IDENTIFICATION OF RELATIONSHIP BETWEEN EMBODIED BY-PRODUCT REQUIREMENTS AND DOMESTIC PRODUCTION TECHNOLOGY IN JAPAN: 1985-1995

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Abstract: There are some doubts about the plausible reasons for the promotion of the domestic recycling system of by-products. One of the doubts is whether the virgin materials embodied in the exogenous final demand are really saved by the promotion of the recycling system. Another is whether the promotion is useful for the saving of energy. With the doubts mentioned above kept in mind, the purpose of this paper is to propose a hybrid rectangular input-output model (HRIO), based on a mixed technology assumption, to estimate the factor endowments (energy, materials, and by-products). From the empirical results, it is clear that the major factor underlying the misconception such that the promotion of the recycling of by-product brings the energy increase and material increase was the large increase in the energy content ratio and the material content ratio from 1985 to 1995.

Key Words: hybrid rectangular input-output model, mixed technology assumption, factor content, factor content ratio

1. INTRODUCTION

The Japanese economy develops by the *laissez-faire* of the domestic market and the foreign trade, and absorbs large quantities of natural resources from abroad as the result. On the other hand, the need for the control of carbon dioxide discharged by the absorption has been emphasized in order to attain the goal of a reduction of 6% on that amount in 1990 since the Kyoto negotiation. The mutual relationship between the development and the control seems like a dilemma that cannot resolve any longer.

The expansion of a domestic recycling system has recently been expected in order to cope with the crucial issue described above. The main reason is very simple, since it is based on the plausible scenario that sees the amount of carbon dioxide emission reduced due to the energy savings resulting from the substitution of recycled materials for virgin materials. However, since additional production processes such as a transportation activity to collect the scrap paper and the scrap iron are inevitably needed in a recycling system, the embodied energy requirements reduced by the substitution might be smaller than that directly and indirectly induced by the additional processes. According to the results of the recycling simulation of the scrap paper (Suga, 1995), in fact, it was shown that as the recycling rate went up, the amount of carbon dioxide emission by the combustion of fossil fuels more and more increased. Of course, it goes without saying that the promotion of the recycling contributes not only to the control of waste disposal of by-products as wastes but also to the saving of the direct virgin materials. In this sense, it is very important to identify the relationship between the by-products requirements embodied in the exogenous final demand such as exports, household consumption, *etc.* and the domestic production technology including the energy input structure and the non-energy input structure.

It is well known that the input-output model is very useful for the life cycle inventory analysis focusing on the national economy. The inventory analysis estimates how much embodied energy requirements are needed throughout the entire economic system and how much embodied pollutants are discharged as a result. There are many studies of the inventory analysis using input-output model in the past (for example, Yoshioka *et al.*, 1992; Kondo *et al.*, 1997). In recent years, the input-output structural decomposition analysis (I-O SDA) has been rapidly developed for empirical impact analysis of life cycle inventory and applied to the real world (for example, Lin *et al.*, 1995; Wier, 1998).

However, most studies with traditional commodity-by-commodity have essential issues due to the assumption of product-mix. That is the problem of the joint-production such as by-products. The problem is that, on including the circular flow of the joint-productions, the traditional input-output system will have an unstable condition which does not allow unique equilibrium solutions. There are some methods to avoid the condition (ten Raa *et al.*, 1984, 1988; Jansen *et al.*, 1990). The negative input method that is so-called Stone's method, has been employed in Japan. Since the inputs and the outputs of by-products are expressed as positive value and negative value respectively and dealt as a competitive input requirements within the traditional framework, it is very difficult to estimate the direct and indirect by-product requirements required to produce general goods and services.

With the problems mentioned above, this paper introduces the rectangular input-output model under the mixed technology assumption (Gigantes, 1970). Since the model used is based on the hybrid rectangular input-output scheme proposed by Kagawa & Inamura (2000, 2001) in order to relax the effects of different energy prices among industrial sectors on the input structure in physical base, our formulation is a little different from Gigantes's.

The purposes of the paper are as follows;

(1) To propose the mixed technology model expressed in both monetary and physical terms.
(2) To estimate by-product content, energy content, and material content embodied in the exogenous final demand such as exports, consumption expenditure outside households, gross domestic fixed capital formation (public, private) in 1985, 1990, and 1995.
(3) To discuss the mutual relationship between embodied by-product requirements and domestic production technology in Japan,

2. FORMULATION OF THE HYBRID RECTANGULAR INPUT-OUTPUT MODEL BASED ON A MIXED TECHNOLOGY ASSUMPTION

The mixed technology model is based on both assumptions of a commodity technology and an industry technology. The input structure of industries under the rectangular system is constructed by the linear combinations of commodity technology of primary and secondary products which industries produce, and by using the fixed market share of by-products. Hence, it is necessary to assume that the production levels of products within industries are technologically constrained, and the market shares of the by-products are stable as Gigantes (1970) has pointed out.

Let $\mathbf{V}_1$ be a hybrid output matrix that represents the outputs of primary and secondary products, and let $\mathbf{V}_2$ be a hybrid output matrix that represents the outputs of by-products. Then the output matrix in the rectangular framework, $\mathbf{V}$ is calculated as:

$$\mathbf{V} = \mathbf{V}_1 + \mathbf{V}_2 \tag{1}$$

Considering hybrid rectangular input-output framework, equation (1) can be rewritten as the following sub-matrix form expressed in both monetary terms (million yen) and physical terms (Tcal).

$$\begin{bmatrix} \mathbf{V}_{11}(\mathbf{TC}) & \mathbf{V}_{12}(\mathbf{MY}) \\ \mathbf{V}_{21}(\mathbf{TC}) & \mathbf{V}_{22}(\mathbf{MY}) \end{bmatrix} = \begin{bmatrix} (\mathbf{V}_1)_{11} & (\mathbf{V}_1)_{12} \\ (\mathbf{V}_1)_{21} & (\mathbf{V}_1)_{21} \end{bmatrix} + \begin{bmatrix} (\mathbf{V}_2)_{11} & (\mathbf{V}_2)_{12} \\ (\mathbf{V}_2)_{21} & (\mathbf{V}_2)_{21} \end{bmatrix} \tag{2}$$

where $\mathbf{V}_{11}$, $(\mathbf{V}_1)_{11}$, and $(\mathbf{V}_2)_{11}$ represent the $(m \times m)$ matrices of the energy outputs, primary and secondary energy outputs, and energy outputs as by-products that are produced by energy-supply industries, respectively. $\mathbf{V}_{12}$, $(\mathbf{V}_1)_{12}$, and $(\mathbf{V}_2)_{12}$ are the $(m \times n)$ matrices of the non-energy outputs, primary and secondary non-energy outputs, and non-energy outputs as by-products that are produced by energy-supply industries. $\mathbf{V}_{21}$; $(\mathbf{V}_1)_{21}$, and $(\mathbf{V}_2)_{21}$ are the $(n \times m)$ matrices the energy outputs, primary and secondary energy outputs, and energy outputs as by-products that are produced by non-energy industries. And $\mathbf{V}_{22}$, $(\mathbf{V}_1)_{22}$, and $(\mathbf{V}_2)_{22}$ are the $(n \times n)$ matrices the non-energy energy outputs, primary and secondary non-energy outputs, and non-energy outputs as by-products that are produced by non-energy industries.

Let $\mathbf{g}_1$ and $\mathbf{g}_2$ be $(m+n)$-dimensional vectors showing the values of total industry outputs of primary and secondary products, and by-products, respectively and let $\mathbf{q}_1$ and $\mathbf{q}_2$ be $(m+n)$-dimensional vectors showing the values of total commodity outputs of primary and secondary products, and by-products. We can write the following hybrid vectors.

$$\mathbf{g}_1 = [(\mathbf{g}_1)_1(\mathrm{TC}) \;\vdots\; (\mathbf{g}_1)_2(\mathrm{MY})]^{\mathrm{T}} \tag{3}$$

$$\mathbf{g}_2 = [(\mathbf{g}_2)_1(\mathrm{TC}) \;\vdots\; (\mathbf{g}_2)_2(\mathrm{MY})]^{\mathrm{T}} \tag{4}$$

$$\mathbf{q}_1 = [(\mathbf{q}_1)_1(\mathrm{TC}) \;\vdots\; (\mathbf{q}_1)_2(\mathrm{MY})]^{\mathrm{T}} \tag{5}$$

$$\mathbf{q}_2 = [(\mathbf{q}_2)_1(\mathrm{TC}) \;\vdots\; (\mathbf{q}_2)_2(\mathrm{MY})]^{\mathrm{T}} \tag{6}$$

where **T** denotes a transposition. Then, the following relationship can be obtained.

$$\mathbf{g}_1 = \mathbf{V}_1\mathbf{i} = \mathbf{C}_1^{-1}\mathbf{q}_1 \tag{7}$$

$$\mathbf{g}_2 = \mathbf{V}_2\mathbf{i} = \mathbf{D}_2(\mathbf{q}_1 + \mathbf{q}_2) = \mathbf{D}_2\mathbf{q} \tag{8}$$

where $\mathbf{i}$ denotes the $(m+n)$-dimensional column vector whose elements are one. $\mathbf{C}_1$ represents the $(m+n \times m+n)$ matrix showing the coefficient of the product-mix of primary and secondary products. $\mathbf{D}_2$ is the $(m+n \times m+n)$ market share matrix of by-products. The $\mathbf{C}_1$ and the $\mathbf{D}_2$ can be defined as:

$$\mathbf{C}_1 = \begin{bmatrix} (\mathbf{C}_1)_{11}(\mathrm{TC/TC}) & (\mathbf{C}_1)_{12}(\mathrm{MY/TC}) \\ (\mathbf{C}_1)_{21}(\mathrm{TC/MY}) & (\mathbf{C}_1)_{22}(\mathrm{MY/MY}) \end{bmatrix}^{\mathrm{T}} \tag{9}$$

$$\mathbf{D}_2 = \begin{bmatrix} (\mathbf{D}_2)_{11}(\mathrm{TC/TC}) & (\mathbf{D}_2)_{12}(\mathrm{MY/MY}) \\ (\mathbf{D}_2)_{21}(\mathrm{TC/TC}) & (\mathbf{D}_2)_{22}(\mathrm{MY/MY}) \end{bmatrix} \tag{10}$$

Here, when focusing on the output balance obtained by substituting equation (10) into equation (8), unfortunately, we realize that the values expressed in non-comparable units are added up together and the problem of summation occurs in the hybrid input-output system. Therefore, the market share structure of the energy by-products produced by non-energy industries and that of the non-energy by-product produced by energy-supply industries are completely ignored. In short, it assumes that $(\mathbf{D}_2)_{21}$ and $(\mathbf{D}_2)_{12}$ does not work under the rectangular input-output system. The hybrid input-output model based on the mixed technology assumption requires the strange operation. There is a criticism against the operation, as some economists have pointed out that input-output theory has to be founded on the balance of prices and materials in physical base. However, the criticism cannot be accepted in order to escape from the effects of different energy prices among industrial sectors on the input structure in physical base.

Let us return to the formulation of mixed technology model. From the relationship between $\mathbf{q}_1$ and $\mathbf{q}_2$,

$$\mathbf{q}_1 = \mathbf{q} - \mathbf{q}_2 \tag{11}$$

From eq.(7), (8), and (11), the industry outputs can be obtained as:

$$\begin{aligned} \mathbf{g} &= \mathbf{g}_1 + \mathbf{g}_2 \\ &= \mathbf{C}_1^{-1}(\mathbf{q} - \widehat{\mathbf{D}_2^{\mathrm{T}}\mathbf{i}}\mathbf{q}) + \mathbf{D}_2\mathbf{q} \\ &= \{\mathbf{C}_1^{-1}(\mathbf{I} - \widehat{\mathbf{D}_2^{\mathrm{T}}\mathbf{i}}) + \mathbf{D}_2\}\mathbf{q} \end{aligned} \tag{12}$$

where $\mathbf{I}$ denotes the $(m+n \times m+n)$ identity matrix and $\widehat{\mathbf{D}_2^T\mathbf{i}}$ is the $(m+n \times m+n)$ matrix whose diagonal elements are total market share of the by-products. Considering the commodity balance in the rectangular input-output framework, the commodity outputs can be formulated as:

$$\begin{aligned}\mathbf{q} &= \mathbf{B}\{\mathbf{C}_1^{-1}(\mathbf{I}-\widehat{\mathbf{D}_2^T\mathbf{i}})+\mathbf{D}_2\}\mathbf{q}+\mathbf{f}\\ &= [\mathbf{I}-\mathbf{B}\{\mathbf{C}_1^{-1}(\mathbf{I}-\widehat{\mathbf{D}_2^T\mathbf{i}})+\mathbf{D}_2\}]^{-1}\mathbf{f}\\ &= (\mathbf{I}-\mathbf{BS})^{-1}\mathbf{f} \end{aligned} \tag{13}$$

$$\mathbf{S} = \mathbf{B}\{\mathbf{C}_1^{-1}(\mathbf{I}-\widehat{\mathbf{D}_2^T\mathbf{i}})+\mathbf{D}_2\} \tag{14}$$

where $\mathbf{B}$ is the $(m+n \times m+n)$ hybrid input coefficient matrix and $\mathbf{f}$ represents the $(m+n)$-dimensional exogenous final demand vector. The industry outputs can be further estimated as:

$$\begin{aligned}\mathbf{g} &= \mathbf{S}(\mathbf{I}-\mathbf{BS})^{-1}\mathbf{f}\\ &= (\mathbf{I}-\mathbf{SB})^{-1}\mathbf{Sf}\end{aligned} \tag{15}$$

From eq. (13), the embodied by-product requirements and the embodied primary and secondary product requirements induced by the exogenous final demand can be obtained as the following equation (16) and (17) respectively.

$$\mathbf{q}_2 = \widehat{\mathbf{D}_2^T\mathbf{i}}(\mathbf{I}-\mathbf{BS})^{-1}\mathbf{f} \tag{16}$$

$$\mathbf{q}_1 = (\mathbf{I}-\widehat{\mathbf{D}_2^T\mathbf{i}})(\mathbf{I}-\mathbf{BS})^{-1}\mathbf{f} \tag{17}$$

The primary and secondary energy requirements $\mathbf{E}_1$ induced by the exogenous final demand are estimated by adding $(\mathbf{q}_1)_i\,(\mathbf{i}=\mathbf{1}\sim\mathbf{m})$ in terms of the energy sectors. The energy by-product requirements $\mathbf{E}_2$ are estimated by adding $(\mathbf{q}_2)_i\,(\mathbf{i}=\mathbf{1}\sim\mathbf{m})$ in the same way. Moreover, the primary and secondary non-energy requirements $\mathbf{M}$ can be obtained by adding up $(\mathbf{q}_1)_i\,(\mathbf{i}=\mathbf{m}+\mathbf{1}\sim\mathbf{m}+\mathbf{n})$ and the non-energy by-product requirements $\mathbf{R}$ are estimated by adding up $(\mathbf{q}_2)_i\,(\mathbf{i}=\mathbf{m}+\mathbf{1}\sim\mathbf{m}+\mathbf{n})$ in terms of non-energy sectors.

Here, let $\mathbf{E}_{exp}$, $\mathbf{E}_{hoe}$, $\mathbf{E}_{hie}$, $\mathbf{E}_{pub}$, and $\mathbf{E}_{pri}$ primary and secondary energy requirements embodied in exports, consumption expenditure outside households, consumption expenditure of households, gross domestic fixed capital formation (public, private) respectively. $\mathbf{M}_{exp}$, $\mathbf{M}_{hoe}$, $\mathbf{M}_{hie}$, $\mathbf{M}_{pub}$, and $\mathbf{M}_{pri}$ can be also defined as the primary and secondary non-energy requirements embodied in each final demand category. $\mathbf{R}_{exp}$, $\mathbf{R}_{hoe}$, $\mathbf{R}_{hie}$, $\mathbf{R}_{pub}$, and $\mathbf{R}_{pri}$ are defined as the non-energy by-product requirements in the same way. These embodied input requirements **E**, **M**, and **R** can be formulated as:

$$\mathbf{E} = \underbrace{\sum_{i=1}^{m}\mathbf{Gf}_{exp}}_{\mathbf{E}_{exp}} + \underbrace{\sum_{i=1}^{m}\mathbf{Gf}_{hoe}}_{\mathbf{E}_{hoe}} + \underbrace{\sum_{i=1}^{m}\mathbf{Gf}_{hie}}_{\mathbf{E}_{hie}} + \underbrace{\sum_{i=1}^{m}\mathbf{Gf}_{pub}}_{\mathbf{E}_{pub}} + \underbrace{\sum_{i=1}^{m}\mathbf{Gf}_{pri}}_{\mathbf{E}_{pri}} \tag{18}$$

$$\mathbf{M} = \underbrace{\sum_{i=m+1}^{m+n} \mathbf{Gf}_{exp}}_{\mathbf{M}_{exp}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{Gf}_{hoe}}_{\mathbf{M}_{hoe}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{Gf}_{hie}}_{\mathbf{M}_{hie}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{Gf}_{pub}}_{\mathbf{M}_{pub}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{Gf}_{pri}}_{\mathbf{M}_{pri}} \tag{19}$$

$$\mathbf{R} = \underbrace{\sum_{i=m+1}^{m+n} \mathbf{Hf}_{exp}}_{\mathbf{R}_{exp}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{Hf}_{hoe}}_{\mathbf{R}_{hoe}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{Hf}_{hie}}_{\mathbf{R}_{hie}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{Hf}_{pub}}_{\mathbf{R}_{pub}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{Hf}_{pri}}_{\mathbf{R}_{pri}} \tag{20}$$

where:

$$\mathbf{G} = \left(\mathbf{I} - \widehat{\mathbf{D}_2^T \mathbf{i}}\right)\left(\mathbf{I} - \mathbf{BS}\right)^{-1} \tag{21}$$

$$\mathbf{H} = \widehat{\mathbf{D}_2^T \mathbf{i}}\left(\mathbf{I} - \mathbf{BS}\right)^{-1} \tag{22}$$

$\mathbf{f}_{exp}$, $\mathbf{f}_{hoe}$, $\mathbf{f}_{hie}$, $\mathbf{f}_{pub}$, and $\mathbf{f}_{pri}$ represent the final demand vector of exports, consumption expenditure outside households, consumption expenditure of households, gross domestic fixed capital formation (public, private) respectively and can be expressed as a hybrid vector like eq. (3), (4), (5), and (6). Given the final demand converter (structure) of each category, say $\tilde{\mathbf{f}}_{exp}$, $\tilde{\mathbf{f}}_{hoe}$, $\tilde{\mathbf{f}}_{hie}$, $\tilde{\mathbf{f}}_{pub}$, and $\tilde{\mathbf{f}}_{pri}$, we have:

$$\tilde{\mathbf{E}} = \underbrace{\sum_{i=1}^{m} \mathbf{G}\tilde{\mathbf{f}}_{exp}}_{\tilde{\mathbf{E}}_{exp}} + \underbrace{\sum_{i=1}^{m} \mathbf{G}\tilde{\mathbf{f}}_{hoe}}_{\tilde{\mathbf{E}}_{hoe}} + \underbrace{\sum_{i=1}^{m} \mathbf{G}\tilde{\mathbf{f}}_{hie}}_{\tilde{\mathbf{E}}_{hie}} + \underbrace{\sum_{i=1}^{m} \mathbf{G}\tilde{\mathbf{f}}_{pub}}_{\tilde{\mathbf{E}}_{pub}} + \underbrace{\sum_{i=1}^{m} \mathbf{G}\tilde{\mathbf{f}}_{pri}}_{\tilde{\mathbf{E}}_{pri}} \tag{23}$$

$$\tilde{\mathbf{M}} = \underbrace{\sum_{i=m+1}^{m+n} \mathbf{G}\tilde{\mathbf{f}}_{exp}}_{\tilde{\mathbf{M}}_{exp}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{G}\tilde{\mathbf{f}}_{hoe}}_{\tilde{\mathbf{M}}_{hoe}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{G}\tilde{\mathbf{f}}_{hie}}_{\tilde{\mathbf{M}}_{hie}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{G}\tilde{\mathbf{f}}_{pub}}_{\tilde{\mathbf{M}}_{pub}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{G}\tilde{\mathbf{f}}_{pri}}_{\tilde{\mathbf{M}}_{pri}} \tag{24}$$

$$\tilde{\mathbf{R}} = \underbrace{\sum_{i=m+1}^{m+n} \mathbf{H}\tilde{\mathbf{f}}_{exp}}_{\tilde{\mathbf{R}}_{exp}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{H}\tilde{\mathbf{f}}_{hoe}}_{\tilde{\mathbf{R}}_{hoe}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{H}\tilde{\mathbf{f}}_{hie}}_{\tilde{\mathbf{R}}_{hie}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{H}\tilde{\mathbf{f}}_{pub}}_{\tilde{\mathbf{R}}_{pub}} + \underbrace{\sum_{i=m+1}^{m+n} \mathbf{H}\tilde{\mathbf{f}}_{pri}}_{\tilde{\mathbf{R}}_{pri}} \tag{25}$$

where $\tilde{\mathbf{E}}$, $\tilde{\mathbf{M}}$, and $\tilde{\mathbf{R}}$ denote the embodied input requirements of the energy, materials, and by-products required to produce the one unit (one million yen) of domestic final demand. Eq. (23), (24), and (25) are very useful tools to analyze the effects of the changes in the production technology changes and the final demand structural changes such as export pattern shifts and consumption pattern shifts on the factor intensity.

There are three questions from the environmental viewpoint of the recycling of the materials. The first question is how much direct and indirect by-product requirements are embodied in the exogenous final demand such as exports in certain time period. The embodied by-product requirements can be estimated by applying the hybrid input-output table in the period to eq. (14), (20) and (25). The second is what is the difference in factor intensities and in factor endowments of exports and household consumption as an example of the final demand. The empirical result enables us to reveal not only the abundance of factors of each final demand but also the difference among the factor endowments embodied in respective categories. The last is how the factor intensity and the factor endowment changed in time series. From the analysis, it is possible to evaluate the contribution of the domestic production technology and the recycling system to the saving of energy or materials in practice. Thus analysis, however, bears the essential issue. The problem is that the allocation system of the by-products from household sector is completely ignored. In order to solve it, it is necessary to endogenously deal with the recycling system within the hybrid rectangular framework.

The next chapter presents the extended hybrid rectangular input-output model which incorporates the distribution of the by-products from household sector. Note that income-distribution is also incorporated to consider the waste disposal originating from household consumption.

3. EXTENSION OF THE HYBRID RECTANGULAR INPUT-OUTPUT MODEL

Let $\mathbf{B}'$ represent the $(m+n+1 \times m+n+1)$ hybrid input coefficient matrix incorporating the household sector. $\mathbf{B}'$ can be also decomposed into the $(m+n+1 \times m+n+1)$ input coefficient matrix of general goods and services $\mathbf{B}'_1$ and the $(m+n+1 \times m+n+1)$ input coefficient matrix of by-products $\mathbf{B}'_2$ such that

$$\mathbf{B}' = \mathbf{B}'_1 + \mathbf{B}'_2 \tag{26}$$

Here $\mathbf{B}'_1$ and $\mathbf{B}'_2$ are respectively defined as:

$$\mathbf{B}'_1 = \left[\begin{array}{c|c} \mathbf{B}_1 & \mathbf{h} \\ \hline \mathbf{l} & \mathbf{0} \end{array}\right] \tag{27}$$

$$\mathbf{B}'_2 = \left[\begin{array}{c|c} \mathbf{B}_2 & \mathbf{w} \\ \hline \mathbf{O} & \mathbf{0} \end{array}\right] \tag{28}$$

where $\mathbf{B}_1$ and $\mathbf{B}_2$ denote the $(m+n \times m+n)$ hybrid input coefficient matrix of general commodities and of by-products that are originated in industries. Hence, $\mathbf{B}$ is equal to $\mathbf{B}_1$ plus $\mathbf{B}_2$. $\mathbf{h}$ in eq. (27) is the $(m+n)$-dimensional column vector of marginal propensity of consumption in terms of general commodities and $\mathbf{l}$ is the $(m+n)$-dimensional row vector of labor input coefficient. $\mathbf{w}$ in eq. (28) is the $(m+n)$-dimensional column vector of marginal propensity of consumption in terms of by-products, especially tangible variables. $\mathbf{O}$ and $\mathbf{0}$ are $(m+n)$-dimensional vector whose elements are zero, and zero respectively. Considering the hybrid rectangular framework, we notice that $\mathbf{h}$, $\mathbf{l}$, and $\mathbf{w}$ take the hybrid forms such that:

$$\mathbf{h} = [\mathbf{h}_1(\mathrm{TC/MY}) \ \vdots \ \mathbf{h}_2(\mathrm{MY/MY})]^T \tag{29}$$

$$\mathbf{l} = [\mathbf{l}_1(\mathrm{MY/TC}) \ \vdots \ \mathbf{l}_2(\mathrm{MY/MY})] \tag{30}$$

$$\mathbf{w} = [\mathbf{w}_1(\mathrm{TC/MY}) \ \vdots \ \mathbf{w}_2(\mathrm{MY/MY})]^T \tag{31}$$

where $\mathbf{h}_1$ and $\mathbf{h}_2$ represent the m-dimensional vector of marginal propensity of consumption in terms of energy commodities and the n-dimensional vector of marginal propensity of consumption in terms of non-energy commodities respectively. $\mathbf{l}_1$ and $\mathbf{l}_2$ represent the m-dimensional vector of labor input coefficient in terms of energy supply industries and the n-dimensional vector of labor input coefficient in terms of non-energy industries. Similarly, $\mathbf{w}_1$ and $\mathbf{w}_2$ represent the m-dimensional vector of marginal propensity of consumption in terms of energy by-products and the n-dimensional vector of marginal propensity of consumption in terms of non-energy by-products respectively.

Next, let us consider the output structure corresponding to the extended hybrid input coefficient mentioned above. The output coefficient matrix shown in eq. (9) can be extended as:

$$\mathbf{C}_1' = \left[\begin{array}{c|c} \mathbf{C}_1 & \mathbf{O} \\ \hline \mathbf{O} & \boldsymbol{\alpha} \end{array}\right] \tag{32}$$

where $\boldsymbol{\alpha}$ is the scalar of labor output coefficient of household sector. If the income which the household sector receives by means of the production of commodities completely shifts to the consumption of goods and services, $\boldsymbol{\alpha}$ is equal to one. However, if the saving and the other expense of household actually exist, the value must be set less than one. The market share matrix of by-products shown in eq. (10) can be defined as:

$$\mathbf{D}_2' = \left[\begin{array}{c|c} \mathbf{D}_2 & \mathbf{O} \\ \hline \mathbf{r} & \mathbf{0} \end{array}\right] \tag{33}$$

where $\mathbf{r}$ represents the $(m+n)$-dimensional vector of market share of by-products originated in household sector and takes hybrid forms in the same way.

$$\mathbf{r} = \left[\mathbf{r}_1(\mathrm{TC}/\mathrm{TC}) \;\vdots\; \mathbf{r}_2(\mathrm{MY}/\mathrm{MY})\right] \tag{34}$$

From eq. (27), (28), (32), (33), the extended production formulae of by-products and general commodities can be obtained as:

$$\mathbf{q}_2' = \widehat{(\mathbf{D}_2')^{\mathrm{T}}\mathbf{i}}(\mathbf{I} - \mathbf{B}'\mathbf{S}')^{-1}\mathbf{f}' \tag{35}$$

$$\mathbf{q}_1' = \left\{\mathbf{I} - \widehat{(\mathbf{D}_2')^{\mathrm{T}}\mathbf{i}}\right\}(\mathbf{I} - \mathbf{B}'\mathbf{S}')^{-1}\mathbf{f}' \tag{36}$$

where:

$$\mathbf{B}' = \mathbf{B}_1' + \mathbf{B}_2' \tag{37}$$

$$\mathbf{S}' = \mathbf{B}'\left[(\mathbf{C}_1')^{-1}\left\{\mathbf{I} - \widehat{(\mathbf{D}_2')^{\mathrm{T}}\mathbf{i}}\right\} + \mathbf{D}_2'\right] \tag{38}$$

The superscript $'$ means that the matrices and the vectors correspond to the extended hybrid rectangular input-output system. Using eq. (36), we can compute the energy requirements $\mathbf{E}'$ (or energy intensities $\tilde{\mathbf{E}}'$) embodied in each final demand category like eq. (18) or eq. (23). The material requirements $\mathbf{M}'$ (or material intensities $\tilde{\mathbf{M}}'$) can also be estimated like eq. (19) or eq. (24). Similarly, from eq. (35), The by-product requirements $\mathbf{R}'$ (or by-products intensities $\tilde{\mathbf{R}}'$) can be estimated as shown in eq. (20) or eq. (25).

4. BASIC DATA

Sets of basic data for this analysis are listed below:
(1) Energy intensities based on the input-output analysis in 1985, 1990, and 1995 (provided by National Institute for Environmental Studies, Environmental Agency of Japan.)
(2) Output matrices: by industry commodity (so called V table) in 1985, 1990, and 1995
(3) Traditional input-output tables: by commodity commodity (so called X table) in 1985, 1990, and 1995
(4) Output table of by-products in 1985, 1990, and 1995
Here, (2), (3), (4) are provided by Management and Coordination Agency of Japan.

First, the inputs of energy goods in the X table (column 527×row 411: basic sector classification) were changed from monetary terms (million yen) into physical terms (terra calorie) by using the amount of energy inputs in physical term estimated by National Institute for Environmental Studies. The input flow 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 terms into physical terms 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 practically. 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 V table corresponds to the V_1 in our model. The V_2 was directly given from the output table of by-products. Since the V_2 table is expressed in monetary terms, it should essentially be converted into hybrid type in order to get the hybrid market share matrix of by-products. It is, however, very difficult to convert due to the lacks of basic data to know the detailed physical transaction of energy by-products and due to the aggregation problem. If it is assumed that the prices of energy-products are stable among industrial sectors, the market share sub-matrix of energy-products in monetary base coincides with that in physical base. Hence V_2 table in monetary base is used in the hybrid rectangular framework under the assumption.

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 (see Kagawa *et al.*, 2000, 2001). The other 88 sectors were dealt with as non-energy sectors.

In this study, both V and U in 1985, 1990, and 1995 were converted by using the base year price in 1990. From the estimated V and U, we obtained a hybrid rectangular I-O table and analyzed by means of the mixed technology model discussed in chapter 2 and 3.

5. FACTOR CONTENTS OF ENERGY, MATERIALS, AND BY-PRODUCTS: 1985-95

Now we discuss the mutual relationship between the embodied by-product requirements and the domestic production technology by using the empirical results from the mixed technology model. Concretely, the shifts in the factor abundance of energy and materials relative to by-products were examined to clear whether Japanese economy acted in the direction of saving energy and materials as the results of the changes in recycling system. Since the two indices are introduced in order to make the discussion clear, let us explain about it. The first index is $\boldsymbol{\lambda} = \tilde{\mathbf{E}}/\tilde{\mathbf{R}}$ which shows the energy content relative to by-products (see equations (23) and (25)). The second is $\boldsymbol{\mu} = \tilde{\mathbf{M}}/\tilde{\mathbf{R}}$ which represents the material content relative to by-products (see equations (24) and (25)). Here note that $\tilde{\mathbf{E}}/\tilde{\mathbf{R}}$ and $\tilde{\mathbf{M}}/\tilde{\mathbf{R}}$ theoretically coincide with $\mathbf{E}/\mathbf{R}$ and $\mathbf{M}/\mathbf{R}$ which are computed by equations (18), (19), and (20). For example, if the energy/by-product content embodied in the exports in time period $\mathbf{t_0}$, say $\boldsymbol{\lambda}_{\mathbf{exp}}^{\mathbf{t_0}} = \tilde{\mathbf{E}}_{\mathbf{exp}}^{\mathbf{t_0}}/\tilde{\mathbf{R}}_{\mathbf{exp}}^{\mathbf{t_0}}$, is smaller than that embodied in the exports in time period $\mathbf{t_1}(> \mathbf{t_0})$, say $\boldsymbol{\lambda}_{\mathbf{exp}}^{\mathbf{t_1}} = \tilde{\mathbf{E}}_{\mathbf{exp}}^{\mathbf{t_1}}/\tilde{\mathbf{R}}_{\mathbf{exp}}^{\mathbf{t_1}}$, the result obviously indicates that the energy requirements per unit of by-product requirements increased due to the export shifts during the periods. This means that the economic structure acted in the direction of the energy abundance relative to by-products. Similarly, if $\boldsymbol{\mu}_{\mathbf{exp}}^{\mathbf{t_0}} = \tilde{\mathbf{M}}_{\mathbf{exp}}^{\mathbf{t_0}}/\tilde{\mathbf{R}}_{\mathbf{exp}}^{\mathbf{t_0}} < \tilde{\mathbf{M}}_{\mathbf{exp}}^{\mathbf{t_1}}/\tilde{\mathbf{R}}_{\mathbf{exp}}^{\mathbf{t_1}} = \boldsymbol{\mu}_{\mathbf{exp}}^{\mathbf{t_1}}$, it can be concluded that the economic structure acted in the direction of the material abundance relative to by-products. It is also useful to employ the factor content ratio, say $\boldsymbol{\lambda}_{\mathbf{exp}}^{\mathbf{t_1}}/\boldsymbol{\lambda}_{\mathbf{exp}}^{\mathbf{t_0}}$ or $\boldsymbol{\mu}_{\mathbf{exp}}^{\mathbf{t_1}}/\boldsymbol{\mu}_{\mathbf{exp}}^{\mathbf{t_0}}$. The discussions can be opened on the changes in the factor abundance relative to by-product content embodied in final demand of one million yen.

Table 1 shows the contents of energy, materials, and by-products embodied in each final demand of one million yen. Since the empirical results was estimated by the extended I-O model in chapter 3, note that the household sector is endogenously dealt in the framework, therefore there is no household consumption in the final demand categories. Table 2 shows the energy content and the material content relative to by-products which are required to produce the output of one million yen of each commodity. Let us consider from the empirical results.

One can clearly see that the energy, materials, and by-products embodied in the total final demand of one million yen largely decreased due to the production technology changes and/or the pattern shifts in final demand (see the total final demand in Table 1). The empirical observation immediately reminds us of the saving energy and materials due to the changes in the domestic production technology. This is certainly correct from the viewpoint of factor content level. However, is the consideration correct from the viewpoint of the factor contents relative to by-product? Let us see the changes in $\boldsymbol{\lambda}_{\mathbf{total}}$, $\boldsymbol{\mu}_{\mathbf{total}}$ in Table 1. The energy/by-product content remarkably goes up from 4.62 to 10.98 during the ten years. This means that if the absolute level of the factor content of by-products can be ignored altogether, the Japanese economy advanced rapidly toward an energy intensive structure. The observation result sharply contradicts the effect, say saving energy, which in general we expect from the promotion of the recycling of by-products. Needless to say, the decrease in the energy content relative to by-product is structurally desirable. Considering the energy content ratio between 1985 and 1995 from the results of each final demand category and computing the value, for example $\boldsymbol{\lambda_{hoe}^{95}/\lambda_{hoe}^{85} = 24.43/12.52 = 1.95}$, it can be seen that the largest driving force toward the energy intensive structure was the consumption expenditure outside household. Similarly, the energy content ratios of exports, gross domestic fixed capital formation (public), and gross domestic fixed capital formation (private) are 1.67, 1.46, and 1.36 respectively and it can be seen that those final demand categories acted as the driving force.

Next, let us consider the material content relative to by-products. As is seen from the results in Table 1, the material content and the energy content had the similar characteristic. The absolute level of material content remarkably decreased by 33%, while the material content relative to by-products increased by 142% (see the total of final demand in Table 1). Unfortunately, the Japanese economy did not advance toward saving materials in the significance of what the recycling policy should essentially be like the above-mentioned context of saving energy. Computing the material content ratios, we can understand that the major driving force toward material intensive structure was also the consumption expenditure outside household.

From Table 2, it can be seen that the major commodities which brought the increase in the factor content ratio in Japanese economy were pulp & paper (No.27), processed paper products (No.28), printing & publishing (No.29), metal ores (No.12) (see Table 2). Although there is a definite recycling policy on these commodities, it is clear that the implementation of the policy was not connected with the reduction of the energy content ratio and the material content ratio at all. Especially, the energy content ratio of pulp & paper remarkably increased from 2 megacalories per yen to 66 megacalories per yen during ten years. Considering the empirical fact that the absolute level of the energy content of pulp & paper was stable and the energy content relative to materials decreased largely, we must say that the recycling policy of the paper-producing industry was not useful for saving energy and materials at least.

Table 1. Energy, Materials, and By-products Embodied in Each Final Demand Category of One Million Yen

Final demand categories	1985	1990	1995
Total final demand			
Embodied energy requirements	27,710	19,407	14,352
Embodied material requirements	3,871,760	3,911,319	2,604,541
Embodied by-product requirements	4,700	2,893	1,307
λ_{total} = energy / by-product	4.62	6.71	10.98
μ_{total} = material / by-product	824	1,352	1,992
Exports			
Embodied energy requirements	63,673	55,530	47,486
Embodied material requirements	4,304,224	4,073,475	2,884,760
Embodied by-product requirements	8,902	5,021	3,985
λ_{exp} = energy / by-product	7.15	11.06	11.92
μ_{exp} = material / by-product	484	811	724
Consumption expenditure outside households			
Embodied energy requirements	31,635	36,025	26,897
Embodied material requirements	3,299,222	3,612,864	2,516,450
Embodied by-product requirements	2,527	1,624	1,101
λ_{hoe} = energy / by-product	12.52	22.19	24.43
μ_{hoe} = material / by-product	1,306	2,225	2,285

Continued Overleaf

Final demand categories	1985	1990	1995
Gross domestic fixed capital formation (public)			
Embodied energy requirements	42,033	39,771	27,713
Embodied material requirements	3,915,891	3,855,234	2,649,471
Embodied by-product requirements	6,029	3,989	2,722
λ_{pub} = energy / by-product	6.97	9.97	10.18
μ_{pub} = material / by-product	650	966	973
Gross domestic fixed capital formation (private)			
Embodied energy requirements	41,092	39,335	27,672
Embodied material requirements	3,961,751	3,911,711	2,769,849
Embodied by-product requirements	5,290	3,678	2,628
λ_{pri} = energy / by-product	7.77	10.69	10.53
μ_{pri} = material / by-product	749	1,064	1,054

Note: The units of embodied energy requirements, embodied material requirements, and embodied by-product requirements are Mcal, Yen, and Yen respectively. The factor content ratios, λ and μ, can be easily calculated and the units are Mcal/Yen and Yen/Yen, say non-dimensional, respectively.

Table 2. Energy Content and Material Content Relative to By-products

No.	88-non-energy commodity	Energy content/Waste content (Mcal / ¥) 1985	1990	1995	Material content/Waste content (¥ / ¥) 1985	1990	1995
07.	Agriculture	4	5	5	445	568	497
08.	Livestock-raising & Sericulture	4	5	3	536	739	569
09.	Agricultural services	9	37	34	765	2,733	2,272
10.	Forestry	13	31	41	1,499	3,149	4,221
11.	Fisheries & Culture	30	62	99	1,536	2,681	3,137
12.	Metal ores	6	43	81	397	2,807	4,770
13.	Non-ferrous metal ores	1	1	1	82	114	59
14.	Slaughtering & Meat processing	5	6	3	733	1,017	865
15.	Livestock-raising foods	8	14	11	909	1,555	1,342
16.	Sea foods	17	36	51	1,459	2,719	3,441
17.	Grain milling & Flour	6	8	6	774	1,098	935
18.	Preserved agricultural foodstuffs etc	11	21	24	1,060	1,981	2,392
19.	Sugar etc & Other foods	11	21	23	1,157	2,015	1,956
20.	Beverages	7	12	12	679	1,195	1,125
21.	Feeds & Organic fertilizers	3	3	2	302	337	196
22.	Tobacco	7	17	17	1,240	2,678	3,685
23.	Fabricated textile products	19	43	71	1,414	2,964	3,669
24.	Wearing apparel & Other textile products	17	34	49	1,566	3,223	4,037
25.	Timber & Wooden products	9	15	38	1,032	1,643	4,176
26.	Furniture & Fixtures	8	12	12	794	1,202	1,020
27.	Pulp & Paper	2	42	66	69	1,833	2,030
28.	Processed paper products	4	38	59	281	2,766	3,453
29.	Printing & Publishing	4	33	48	426	3,084	3,955
30.	Chemical fertilizer	1	2	2	48	49	34
31.	Industrial inorganic chemicals	17	30	32	542	863	818
32.	Industrial organic chemicals	60	123	191	1,093	2,048	2,051
33.	Resins	45	86	125	1,226	2,330	2,506
34.	Chemical fibers	29	86	141	908	2,754	3,281
35.	Final chemical products	16	32	39	972	2,034	2,212
36.	Plastic products	24	47	63	1,359	2,564	2,720
37.	Rubber products	20	44	62	1,112	2,186	2,206

Continued Overleaf

No. 88-non-energy commodity	Energy content / Waste content (Mcal / ¥)			Material content / Waste content (¥ / ¥)		
	1985	1990	1995	1985	1990	1995
38. Leather, Leather products & Fur skins	11	23	30	1,239	2,481	2,935
39. Glass & Glass products	2	2	2	90	115	72
40. Cement & Cement products	6	10	11	405	617	523
41. Pottery, China & earthenware	11	20	23	776	1,352	1,275
42. Miscellaneous ceramic, Stone & Clay products	10	16	16	534	878	732
43. Pig iron & Crude steel	3	3	4	56	53	50
44. Steels	3	4	5	105	119	120
45. Steel products	5	5	7	179	246	229
46. Non-ferrous metals	2	1	1	73	67	55
47. Non-ferrous metal products	3	2	2	146	159	132
48. Metal products for construction, architecture	5	6	6	337	432	390
49. Other metal products	5	6	7	328	421	406
50. General industrial machinery	6	8	8	518	700	673
51. Special industrial machinery	7	9	9	604	832	805
52. Other general machines	7	8	8	630	604	566
53. Office machines & Machinery for service industry	8	13	13	766	1,482	1,553
54. Household electric appliance	7	12	11	699	1,188	1,297
55. Electric & Communication equipment	9	13	12	844	1,402	1,552
56. Heavy electrical equipment	6	8	8	533	733	777
57. Other electrical equipment	7	6	5	602	526	466
58. Motor vehicles	7	10	10	686	1,032	1,036
59. Ships & Its Repair	6	8	8	481	645	558
60. Other transport equipment & Its Repair	7	9	10	669	856	904
61. Scientific instruments	7	11	10	741	1,199	1,083
62. Miscellaneous manufacturing products	8	12	11	727	1,079	931
63. Residential & Non-Residential construction	7	11	11	757	1,099	1,131
64. Repair of construction	7	11	11	709	1,006	1,017
65. Civil engineering	7	9	10	600	900	897
66. Water supply	26	51	72	1,557	2,799	3,726
67. Waste disposal services	17	32	48	1,650	3,004	3,517
68. Wholesale trade & Retail trade	14	29	36	1,691	3,213	4,354
69. Financial service & Insurance	13	28	34	1,617	3,544	5,311
70. Real estate rental service	15	34	45	2,483	4,279	5,905
71. House rent	9	18	19	2,687	4,563	7,663
72. Railway transport	17	33	46	1,369	2,828	3,609
73. Road transport	23	45	65	1,622	3,003	3,560
74. Ocean transport & Coastal transport	45	83	180	1,775	3,115	3,744
75. Air transport	31	76	138	1,527	3,022	4,696
76. Storage facility service	16	34	46	1,610	3,223	4,301
77. Services relating to transport	10	25	33	1,130	2,643	3,587
78. Telecommunication	15	30	38	1,667	3,474	5,513
79. Broadcasting	15	30	36	1,737	3,559	4,601
80. Education	15	28	36	1,469	2,826	3,354
81. Research	15	33	41	1,397	2,927	3,497
82. Medical service, Health & Hygiene	16	31	38	1,475	2,832	3,328
83. Other public services	13	28	34	1,450	3,000	3,678
84. Advertising services	8	32	42	1,068	3,838	5,248
85. Information services	12	29	36	1,541	3,500	4,874
86. Goods rental & leasing	12	22	26	2,306	3,531	5,971
87. Repair of motor vehicles and machine	10	15	15	1,085	1,632	1,673
88. Other business services	11	29	35	1,242	3,311	4,123
89. Amusement and recreation services	16	32	42	1,709	3,290	4,058
90. Eating and drinking place	13	23	25	1,410	2,429	2,553
91. Hotel and other lodging places	14	27	31	1,541	2,708	3,001
92. Other personal services	17	32	40	1,729	3,118	3,808
93. Activities not elsewhere classified	13	20	20	875	1,399	2,410
94. Office supplies	14	26	31	1,463	2,565	3,044

6. POLICY IMPLICATION

As far as our empirical observations go, it can be indicated that it is important to consider not only the level changes in the energy content and the material content but also the changes in the energy content ratio and the material content ratio relative to by-products. The importance is concretely accentuated in the following.

In Japan, as the level of the energy content decreases, the energy content ratio relative to by-products decreases. Similarly, as the level of the material content decreases, the material content ratio relative to by-products decreases. This is the specific structure of the Japanese economy from the viewpoint of the interdependence among energy, materials and by-products. The misconception such that the promotion of the recycling of by-product brings about energy increase and material increase throughout the entire economic system rests on the large increases in factor content ratio relative to by-products. Considering the decrease in the energy content and the material content from our results, it is clear that the changes in Japanese economic system including the recycling system totally led to saving energy and materials. However, as is seen from the results of pulp & paper (No.27) in Table 2, we must not overlook the empirical fact that there exist some commodities which rapidly advance in the opposite direction of the intention of the recycling policy.

What should be accentuated for policy-makers is to empirically identify the rapid changes in factor content and factor content ratio relative to by-products and then to examine the usefulness of recycling policy focused on not only the individual sector but also the national economy. Furthermore, by focusing on the individual commodity and estimating the engineering production function, it is also necessary to follow up the circulation of the energy and the materials induced by the promotion of recycling from technological aspects.

7. CONCLUDING REMARKS

We proposed a mixed technology model expressed in both monetary and physical terms. The method made clear the mutual relationship among energy, materials, and by-products without the problem of energy prices. According to our observation between 1985 and 1995, the energy content and/or material content embodied exogenous final demand decreased during the ten years, while the energy content ratio and the material content ratio relative to by-products remarkably increased. One of the factors underlying the misconception such that the promotion of the recycling of by-product brings about the energy increase and material increase was the large increase in the energy content ratio and the material content ratio from 1985 to 1995.

Since our hybrid model is an analytical tool to quantitatively evaluate the interdependence among energy, materials, and by-products, there are some limitations. One of the limitations is to estimate the impacts of the changes in for example the input-output structure of by-products on the factor content and/or factor content ratio. The I-O SDA based on the mixed technology model should be proposed in order to discuss whether the changes in the input-output structure of by-products really save the embodied energy requirements and the embodied material requirements or not. So, we are now conducting a research work to determine the I-O SDA based on mixed technology model and its desirable conditions.

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