Measuring Spatial Repercussion Effects of Regional Waste Recycling

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ABSTRACT

The present paper proposes an analytical framework to measure the spatial pollution repercussion effects of regional waste recycling. The empirical analysis using the 1995 nine-region waste input-output table reveals that the completely closed intra-regional treatment system was not better for the environment in the Kanto, Kinki, Shikoku, and Okinawa regions than the actual system, considering both regional differences in waste treatment techniques and the overall interregional feedback effects of intermediate energy and chemical product inputs for the treatment techniques. In contrast, the Tohoku and Kyusyu regions suffer from the interregional waste shipments. The total CO_2 emissions throughout the entire economic system in the complete intra-regional treatment system for each region increased by 600 (t-C) in 1995, revealing the location advantage of the intermediate inputs for waste treatment and regional technological differences. For the waste landfill quantity, only a very slight difference between both systems was observed.

Keywords: Multiregional waste input-output account; spatial repercussion effects

1. Introduction

Environmental input-output analyses (EIOA) have played a key role not only in identifying pollution- and energy-intensive production activities but also in examining the effects of changes in production and consumption patterns on embodied energy requirements and embodied pollutants (see Isard et al. (1968), Ayres and Kneese (1969), Leontief (1970, 1972), Wright (1974), Bullard and Herendeen (1975a, 1975b) for pioneering works, and section 6 of Polenske (2004) for a short overview). The pioneering works stimulated more sophisticated empirical frameworks, such as environmental and energy structural decomposition analyses (for example, Lin and Polenske (1995), Wier (1998), De Haan (2001), Kagawa and Inamura (2002)), key sector identification analyses (for example, Weber and Schnabl (1998), Lenzen (2003)), and social accounting analyses, and extended the scopes of the studies to include various environmental burdens.

For the waste analysis, Nakamura and Kondo (2002) proposed a relevant waste input-output analysis (WIOA) by relaxing two troublesome limitations: that the number of waste types had to be equal to the number of waste treatment methods under the standard EIOA; and, that the joint treatment of multiple pollutants in a single abatement process and the joint application of multiple treatment methods to a single pollutant were excluded from analysis (see Duchin (1990) for basic framework). The extension enables us to account for the energy, air pollutants, water pollutants, and social costs embodied in the waste treatment activities throughout the entire economic system. Kagawa et al. (2004) proposed a simple multi-regional waste redistribution model using the make-use framework. The former focused especially on intermediate input usages for waste treatment activities and pollution emissions induced by the waste recycling activities, while the latter elucidated the interregional waste redistribution flow.

The two approaches are interrelated and the mathematical connection between them facilitates a deeper understanding of the waste input-output system. Previous studies of the waste input-output model did not consider the spatial repercussion effects of regional waste recycling, which represent the outputs of goods and services in other regions induced by the waste recycling activities of a particular region in question. However, the present paper succeeds in modeling and measuring the following repercussion effects: goods and waste disposal services outputs from “goods industries” in the concerned region induced by the goods production activities (or by the waste recycling activities) in the other regions, and recycled goods and waste disposal services outputs from “waste disposal industries” in the concerned region induced by the goods production activities (or by the waste recycling activities) in the other regions.[1]

From the estimated results, the present study determined whether goods production activities in the concerned region remarkably affected waste recycling of goods and waste recycling industries in other regions through the 1995 intra- and interregional linkage and, consequently, brought about recycled goods production and pollution emissions, and evaluated whether critical regional differences existed

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[1]If an industry mainly produces waste disposal services in *monetary base*, the industry can be defined as a waste disposal industry. If an industry mainly produces recycled products by combining waste treatment technologies with commodity production technologies, the industry can be defined as a waste recycling industry.

in the spatial repercussion effects. The previous literature did not fully examine the site-specific economic benefits and environmental externalities related to regional waste recycling.

The objective of the present paper is to theoretically connect the well-known WIOA and the System of National Accounts-based waste flow approach by considering the production activities of goods and waste disposal industries and to demonstrate the advantages of the connection by performing the empirical analysis using the rich 1995 multi-regional waste make-use data.

The present paper is organized as follows: following the introduction, section 2 formulates the two-region model, section 3 illustrates the application of basic data and section 4 provides major findings. Finally, section 5 is the conclusion.

2. The two-region model

Let us suppose that the number of commodities and industries is m and also the number of commodity-oriented available production technologies is m. This is based on the commodity technology assumption that there exists an industry mainly producing the concerned commodity by means of a well-defined production technology. If the well-defined m production technologies are partitioned into l goods and services technologies and m-l waste treatment technologies, we can express the partitioned technical matrix including four sub-matrices as the (l×l)

technical coefficient sub-matrix $\mathbf{A}_{11} = a_{ij}(i,j = 1,\cdots,l)$ showing the intermediate input requirement of good *i* per unit output of good *j*, the (*l*×*m*-*l*) technical coefficient sub-matrix $\mathbf{A}_{12} = a_{ij}(i = 1,\cdots,l;\ j = l+1,\cdots,m)$ showing the intermediate input requirement of good *i* per unit of waste intermediately disposed of by waste treatment *j*, $\mathbf{A}_{21} = a_{ij}(i = l+1,\cdots,l+n, j = 1,\cdots,l)$ showing the output of waste *i* per unit production of good *j*, and the (*n*×*m*-*l*) output coefficient matrix $\mathbf{A}_{22} = a_{ij}(i = l+1,\cdots,l+n;\ j = l+1,\cdots,m)$ showing the residual of waste *i* per unit of waste intermediately disposed of by waste treatment *j*.

Since the number of the waste treatment technologies *m*-*l* is actually smaller than that of jointly-generated waste *n*, the correspondence between the waste treatment technologies and the intermediate waste inputs needs to be considered through engineering. More concretely, defining the non-negative rectangular allocation matrix $\mathbf{S} = S_{ik}(i = 1,\cdots,m-l; k = 1,\cdots,n)$, representing the share of waste *j* disposed of by the waste treatment technology *i*, the (*n*×*l*) output coefficient sub-matrix $\mathbf{A}_{21}$ and the (*n*×*m*-*l*) output coefficient matrix $\mathbf{A}_{22}$ can be converted into $\mathbf{SA}_{21} = \sum_{k=1}^{n} S_{ik} a_{l+k,j}(i = 1,\cdots,m-l;\ j = 1,\cdots,l)$ and $\mathbf{SA}_{22} = \sum_{k=1}^{n} S_{ik} a_{l+k,j} = (i = 1,\cdots,m-l;\ j = l+1,\cdots,m)$, respectively. The mathematical operation enables us to define the following (*m*×*m*) augmented square technical coefficient matrix:

$$\mathbf{A} = \begin{matrix} & \overbrace{\phantom{\mathbf{SA}_{21}}}^{l} & \overbrace{\phantom{\mathbf{SA}_{22}}}^{m\text{-}l} \\ l\{ & \mathbf{A}_{11} & \mathbf{A}_{12} \\ m\text{-}l\{ & \mathbf{SA}_{21} & \mathbf{SA}_{22} \end{matrix}. \tag{1}$$

This conversion is based on Nakamura and Kondo (2002).

In cases where industries use the available production technologies and jointly generate the waste, a product-mix structure within the activity framework is introduced. Let us categorize *m* industries into *l* goods and services industries as G-industries, and *m-l* waste treatment service industries as W-industries. Although there are industries, such as the steel industry, which have both production technology and waste treatment technology, the respective technologies must be identified for the analysis. In addition, the categorization implicitly presumes that the waste treatment service industry in question mainly uses one of the available waste treatment technologies. Practically, the main waste treatment service can be identified from the waste treatment activity levels in physical and monetary base. Following the presumption, the ($m \times m$) augmented product-mix matrix can be defined as:

$$\mathbf{C} = \begin{matrix} l\{ \\ m\text{-}l\{ \end{matrix} \overset{\quad\overbrace{\phantom{C_{11}}}^{l}\quad\overbrace{\phantom{C_{12}}}^{m\text{-}l}}{\begin{bmatrix} \mathbf{C}_{11} & \mathbf{C}_{12} \\ \mathbf{C}_{21} & \mathbf{C}_{22} \end{bmatrix}} \tag{2}$$

where $\mathbf{C}_{11} = c_{ij}(i, j = 1, \cdots, l)$ represents the output of good *i* per unit production of G-industry *j*; $\mathbf{C}_{12} = c_{ij}(i = 1, \cdots, l; j = l + 1, \cdots, m)$ the output of good *i* per unit treatment of W-industry *j*; $\mathbf{C}_{21} = c_{ij}(i = l + 1, \cdots, m; j = l + 1, \cdots, m)$ the amount of waste disposed of by treatment technology *i* per unit production of G-industry *j*; $\mathbf{C}_{22} = c_{ij}(i, j = l + 1, \cdots, m)$ the amount of waste disposed of by treatment technology *i* per unit treatment of W-industry *j*. From equations (1) and (2), the intermediate input structures of the G-industries and the W-industries can be formulated as:

$$\begin{bmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} \\ \mathbf{B}_{21} & \mathbf{B}_{22} \end{bmatrix} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} \\ \mathbf{SA}_{21} & \mathbf{SA}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{C}_{11} & \mathbf{C}_{12} \\ \mathbf{C}_{21} & \mathbf{C}_{22} \end{bmatrix}$$

$$= \begin{bmatrix} \mathbf{A}_{11}\mathbf{C}_{11} + \mathbf{A}_{12}\mathbf{C}_{21} & \mathbf{A}_{11}\mathbf{C}_{12} + \mathbf{A}_{12}\mathbf{C}_{22} \\ \mathbf{SA}_{21}\mathbf{C}_{11} + \mathbf{SA}_{22}\mathbf{C}_{21} & \mathbf{SA}_{21}\mathbf{C}_{12} + \mathbf{SA}_{22}\mathbf{C}_{22} \end{bmatrix}. \quad (3)$$

Here $\mathbf{B}_{11} = \mathbf{A}_{11}\mathbf{C}_{11} + \mathbf{A}_{12}\mathbf{C}_{21}$ and $\mathbf{B}_{21} = \mathbf{SA}_{21}\mathbf{C}_{11} + \mathbf{SA}_{22}\mathbf{C}_{21}$ represent the intermediate input coefficient sub-matrix and the waste output coefficient sub-matrix of the G-industries, respectively, and similarly, $\mathbf{B}_{12} = \mathbf{A}_{11}\mathbf{C}_{12} + \mathbf{A}_{12}\mathbf{C}_{22}$ and $\mathbf{B}_{22} = \mathbf{SA}_{21}\mathbf{C}_{12} + \mathbf{SA}_{22}\mathbf{C}_{22}$ describe the intermediate input coefficient sub-matrix and the waste output coefficient sub-matrix of the W-industries, respectively.

Equation (3) states that the G-industries and the W-industries use the same waste treatment technologies representing goods and services inputs for the waste treatments, however this may not be true in the real world. Engineering knowledge helps us to evaluate the robustness of our framework. If the relevant waste treatment technologies, such as waste incineration and crushing can be focused, the above-mentioned assumption can be called a waste treatment technology assumption. Although under actual circumstances there are physical differences between the waste incineration technologies of a steel industry and of a waste disposal service industry that sells the incineration service as a main product, the detailed differences are not understood and the validity of the waste treatment technology assumption is verified. To avoid this problem, the outputs of the waste disposed by production technologies of G-industry are excluded from the waste output matrix of industries $\mathbf{C}_{21}$ and are treated as exogenous. The present paper focuses on the waste disposed of using the well-defined waste treatment technologies.

From equation (3), the inter-industry material balance of the commodities and of the wastes can be written as:

$$\begin{bmatrix}\mathbf{q}_1\\ \mathbf{q}_2\end{bmatrix}=\begin{bmatrix}\mathbf{A}_{11} & \mathbf{A}_{12}\\ \mathbf{SA}_{21} & \mathbf{SA}_{22}\end{bmatrix}\begin{bmatrix}\mathbf{q}_1\\ \mathbf{q}_2\end{bmatrix}+\begin{bmatrix}\mathbf{f}_1\\ -\mathbf{f}_2\end{bmatrix}$$

$$=\begin{bmatrix}\mathbf{B}_{11} & \mathbf{B}_{12}\\ \mathbf{B}_{21} & \mathbf{B}_{22}\end{bmatrix}\begin{bmatrix}\mathbf{g}_1\\ \mathbf{g}_2\end{bmatrix}+\begin{bmatrix}\mathbf{f}_1\\ -\mathbf{f}_2\end{bmatrix}$$

$$=\begin{bmatrix}\mathbf{B}_{11} & \mathbf{B}_{12}\\ \mathbf{B}_{21} & \mathbf{B}_{22}\end{bmatrix}\begin{bmatrix}\mathbf{C}_{11} & \mathbf{C}_{12}\\ \mathbf{C}_{21} & \mathbf{C}_{22}\end{bmatrix}^{-1}\begin{bmatrix}\mathbf{q}_1\\ \mathbf{q}_2\end{bmatrix}+\begin{bmatrix}\mathbf{f}_1\\ -\mathbf{f}_2\end{bmatrix} \qquad (4)$$

where

$\mathbf{q}_1=(q_1)_i$ = *l*-dimensional commodity output column vector showing the monetary output of commodity *i*

$\mathbf{q}_2=(q_2)_i$ = *m-l* dimensional waste service output column vector showing the physical service output of waste treatment *i*

$\mathbf{g}_1=(g_1)_i$ = *l*-dimensional industrial output column vector showing the monetary output of G-industry *i*

$\mathbf{g}_2 = (g_2)_i$ = *m*-*l* dimensional waste output column vector showing the physical service output (disposal) of W-industry *i*

$\mathbf{f}_1 = (f_1)_i$ = *l*-dimensional final demand column vector showing the final consumption of commodity *i*

$\mathbf{f}_2 = (f_2)_i$ = *m*-*l* dimensional column vector of the net generation of waste *i*, which remains untreated

In the well-known Leontief anti-pollution model (1970, 1972), the variable, $\mathbf{f}_2 = (f_2)_i$, was treated as the release to the environment, but in our waste recycling model this is not true because the household and government sectors emit municipal solid waste (MSW) related to durable goods, for example, waste automobiles and waste computers, and related to non-durable goods, for example, kitchen garbage and waste paper (see Steenge (1978) and Luptacik and Bohm (1994) for non-negative solutions of the augmented Leontief model). Hence, if the waste related to the household and government sectors was completely disposed of by the waste treatment technologies, $\mathbf{f}_2$ definitely includes the exogenous disposal levels for the household- and government-oriented waste. If the household- and government-oriented waste was not completely disposed of from the viewpoint of the physical material balance, the residuals can be treated as releases to the environment. Considering this point, the exogenous vector $-\mathbf{f}_2$ can be precisely expressed as the net generation $-\mathbf{f}_2 = \mathbf{f}_2^w - \mathbf{f}_2^s - \mathbf{f}_2^h$ where $\mathbf{f}_2^w = (f_2^w)_i$ represents the generation of MSW disposed of by the waste treatment *i*; $\mathbf{f}_2^s = (f_2^s)_i$ an environmental release of the industrial waste from the waste treatment *i*; $\mathbf{f}_2^h = (f_2^h)_i$ an environmental release of the MSW from the waste treatment *i*. Practically, it may be very difficult to identify the residuals as industrial waste and MSW after waste treatment.

Equation (4) can be further rewritten as:

$$\begin{bmatrix} \mathbf{q}_1 \\ \mathbf{q}_2 \end{bmatrix} = \left(\begin{bmatrix} \mathbf{I}_l & \mathbf{O} \\ \mathbf{O} & \mathbf{I}_{m\text{-}l} \end{bmatrix} - \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} \\ \mathbf{SA}_{21} & \mathbf{SA}_{22} \end{bmatrix} \right)^{-1} \begin{bmatrix} \mathbf{f}_1 \\ -\mathbf{f}_2 \end{bmatrix}$$

$$= \left(\begin{bmatrix} \mathbf{I}_l & \mathbf{O} \\ \mathbf{O} & \mathbf{I}_{m\text{-}l} \end{bmatrix} - \begin{bmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} \\ \mathbf{B}_{21} & \mathbf{B}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{C}_{11} & \mathbf{C}_{12} \\ \mathbf{C}_{21} & \mathbf{C}_{22} \end{bmatrix}^{-1} \right)^{-1} \begin{bmatrix} \mathbf{f}_1 \\ -\mathbf{f}_2 \end{bmatrix} \qquad (5)$$

where $\mathbf{I}_l$ and $\mathbf{I}_{m\text{-}l}$ represent the *l*-dimensional and *m*-*l*-dimensional identity matrix. Equation (5) is another version of Nakamura and Kondo (2002). Considering that the outputs of the goods and services depend not only on the G-industry activity level but also on the W-industry activity level, while the outputs of the waste treatment services depend not only on the W-industry activity level but also on the G-industry activity level, we have the following relationship between commodities and industry output:

$$\begin{bmatrix} \mathbf{q}_1 \\ \mathbf{q}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{C}_{11} & \mathbf{C}_{12} \\ \mathbf{C}_{21} & \mathbf{C}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{g}_1 \\ \mathbf{g}_2 \end{bmatrix} \qquad (6)$$

The matrix component in equation (6), $\mathbf{C}_{21}\mathbf{g}_1$, captures that G-industry produces not only goods but also waste treatment services, while the matrix component,

$\mathbf{C}_{12}\mathbf{g}_2$, captures that W-industry disposes of a waste and then recycles the waste into products.

The important problem is whether critical technological differences exist between ordinary plastic products and recycled plastic products and whether the waste is completely disposed of using available waste treatment technologies. If there is a critical technological difference between a virgin product and a homogeneous recycled product, total intermediate input requirements for the waste recycling activities are overestimated or underestimated. For the distortion problem, recycling technologies exist that have remarkable technological differences from the virgin products in the real world, although technological differences between them are not significant, at least in the present commodity technology model. In addition, if G-industry disposes of the waste without using waste treatment technologies[2], equation (6) results in an overestimation of total intermediate input requirements for the waste treatment activities by G-industry.

The former problem can be lessened by appropriately setting the recycling activity levels of W-industry at zero, while the latter problem can be relaxed by appropriately setting the waste treatment activity levels of G-industry, which does not use the defined waste treatment technologies, at zero. The special case, completely abandoning these problems, can be expressed as:

$$\begin{bmatrix} \mathbf{q}_1 \\ \mathbf{q}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{C}_{11} & \mathbf{O} \\ \mathbf{O} & \mathbf{C}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{g}_1 \\ \mathbf{g}_2 \end{bmatrix}, \qquad (6)'$$

[2] In the real world, there is a waste disposed of using production technologies for primary and secondary products. The typical example is the waste treatment of a cement products industry.

following the commodity technology assumption. Without a loss of generality, equation (6) can be used in the formulation.

Substituting the inverse of equation (6) into (5) finally yields:

$$\begin{bmatrix} \mathbf{g}_1 \\ \mathbf{g}_2 \end{bmatrix} = \left(\begin{bmatrix} \mathbf{I}_l & \mathbf{O} \\ \mathbf{O} & \mathbf{I}_{m-l} \end{bmatrix} - \begin{bmatrix} \mathbf{C}_{11} & \mathbf{C}_{12} \\ \mathbf{C}_{21} & \mathbf{C}_{22} \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} \\ \mathbf{B}_{21} & \mathbf{B}_{22} \end{bmatrix} \right)^{-1} \begin{bmatrix} \mathbf{C}_{11} & \mathbf{C}_{12} \\ \mathbf{C}_{21} & \mathbf{C}_{22} \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{f}_1 \\ -\mathbf{f}_2 \end{bmatrix}. \quad (7)$$

The above-described model considers the case of a single region. Next, we formulate a two-region input-output model that definitely considers waste treatment technologies. As with the ordinary production technologies, we assume, for simplicity, that the waste treatment technologies can be well defined across industries and regions. The difference in the single-region model is that the multi-region model for waste analysis requires intra- and interregional trade coefficients for waste to be introduced within the conventional model for goods and services.

Let us define the extended product-mix matrix for the regions *r* and *s* as:

$$\begin{bmatrix} \mathbf{q}^r \\ \mathbf{q}^s \end{bmatrix} = \begin{bmatrix} \mathbf{C}^r & \mathbf{O} \\ \mathbf{O} & \mathbf{C}^s \end{bmatrix} \begin{bmatrix} \mathbf{g}^r \\ \mathbf{g}^s \end{bmatrix} \quad (8)$$

where

$$\mathbf{q}^{r(s)} = \begin{bmatrix} \mathbf{q}_1^{r(s)} \\ \mathbf{q}_2^{r(s)} \end{bmatrix}, \ \mathbf{C}^{r(s)} = \begin{bmatrix} \mathbf{C}_{11}^{r(s)} & \mathbf{C}_{12}^{r(s)} \\ \mathbf{C}_{21}^{r(s)} & \mathbf{C}_{22}^{r(s)} \end{bmatrix} \text{ and } \mathbf{g}^{r(s)} = \begin{bmatrix} \mathbf{g}_1^{r(s)} \\ \mathbf{g}_2^{r(s)} \end{bmatrix},$$

and the extended technical coefficient matrix and the geographical input coefficient matrix as:

$$\begin{bmatrix} \mathbf{A}^r & \mathbf{O} \\ \mathbf{O} & \mathbf{A}^s \end{bmatrix} \text{ with } \mathbf{A}^{r(s)} = \begin{bmatrix} \mathbf{A}_{11}^{r(s)} & \mathbf{A}_{12}^{r(s)} \\ \mathbf{A}_{21}^{r(s)} & \mathbf{A}_{22}^{r(s)} \end{bmatrix}. \tag{9}$$

and

$$\mathbf{A}^* = \begin{bmatrix} \mathbf{A}^{rr} & \mathbf{A}^{rs} \\ \mathbf{A}^{sr} & \mathbf{A}^{ss} \end{bmatrix} \text{ with } \mathbf{A}^{ij} = \begin{bmatrix} \mathbf{A}_{11}^{ij} & \mathbf{A}_{12}^{ij} \\ \mathbf{A}_{21}^{ij} & \mathbf{A}_{22}^{ij} \end{bmatrix}, \tag{10}$$

for $i = r,s; \ j = r,s$, respectively, where $\mathbf{A}_{11}^{ij}$ and $\mathbf{A}_{12}^{ij}$ represent the goods and services from region *i* required for the production activities and the waste treatment activities in region *j* and $\mathbf{A}_{21}^{ij}$ and $\mathbf{A}_{22}^{ij}$ represent the industrial waste generated by the production activities and the waste treatment activities in region *j* and flowing into region *i*. If, following the regional waste allocation matrix, the wastes flowing into the region *i* are disposed of at the waste treatment plants in region *i*, the intra- and interregional make-use balance for goods and waste can be formulated as:

$$\begin{bmatrix} \mathbf{q}_1^r \\ \mathbf{q}_2^r \\ \mathbf{q}_1^s \\ \mathbf{q}_2^s \end{bmatrix} = \begin{bmatrix} \mathbf{A}_{11}^{rr} & \mathbf{A}_{12}^{rr} & \mathbf{A}_{11}^{rs} & \mathbf{A}_{12}^{rs} \\ \mathbf{S}^r\mathbf{A}_{21}^{rr} & \mathbf{S}^r\mathbf{A}_{22}^{rr} & \mathbf{S}^r\mathbf{A}_{21}^{rs} & \mathbf{S}^r\mathbf{A}_{22}^{rs} \\ \mathbf{A}_{11}^{sr} & \mathbf{A}_{12}^{sr} & \mathbf{A}_{11}^{ss} & \mathbf{A}_{12}^{ss} \\ \mathbf{S}^s\mathbf{A}_{21}^{sr} & \mathbf{S}^s\mathbf{A}_{22}^{sr} & \mathbf{S}^s\mathbf{A}_{21}^{ss} & \mathbf{S}^s\mathbf{A}_{22}^{ss} \end{bmatrix} \begin{bmatrix} \mathbf{q}_1^r \\ \mathbf{q}_2^r \\ \mathbf{q}_1^s \\ \mathbf{q}_2^s \end{bmatrix} + \begin{bmatrix} \mathbf{f}_1^r \\ -\mathbf{f}_2^r \\ \mathbf{f}_1^s \\ -\mathbf{f}_2^s \end{bmatrix}$$

$$= \left(\mathbf{I}_m - \begin{bmatrix} \mathbf{A}_{11}^{rr} & \mathbf{A}_{12}^{rr} & \mathbf{A}_{11}^{rs} & \mathbf{A}_{12}^{rs} \\ \mathbf{S}^r\mathbf{A}_{21}^{rr} & \mathbf{S}^r\mathbf{A}_{22}^{rr} & \mathbf{S}^r\mathbf{A}_{21}^{rs} & \mathbf{S}^r\mathbf{A}_{22}^{rs} \\ \mathbf{A}_{11}^{sr} & \mathbf{A}_{12}^{sr} & \mathbf{A}_{11}^{ss} & \mathbf{A}_{12}^{ss} \\ \mathbf{S}^s\mathbf{A}_{21}^{sr} & \mathbf{S}^s\mathbf{A}_{22}^{sr} & \mathbf{S}^s\mathbf{A}_{21}^{ss} & \mathbf{S}^s\mathbf{A}_{22}^{ss} \end{bmatrix} \right)^{-1} \begin{bmatrix} \mathbf{f}_1^r \\ -\mathbf{f}_2^r \\ \mathbf{f}_1^s \\ -\mathbf{f}_2^s \end{bmatrix} \qquad (11)$$

and

$$\begin{bmatrix} \mathbf{g}_1^r \\ \mathbf{g}_2^r \\ \mathbf{g}_1^s \\ \mathbf{g}_2^s \end{bmatrix} = \begin{bmatrix} \mathbf{C}_{11}^r & \mathbf{C}_{21}^r & \multicolumn{2}{c}{\mathbf{O}} \\ \mathbf{C}_{12}^r & \mathbf{C}_{22}^r & & \\ \multicolumn{2}{c}{\mathbf{O}} & \mathbf{C}_{11}^s & \mathbf{C}_{12}^s \\ & & \mathbf{C}_{21}^s & \mathbf{C}_{22}^s \end{bmatrix}^{-1} \left(\mathbf{I}_m - \begin{bmatrix} \mathbf{A}_{11}^{rr} & \mathbf{A}_{12}^{rr} & \mathbf{A}_{11}^{rs} & \mathbf{A}_{12}^{rs} \\ \mathbf{S}^r\mathbf{A}_{21}^{rr} & \mathbf{S}^r\mathbf{A}_{22}^{rr} & \mathbf{S}^r\mathbf{A}_{21}^{rs} & \mathbf{S}^r\mathbf{A}_{22}^{rs} \\ \mathbf{A}_{11}^{sr} & \mathbf{A}_{12}^{sr} & \mathbf{A}_{11}^{ss} & \mathbf{A}_{12}^{ss} \\ \mathbf{S}^s\mathbf{A}_{21}^{sr} & \mathbf{S}^s\mathbf{A}_{22}^{sr} & \mathbf{S}^s\mathbf{A}_{21}^{ss} & \mathbf{S}^s\mathbf{A}_{22}^{ss} \end{bmatrix} \right)^{-1} \begin{bmatrix} \mathbf{f}_1^r \\ -\mathbf{f}_2^r \\ \mathbf{f}_1^s \\ -\mathbf{f}_2^s \end{bmatrix} \qquad (12)$$

where $\mathbf{I}_m$ is a *m*-dimensional identity matrix (see Oosterhaven (1984) for an exposition on the rectangular interregional model). In this case, it holds that

$$\begin{bmatrix} \mathbf{B}_{11}^{rr} & \mathbf{B}_{12}^{rr} & \mathbf{B}_{11}^{rs} & \mathbf{B}_{12}^{rs} \\ \mathbf{B}_{21}^{rr} & \mathbf{B}_{22}^{rr} & \mathbf{B}_{21}^{rs} & \mathbf{B}_{22}^{rs} \\ \mathbf{B}_{11}^{sr} & \mathbf{B}_{12}^{sr} & \mathbf{B}_{11}^{ss} & \mathbf{B}_{12}^{ss} \\ \mathbf{B}_{21}^{sr} & \mathbf{B}_{22}^{sr} & \mathbf{B}_{21}^{ss} & \mathbf{B}_{22}^{ss} \end{bmatrix} = \begin{bmatrix} \mathbf{A}_{11}^{rr} & \mathbf{A}_{12}^{rr} & \mathbf{A}_{11}^{rs} & \mathbf{A}_{12}^{rs} \\ \mathbf{S}^r\mathbf{A}_{21}^{rr} & \mathbf{S}^r\mathbf{A}_{22}^{rr} & \mathbf{S}^r\mathbf{A}_{21}^{rs} & \mathbf{S}^r\mathbf{A}_{22}^{rs} \\ \mathbf{A}_{11}^{sr} & \mathbf{A}_{12}^{sr} & \mathbf{A}_{11}^{ss} & \mathbf{A}_{12}^{ss} \\ \mathbf{S}^s\mathbf{A}_{21}^{sr} & \mathbf{S}^s\mathbf{A}_{22}^{sr} & \mathbf{S}^s\mathbf{A}_{21}^{ss} & \mathbf{S}^s\mathbf{A}_{22}^{ss} \end{bmatrix} \begin{bmatrix} \mathbf{C}_{11}^r & \mathbf{C}_{21}^r & \multicolumn{2}{c}{\mathbf{O}} \\ \mathbf{C}_{12}^r & \mathbf{C}_{22}^r & & \\ \multicolumn{2}{c}{\mathbf{O}} & \mathbf{C}_{11}^s & \mathbf{C}_{12}^s \\ & & \mathbf{C}_{21}^s & \mathbf{C}_{22}^s \end{bmatrix} \qquad (13)$$

from the commodity technology assumption where $\mathbf{B}_{11}^{ij}$ and $\mathbf{B}_{12}^{ij}$ represent the goods and services from region *i* required for the G-industries and the W-industries in region j, and $\mathbf{B}_{21}^{ij}$ and $\mathbf{B}_{22}^{ij}$ represent the industrial waste generated by the G-industries and the W-industries in region j and flowing into region i.

If we are interested in the well-known Chenery-Moses formulation of equation (9), partitioning the standard domestic trade coefficient matrix from region i to region j, $\mathbf{T}^{ij}\,(i=r,s;\, j=r,s)$ into two sub-matrices $\mathbf{T}_1^{ij}$ and $\mathbf{T}_2^{ij}$ showing the interregional *goods inflow* and *waste outflow* from region i to region j, respectively, yields:

$$\mathbf{T}^{ij}=\left[\begin{array}{c|c}\mathbf{T}_1^{ij} & \mathbf{O}\\ \hline \mathbf{O} & \mathbf{T}_2^{ij}\end{array}\right]=\left[\begin{array}{ccc|ccc} t_1^{ij} & \cdots & 0 & 0 & \cdots & 0\\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots\\ 0 & \cdots & t_l^{ij} & 0 & \cdots & 0\\ \hline 0 & \cdots & 0 & t_{l+1}^{ij} & \cdots & 0\\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots\\ 0 & \cdots & 0 & 0 & \cdots & t_m^{ij}\end{array}\right]. \tag{14}$$

Then, we have the following geographical input coefficient matrix from equations (9) and (10),

$$\mathbf{A}^*=\begin{bmatrix}\mathbf{A}^{rr} & \mathbf{A}^{rs}\\ \mathbf{A}^{sr} & \mathbf{A}^{ss}\end{bmatrix}=\begin{bmatrix}\mathbf{T}^{rr} & \mathbf{T}^{rs}\\ \mathbf{T}^{sr} & \mathbf{T}^{ss}\end{bmatrix}\begin{bmatrix}\mathbf{A}^{r} & \mathbf{O}\\ \mathbf{O} & \mathbf{A}^{s}\end{bmatrix} \text{ with } \mathbf{A}^{ij}=\begin{bmatrix}\mathbf{T}_1^{ij}\mathbf{A}_{11}^{j} & \mathbf{T}_1^{ij}\mathbf{A}_{12}^{j}\\ \mathbf{S}^i\mathbf{T}_2^{ij}\mathbf{A}_{21}^{j} & \mathbf{S}^i\mathbf{T}_2^{ij}\mathbf{A}_{22}^{j}\end{bmatrix}, \tag{15}$$

where $\mathbf{S}^i\mathbf{T}_2^{ij}\mathbf{A}_{21}^{j}$ and $\mathbf{S}^i\mathbf{T}_2^{ij}\mathbf{A}_{22}^{j}$ especially represent the waste generated by the production activities and the waste treatment activities in region j and flowing into the waste treatment plants in region i. Equation (15) is very helpful in discussing the relationship between the transportation policy and the waste management policy. The Chenery-Moses quantity model can be easily derived from equations (11) and (12).

Focusing on equation (11), the waste disposal levels in region *s*, $\mathbf{q}_2^s$, largely depend on both the disposed waste generated in its own region, $\mathbf{S}^s\mathbf{A}_{21}^{ss}\mathbf{q}_1^s$ and $\mathbf{S}^s\mathbf{A}_{22}^{ss}\mathbf{q}_2^s$, and the disposed waste redistributed from another region *r*, $\mathbf{S}^s\mathbf{A}_{21}^{sr}\mathbf{q}_1^r$ and $\mathbf{S}^s\mathbf{A}_{22}^{sr}\mathbf{q}_2^r$. Furthermore, the sub-matrix $\mathbf{C}_{12}^s$ of equation (12) states that the waste redistributed from region *r* to *s* brings about the reproduced commodities after the treatment activity by G-industries and W-industries, as waste-disposal (waste-recycling) businesses. Mathematically, defining equations (11) and (12) as:

$$\begin{bmatrix} \mathbf{q}_1^r \\ \mathbf{q}_2^r \\ \hline \mathbf{q}_1^s \\ \mathbf{q}_2^s \end{bmatrix} = \left[\begin{array}{cc|cc} \mathbf{L}_{11}^{rr} & \mathbf{L}_{12}^{rr} & \mathbf{L}_{11}^{rs} & \mathbf{L}_{12}^{rs} \\ \mathbf{L}_{21}^{rr} & \mathbf{L}_{22}^{rr} & \mathbf{L}_{21}^{rs} & \mathbf{L}_{22}^{rs} \\ \hline \mathbf{L}_{11}^{sr} & \mathbf{L}_{12}^{sr} & \mathbf{L}_{11}^{ss} & \mathbf{L}_{12}^{ss} \\ \mathbf{L}_{21}^{sr} & \mathbf{L}_{22}^{sr} & \mathbf{L}_{21}^{ss} & \mathbf{L}_{22}^{ss} \end{array}\right] \begin{bmatrix} \mathbf{f}_1^r \\ -\mathbf{f}_2^r \\ \hline \mathbf{f}_1^s \\ -\mathbf{f}_2^s \end{bmatrix}, \tag{14}$$

and

$$\begin{bmatrix} \mathbf{g}_1^r \\ \mathbf{g}_2^r \\ \hline \mathbf{g}_1^s \\ \mathbf{g}_2^s \end{bmatrix} = \left[\begin{array}{cc|cc} \mathbf{M}_{11}^{rr} & \mathbf{M}_{12}^{rr} & \mathbf{M}_{11}^{rs} & \mathbf{M}_{12}^{rs} \\ \mathbf{M}_{21}^{rr} & \mathbf{M}_{22}^{rr} & \mathbf{M}_{21}^{rs} & \mathbf{M}_{22}^{rs} \\ \hline \mathbf{M}_{11}^{sr} & \mathbf{M}_{12}^{sr} & \mathbf{M}_{11}^{ss} & \mathbf{M}_{12}^{ss} \\ \mathbf{M}_{21}^{sr} & \mathbf{M}_{22}^{sr} & \mathbf{M}_{21}^{ss} & \mathbf{M}_{22}^{ss} \end{array}\right] \begin{bmatrix} \mathbf{f}_1^r \\ -\mathbf{f}_2^r \\ \hline \mathbf{f}_1^s \\ -\mathbf{f}_2^s \end{bmatrix}, \tag{15}$$

we can finally formulate the following spatial repercussion effects for region *s*:

$\overline{\mathbf{q}}_1^s = \mathbf{L}_{11}^{sr}\mathbf{f}_1^r + \mathbf{L}_{11}^{ss}\mathbf{f}_1^s$, $\overline{\mathbf{q}}_2^s = \mathbf{L}_{21}^{sr}\mathbf{f}_1^r + \mathbf{L}_{21}^{ss}\mathbf{f}_1^s$, $\overline{\mathbf{g}}_1^s = \mathbf{M}_{11}^{sr}\mathbf{f}_1^r + \mathbf{M}_{11}^{ss}\mathbf{f}_1^s$, and

$\overline{\mathbf{g}}_2^s = \mathbf{M}_{21}^{sr}\mathbf{f}_1^r + \mathbf{M}_{21}^{ss}\mathbf{f}_1^s$ where $\overline{\mathbf{q}}_1^s$ represents the *l*-dimensional vector showing the commodity outputs in region *s* induced by the final goods production in both regions *r* and *s*; $\overline{\mathbf{q}}_2^s$ the (*m*-*l*)-dimensional vector showing the waste disposal service outputs in region *s* induced by the final demand in both regions *r* and *s*; $\overline{\mathbf{g}}_1^s$ the *l*-dimensional vector showing the commodity outputs from G-industries located in region *s* induced by the final demand in both regions *r* and *s*; $\overline{\mathbf{g}}_2^s$ the (*m*-*l*)-dimensional vector showing the waste disposal service outputs from W-industries located in region *s* induced by the final demand in both regions *r* and *s*; and so forth. The waste disposal service outputs from G-industries, and the reproduced (recycled) commodity outputs from W-industries located in region *s*, are described by $\mathbf{C}_{12}^s\overline{\mathbf{g}}_1^s = \mathbf{C}_{12}^s\mathbf{M}_{11}^{sr}\mathbf{f}_1^r + \mathbf{C}_{12}^s\mathbf{M}_{11}^{ss}\mathbf{f}_1^s$ and $\mathbf{C}_{21}^s\overline{\mathbf{g}}_2^s = \mathbf{C}_{21}^s\mathbf{M}_{21}^{sr}\mathbf{f}_1^r + \mathbf{C}_{21}^s\mathbf{M}_{21}^{ss}\mathbf{f}_1^s$, respectively. However, the measurement method relies on the strong commodity technology assumption that the commodity in question and a recycled homogeneous commodity use the same production technology.[3]

Policy makers engaged in the waste management problem, may be concerned with the differences in the regional waste treatment activity levels in cases where industrial wastes generated by firms located in the region in question are completely disposed of within the region, and in the actual case where industrial wastes generated by firms located in the region in question are partially shipped to

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[3] This sentence may be vague. The same technology implies that the intermediate inputs required for the ordinary commodity production using virgin materials coincide with those required for the commodity reproduction using wastes. The assumption is obviously false if, for example, ordinary paper from virgin pulp is compared with recycled paper from waste newspapers. However, in comparing ordinary light and heavy oil from crude oil with the recycled oil from waste plastics, it is possible to use the assumption to some extent. In addition to the shortcomings of the assumption presented by Professor Louis de Mesnard (2004), the definition problem is also fundamental to waste management analysis.

and disposed of in other regions. In the former case, the complete intra-regional treatment case, the waste re-distribution models should be modified in the Isard style only for goods and services:

$$\begin{bmatrix} \mathbf{q}_1^r \\ \mathbf{q}_2^r \\ \mathbf{q}_1^s \\ \mathbf{q}_2^s \end{bmatrix} = \begin{bmatrix} \mathbf{A}_{11}^{rr} & \mathbf{A}_{12}^{rr} & \mathbf{A}_{11}^{rs} & \mathbf{A}_{12}^{rs} \\ \mathbf{S}^r\mathbf{A}_{21}^r & \mathbf{S}^r\mathbf{A}_{22}^r & \mathbf{O} & \mathbf{O} \\ \mathbf{A}_{11}^{sr} & \mathbf{A}_{12}^{sr} & \mathbf{A}_{11}^{ss} & \mathbf{A}_{12}^{ss} \\ \mathbf{O} & \mathbf{O} & \mathbf{S}^s\mathbf{A}_{21}^s & \mathbf{S}^s\mathbf{A}_{22}^s \end{bmatrix} \begin{bmatrix} \mathbf{q}_1^r \\ \mathbf{q}_2^r \\ \mathbf{q}_1^s \\ \mathbf{q}_2^s \end{bmatrix} + \begin{bmatrix} \mathbf{f}_1^r \\ -\mathbf{f}_2^r \\ \mathbf{f}_1^s \\ -\mathbf{f}_2^s \end{bmatrix}$$

$$= \left(\mathbf{I}_m - \begin{bmatrix} \mathbf{A}_{11}^{rr} & \mathbf{A}_{12}^{rr} & \mathbf{A}_{11}^{rs} & \mathbf{A}_{12}^{rs} \\ \mathbf{S}^r\mathbf{A}_{21}^r & \mathbf{S}^r\mathbf{A}_{22}^r & \mathbf{O} & \mathbf{O} \\ \mathbf{A}_{11}^{sr} & \mathbf{A}_{12}^{sr} & \mathbf{A}_{11}^{ss} & \mathbf{A}_{12}^{ss} \\ \mathbf{O} & \mathbf{O} & \mathbf{S}^s\mathbf{A}_{21}^s & \mathbf{S}^s\mathbf{A}_{22}^s \end{bmatrix} \right)^{-1} \begin{bmatrix} \mathbf{f}_1^r \\ -\mathbf{f}_2^r \\ \mathbf{f}_1^s \\ -\mathbf{f}_2^s \end{bmatrix}$$

$$= \left[\begin{array}{cc|cc} \mathbf{L}_{11}^{rr*} & \mathbf{L}_{12}^{rr*} & \mathbf{L}_{11}^{rs*} & \mathbf{L}_{12}^{rs*} \\ \mathbf{L}_{21}^{rr*} & \mathbf{L}_{22}^{rr*} & \mathbf{L}_{21}^{rs*} & \mathbf{L}_{22}^{rs*} \\ \hline \mathbf{L}_{11}^{sr*} & \mathbf{L}_{12}^{sr*} & \mathbf{L}_{11}^{ss*} & \mathbf{L}_{12}^{ss*} \\ \mathbf{L}_{21}^{sr*} & \mathbf{L}_{22}^{sr*} & \mathbf{L}_{21}^{ss*} & \mathbf{L}_{22}^{ss*} \end{array} \right] \left[\begin{array}{c} \mathbf{f}_1^r \\ -\mathbf{f}_2^r \\ \hline \mathbf{f}_1^s \\ -\mathbf{f}_2^s \end{array} \right], \tag{16}$$

and

$$\begin{bmatrix} \mathbf{g}_1^r \\ \mathbf{g}_2^r \\ \mathbf{g}_1^s \\ \mathbf{g}_2^s \end{bmatrix} = \begin{bmatrix} \mathbf{C}_{11}^r & \mathbf{C}_{21}^r & & \\ \mathbf{C}_{12}^r & \mathbf{C}_{22}^r & \multicolumn{2}{c}{\mathbf{O}} \\ & & \mathbf{C}_{11}^s & \mathbf{C}_{12}^s \\ \multicolumn{2}{c}{\mathbf{O}} & \mathbf{C}_{21}^s & \mathbf{C}_{22}^s \end{bmatrix}^{-1} \left(\mathbf{I}_m - \begin{bmatrix} \mathbf{A}_{11}^{rr} & \mathbf{A}_{12}^{rr} & \mathbf{A}_{11}^{rs} & \mathbf{A}_{12}^{rs} \\ \mathbf{S}^r\mathbf{A}_{21}^r & \mathbf{S}^r\mathbf{A}_{22}^r & \mathbf{O} & \mathbf{O} \\ \mathbf{A}_{11}^{sr} & \mathbf{A}_{12}^{sr} & \mathbf{A}_{11}^{ss} & \mathbf{A}_{12}^{ss} \\ \mathbf{O} & \mathbf{O} & \mathbf{S}^s\mathbf{A}_{21}^s & \mathbf{S}^s\mathbf{A}_{22}^s \end{bmatrix} \right)^{-1} \begin{bmatrix} \mathbf{f}_1^r \\ -\mathbf{f}_2^r \\ \mathbf{f}_1^s \\ -\mathbf{f}_2^s \end{bmatrix}$$

$$
= \left[\begin{array}{cc|cc} \mathbf{M}_{11}^{rr*} & \mathbf{M}_{12}^{rr*} & \mathbf{M}_{11}^{rs*} & \mathbf{M}_{12}^{rs*} \\ \mathbf{M}_{21}^{rr*} & \mathbf{M}_{22}^{rr*} & \mathbf{M}_{21}^{rs*} & \mathbf{M}_{22}^{rs*} \\ \hline \mathbf{M}_{11}^{sr*} & \mathbf{M}_{12}^{sr*} & \mathbf{M}_{11}^{ss*} & \mathbf{M}_{12}^{ss*} \\ \mathbf{M}_{21}^{sr*} & \mathbf{M}_{22}^{sr*} & \mathbf{M}_{21}^{ss*} & \mathbf{M}_{22}^{ss*} \end{array}\right] \left[\begin{array}{c} \mathbf{f}_1^r \\ -\mathbf{f}_2^r \\ \hline \mathbf{f}_1^s \\ -\mathbf{f}_2^s \end{array}\right], \quad (17)
$$

, respectively. In the case of complete intra-regional treatment, the following spatial repercussion effects for region *s* can be written as $\overline{\mathbf{q}}_1^{s*} = \mathbf{L}_{11}^{sr*}\mathbf{f}_1^r + \mathbf{L}_{11}^{ss*}\mathbf{f}_1^s$, $\overline{\mathbf{q}}_2^{s*} = \mathbf{L}_{21}^{sr*}\mathbf{f}_1^r + \mathbf{L}_{21}^{ss*}\mathbf{f}_1^s$, $\overline{\mathbf{g}}_1^{s*} = \mathbf{M}_{11}^{sr*}\mathbf{f}_1^r + \mathbf{M}_{11}^{ss*}\mathbf{f}_1^s$, and $\overline{\mathbf{g}}_2^{s*} = \mathbf{M}_{21}^{sr*}\mathbf{f}_1^r + \mathbf{M}_{21}^{ss*}\mathbf{f}_1^s$ from equations (16) and (17). The repercussion effects can be interpreted similarly to those from equations (14) and (15).

Defining the (*m*-*l*)-dimensional pollution intensity row vector showing the CO_2 emission coefficient for waste treatment activity *j* in region *r* and *s* as $\boldsymbol{\alpha}^r$ and $\boldsymbol{\alpha}^s$, respectively, we can formulate the pollution emissions from the waste treatment activities induced by the above-mentioned spatial repercussion effects in both cases and estimate the regional pollution concentration differences between the complete intra-regional treatments and the actual ones using the following equation:

$$
\begin{bmatrix} \Delta Q_c^r \\ \Delta Q_c^s \end{bmatrix} = \begin{bmatrix} \boldsymbol{\alpha}^r\left(\mathbf{L}_{21}^{rr} - \mathbf{L}_{21}^{rr*}\right) & \boldsymbol{\alpha}^r\left(\mathbf{L}_{21}^{rs} - \mathbf{L}_{21}^{rs*}\right) \\ \boldsymbol{\alpha}^s\left(\mathbf{L}_{21}^{sr} - \mathbf{L}_{21}^{sr*}\right) & \boldsymbol{\alpha}^s\left(\mathbf{L}_{21}^{ss} - \mathbf{L}_{21}^{ss*}\right) \end{bmatrix} \begin{bmatrix} \mathbf{f}_1^r \\ \mathbf{f}_2^s \end{bmatrix} \quad (18)
$$

In addition, defining the (*m*-*l*)-dimensional operation row vector $\mathbf{e}$ as having only the *n*-dimensional column vector in which the element for waste landfill is equal to one and the other elements are all equal to zero, the regional waste landfill differences between the two cases can be estimated by:

$$\begin{bmatrix} \Delta Q_w^r \\ \Delta Q_w^s \end{bmatrix} = \begin{bmatrix} \mathbf{e}(\mathbf{L}_{21}^{rr} - \mathbf{L}_{21}^{rr*}) & \mathbf{e}(\mathbf{L}_{21}^{rs} - \mathbf{L}_{21}^{rs*}) \\ \mathbf{e}(\mathbf{L}_{21}^{sr} - \mathbf{L}_{21}^{sr*}) & \mathbf{e}(\mathbf{L}_{21}^{ss} - \mathbf{L}_{21}^{ss*}) \end{bmatrix} \begin{bmatrix} \mathbf{f}_1^r \\ \mathbf{f}_2^s \end{bmatrix}. \tag{19}$$

3. Data

The spatial repercussion effects of regional waste recycling were measured using both the 1995 intra-regional and interregional make-use table of primary and secondary products in monetary base and the 1995 intra-regional and interregional make-use table of industrial waste in physical base estimated by the rich waste survey data, both of which the local government collects regularly. The waste make-use table shows the intra- and interregional physical redistribution flow among nine regions of Japan (Hokkaido (1), Tohoku (2), Kanto (3), Chubu (4), Kinki (5), Chugoku (6), Shikoku (7), Kyusyu (8), and Okinawa (9)) (see Kagawa et al. (2004) for a detailed explanation).

Although the waste make-use data in Kagawa et al. (2004) did not consider the waste treatment technologies and waste treatment service industries specifically, the present study defined the waste treatment sectors as Incineration (J43), Dehydration (J44), Sun-drying (J45), Machine-drying (J46), Oil-water separation (J47), Waste-neutralizing (J48), Waste-crushing (J49), Waste-compressing (J50), Waste-separating and classifying (J51), Waste-melting (J52), Waste-cutting (J53), Waste-composting (J54), Waste landfill (J55), Other waste treatments (J56) using industry-to-activity correspondence.[4] The troublesome computation of intermediate material and service inputs for the waste treatment activities was resolved using energy and materials utilization data obtained from representative waste treatment plants in the region in question. The energy and material inputs were estimated by multiplying monetary energy and material inputs per unit waste disposal at the representative waste treatment plant by actual waste disposal levels at the same waste treatment plants in the same region.[5] The service, labor and capital inputs were completely ignored. Furthermore, the interregional shipments of energy and materials for waste treatments were estimated using the interregional trade coefficient matrix for goods and services production obtained from the Chenery-Moses formulation.

The present study focused on 21 industrial wastes with negative prices. Marketable industrial wastes with positive prices and municipal wastes generated by direct government and household disposal behavior were excluded from the framework. The industrial waste sectors and the commodity and industry sectors were defined as shown in Tables 1 and 2, and the 14 waste treatments by 21 industrial wastes allocation matrices for the nine regions of Japan were generated.

For the CO_2 emission intensity vector of the waste treatment activities mentioned above, knowledge of materials and primary and secondary energy requirements for waste treatment was necessary. Waste input patterns and

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[4] More precisely, the waste treatment service industries were defined by focusing on the amount of main waste disposals in physical base.
[5] We considered chemical products, coal and oil products, and electricity as the material and energy inputs for the waste treatment activities.

end-of-pipe pollution abatement technologies in the waste treatment plant remarkably affect material and energy efficiency and carbon emissions. The present study focused on the material and energy efficiency of representative waste treatment plans in the region in question and estimated the monetary (physical) intermediate inputs for the waste treatment activities by multiplying the monetary (physical) material and energy requirements such as heavy oil, caustic soda, electricity, per unit treatment activity levels of the representative plans by the actual activity levels of the other existing plants in the region. The carbon emission coefficients for the waste treatment activities were estimated by multiplying the monetary intermediate inputs by CO_2 emission coefficients for commodity sectors provided by Nansai et al. (2003).

The next section presents the major findings from equations (1)-(4).

[**Table 1** here]

[**Table 2** here]

4. Empirical Findings

4.1. Relationship between regional waste treatment activities and consumption

Although Kagawa et al. (2004) clarified the relationship between the regional waste generation and landfills and regional final consumption by estimating the interregional waste redistribution flow, the research did not explain the relationship between regional waste treatment activities such as waste incineration and waste-melting, and regional final consumptions. To discuss the serious dioxin, heavy metals, and PCB emissions problem and abatement possibilities during final and intermediate waste treatments, it is crucial to provide the objective emission inventories focusing on a spatial life cycle chain. Table 3 shows the regional waste treatment activity levels embodied in regional final consumption for 1995. Table 3 illustrates that the Kanto region had the highest activity level of waste treatments, excluding the waste landfills (65,555 thousand tons), and that the Kinki, Chubu, and Kyusyu regions also show high values, 30,564, 17,108, and 14,892, respectively (see final row).

These results indicate that goods production for intra-regional consumption was the main contributor to the Okinawa, Kanto and Kinki waste treatments, while waste treatment in Shikoku and Chugoku was indirectly supplied by final consumption in the Kanto and Kinki regions. Household consumption behaviors in the Kanto and Kinki regions indirectly brought about the remarkable levels of waste incineration, waste dehydration, waste-crushing, and waste-composting in the Chugoku and Shikoku regions.

Figures 1-4 show the spectra of the waste treatment activity levels directly and indirectly induced by the regional productions of household goods consumed in the Kanto region. Figure 1 indicates that waste incineration activity in the Chugoku and Kanto regions indirectly largely depends on the household consumption of food and tobacco products, printing and publishing, wholesale and retail service, and services for person, produced and consumed in Kanto. The production activities of food and tobacco products and wholesale and retail service in the Kanto region requires food and tobacco products from the Chugoku and Kanto regions and the large quantity of waste residuals from animals and plants generated through the manufacturing processes was disposed of by incineration in both regions. Although the manufacturing processes also induced the indirect generation of dung and urine from animals through the production of livestock, such as hogs and beef, the waste was completely shipped to landfills, as reported in Kagawa et al. (2004).

Printing and publishing activities in the Kanto region indirectly promoted the production of pulp and paper products especially in the Shikoku region, and consequently induced paper sludge production from the manufacturing processes. Spectrum analysis reveals that the large quantity of paper sludge relating to the households in Kanto was disposed of by the waste dehydration and incineration in the Shikoku region (see Figure 2). Figure 3 also shows that the production activities of wholesale and retail trade and transportation services consumed in Kanto, contributed to the waste-crushing activities in the Chugoku and Shikoku regions mainly thorough the generation of waste plastics and other construction waste. Railroad maintenance work led to the waste-crushing treatment of the other construction waste such as gravel and concrete.

Policy makers should recognize that the household consumption activities in the Kanto region remarkably affected various waste treatments in the other regions.

The waste treatment activities can be hazardous, but sometimes provide beneficial new disposal and recycling businesses. Although the vertical axes of Figures 1-4 may be interpreted as hazardous indicators considering the proportional pollution emissions, the treatment activities create new recycling products such as cement materials from waste incineration activity and composts from waste composting.

The consumption activity of food and tobacco and pulp and paper products in Kanto *potentially* contributed to the compost-recycling in the Chugoku and Shikoku regions from the point of view of regional recycling promotion (see Figure 4). The augmented product-mix sub-matrices $\mathbf{C}_{12}$ and $\mathbf{C}_{22}$ of equation (6) provide information about recycled product outputs and waste treatment services produced by W-industries, however, the $\mathbf{C}_{12}$ matrix could not be estimated due to the lack of waste statistics on outputs and reliable market prices of the recycled products and the economic benefits from the regional recycling activities could not be evaluated. For natural resource and waste management analysis, it is crucial to obtain the basic prices.

[**Table 3** here]

[**Figure 1** here]

[**Figure 2** here]

[**Figure 3** here]

[**Figure 4** here]

4.2. Regional pollution concentrations by waste treatment activities

Since the waste input-output data *partially* includes the relevant energy and material inputs required to produce the waste treatment services in each region, applying the data to our model enables an accounting of the pollution emissions embodied in the regional waste treatments. Table 4 shows the results. The total CO_2 emissions (t-C) from waste treatment activities, for example in Kanto, indicate that the incineration activity shows the highest value, 108,988 (t-C) of the embodied CO_2 emissions of the waste treatments and account for approximately 40% of the total quantity 274,783 (t-C). The dehydration and waste-crushing activities also show high values, 88,422 and 54,233 (t-C), respectively. Other regions showed similar results because these three activities required larger quantities of electricity, coal and petroleum products, and chemical products than the other treatment activities.

Although the transportation service inputs for the waste treatment activities also affected the embodied CO_2 emissions through vehicle fuel combustion, the present study did not consider the impacts due to a lack of basic data. The CO_2 emissions were underestimated because of a focus on only the treatment processes within the plant. Although if the transportation inputs for waste shipments decreased, the embodied CO_2 emissions also decrease, this condition would not impact the present study as almost all the waste was shipped by truck in 1995.[6] The location advantages of shipping intermediate inputs such as energy and materials may be important, because emissions are contributed through the interregional life cycle chain including the mining processes, manufacturing processes, transportation processes required for energy and material production.

Policy makers engaged in waste management policy-making may be interested in determining the location advantage effects of the *intermediate inputs* required for the waste treatment activities on regional pollution concentrations related to the activities. Figure 5 shows the regional pollution concentration differences between the theoretical complete intra-regional treatment case and the 1995 actual case estimated by equation (18). The numbers of the x- and y-axis denote the regional codes. If the regional pollution concentration in the theoretical case is larger than in the actual case and the value of z-axis is negative, the complete intra-regional treatment was worse for the environment in the region in question than in the actual one because the pollution intensiveness included all interregional feedback effects induced by intermediate inputs for waste treatments.

Figure 5 reveals that the complete waste treatments in Kanto pushed the total CO_2 emission embodied in the waste treatments in Kanto up to 4,067 (t-C). The CO_2 emissions embodied in the incineration and waste-crushing activities increased

[6] The use of other transportation modes such as a container shipping may increase emissions due to fuel combustion, even if the transportation inputs decrease.

by 3,039 (t-C) and 481 (t-C), respectively. Conversely, the complete waste treatments in Kanto contributed to the reduction in total CO_2 emissions in the Tohoku, Chubu, and Kyusyu regions. The complete intra-regional waste treatments in each region totally increased emissions by 600 (t-C) throughout the entire economic system in 1995. Our empirical findings reveal that the complete intra-regional treatment case did not benefit the environment in the Kanto, Kinki, Shikoku, and Okinawa, considering both, regional differences in the waste treatment techniques and overall interregional feedback effects of intermediate inputs for the treatment techniques.

Figure 6 shows the regional waste landfill differences between the theoretical complete intra-regional treatment case and the 1995 actual case estimated by equation (19). For the waste landfills, there are slight differences between the two cases. However, our model captures the fact that local waste landfills embodied final consumption in Kanto, Chubu, and Kinki, controlled by the waste shipments to the other regions, while the Chugoku and Kyusyu regions suffered from the interregional shipments.

[**Table 4** here]

[**Figure 5** here]

[**Figure 6** here]

5. Conclusion

The present paper formulates the multi-regional waste input-output model to measure the site-specific economic benefits and environmental externalities embodied in regional waste treatments and recycling. Although we failed to measure the economic benefits due to a lack of basic data on the product-mix structure of the waste treatment and recycling industries, we succeeded in capturing the waste treatment levels embodied in regional final consumption and the spatial pollution repercussion effects of the regional waste treatments by applying the 1995 intra- and interregional waste input-output data to our model.

In discussing the regional waste management, the closed intra-regional waste treatment system seems to be better for the environment than the open interregional system because unnecessary transportation inputs for waste shipments are eliminated. However, the intra-regional system may require large quantities of energy, material, transportation services for material productions and waste treatment from other regions, possibly leading to increased pollution and waste emissions in the other regions.

Thus, the regional waste management problem is not simple. In fact, our analysis reveals that the completely closed intra-regional treatment system was not better for the environment than the actual open system because of the location advantage of the intermediate energy and chemical product inputs required for regional waste treatment activities and the regional differences in the waste treatments. The present paper completely ignored the transportation service inputs for the actual treatment activities, therefore, the additional pollution emissions induced by the transportation activities may offset the pollution reduction attained by the location advantage and the technological differences. The well-known waste-recycling paradox problem becomes more complicated once we focus on the interregional and international feedback effects of goods and waste, and consider the regional technological differences, regional natural capacities, and the relevant spatial elements from the location theory.[7]

[7] The waste-recycling paradox problem states that the more society tries to dispose of (recycle) a waste, saving virgin materials toward a sustainable economic system, the larger the society's material requirements become in the economic system.

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Table 1. Industrial waste classifications

21 industrial wastes	59 industrial wastes
1. Incineration ash	1. Waste active carbon, waste carbon
	2. Unclassified incineration ash
2. Sludge	3. Sewerage sludge
	4. Other organic sludge
	5. Construction sludge
	6. Waterworks sludge
	7. Other inorganic sludge
3. Waste oil	8. Mineral oil
	9. Oils and fats of animals and plants
	10. Benzine
	11. Unclassified general waste fluid
	12. Waste solvents
	13. Solid oil
	14. Oil mud
	15. Clothes including oil
4. Acid waste fluid	16. Inorganic acid waste fluid
	17. Waste fluid from photographic fixing
	18. Corrosive waste fluid
	19. Strong acid waste fluid
5. Alkaline waste fluid	20. Alkaline waste fluid
	21. Developing solution of photograph
	22. Strong alkaline waste fluid
6. Waste plastics	23. Synthetic fiber
	24. Fiber reinforced plastic
	25. Plastics plasticized by high heat
	26. Resins reinforced high heat
	27. General scrap plastics
	28. Synthetic rubber
	29. Agricultural plastic wastes
	30. Waste tires
7. Waste papers	31. Waste papers
8. Wood chips	32. Wood chips
9. Waste fiber	33. Waste fiber
21 industrial wastes	59 ndustrial wastes
10. Waste residuals of animals and plants	34. Waste residuals of animals
	35. Waste residuals of plants
	36. Unclassified waste residuals of animals and plants
11. Waste rubber	37. Waste rubber
12. Waste metal	38. Waste metal
13. Waste glass and ceramics	39. Waste glasses
	40. Waste ceramics
	41. Plaster board
	42. Asbestos etc.
	43. Unclassified waste glass and ceramics
14. Slag	44. Waste sand
	45. Blast furnace slag
	46. Slag
	47. Unclassified slag
15. Construction wastes	48. Waste concrete
	49. Waste asphalt
	50. Other construction wastes
16. General waste particles	51. General waste particles
17. Dung and urine of animals	52. Dung and urine of animals
18. Infectious medical wastes	53. Infectious medical wastes
19. Solid concrete wastes	54. Solid concrete wastes
20. Others	55. Shredder dust
	56. Unclassified wastes
	57. Melting wastes
21. Cinders	58. Cinders

Table 2. Commodity (industry) classifications (42 sectors)

No.	Commodity (industry) sectors (1-21)	No.	Commodity (industry) sectors (22-42)
1.	Agriculture	22.	Heavy electrical equipment and other electrical devices
2.	Mining	23.	Automobile
3.	Food and tobacco products	24.	Other transportation equipment
4.	Apparel and textile products	25.	Precision instrument
5.	Lumber and wood products	26.	Other manufacturing
6.	Furniture and fixtures	27.	Construction
7.	Pulp, paper and paper products	28.	Electricity supply
8.	Printing and publishing	29.	Gas and heat supply
9.	Chemical and allied products	30.	Water supply and waste processing
10.	Petroleum and coal products	31.	Wholesale and retail
11.	Plastic products	32.	Financial service and insurance
12.	Rubber products	33.	Real estate
13.	Leather and leather products	34.	Transportation service
14.	Stone, clay and glass products	35.	Communication and Broadcasting
15.	Primary metal products	36.	Public administration
16.	Nonferrous metal products	37.	Education and research
17.	Metal products	38.	Medical service and social insurance
18.	Industrial machinery and equipment	39.	Other public service
19.	Office machines and machinery for service industry	40.	Service for business
20.	Household electric appliance	41.	Service for person
21.	Electric and communication equipment	42.	Others

Table 3. Regional waste treatment levels induced by regional final consumption

(thousand tons)

	Regional waste treatment levels (Contributions of regional final consumption to regional waste treatments (%))									
Regional final consumption	Hokkaido	Tohoku	Kanto	Chubu	Kinki	Chugoku	Shikoku	Kyusyu	Okinawa	Totals
Hokkaido	6,041	219	1,095	270	360	126	78	104	2	8,295
	(69.6)	(2.0)	(1.7)	(1.6)	(1.2)	(1.3)	(1.4)	(0.7)	(0.2)	(5.0)
Tohoku	385	7,357	2,022	458	549	218	137	192	3	11,321
	(4.4)	(65.6)	(3.1)	(2.7)	(1.8)	(2.2)	(2.4)	(1.3)	(0.2)	(6.9)
Kanto	1,327	2,480	53,095	3,193	3,774	1,713	1,173	1,663	46	68,463
	(15.3)	(22.1)	(81.0)	(18.7)	(12.3)	(17.1)	(20.5)	(11.2)	(3.8)	(41.5)
Chubu	259	318	2,685	10,382	1,566	567	345	502	7	16,632
	(3.0)	(2.8)	(4.1)	(60.7)	(5.1)	(5.7)	(6.0)	(3.4)	(0.6)	(10.1)
Kinki	380	445	3,111	1,641	21,625	1,100	809	1,142	21	30,275
	(4.4)	(4.0)	(4.7)	(9.6)	(70.8)	(11.0)	(14.1)	(7.7)	(1.8)	(18.4)
Chugoku	97	128	1,095	396	1,124	5,464	258	625	7	9,193
	(1.1)	(1.1)	(1.7)	(2.3)	(3.7)	(54.5)	(4.5)	(4.2)	(0.6)	(5.6)
Shikoku	49	64	568	199	468	224	2,586	215	2	4,376
	(0.6)	(0.6)	(0.9)	(1.2)	(1.5)	(2.2)	(45.1)	(1.4)	(0.2)	(2.7)
Kyusyu	137	192	1,744	517	1,015	580	318	10,372	26	14,900
	(1.6)	(1.7)	(2.7)	(3.0)	(3.3)	(5.8)	(5.5)	(69.6)	(2.2)	(9.0)
Okinawa	9	14	140	52	82	31	26	77	1,080	1,512
	(0.1)	(0.1)	(0.2)	(0.3)	(0.3)	(0.3)	(0.5)	(0.5)	(90.5)	(0.9)
Totals	8,685	11,216	65,555	17,108	30,564	10,022	5,731	14,892	1,194	164,967
	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)

Note: The results do not include the regional waste landfills induced by regional final consumption. See Kagawa et al. (2004) for the redistribution effects. Kagawa et al. (2004) did not consider the regional waste landfills induced by goods and services inputs for the waste treatment activities.

Table 4. Regional CO2 emissions from waste treatment activities

induced by regional final consumption patterns (t-C)

		Regional final consumption patterns									Totals
		Hokkaido	Tohoku	Kanto	Chubu	Kinki	Chugoku	Shikoku	Kyusyu	Okinawa	
Hokkaido	Incineration	9,235	725	2,994	578	858	202	105	316	21	15,034
	Dehydration	7,233	564	1,863	358	534	138	69	189	13	10,962
	Sun-drying	0	0	0	0	0	0	0	0	0	0
	Machine-drying	703	55	183	35	53	14	7	19	1	1,069
	Oil-water separation	20	1	6	1	2	0	0	1	0	32
	Waste-neutralizing	0	0	0	0	0	0	0	0	0	0
	Waste-crushing	5,513	44	189	34	47	13	6	17	1	5,863
	Waste-compressing	27	1	8	2	3	1	0	1	0	42
	Waste-classifying	108	1	3	1	1	0	0	0	0	114
	Waste-melting	191	12	69	15	26	6	3	8	1	330
	Waste-cutting	11	0	2	0	1	0	0	0	0	15
	Waste-composting	1,232	101	359	68	102	25	13	37	2	1,939
	Other treatments	—	—	—	—	—	—	—	—	—	—
	Totals	24,273	1,504	5,676	1,092	1,627	399	203	588	39	35,400
Tohoku	Incineration	450	10,874	6,417	852	1,105	310	159	470	32	20,668
	Dehydration	399	9,023	3,875	497	735	207	102	310	22	15,169
	Sun-drying	0	0	0	0	0	0	0	0	0	0
	Machine-drying	18	405	176	23	33	9	5	14	1	685
	Oil-water separation	2	25	19	3	4	1	1	2	0	56
	Waste-neutralizing	0	0	0	0	0	0	0	0	0	0
	Waste-crushing	49	10,237	727	87	113	37	18	51	4	11,322
	Waste-compressing	1	38	17	3	4	1	1	2	0	65
	Waste-classifying	1	202	12	2	2	1	0	1	0	220
	Waste-melting	12	336	175	29	42	12	6	17	1	630
	Waste-cutting	0	15	7	1	1	0	0	1	0	27
	Waste-composting	54	1,214	562	69	102	27	14	41	3	2,086
	Other treatments	—	—	—	—	—	—	—	—	—	—
	Totals	986	32,369	11,987	1,566	2,141	605	306	909	63	50,928
Kanto	Incineration	2,283	4,388	81,925	5,840	6,769	2,423	1,287	3,781	292	108,988
	Dehydration	1,673	3,034	70,134	3,771	4,575	1,587	823	2,609	215	88,422
	Sun-drying	0	0	3	0	0	0	0	0	0	4
	Machine-drying	80	145	3,305	181	219	76	39	124	10	4,179
	Oil-water separation	10	18	243	25	29	12	6	19	1	363
	Waste-neutralizing	0	0	0	0	0	0	0	0	0	0
	Waste-crushing	266	539	50,768	864	847	303	154	459	34	54,233
	Waste-compressing	12	22	372	31	39	14	7	20	2	520
	Waste-classifying	5	10	991	16	16	6	3	9	1	1,057
	Waste-melting	127	227	3,322	312	403	142	75	210	16	4,834
	Waste-cutting	4	7	120	10	11	4	2	6	0	165
	Waste-composting	231	426	9,498	526	635	214	111	348	28	12,018
	Other treatments	—	—	—	—	—	—	—	—	—	—
	Totals	4,691	8,816	220,681	11,576	13,543	4,781	2,507	7,585	599	274,783

—: not available.

Table 4. (continued)

		Regional final consumption patterns									Totals
		Hokkaido	Tohoku	Kanto	Chubu	Kinki	Chugoku	Shikoku	Kyusyu	Okinawa	
Chubu	Incineration	715	1,190	8,899	17,453	4,262	1,048	547	1,394	119	35,626
	Dehydration	401	681	4,600	12,101	2,517	555	279	752	81	21,965
	Sun-drying	0	0	0	1	0	0	0	0	0	1
	Machine-drying	22	38	260	678	142	31	16	42	5	1,235
	Oil-water separation	3	5	35	50	19	5	3	6	1	125
	Waste-neutralizing	0	0	0	0	0	0	0	0	0	0
	Waste-crushing	101	177	1,200	13,444	566	157	76	192	18	15,931
	Waste-compressing	3	4	31	67	14	4	2	5	0	131
	Waste-classifying	1	3	18	260	8	2	1	3	0	297
	Waste-melting	32	55	392	770	171	50	27	67	6	1,570
	Waste-cutting	1	2	12	26	5	2	1	2	0	51
	Waste-composting	50	87	608	1,572	332	71	36	95	10	2,861
	Other treatments	—	—	—	—	—	—	—	—	—	—
	Totals	1,329	2,242	16,055	46,422	8,036	1,925	988	2,558	240	79,793
Kinki	Incineration	817	1,186	8,111	3,467	28,803	1,748	922	2,064	165	47,283
	Dehydration	477	724	4,936	1,940	27,585	1,103	616	1,337	113	38,831
	Sun-drying	0	0	0	0	1	0	0	0	0	1
	Machine-drying	17	26	176	70	961	39	22	48	4	1,363
	Oil-water separation	3	5	31	14	84	7	4	9	1	157
	Waste-neutralizing	0	0	0	0	0	0	0	0	0	0
	Waste-crushing	109	178	1,223	624	23,841	297	153	318	24	26,768
	Waste-compressing	4	7	44	18	146	10	5	12	1	246
	Waste-classifying	2	3	21	11	464	5	3	6	0	514
	Waste-melting	37	60	397	154	1,045	90	45	105	9	1,942
	Waste-cutting	1	2	15	6	50	3	2	4	0	84
	Waste-composting	65	95	664	270	3,555	149	84	178	15	5,075
	Other treatments	—	—	—	—	—	—	—	—	—	—
	Totals	1,532	2,286	15,618	6,574	86,535	3,451	1,856	4,081	332	122,264
Chugoku	Incineration	297	525	4,048	1,410	3,551	9,816	609	1,510	82	21,848
	Dehydration	193	323	2,698	804	1,654	6,627	324	985	48	13,656
	Sun-drying	0	0	0	0	0	0	0	0	0	0
	Machine-drying	12	20	166	50	103	405	21	61	3	841
	Oil-water separation	1	2	14	5	9	24	2	5	0	62
	Waste-neutralizing	0	0	0	0	0	0	0	0	0	0
	Waste-crushing	41	73	568	184	422	7,481	73	176	11	9,028
	Waste-compressing	1	1	11	3	8	31	2	4	0	61
	Waste-classifying	1	1	9	3	6	146	1	3	0	170
	Waste-melting	9	16	119	38	88	302	18	43	2	636
	Waste-cutting	0	1	4	1	3	12	1	1	0	23
	Waste-composting	26	44	368	115	257	945	52	141	7	1,954
	Other treatments	—	—	—	—	—	—	—	—	—	—
	Totals	581	1,006	8,005	2,613	6,101	25,789	1,103	2,929	153	48,279

—: not available.

Table 4. (continued)

		Regional final consumption patterns									Totals
		Hokkaido	Tohoku	Kanto	Chubu	Kinki	Chugoku	Shikoku	Kyusyu	Okinawa	
Shikoku	Incineration	329	592	5,058	1,458	3,768	1,154	7,532	1,339	129	21,358
	Dehydration	146	250	2,191	610	1,387	450	2,715	602	46	8,398
	Sun-drying	0	0	0	0	0	0	0	0	0	0
	Machine-drying	32	55	478	133	303	98	594	131	10	1,834
	Oil-water separation	0	1	5	2	3	1	9	1	0	22
	Waste-neutralizing	0	0	0	0	0	0	0	0	0	0
	Waste-crushing	9	17	124	40	106	45	3,898	36	2	4,277
	Waste-compressing	0	1	7	2	5	2	13	2	0	30
	Waste-classifying	0	0	2	1	2	1	77	1	0	84
	Waste-melting	5	8	69	19	44	15	114	18	2	294
	Waste-cutting	0	0	2	1	2	1	6	1	0	12
	Waste-composting	31	53	467	134	328	102	621	128	11	1,874
	Other treatments	—	—	—	—	—	—	—	—	—	—
	Totals	552	977	8,403	2,400	5,948	1,869	15,579	2,259	200	38,183
Kyusyu	Incineration	183	332	3,652	833	1,904	1,054	341	13,934	203	22,438
	Dehydration	144	276	2,255	721	1,745	901	305	12,874	107	19,328
	Sun-drying	0	0	0	0	0	0	0	0	0	0
	Machine-drying	5	9	75	24	58	30	10	419	4	633
	Oil-water separation	1	2	13	4	7	5	2	42	0	75
	Waste-neutralizing	0	0	0	0	0	0	0	0	0	0
	Waste-crushing	29	56	591	123	281	162	57	11,692	23	13,014
	Waste-compressing	1	1	13	3	7	4	1	61	1	92
	Waste-classifying	0	1	9	2	5	3	1	233	0	253
	Waste-melting	7	13	118	29	59	35	13	481	6	760
	Waste-cutting	0	1	5	1	2	1	1	24	0	36
	Waste-composting	19	37	333	100	247	127	42	1,771	18	2,693
	Other treatments	—	—	—	—	—	—	—	—	—	—
	Totals	389	728	7,064	1,840	4,315	2,322	773	41,531	362	59,322
Okinawa	Incineration	3	5	57	10	26	8	2	26	1,064	1,201
	Dehydration	3	4	65	9	31	11	3	37	1,342	1,505
	Sun-drying	0	0	0	0	0	0	0	0	0	0
	Machine-drying	0	0	2	0	1	0	0	1	32	36
	Oil-water separation	0	0	1	0	0	0	0	0	5	6
	Waste-neutralizing	0	0	0	0	0	0	0	0	0	0
	Waste-crushing	0	1	8	1	3	1	0	4	939	958
	Waste-compressing	0	0	0	0	0	0	0	0	6	6
	Waste-classifying	0	0	0	0	0	0	0	0	19	19
	Waste-melting	0	0	2	0	1	0	0	1	43	49
	Waste-cutting	0	0	0	0	0	0	0	0	2	2
	Waste-composting	1	1	14	2	6	2	1	7	226	259
	Other treatments	—	—	—	—	—	—	—	—	—	—
	Totals	7	11	149	22	68	22	6	76	3,678	4,041

—: not available.

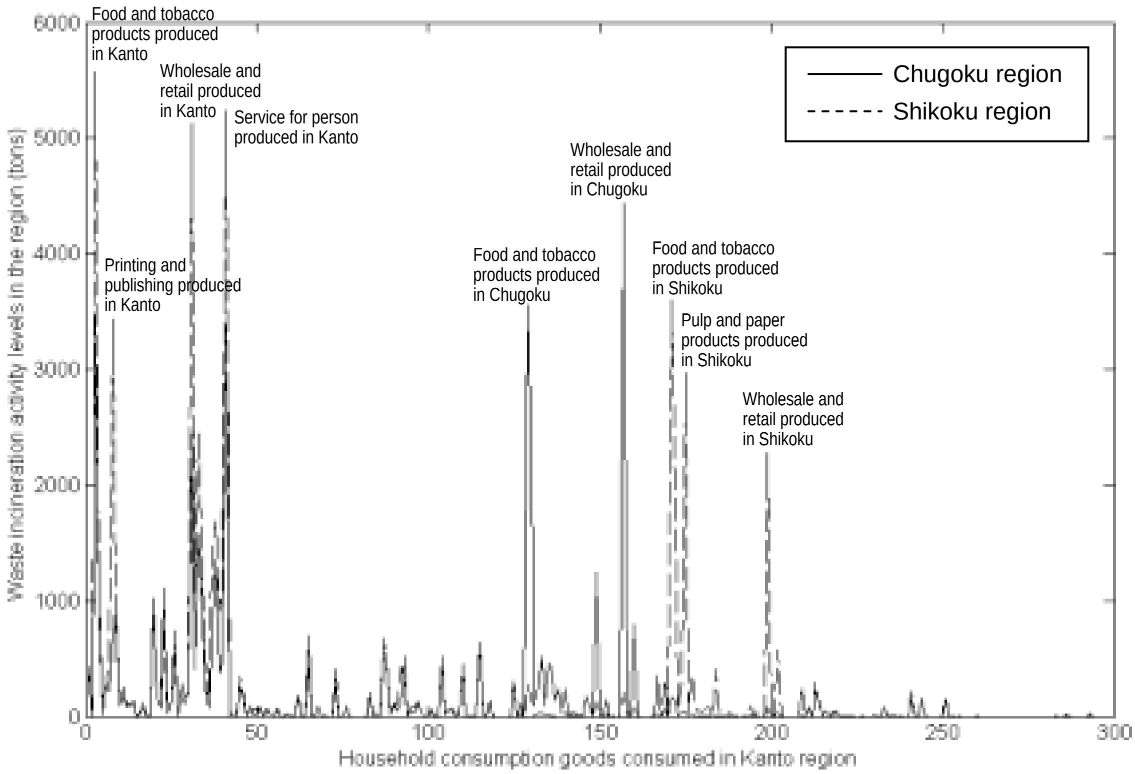

Figure 1. Waste incineration activity levels in Chugoku and Shikoku induced by household consumption activities in Kanto

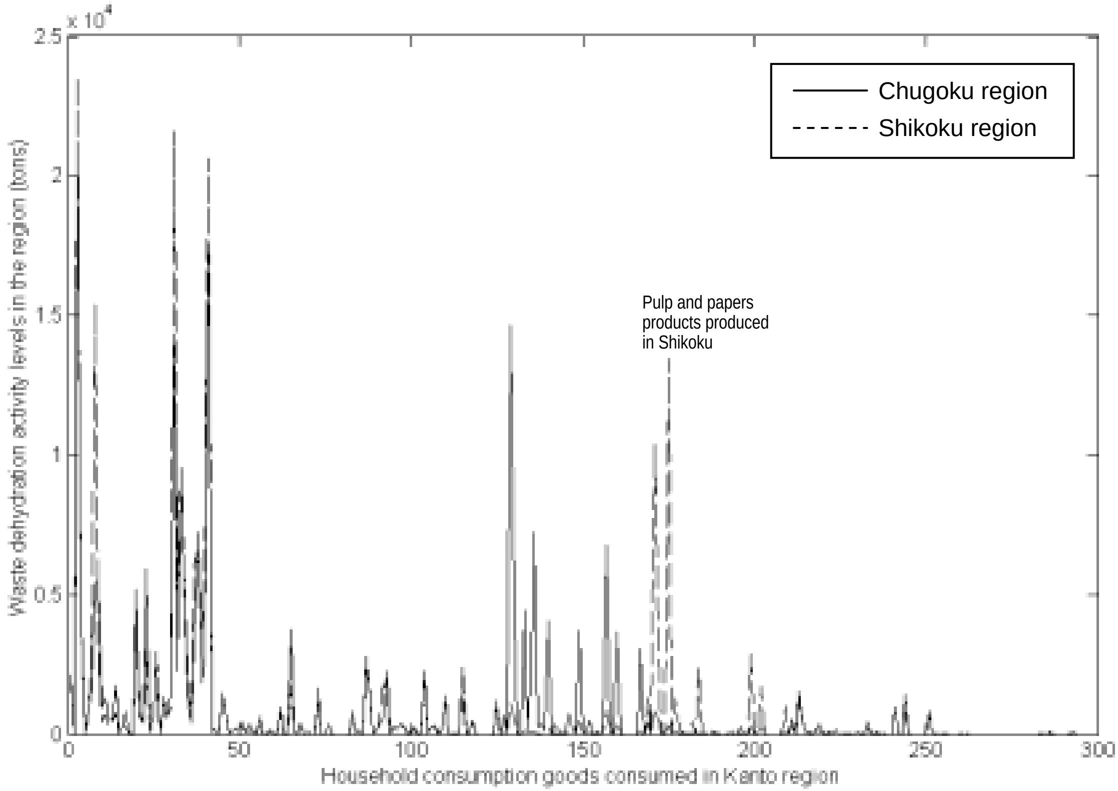

Figure 2. Waste dehydration activity levels in Chugoku and Shikoku induced by household consumption activities in Kanto

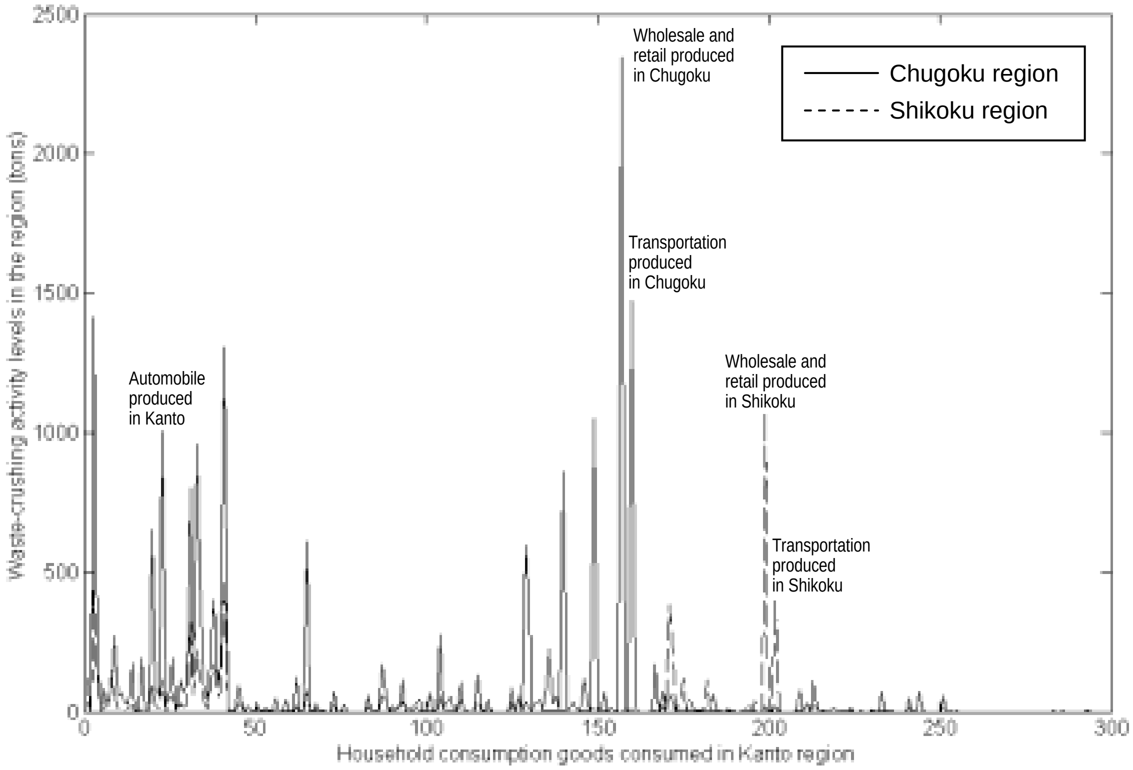

Figure 3. Waste-crushing activity levels in Chugoku and Shikoku induced by household consumption activities in Kanto

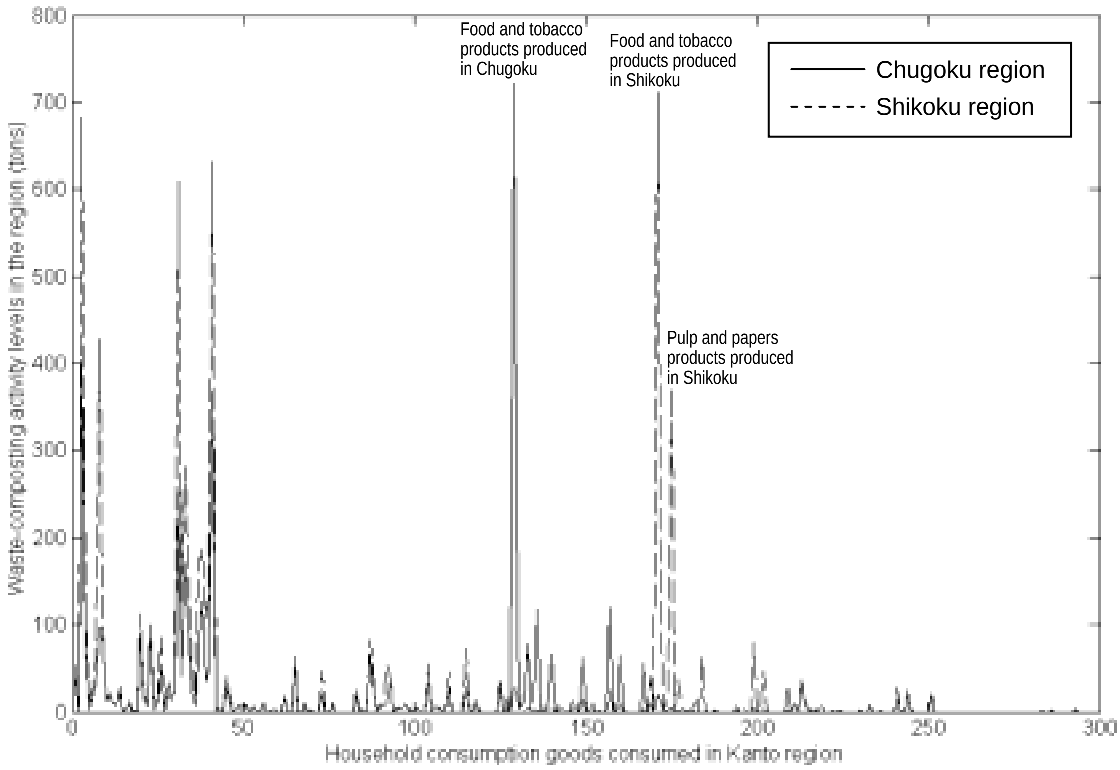

Figure 4. Waste-composting activity levels in Chugoku and Shikoku induced by household consumption activities in Kanto

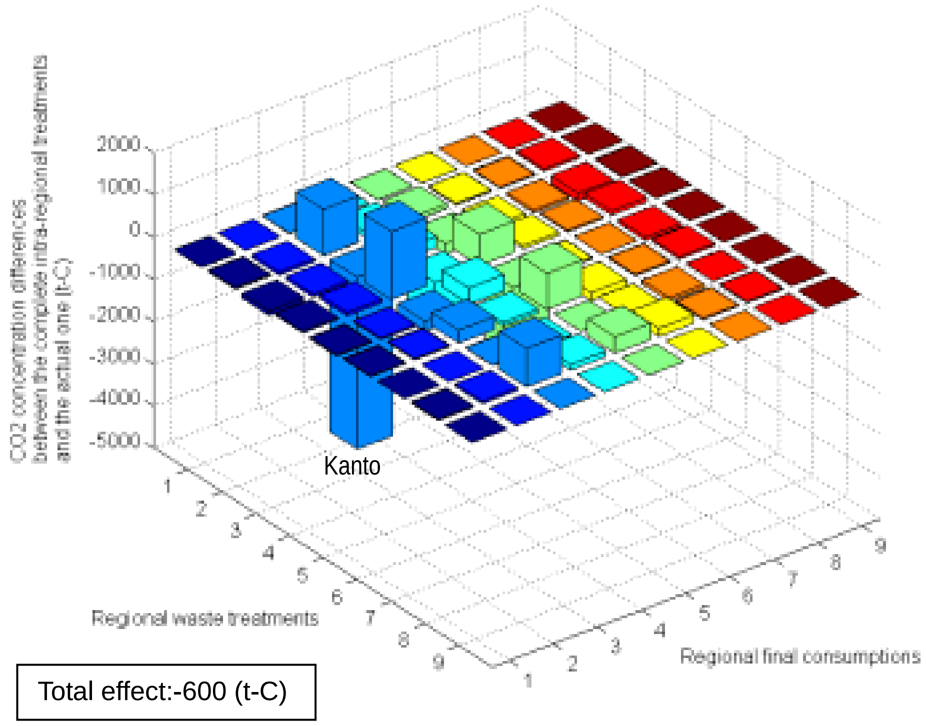

Figure 5. Regional pollution concentration differences
between the complete intra-regional treatments and the actual ones

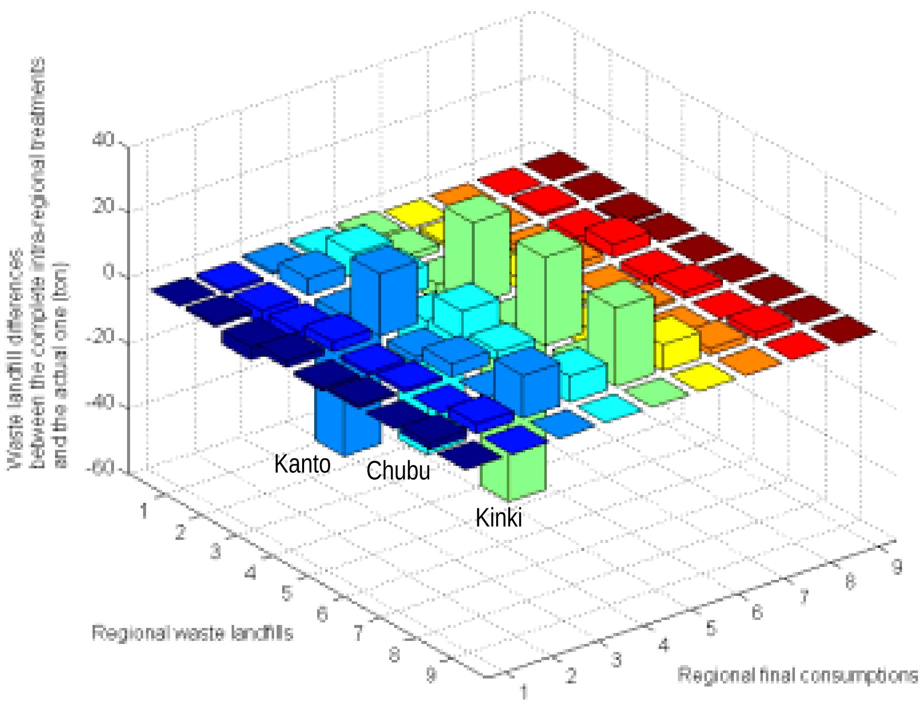

Figure 6. Regional waste landfill differences
between the complete intra-regional treatments and the actual ones