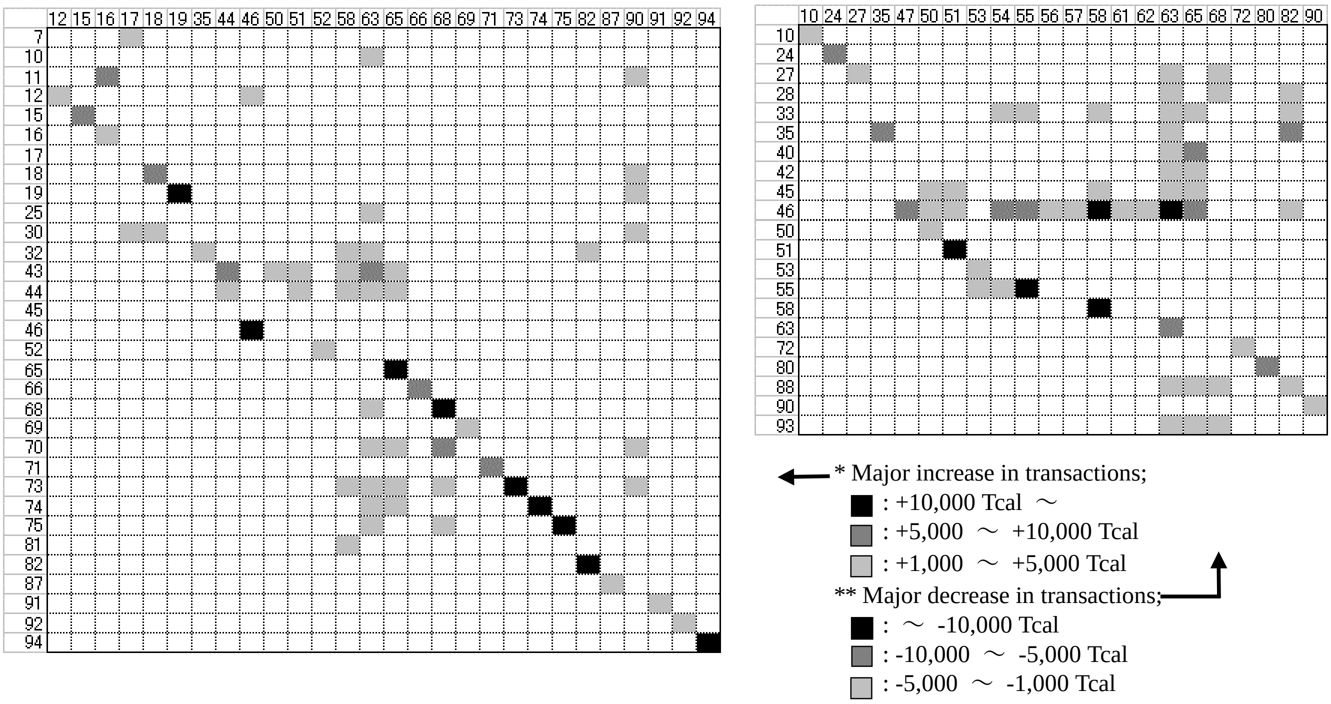

Figure 1. Major effect of $\Delta\mathbf{W}$ on total energy requirement between non-energy sectors

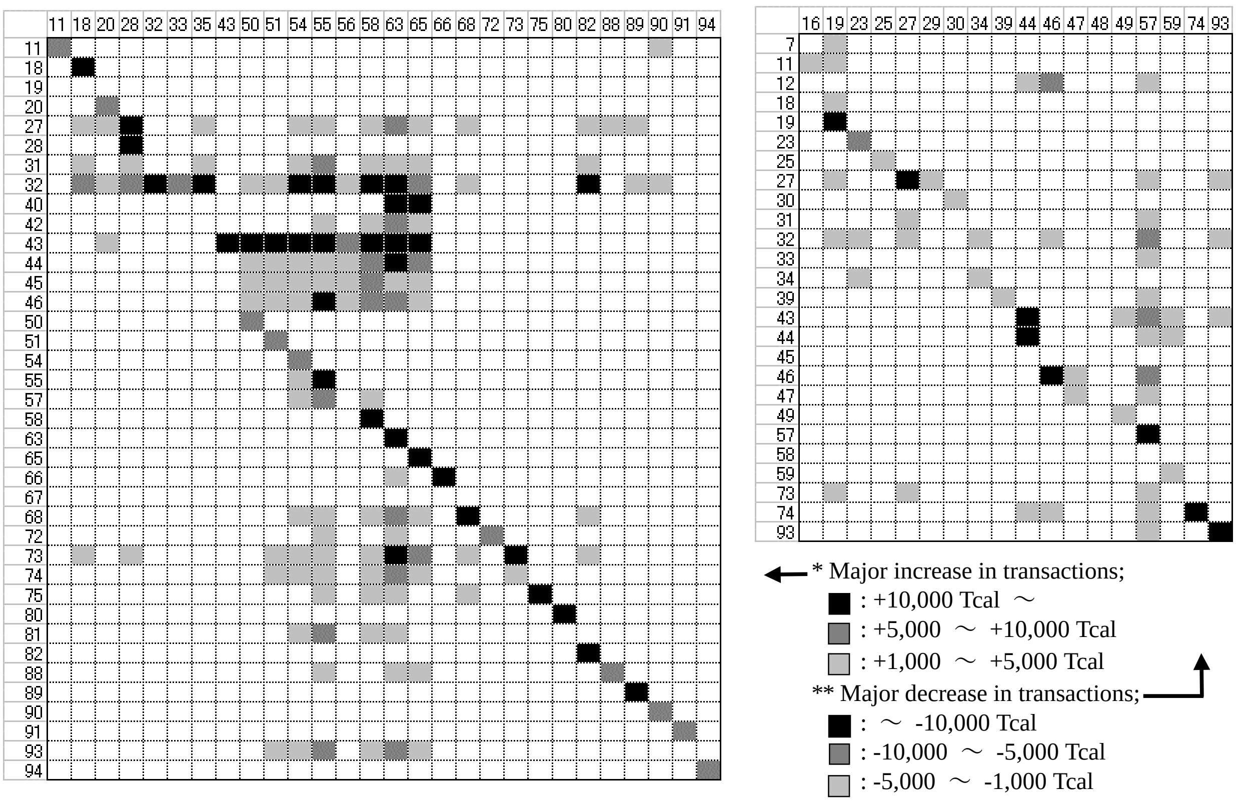

Figure 2. Major effect of $\Delta\mathbf{f}_{ne}$ on total energy requirement between non-energy sectors

Source: Author's calculations.

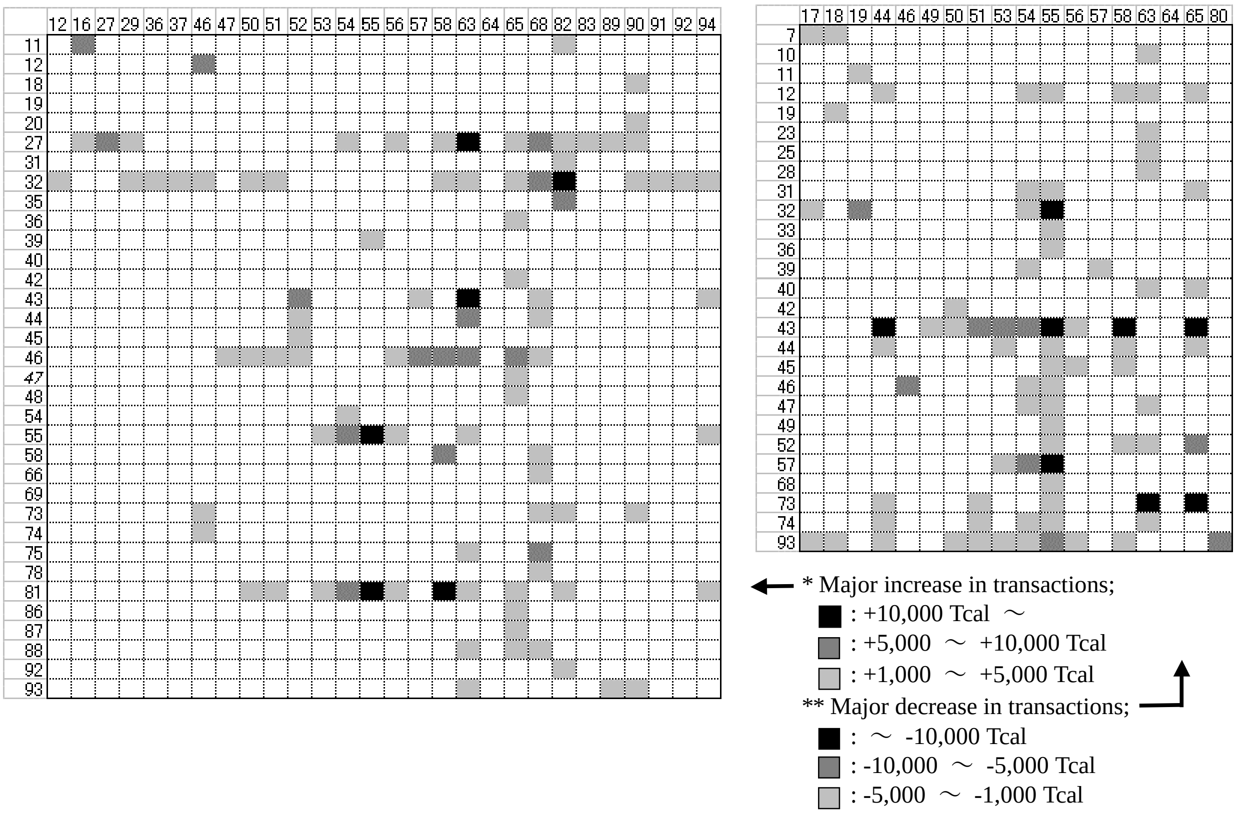

Figure 3. Major effect of $\Delta \mathbf{B}_{ne}$ on total energy requirement between non-energy sectors

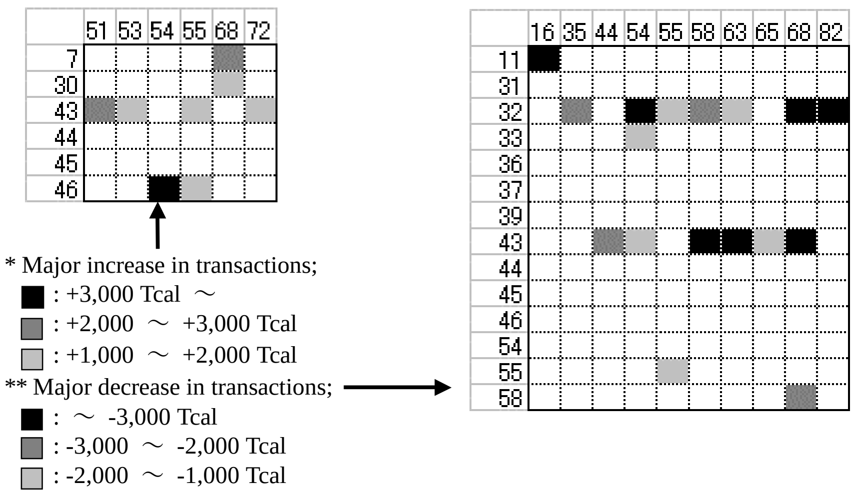

Figure 4. Major effect of $\Delta[\mathbf{C}^{-1}]_{ne}$ on total energy requirement between non-energy sectors

Source: Author's calculations.

7. Conclusions

We conducted a SDA method based on the hybrid rectangular input-output model. It is not only to escape from the effects of the drastic changes of energy prices on the input structure in physical terms, but also to analyze the impacts of the changes in non-energy product-mix. Our method made clear the mutual relationships between the energy demand structure and the non-energy product-mix by applying a hierarchical method to the hybrid rectangular IO model.

The major findings of this paper can be summarized as follows;

(1) The energy intensities of each non-energy commodity have fluctuated on the whole because of the changes in the energy demand structure and the non-energy production technology between 1985 to 1990.

(2) The total energy requirement in Japan has greatly increased mainly because of the changes in non-energy final demand, the second, the changes in energy demand structure and the third, the changes in non-energy input structure.

(3) The product-mix changes have reverse effects, that is, saving of energy.

(4) The above results proved a practical use of the proposed method.

In this paper, although an emphasis is placed on energy requirements, it is natural that emissions (CO_2, NO_x, SO_x) from the productive activities should be considered in the same way. The framework of the rectangular system shown in this paper can be very convenient for analyses. So, we are now conducting a research work to determine the Life Cycle Assessment for production, consumption and waste disposal by using extended hybrid rectangular IO model based on the assumption of a commodity technology.

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