The impact and effects of modal shift of waste transportation by IR-WIO (interregional waste input-output) analysis

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1. Introduction

The creation of a recycling society is one of the most urgent and important issues that could reduce global warming gases, use natural resources effectively, and reduce waste, especially for landfilling. Hence, the improvement of the efficiency of waste treatment and recycling is one of the issues to consider in creating such a society. In particular, policies for the implementation of a waste transportation system and the choosing of modes of transportation need to be created while considering such factors as cost, reducing the use of natural resources and reducing environmental loads, including global warming gasses. A modal shift i.e. the change of transportation means from automobile or air, to ship or railway is an effective method for dealing with such issues.

Interregional waste input-output (IR-WIO) analysis is one of the powerful tools to analyze the economic activities and waste emissions simultaneously. In our previous work (Tsukui 2007), we compiled IR-WIO table of Tokyo. However, we didn’t sufficiently consider the environmental loads and the inputs of goods, services, and energy that were necessarily accompanied with the waste transportation between regions. Kagawa et al. (2007) considered the problem in the case of only track transportation in their multiregional waste input-output model. In this study, we improved the estimation method of waste treatment model of our previous work. We also constructed a waste transportation model with more practical and detailed assumptions than the preceding study.

Based on practical data, we constructed a waste transportation model which can be applied to the estimation of IR-WIO table with improved waste treatment sub-model. In the model, we first estimated the inputs and the environmental loads of each region. Then we applied the waste transportation model to estimate those inventories accompanied with the waste transportation between regions or areas.

1. The Interregional waste input-output (IR-WIO) model
	1. The structure of IR-WIO model

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | industrial sectors | waste treatment sectors | final demands | summation |
| target area | other area | target area | other area | target area | other area |
| industrial sectors | target area |  |  |  |  |  |  |  |
| other area |  |  |  |  |  |  |  |
| waste emission | target area |  |  |  |  |  |  |  |
| other area |  |  |  |  |  |  |  |
| value added |  |  |  |  |  |  |  |
| environmental loads | target area |  |  |  |  |  |  |  |
| other area |  |  |  |

Table 　The 2-area extended Isard-type model of the IR-WIO table

The IR-WIO model is the expansion of the conventional interregional input-output model (Isard 1951) and the waste input-output model (Nakamura & Kondo 2002). The main concept of IR-WIO model is similar to the multiregional waste input-output model that was proposed by Kagawa et.al (2007). The difference between them is the waste transportation model between regions. In this study, we discussed our improvement to the multiregional waste input-output model and showed the detail of the IR-WIO model hereafter.

 Consider an economy, as in Table 1, that consists of *nO* industry sectors, *nW* waste emission sectors, *nZ* waste treatment sectors, *nF* final demand sectors, *nV* value added sectors and *nE* environmental load sectors. The matrices *X*, *W*, *V* and *E* denote　the output flow of the industrial sectors, waste emission sectors, value added sectors, and the environmental load sectors, respectively. The subscripts *O*, *Z* and *F* denote the input flow of the industrial sectors, the waste treatment sectors and the final demand sectors, respectively. The final demand sectors consist of the fixed capital formation sectors, the export sectors, the import sectors and the consumption and stock sectors, which are denoted as subscripts *k*, *ex*, *im* and *f*. The relationship of those sectors can be described as  .

For the purpose of the study, each sector is divided into regions, which, in this study, are the smallest units of the wide-area transportation of waste. The number of regions is defined as *nR.*, where o $(1\leq o\leq n\_{R})$ denotes the departure region and *i* $(1\leq i\leq n\_{R})$ denotes the destination region. When we apply the waste transportation model proposed in this study (IR-WTM) to IR-WIO model as a sub-model, these regions are usually divided into groups which depend on purposes of empirical analysis. For example, Tsukui (2009) assumed *nR*as 47 regions of Japan and formed them into two groups of areas, Tokyo and other regions. Kagawa et.al (2007) also formed 47 regions of Japan into 9 areas and investigated their relationship. Even the standard WIO model can be described as *nT*regions into one group. The number of the areas of this model is not limited. However, to make the explanation of the model simpler, we adopted a 2-area model. One area is called the “target area” and the rest of regions are called the “other area”. The superscript T and R denote target area and other area, respectively. Other subscripts are defined in the definitions of variables to be hereinafter described.

Now, let *A* be the matrix of input coefficients, and *G*, the matrix of net waste emission coefficients with its *(i,j)* element referring to the net emission of waste *i* per unit activity of sector *j*, then

|  |  |
| --- | --- |
| , | (1) |

where

, , , ,

, ,

and the operator “diag”transforms the following vector into the diagonal matrix with its elements.

As we already defined before, the dimension of waste emission sectors *nW* and that of waste treatment sectors *nZ* are generally different.  is an  transformation matrix that makes *A* into a square matrix.

|  |  |
| --- | --- |
|  | (2) |

Then, by defining *Z* as the vector of activity levels, we have the following system;

|  |  |
| --- | --- |
| , | (3) |

where

, , , ,

and *I* denotes the unit matrix of .

As the waste treatment facilities depend on the amount of emission and , the input matrices , ,  and  have to be estimated by reflecting the status of the facilities. We estimated these input coefficients by using the data on municipal solid waste (MSW) and industrial waste published by the Tokyo Metropolitan Government. We obtained detailed information on MSW (composition, calorific value, bulk density, etc.) and waste treatment technologies from Tanaka and Matsuto et al. (Matsuto, 2005).

Finally, letting  and  be the value-added coefficient and the environmental load coefficient, respectively, we shall calculate the valued added and the environmental loads as  and , respectively.

|  |  |
| --- | --- |
| ,, | (4) |

where

, , , .

 For empirical analysis, each matrix in equations (1) to (4) has to be estimated. Especially, the estimation of  and  are important when considering the impact of waste treatment between regions. We shall show the estimation algorithm for solving the equilibrium equation in the following.

* 1. The iterative algorithm for solving the equilibrium equation

The iterative algorithm to solve the equilibrium equation is as follows (Nakamura and Kondo, 2002). As an initial step,  and  are estimated under the condition of  and  being zero matrices, which gives as the initial value *W(0)*.

|  |  |  |
| --- | --- | --- |
| Step 1:  |  | (5) |

In the step 2, *i* is incremented and *AZ* and *GZ* are estimated by using the sub-model.

|  |  |  |
| --- | --- | --- |
| Step 2:  |  | (6) |

where *i* is the count variable of the number of iteration and *fsub* is the function of the sub-model. In the next step, the equilibrium value *Z(i+1)* and *W(i+1)* are calculated.

|  |  |  |
| --- | --- | --- |
| Step 3:  |  | (7) |

where

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We repeat step 2 and step 3 processes until that *W(i)* converges sufficiently, to a constant value.

 In this study, we applied two sub models to estimates *AZ* and *GZ* . The first one was to estimate the inventory of waste treatment activities and the second one was to estimate the effect of wide-area waste transportation. In the following discussion, we shall show the interregional waste transportation model which is related to the multiple transportation means (IR-WTM).

* 1. The interregional waste transportation model considering the multiple transportation means (IR-WTM)

The waste transportation model between regions in this study estimates the energy consumption and environmental loads which are associated with the waste transportation and waste properties, such as classification, departure place, destination and transportation means. To analyze the detail of the waste transportation between regions, it is better to assume, the number of regions to be a relatively large number if the related statistical data can be obtained. can be defined as a -dimensional vector, which denotes the amount of waste transported where  denotes the number of the classification of waste. As previously defined, the superscript *(oi)* denotes the departure region of waste *o* and the destination region *i*. The k-th element of  is defined as. In case of the interregional waste transportation, the waste is assumed to be transported by its classification. The matrix  denotes the total of the transported waste which is composed of the block matrices of,

|  |  |
| --- | --- |
|  | (5) |

where all elements of are 0 when.

　To connect the interregional waste input-output analysis model (IR-WIO model) and the interregional waste transportation model concerning multiple transportation means (IR-WTM), the areas (*T, R*) , in the definition of the IR-WIO model, are related to the regions () in the IR-WTM by a square matrix . For example, considering the transportation of the industrial waste for intermediate treatment, can be converted to  by using the following equation (2),

|  |  |
| --- | --- |
|  | (6) |

where  indicates Kronecker product and all diagonal components of are 0. We can define all kinds of the amount of waste transportation between regions of the IR-WIO model, such as the general waste from household, the waste which is emitted according the activity of the waste treatment sectors and the amount of landfill, in the same way.

In this study,  the amount of transported waste between regions, is transported by the multiple means of transportation. The number of the transportation means is assumed to be , and the amount of transported waste by ratio is also assumed by each mode of transportation and each waste classification.  indicates the ratio of the amount of transported waste from region o to region *i* of the waste classification *h* by the transportation mean k (), where

|  |  |
| --- | --- |
|  | (7) |

If we let  denote the  matrix, whose components are,  is defined by the following equation (3),

|  |  |
| --- | --- |
|  | (8) |

where diag() is an operator as we defined in the equation . In this equation, can be represented by the  matrix in which row sectors indicate the waste classification and column sectors indicate the modes transportation.

In this section, we define , which indicates the matrix of the energy consumption and the environmental loads by the transportation of waste from the departure region *o* to the destination region *i*. There are many environmental loads, which are associated with transportation, to consider such as CO2, SOX, NOX, SPM and OX (MOE 2009). There are also many estimation methods. These environmental loads can be divided into 2 types: the emissions of CO2 and SOx which are determined by the character of the fuel; and the emissions of NOX, SPM and OX. , which are rather difficult to estimate because the emission varies according to the combustion state (Nansai et al. 2002, Nomura Research Institute 1998, Ocean Policy Research Foundation 2002). In this study, we will only consider CO2 and SOX as the first step in the estimation of environmental loads. These emissions can be estimated by calculation methods published in the guidelines by the Ministry of Economy and the Ministry of Land, Infrastructure, Transport and Tourism of Japan. We chose the ton kilometer method which can be used to estimate energy consumption and environmental loads according to multiple means of transportation such as, truck, railway, ship and air. This method allows us to consider a shift in the mode of transportation such as automobile and air, to ship or railway to reduce the emission of greenhouse gases.

 The distance between regions by transportation means is defined as follows. For the selected transportation means , the distance between a departure region *o* and a destination region *i* is defined as , and is a vector whose components are . We can estimate the freight ton kilometer by multiplying  and the transported weight of waste. For the classification of waste , and the selected transportation means , the freight ton kilometer of the transported waste can be estimated by letting each component of the amount of transported waste between regions by transportation means to .

|  |  |
| --- | --- |
|  | (9) |

We can define  in the following equation (10), where the vector  is comprised of  in equation (9).

|  |  |
| --- | --- |
|  | (10) |

By using , we can estimate the environmental loads associated with the waste transportation between regions. By letting  be the environmental loads matrix and  be the coefficient matrix of energy consumptions and emissions by each transportation mean,  can be estimated in equation (11).

|  |  |
| --- | --- |
|  | (11) |

The calculated environmental loads  is added to the related sectors of IR-WIO model; the energy consumption is added to the related sectors of  and the environmental loads is added to those of .

The actual value of  depends on whether or not we can obtain the necessary statistical data. How the data is collected and accumulated differs from country to country. For example, in Japan these kinds of statistical data are relatively easily available. We can construct a specific model for Japan which can be estimated the effects of modal shift of waste transportation.

1. Concluding Remarks

In this study, we construct the interregional waste input-output model whose sub-model is the interregional the interregional waste transportation model which can estimate the impact and effects of modal shift. We constructed the general model, which can be applied to any countries or areas of world. However, this model has to be specialized to some extent depending on the related statistical data which is obtained.

This model can be applied to the empirical analysis to estimate the energy consumption and the environmental loads by each mode of waste transportation. This can be done in the future studies.

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