Regional Input-Output analysis of Industrial Waste: Developing a Price Model for Hyogo Prefecture, Japan[1]

By
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Abstract

This paper proposes a new framework to describe the relationship between industrial waste and economic activity, using a waste input-output model. An industrial waste input-output table is constructed by extending the Hyogo Prefecture I-O table for 1990, which has 38 sectors, 19 types of industrial waste, industrial waste incineration and landfill sites. Using empirical analysis, we examine the effect of taxation on industrial waste emission, including the size of the impact of price changes on other sectors. The analysis shows that the rate of price increase for incineration is 2.55%.

1. Introduction

The Japanese economy generates more than 400,000,000 tons of industrial waste every year, leading to problems of illegal disposal, pollution, and shrinking landfill space. The amount of waste has largely leveled off in recent years. One hundred and eighty-seven million tons of waste, or 46% of the original volume, is eliminated through intermediate processing, including incineration and dehydration. One hundred and fifty million tons, or 37% of the original volume, is reused and recycled. The remaining 68,000,000 tons, 17% of the original volume, goes to ultimate disposal, such as landfill sites. Acquisition of disposal sites is becoming more difficult, and in the 1996 fiscal year it was estimated that the capacity of existing landfill sites would be reached in 3.1 years.

Economic activity inevitably generates waste. The 1997 Amendment of Waste Management Law mandates that within reason entrepreneurs must process waste arising from their production activities. Since companies that create waste by-products

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have direct liability for their waste, they are responsible for disposing of it directly, or indirectly by contracting with a waste-processing company. Thus, there is interdependence between the industrial-waste-processing sector – the vein industry – and the waste-processing sector – the artery. There has been, however, little economic investigation of the relationship between the vein and artery sectors.

In this paper we analyze the interdependence of industrial waste and the economy. Input-output (I-O) analysis is a useful tool to analyze mutual dependence in the artery sector, but the generation of waste and its relation to the economy has not been well described in traditional I-O analysis. To express the relationship between the vein and artery sectors, the I-O table should be extended to include waste generation.

2.Theoretical Background

Leontief (1970) pioneered environmental I-O analysis by including air contamination removal in I-O tables. Duchin (1990) and Nakamura (1999) extended Leontief's approach to the problem of other waste. Nakamura's waste input-output model includes the waste-disposal sector, which includes the sorting & shredding, incineration, melting & solidification, and landfill-disposal industries. Assuming a linear relationship between waste production and the production of goods and services, he analyzed the effect of waste processing, power generation from waste through the broadening of waste disposal, the cost to industrial production of blast-furnace reduction of waste plastic, the amount of ultimate disposal, and carbon-dioxide emissions.

Nakamura (2001) also developed WIO (Waste Input-Output Table) price model. The model reveals that the unit price of waste recycling sector depends on the activity of other sectors, even if specification of the model is under fixed coefficient, therefore the model is nonlinear. Because the price model must be a nonlinear one. This paper extends Nakamura's waste input-output table framework and contributes two additional features. First, it includes an intra-regional waste input-output table. Second, Nakamura(2001) implies that unit price of waste recycling sector depends on activity of other sector under fixed coefficient, but our model doesn't include recycling sector.

3. Industrial Waste Input-Output model

3.1. Definition; discharge of waste

The creation of industrial waste is described as follows.

1) Industrial waste is generated by inputs in the production process.
2) Industrial waste is also generated by the depreciation or disposal of durable goods.

3) There is no industrial waste generated from final demand.

For 1), which is waste generation from an economic flow, we assume that this type of waste production is proportional to industrial sector output levels. Type 2) waste refers to the generation of waste from goods in an economy, and we assume this type of waste is also proportional to industrial sector output levels, as the waste arises from rebuilding or renewal activities. Although it is better to measure both the level of waste emissions and the amount of incineration or landfill disposal, it is difficult to model both because of variable technological change and exchange rate fluctuations. Consequently, we extrapolate the ratio of incineration and landfill to measure the total amount of waste. For 3), there is clearly no industrial waste generation from households as defined in Japanese Waste Management Law. The model consists of n>1 industries in the output-producing sector, o; and k types of waste treatment processes in the waste-disposal sector, z. The industrial sector produces goods and services from inputs and generates m kinds of waste as by-products. The waste treatment sector treats waste through incineration or landfill disposal.

Table 1:Industrial Waste Input-Output Table (IWIOT), Waste Generation

	Industry	Waste disposal	Final demand	Sum of row
Industry	X_o	X_z	X_f	X
Waste generation	W_o	W_z	0	W
Value-added	V_o	V_z		V

Table 1 presents a simplified picture of the economy. X_o is a matrix of the $n{\times}n$ output-producing industries. $\boldsymbol{W}$ is the net waste generation of the $\boldsymbol{m}$ types of waste. Net waste generation is calculated by excluding valuable waste that is reused and recycled. The remaining waste is incinerated or disposed of. For instance, $X_{o:ij}$ refers to the input from industry i required to produce the output of industry j. Waste W_{omij} refers to the tonnage of type m waste (e.g., construction waste) resulting from production in industry j (e.g., the construction industry). The waste-treatment sector converts waste with chemical inputs and energy into output, $\underline{X_z}$, and waste, W_z, which is the amount of waste generated from the waste-treatment sector, e.g., ashes from incineration. V_o and V_z are the value added for the industrial and waste treatment sectors, respectively.

3.2. Allocation matrix

The number of waste-treatment processes is generally less than the types of waste ($k<m$), and hence, the matrix of Table 1 is non-square. For simplicity of computation, a waste-generation row needs to be converted into a waste-disposal row. For this purpose, we use an allocation matrix, s_{km} ($k{\times}m$), to describe the allocation ratio for

each type of treatment.

$$\sum_k s_{km} = 1 \qquad (m = 1,2,\cdots,M) \tag{1}$$

s_{km} means the rate of waste j processed by waste-treatment k. For example, when considering an economy composed of two output-producing industries (e.g., 1:agriculture 2:manufacturing), each industry produces a final output product and produces wastes as by-products. We assume that the waste is not recycled but disposed of through incineration or landfill. We also assume that three kinds of industrial waste - sludge, waste plastic, and rubber waste - are generated by each industry. Then the amount of waste generated by each industry is expressed by the following equation.

$$W_{mj} = \begin{pmatrix} w_{11} \, w_{21} \\ w_{12} \, w_{22} \\ w_{13} \, w_{23} \end{pmatrix} \qquad \begin{cases} m = & 1: \mathit{sludge} \quad 2: \mathit{plastic} \quad 3: \mathit{rubber} \\ j = & 1: \mathit{Agriculture} \quad 2: \mathit{Manufacturing} \end{cases} \tag{2}$$

The rate of incineration and landfill attributed to each industry is given exogenously.

$$S_{km} = \begin{pmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \end{pmatrix} \qquad \begin{cases} k = & 1: \mathit{Incineration} \quad 2: \mathit{Landfill} \\ m = & 1: \mathit{sludge} \quad 2: \mathit{plastic} \quad 3: \mathit{rubber} \end{cases} \tag{3}$$

$$s_{1m} + s_{2m} = 1 \tag{4}$$

S multiplied from the left-hand side of w_{ij}

$$\begin{aligned} SW &= \begin{pmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \end{pmatrix} \begin{pmatrix} w_{11} & w_{12} \\ w_{21} & w_{22} \\ w_{31} & w_{32} \end{pmatrix} \\ &= \begin{pmatrix} s_{11}w_{11} + s_{12}w_{21} + s_{13}w_{31} & s_{11}w_{12} + s_{12}w_{22} + s_{13}w_{32} \\ s_{21}w_{11} + s_{22}w_{21} + s_{23}w_{31} & s_{21}w_{12} + s_{22}w_{22} + s_{23}w_{32} \end{pmatrix} \end{aligned} \tag{5}$$

For instance, $s_{11}w_{11}+s_{12}w_{21}+s_{13}w_{31}$ is the amount of incineration required for the sludge, plastic, and rubber generated by the agricultural industry. By applying an allocation matrix, waste generation is converted to the waste disposal requirement for each waste-treatment process. Please note that the converted matrix is not the amount of net waste generated, but the amount of processing required by the waste-disposal sector. It is regarded as a given parameter in this model, so that fixed technology and institutional structures determine the value of s_{km}.

3.3. Input and generation coefficient table

SW_i, $i=o, z$ in Table 2 shows the amount of industrial waste processing required. Thus, Table 2 represents our quantitative model.

Table 2: IWIOT: Waste Disposal

	Industry	Waste disposal	Final demand	Sum of row
Industry	X_o	X_z	X_f	X
Waste disposal	SW_o	SW_z	0	SW
Value-added	V_o	V_z		V

The physical unit of equation (6) is demand and supply for the waste from treatment sector k, it determined as follows:

$$s_{km}\sum_j w_{o:mj} + s_{km}\sum_k w_{z:mk} = s_{km}w_{m\cdot} \quad k = 1,\cdots,K \tag{6}$$

s_{km} : Allocation matrix, $w_{o:mj}$: waste emission matrix of industry sector, $w_{z:mk}$: waste emission matrix of waste treatment sector, and $w_{m\cdot}$: sum of waste (vector).
If production of waste treatment sector (Z_k) is given, production of waste treatment price (p_k) is decided.

$$p_k = \frac{Z_k}{s_{km}w_{m\cdot}} \quad k = 1,\cdots,K \tag{7}$$

If price of p_k is multiplied to both sides of equation (6), the equation of price unit is decided as follows,

$$p_k s_{km}\sum_j w_{o:mj} + p_k s_{km}\sum_k w_{z:mk} = Z_k \tag{8}$$

Table 3: IWIOT: Input and Generation Coefficient Table

	Industry	Waste disposal
Industry	A_o	A_z
Waste disposal	SG_o	SG_z

We obtain Table 3, which consists of input and generation coefficients, by dividing each element of a sector in Table 2 by the amount of activity, as measured in the nominal currency value of output or the amount of processing. A_i, $i=o, z$, are conventional input-output coefficients. For example, element a_{ij}^{o} of matrix A_o represents the input from industry i required to produce the output of industry j. G_i, $i=o, z$ are generation coefficients showing the amount of waste-processing activity required for each output, where an element g_{lk}^{z} of G_z means waste disposal k requires l amounts of processing activity.

We can express such conditions using coefficients from Table 3 as follows.

$$\begin{pmatrix} \mathbf{A_o} & \mathbf{A_z} \\ \mathbf{SG_o} & \mathbf{SG_z} \end{pmatrix}\begin{pmatrix} \mathbf{X} \\ \mathbf{Z} \end{pmatrix}+\begin{pmatrix} \mathbf{X_f} \\ \mathbf{0} \end{pmatrix}=\begin{pmatrix} \mathbf{X} \\ \mathbf{Z} \end{pmatrix} \tag{9}$$

$$\begin{pmatrix} \mathbf{X} \\ \mathbf{Z} \end{pmatrix}=\begin{pmatrix} \mathbf{I-A_o} & \mathbf{-A_z} \\ \mathbf{-SG_o} & \mathbf{I-SG_z} \end{pmatrix}^{-1}\begin{pmatrix} \mathbf{X_f} \\ \mathbf{0} \end{pmatrix}$$

$$=\begin{pmatrix} \mathbf{B_{oo}} & \mathbf{B_{oz}} \\ \mathbf{B_{zo}} & \mathbf{B_{zz}} \end{pmatrix}\begin{pmatrix} \mathbf{X_f} \\ \mathbf{0} \end{pmatrix} \tag{10}$$

While B_{oo}, B_{oz} are elements of the conventional Leontief inverse matrix, B_{zo}, B_{zz} are elements particular to an industrial waste input-output table. Element $b_{zo:ij}$ of B_{zo} is the input from waste-disposal sector i required by industry j, directly and indirectly, in order to satisfy final demand. Since the amount of industrial waste discharged by the final demand sector is zero, if the final demand for goods and services, X_f, is given, X and Z are determined by the inverse matrix. (Refer to Appendix A for the precise procedure for constructing an industrial waste input-output table.)

4. Analysis using IWIOT

We empirically examine the effect of taxation of industrial waste. Some prefectures are planning to initiate an industrial waste tax as a local environmental tax. This tax will be imposed on a company when it contracts with an intermediary to process its waste or when it seeks ultimate disposal. This tax aims to allot a reasonable waste-processing cost and to reduce the volume of industrial waste. It also stimulates recycling and reduction of waste. For example, Mie Prefecture will introduce such a tax at the rate of 1,000 yen per ton of industrial waste. If this tax were introduced in Hyogo Prefecture, how large would the direct and indirect impact be?

4.1. Price model

Taxation of industrial waste leads to an increase in the waste-processing costs of each industry, directly and indirectly, and results in new output prices. Equation (11)explains the price model. With an input-coefficient matrix, A, price vector, P, and value-added vector, V, the conventional price model is as follows.

$$\begin{aligned} \mathbf{P} &= \mathbf{PA} + \mathbf{V} \\ \mathbf{P} &= \mathbf{V}(\mathbf{I} - \mathbf{A})^{-1} \end{aligned} \qquad (11)$$

An element of equation (12) can be written as follows.

$$P_j X_j = \sum_i P_i a_{ij} X_j + v_j X_j \quad (j = 1,2,\ldots,n,n+1,\cdots n+K) \qquad (12)$$

$$P_j = \sum_i P_i a_{ij} + v_j \qquad (13)$$

Element a_{ij} is an input coefficient and shows the amount of input required from industry i to produce a unit of industry j output. Equation (13) shows the conventional price model of the jth sector. Taxation of industrial waste, T_j, is imposed on the jth sector at a tax rate of t_j, yen per unit of incineration and landfill service. The equation is as follows.

$$P_j^* X_j = \sum_i P_i^* a_{ij} X_j + v_j X_j + T_j \qquad (14)$$

$$P_j^* = \sum_i P_i^* a_{ij} + v_j + t_j \qquad (15)$$

$$where \;\; t_j = T_j / X_j$$

In equation(15), t_j expresses the rate of taxation for each sector. Subtracting equation (15) from equation(13), we get equation(16).

$$\Delta P_j = \sum_i \Delta P_i a_{ij} + t_j \tag{16}$$

$$\text{where } \Delta P_i = P_i^* - P_i$$
$$\Delta P_j = P_j^* - P_j$$

Equation (14) shows the new price level when taxation is imposed on industrial waste production. In vector form,

$$\begin{pmatrix} \Delta p_1 & \cdots & \Delta p_{n+l} \end{pmatrix} = \begin{pmatrix} t_1 & \ldots & t_j & \ldots & t_{n+l} \end{pmatrix} \begin{pmatrix} b_{11} & \cdots & b_{1n+l} \\ \vdots & \ddots & \vdots \\ b_{n+l1} & \cdots & b_{n+ln+l} \end{pmatrix} \tag{17}$$

Element b_{ij} is an element of the Leontief inverse matrix and ΔP is the rate of increase in output prices. Results are shown in Table 4 and Figure 1. The price of waste treatment is decided in the region, therefore net waste transfusion is exogenous.

4.2. Results of price analysis

Figure 1,2,3 show direct and indirect impact of tax on price. These Figures show the results of three patterns of taxation, 1) taxation on incineration, 2) taxation on landfill disposal, and 3) taxation on incineration and landfill disposal. The figures show, from back to the front, **(I-A)**$^{-1}$, tax, 1st, and 2nd, displaying respectively, whole repercussion effect, tax levying, 1st repercussion effect, and 2nd repercussion effect. The number 1 to 37 correspond to sectors (refer to Table 5). With taxation on incineration, the Petroleum & Coal Production industry is the industry most affected, with a price increase of 0.0075%. This industry generates a great deal of waste oil, waste alkali and waste plastic. Steel is the second most affected industry, and experiences price increases of 0.0037%, generating waste plastic, metal waste and waste oil. The Pulp, Paper & Wooden Product industry, which generates wood waste, organic waste and paper waste, is the third most affected. Most of the waste from these industries is incinerated.

With taxation on landfill disposal, the incineration industry is the industry most affected, with a price increase of 0.2105%, because of bulk disposal of the ash from incineration. Prices in the ceramic, clay and stone product industry rise by 0.01712%, with this industry generating inorganic sludge, as well as glass cullet & waste ceramics, which have one of the lowest rates of recycling among all kinds of industrial waste. The construction industry has a price increase of 0.0172% and generates construction waste, glass cullet & waste ceramics, and inorganic slag. Despite the high recycling rate of construction waste (70%), the net amount of waste produced by this industry is huge and results in large environmental loads on landfill sites.

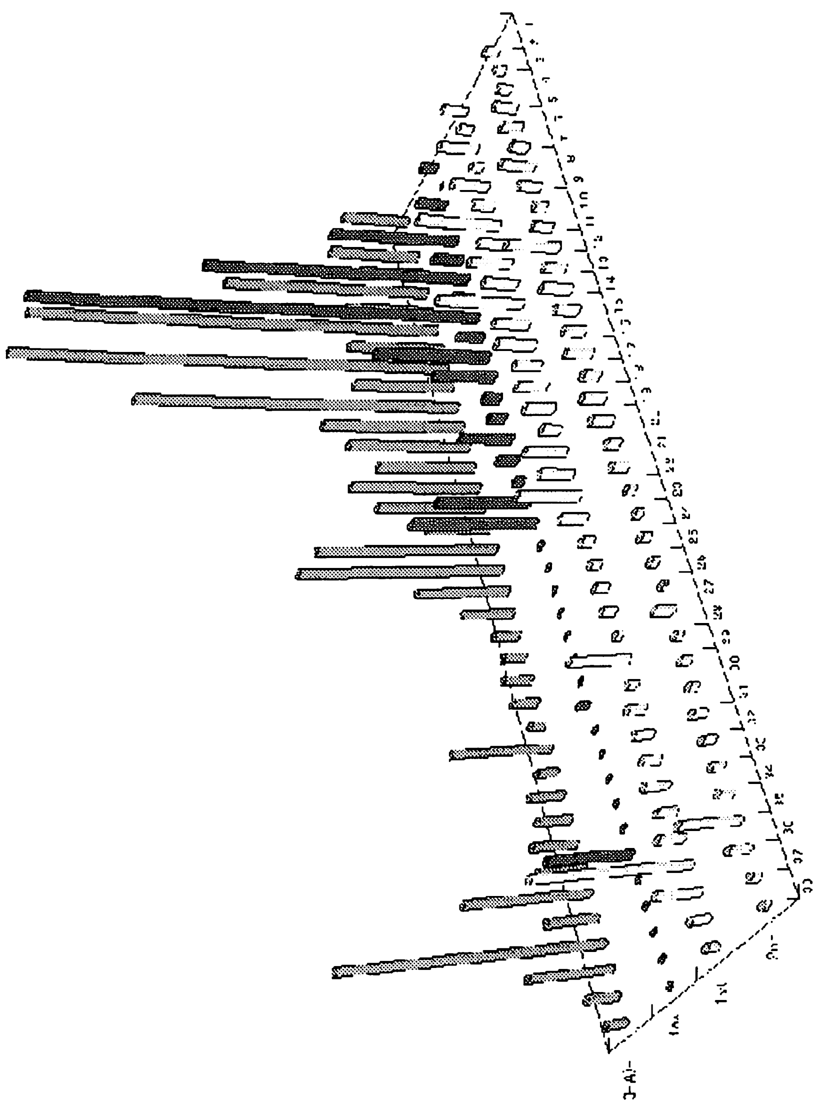

Figure 1: Rates of Price Increase: Direct and Indirect repercussion effect, Taxation of Incineration Waste

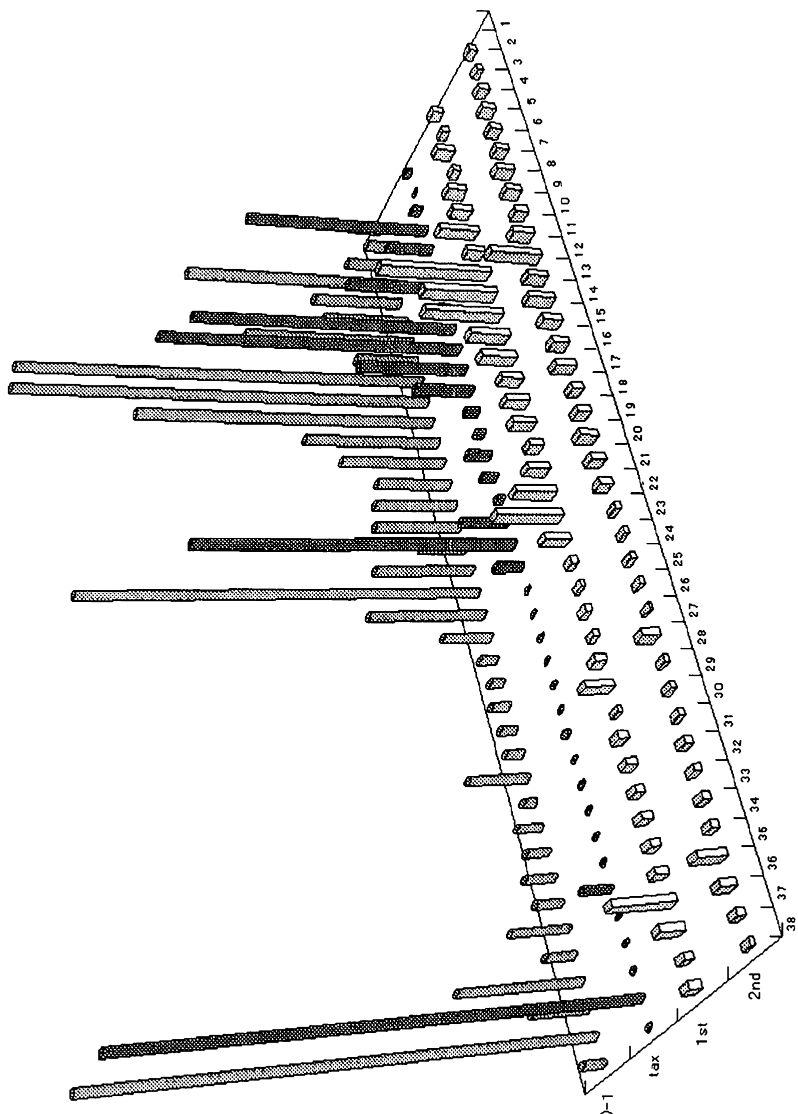

Figure 2: Rates of Price Increase: Direct and Indirect repercussion effect, Taxation of Landfill Waste

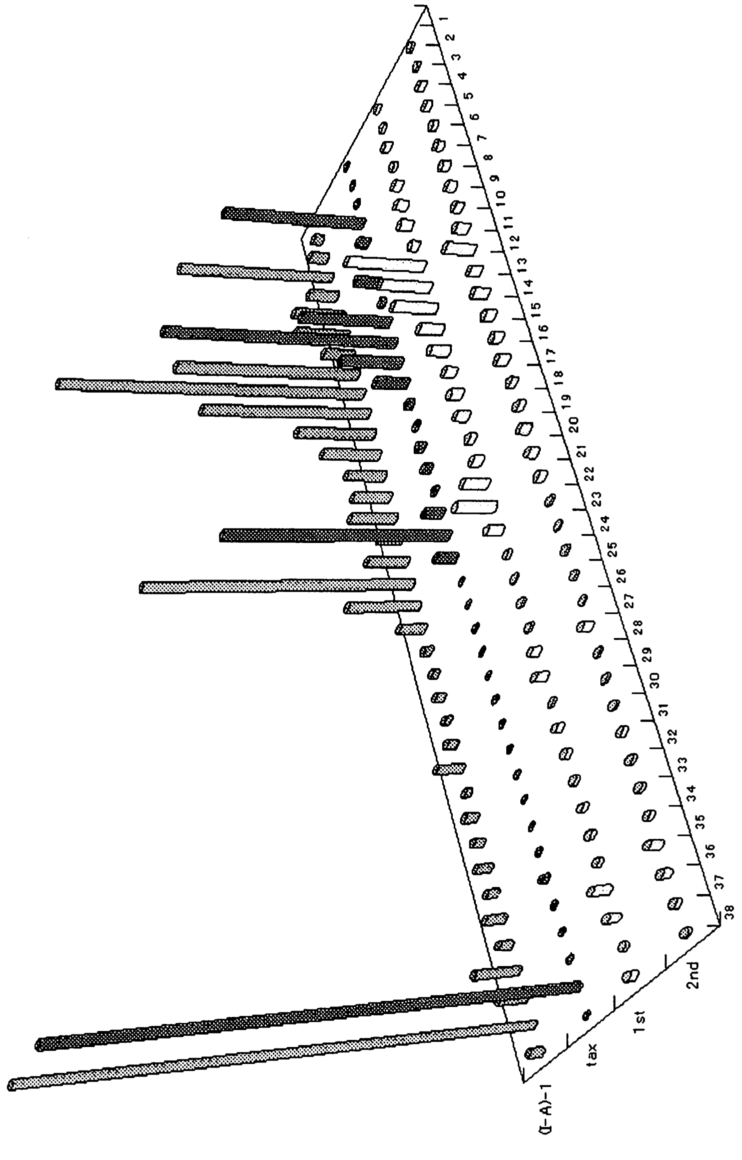

Figure 3: Rates of Price Increase: Direct and Indirect repercussion effect, Taxation of All Industrial Waste

Finally, we show the effect of taxation when it is imposed on both incineration and landfill disposal. The prices of the incineration industry rise by 0.2109%; prices in the ceramic, clay and stone product industry rise by 0.0184%; and prices in the petroleum & coal product industry rise by 0.01803%.

It is interesting to note that the price increase is greater in the ceramic, clay and stone product industry than in the construction industry, although the total volume of waste generated by the former is only 2% of the volume generated by the latter. This can be attributed to the fact that the ceramic, clay and stone product industry has a larger input coefficient for landfill processing than do other industries. In general, processing industries have higher price increases. The results show that industries that generate a large volume of non-recyclable waste have a higher price increase when waste disposal is taxed.

Conversely, it is thought that service industries are seldom affected by increases in waste-processing costs, and the volume of waste that is sent for incineration or ultimate disposal is also small. We show that price increases are generally high in basic processing industries and low in service industries.

5. Conclusion

In order to investigate the relationship between industrial waste and economic activity, we developed a framework using input-output analysis applied to industrial waste production. Since Nakamura's model (1999) contains the household sector, the price model, which is dual to the quantity model, cannot be constructed in his framework. Money-based analysis is not possible, because the disposal of waste is covered by the budget of a local government, unless the burden to the household sector becomes clear. However, a price model can be constructed for industrial waste, since waste-producing industries or waste-processing traders commissioned for disposal pay the cost of waste processing. Using the amount of waste-processing activity derived by the quantitative model, this paper formulated a price model using the average processing cost.

For empirical analysis, we used the industrial-waste input-output table (IWIOT) and analyzed the magnitude of the price-spread effect of an industrial waste tax. However, since the static framework of input-output analysis makes it hard to distinguish waste products, such as construction waste and shredder dust from car waste, this paper follows the approach of Nakamura in assuming that stock wastes are discharged in connection with output production. Incorporating recycling into this paper's model would also be possible and provide an interesting extension. These are issues to be examined in future research.

Table 4. Rates of Price Increase; The Impact of a Price Change

	Incineration	Landfill	Total effect
Incineration (Industrial)	0.00036%	0.21050%	0.21086%
Ceramic, stone & clay products	0.00120%	0.01715%	0.01835%
Petroleum & coal products	0.00745%	0.01058%	0.01803%
Construction	0.00233%	0.01485%	0.01718%
Steel	0.00372%	0.00967%	0.01339%
Mining	0.00079%	0.00910%	0.00988%
Pulp, paper & wooden products	0.00472%	0.00314%	0.00785%
Non-ferrous metals	0.00167%	0.00457%	0.00625%
Office supplies	0.00286%	0.00241%	0.00527%
Electricity, gas & thermal energy supply	0.00107%	0.00415%	0.00522%
Metal products	0.00144%	0.00339%	0.00482%
Other manufactured products	0.00209%	0.00240%	0.00449%
Food	0.00244%	0.00179%	0.00423%
Textile products	0.00108%	0.00296%	0.00403%
Transportation equipment	0.00129%	0.00272%	0.00401%
Electrical machinery	0.00153%	0.00225%	0.00378%
General machinery	0.00116%	0.00228%	0.00344%
Chemical products	0.00114%	0.00179%	0.00293%
Transport	0.00113%	0.00151%	0.00263%
Miscellaneous business services	0.00142%	0.00107%	0.00249%
Activities not classified elsewhere	0.00093%	0.00150%	0.00242%
Fishing	0.00110%	0.00107%	0.00216%
Water supply	0.00061%	0.00155%	0.00216%
Precision machinery	0.00074%	0.00140%	0.00214%
Agriculture	0.00082%	0.00075%	0.00157%
Personal services	0.00057%	0.00074%	0.00131%
Medical & health service	0.00051%	0.00079%	0.00131%
Other public supplies	0.00052%	0.00062%	0.00115%
Public services	0.00039%	0.00069%	0.00108%
Forestry	0.00041%	0.00057%	0.00098%
Education & research	0.00038%	0.00059%	0.00097%
Landfill (industrial)	0.00022%	0.00069%	0.00091%
Commerce	0.00033%	0.00048%	0.00082%
Waste-disposal services (public)	0.00030%	0.00047%	0.00077%
Real estate	0.00016%	0.00060%	0.00076%
Financial services & insurance	0.00030%	0.00036%	0.00066%
Waste-disposal services (industrial, excl. landfill)	0.00026%	0.00034%	0.00060%
Communications & broadcasting	0.00023%	0.00031%	0.00054%

Appendix A Industrial Waste Input-Output Table for Hyogo Prefecture

A.1. Procedure of IWIOT

In this section we show how to produce an industrial waste input-output table from the input-output table for Hyogo Prefecture [3]. Industrial classification is the same as for Table 5.

Table 5: Industrial Classification

1	Agriculture	20	Electricity, gas & thermal energy supply
2	Forestry	21	Water supply
3	Fishing	22	Waste-disposal services (public)
4	Mining	23	Other waste-disposal services (industrial, excl. landfill)
5	Food	24	Commerce
6	Textile products	25	Financial services & insurance
7	Pulp, paper & wooden products	26	Real estate
8	Chemical products	27	Transport
9	Petroleum & coal products	28	Communication & broadcasting
10	Ceramic, stone & clay products	29	Public services
11	Steel	30	Education & research
12	Non-ferrous metals	31	Medical & health services
13	Metal products	32	Other public supplies
14	General machinery	33	Miscellaneous business services
15	Electrical machinery	34	Personal services
16	Transportation equipment	35	Office supplies
17	Precision machinery	36	Activities not classified elsewhere
18	Other manufactured products	37	Incineration (industrial)
19	Construction	38	Landfill (industrial)

A.1.1 Division of the waste-treatment sector

To include industrial waste in the analysis, we divide the water service & waste-disposal industry into water-service, waste disposal (public) and waste disposal (industrial), and further divide waste disposal (industrial) into incineration (industrial), landfill (industrial) and other waste-disposal services (industrial, excluding landfill) (see Table 5). Waste-disposal services (public) consist of public-sector collection and processing of human waste and garbage, and waste disposal (industrial) consists of private-sector industrial-waste collection, transportation and processing. However, there is no division between waste disposal (public) and waste disposal (industrial) in the classification of Hyogo Prefecture's I-O table. Therefore, we used an input coefficient for basic assortments from Japan's 1990 I-O table.

A.1.2. Estimation of incineration and landfill disposal

We divided waste disposal (industrial) into incineration, landfill and other waste disposal. Incineration is private-sector industrial-waste processing specializing in incineration. Landfill is the private-sector industrial-waste processing specializing in land reclamation. Other waste disposal is private-sector industrial-waste processing using other types of waste processing. However incineration and landfill industries do not exist in the basic industry classification of the most detailed division of a national I-O table. Therefore, we estimated their production and calculated input coefficients using financial statements of the industrial-waste-processing sector [16] and average production levels per company. As there are no separate data by industry within this sector, we assumed the ratio of waste production by the incineration and landfill industries to be the same as for the industrial-waste sector.

Coefficients for the incineration and landfill industries were estimated from data for the cost of public waste disposal in the city of Kobe [6], as it is difficult to obtain cost data for waste disposal by the private sector.

A.2. Conversion Matrix

Next we estimated the relative ratio of how each type of waste is processed. We integrated the classification of 18 industrial wastes and 46 industries (18×46)[5] to create an IWIOT with 19 industrial wastes and 38 industries[2].

A.2.1.Allocation matrix

Table 6 shows the relative ratio of how each waste is processed. Waste is ultimately processed in two ways: incineration and landfill. We used data from other prefectures [13] because of a lack of data for Hyogo.

[2] Sludge is the dominant industrial waste. There are many kinds of sludge. For instance, sewage sludge, food sludge etc. are called organic sludge. Lime sludge, plating sludge etc. are called inorganic sludge. Since organic and inorganic sludge use different disposal processes, they are accounted for separately. We separated organic and inorganic sludge using the ex post ratio of generation by each industry from the data of Nakamura (2001, p. 23, Figure 17).

Table 6: Allocation Matrix

	Classification of waste	Incineration	Landfill
1	Incineration ash	0.000	1.000
2.1	Organic waste	0.758	0.242
2.2	Inorganic waste	0.016	0.984
3	Waste oil	0.668	0.332
4	Waste acid	0.191	0.809
5	Waste alkali	0.987	0.013
6	Waste plastic	0.721	0.279
7	Waste paper	0.030	0.970
8	Wooden waste	0.995	0.005
9	Waste textile	1.000	0.000
10	Animal & plant residues	0.526	0.474
11	Waste rubber	0.000	1.000
12	Scrap metal	0.064	0.936
13	Glass cullet & waste ceramics	0.000	1.000
14	Slag	0.000	1.000
15	Construction waste	0.001	0.999
16	Animal waste	0.224	0.776

A.2.2. Coefficient of the industrial-waste-disposal sector and coefficient of within-prefecture disposal

A company that produces waste by-products can either process the waste itself or contract with a waste-processing company that undertakes intermediate processing and landfill disposal. The basic I-O table includes self-processing in nominal currency terms. To calculate the amount of processing by the incineration and landfill disposal industries, we use a disposal coefficient for each of the 19 industrial waste items processed by these industries (Refer to Table 7).

Since industrial waste may be transferred outside a prefecture, we use net waste transferred outside Hyogo Prefecture [4]. The coefficient for within-prefecture disposal is shown in the last row of Table 7.

Table 7: Coefficient of The Industrial-Waste-Disposal Sector and Coefficient of Within-Prefecture Disposal

	Classification of waste	Coefficient of the industrial-waste-disposal sector	Coefficient of within-prefecture disposal
1	Incineration ash	0.850	0.139
2.1	Organic waste	0.785	0.590
2.2	Inorganic waste	0.495	0.403
3	Waste oil	0.988	0.261
4	Waste acid	0.949	0.016
5	Waste alkali	1.000	0.217
6	Waste plastic	0.887	0.606
7	Waste paper	0.945	0.818
8	Wooden waste	0.262	0.938
9	Waste textile	0.253	0.101
10	Animal & plant residues	0.905	0.521
11	Waste rubber	0.608	0.211
12	Scrap metal	0.727	0.688
13	Glass cullet & waste ceramics	0.594	0.569
14	Slag	0.916	0.050
15	Construction waste	0.261	0.841
16	Animal waste	0.523	0.429
17	Carcasses	0.523	0.429
18	Fly ash	0.343	0.107

A.2.3. Weight-loss ratio of wastes

Industrial waste goes to incineration and landfill sites after other intermediate processing, such as neutralization, dehydration and sorting & shredding. Table 8 shows these intermediate processes, with weight-loss ratios calculated from the data of [13], exogenously decided ex post facto.

Table 8: Weight-Loss Ratio of Wastes

Waste treatment	Weight-loss ratio
Dehydration	0.130
Dehydration→Other treatment	0.130
Dehydration→Drying	0.090
Drying	0.340
Separation of oily water	0.160
Separation of oily water→Drying	0.330
Sorting & shredding	1.000
Compression	1.000
Neutralizing	0.980

Since the data are for Osaka Prefecture, we assumed that Hyogo has the same waste-disposal technology. For example, if organic sludge is incinerated after dehydration, its weight-loss ratio is 87%. The weight-loss ratio for Hyogo is calculated using this table.

A.2.4. Coefficient of incineration ash

The waste input-output table assumes that waste doesn't vanish through incineration, but is converted to another form. Section 3.1 points out that incineration generates incineration ash. We calculate the coefficient of incineration ash in Table 9, whose construction is explained in[13]. For example, if a unit of wood waste is burned, the volume of ash is 0.07. Incineration ash goes to landfill sites.

Table 9: Coefficient of Incineration Ash

	Classification of waste	Coefficient of incineration ash
1	Incineration ash	———
2.1	Organic waste	0.013
2.2	Inorganic waste	0.073
3	Waste oil	0.009
4	Waste acid	0.003
5	Waste alkali	0.009
6	Waste plastic	0.046
7	Waste paper	0.139
8	Wood waste	0.070
9	Waste textiles	0.076
10	Animal & plant residues	0.081
11	Waste rubber	———
12	Scrap metal	0.458
13	Glass cullet & waste ceramics	———
14	Slag	———
15	Construction waste	0.800
16	Animal waste	0.100
17	Carcasses	0.086
18	Fly ash	———

A.3. Integration of the conversion matrix

The following operations are carried out making 38 divisions in the IWIOT, including the allocation matrix, coefficients for the industrial-waste-disposal sector, coefficients for within-prefecture disposal, and waste weight-loss ratios.

$$W_j^* = S^T \hat{T} \hat{H} \hat{G} W_{ij} \qquad (A1)$$

where

S^T = transposed matrix of the allocation table

$\hat{T}$ = diagonal matrix of coefficients of the industrial - waste - disposal sector

$\hat{H}$ = diagonal matrix of coefficient of within - prefecture disposal

$\hat{G}$ = diagonal matrix of decreasing rate of waste disposal sector

W_{ij} = (matrix of classification of industrial wastes) × (matrix of classification of industrial sector)

W_j^* = matrix of waste - disposal sector × the matrix of classification of industrial waste treated by incineration

The coefficient of incineration ash is multiplied by waste input into the incineration industry and its waste by-product, incineration ash, goes to the landfill industry. The total volume of incineration ash is calculated by multiplying the coefficient of incineration ash by equation (A-2).

$$Incineration\ ash = S^T \hat{T} \hat{H} \hat{G} \hat{B} W_{ij} \qquad (A2)$$

where

$\hat{B}$ = diagonal matrix of the coefficient of incineration

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