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ORIGINAL PAPER

A nonsurvey multiregional input–output estimation allowing cross-hauling: partitioning two regions into three or more parts

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Abstract This paper describes a nonsurvey method for estimating multiregional trades without eliminating cross-hauling, when a national biregional input–output table is available. Domestic outflows are assigned by interpolating the biregional trades on the basis of the gravity ratio between the origin and the destinations, with parameters estimated from an earlier survey on interregional transactions. The method is then applied to evaluate multiregional industrial waste disposal and landfill attributed to consumption in the city of Nagoya. Three-regional input–output tables with and without cross-hauling are estimated by partitioning the biregional table between Aichi prefecture and the rest of Japan.

JEL Classification C67 · D57 · R15

1 Introduction

Regional economic impact is well assessed by relevant local area multipliers. Multiregional input–output (MRIO) analysis may be one of the primary models for incorporating regional interdependencies into an input–output framework. In Chenery-Moses-type MRIO model, the intra-regional coefficient matrices are located along the main diagonal, while another cross-regional trade matrix functions to incorporate the cross-regional effects (Hewings and Jensen 1987; Oosterhaven and Polenske 2009). It is said that MRIO models have an advantage over Isard-type interregional (IRIO)

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models, as they are able to use data that are more available (Polenske and Hewings 2004).[1] Despite the simplification in the MRIO models, however, collecting real data of cross-regional trades is very costly.

Thus, preceding papers with nonsurvey approaches employed location quotients (LQ) as the primary reference to cross-regional trades (see e.g., Isserman 1977). With this approach, the domestic outflows and inflows (cross-regional trades) are estimated independent of the other figures such as the regional control totals, final demand, and imports and exports in the multiregional table. While LQ techniques are convenient to use, they also have some limitations; these techniques inevitably eliminate *cross-hauling* in cross-regional trades.[2] Without cross-hauling, as suggested by many articles such as Roginson and Miller (1988), there is the risk of underestimating the regional propagation effect.

Consistent cross-regional trades can be estimated using given regional input–output tables. If we set the estimates on all the regional figures (including regional imports and exports) besides net regional trades, we can restrict to some extent the degrees of freedom in cross-regional trades estimation, as done in the commodity balance (CB) approach. In such cases, biproportional matrix reconciliation techniques using reference regional trades can be applied (see e.g., Lahr 2004; Canning and Wang 2005). However, the estimate will not include cross-hauling unless the reference domestic trades include cross-hauling. One-way method is to apply gravity trade flow models (Olson 1972) that permit cross-hauling. Regression-type gravity models (e.g., Begg 1985) have been applied and have shown to produce results by and large close to the survey data (Riddington et al. 2006). Kronenberg (2010) estimated biregional trades using the Leontief-Strout-type exact solution nonsurvey method that allows cross-hauling, which was then discussed in Flegg and Tohmo (2011).

Meanwhile, there are requests that the given multiregional transactions be disaggregated into smaller regions, such as in the case of Japan, rather than obtaining all cross-regional trades among the given regions. In other words, our objective in the study is to decompose one of the regions of a given cross-hauled MRIO table into two to obtain a more detailed MRIO table while maintaining the given structure of regional transactions. In such a context, however, the approaches mentioned above could spoil the original measured transactions. Thus, we consider an approach that requires less involvement. We partition the regional outflows into disaggregated regions where the inflows are determined accordingly. Further, for reallocating outflows, we use the gravity ratios.

For our empirical study, we use the biregional table of Aichi prefecture and the rest of Japan, 2005, and apply the calculation in order to disaggregate Aichi into Nagoya and the rest of Aichi, thus producing a three-region multiregional table. For evaluating multiregional transactions, we call on the gravity ratios that rule the outflow split between regions, in addition to meeting the entire commodity balance; the gravity ratios can be obtained from the market sizes and the distances between regions with

[1] For definitions of MRIO and IRIO, we rely on Polenske (1995).

[2] There are many variations to the LQ techniques, those proposed by Round (1972), Morrison and Smith (1974), Flegg and Webber (2000), for example, but all without cross-hauling. Richardson (1985), and, more recently, Gallego and Lenzen (2009) give a thorough review of the regional input–output framework.

the aid of the gravity parameters, which we estimate using the reference nine-region multiregional table of Japan. This method hence allows to partition a cross-hauled biregional table into three or more parts in an arbitrary manner, while being consistent with the original regional transactions. We proceed to use this three-region table for the analysis of industrial waste and landfill, which are attributed to the exogenous consumption boost in Nagoya.

The rest of the paper is organized as follows. In the next section, we introduce models with and without cross-hauling for partitioning biregional input–output models. Section 3 describes the estimation of gravity parameters of regional trades using survey data, along with the population-weighted distances across the regions. In Sect. 4, we introduce data on regional industrial waste generation and perform a multiregional analysis with and without cross-hauling. Section 5 concludes the paper.

2 The model

2.1 Regional partitioning

First, we partition a nationwide input–output system into two regions. The physical equivalence in an economy can be described as follows:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} + \mathbf{e} - \mathbf{m} \tag{1}$$

where $\mathbf{x}$ is the output vector, $\mathbf{A}$ is the input–output coefficient matrix, $\mathbf{f}$ is the final demand vector, $\mathbf{e}$ is the foreign export vector, and $\mathbf{m}$ is the foreign import vector. Note that vectors and matrices hereafter have the dimension of existing goods and services (or sectors), unless indicated otherwise.

We now partition formula (1) into region i and the rest of the nation. In this event, $\mathbf{x}$ is divided into its proportion using the number of a shipments and employees. As for the final demand $\mathbf{f}_i$, we use the value-added (row) vector for nonhousehold expenses; for households, we may divide in proportion to the number of households; we may divide household expenses in proportion to the number of households, and government expenses, in proportion to the expenses of local governments. As for foreign imports $\mathbf{m}_i$ and exports $\mathbf{e}_i$, we may consult on the regional data, at least in the case of Japan, or divide them in proportion to market sizes such as total outputs and total domestic final use. We note that $\mathbf{A}_i$ should be estimated separately if possible, but we may assume that it is the same as the nationwide $\mathbf{A}$ matrix if there is no other way.

When these figures are all set, we can call on the *net* domestic inflows $\mathbf{s}_i$ as follows:

$$\mathbf{s}_i = \mathbf{A}_i\mathbf{x}_i + \mathbf{f}_i + \mathbf{e}_i - \mathbf{m}_i - \mathbf{x}_i \tag{2}$$

At the same time, $\mathbf{s}_i$ must equal the difference between the unknown gross domestic inflows $\mathbf{n}_i$ and outflows $\mathbf{h}_i$; that is,

$$\mathbf{s}_i = \mathbf{n}_i - \mathbf{h}_i \tag{3}$$

If we assume R regions instead of two, the sum of the regional physical balance must coincide with the nationwide balance; that is,

$$\sum_{i=1}^{R} \mathbf{s}_i = \sum_{i=1}^{R} [\mathbf{A}_i\mathbf{x}_i + \mathbf{f}_i + \mathbf{e}_i - \mathbf{m}_i - \mathbf{x}_i] \\ = \mathbf{A}x + \mathbf{f} + \mathbf{e} - \mathbf{m} - \mathbf{x} = 0 \tag{4}$$

As (4) is an identity subject to (1), Eq. (3) will consist of $R-1$ independent equations.[3]

2.2 Cross-regional trades

Interregional transactions are denoted with the amount of domestic trade vector $\mathbf{t}_{ij}$ from region i to region j. By definition, we have the following identities:

$$\mathbf{h}_i = \sum_{j=1}^{R} \mathbf{t}_{ij} \qquad \mathbf{n}_j = \sum_{i=1}^{R} \mathbf{t}_{ij} \tag{5}$$

Note that $\mathbf{t}_{ij} = 0$ for any $i = j$ since we exclude intra-regional trades. Since these equations imply the following identity

$$\sum_{j=1}^{R} \mathbf{n}_j = \sum_{i=1}^{R} \mathbf{h}_i$$

Equation (5) will consist of $2R - 1$ independent equations altogether.

Let us now verify the number of unknowns and equations. The unknowns are $\mathbf{t}_{ij}$ $(i, j = 1, \ldots, R)$ while omitting the intra-regional transactions $i = j, \mathbf{h}_i$ $(i = 1, \ldots, R)$ and $\mathbf{n}_j$ $(j = 1, \ldots, R)$, which total to $R^2 + R$ unknown variables.[4] On the other hand, independent equations are (3) and (5), total to $3R - 2$. Hence, we must specify the system further in order to set all the unknown variables. In what follows, we presuppose that cross-hauled transactions in one region is available. For this region R, we know $\mathbf{h}_R$ and $\mathbf{n}_R$. Thus, there are $3R-2$ independent equations with R^2+R-2 unknowns so that we will need $R^2 - 2R$ more independent equations to specify the domestic trades. We will use the gravity ratio described in the next subsection to obtain these equations.

[3] We mean that there are $R - 1$ independent vector equations of dimension C, where C denotes the number of sectors.

[4] We have $R^2 - R$ unknowns for the interregional transaction vectors and $2R$ for the outflow and inflow vectors.

2.3 Multiregional outflow ratio

In this subsection, we focus on a good or service $c \in C$ but do not use the subscript c for the sake of simplicity. Let y_j be the local absorption at destination j for c, or the cth entry of region j's total demand vector $\mathbf{A}_j\mathbf{x}_j + \mathbf{f}_j$. Let x_i be the local production at source i for c, or the cth entry of region i's total production $\mathbf{x}_i$. According to Riddington et al. (2006), in gravity regression models, the trade flow t_{ij} from region i to j will have the form as given below, where we denote the distance between regions i and j by d_{ij}. Greek letters designate parameters to be estimated, and u_{ij} denotes the iid disturbance term.

$$\ln t_{ij} = \alpha + \beta \ln y_i + \gamma \ln y_j + \delta \ln d_{ij} + u_{ij}$$

Hence, the outflow ratio from region r to i with respect to region r to j will be as given below:

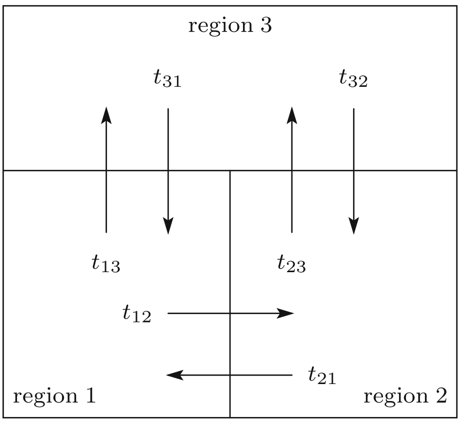
$$\ln \frac{t_{ri}}{t_{rj}} = \gamma \ln \frac{y_i}{y_j} + \delta \ln \frac{d_{ri}}{d_{rj}} + u_{ri} - u_{rj} \tag{6}$$

If we can estimate parameters γ and δ, we will have $R - 2$ independent equations for each of the R regions. In all regions, (6) totals to $R^2 - 2R$ equations, and we have sufficient number of equations to solve all the unknowns.

2.4 Three-region case

In this subsection, we partition one of the two regions of a biregional (two regions) table and obtain three-region cross-regional trades. The three-regional trades are illustrated in Fig. 1. Note that one of the original two regions is region 3 and that the other region is partitioned into two regions, 1 and 2.

Fig. 1 Trades in three-regions



Here, we write down Eqs. (3), (5), and (6) as given below. There are ten independent equations, while there are ten unknowns since we know n_3 and h_3. Thus, the unknowns can now be solved.

$$\begin{aligned} s_1 &= n_1 - h_1, & n_1 &= t_{21} + t_{31}, & h_1 &= t_{12} + t_{13}, & t_{12}/t_{13} &= \widehat{t_{12}/t_{13}} \\ s_2 &= n_2 - h_2, & n_2 &= t_{12} + t_{32}, & h_2 &= t_{21} + t_{23}, & t_{21}/t_{23} &= \widehat{t_{21}/t_{23}} \\ s_3 &= n_3 - h_3, & n_3 &= t_{13} + t_{23}, & h_3 &= t_{31} + t_{32}, & t_{31}/t_{32} &= \widehat{t_{31}/t_{32}} \end{aligned}$$

Note that the hat indicates the values estimated using formula (6) via the parameters that we estimate later.

While on the subject, we can determine the cross-regional trades *without* cross-hauling as long as there are three-regions or less. If there is no cross-hauling, every region is either a domestic importer or an exporter; that is, we must have

$$\mathbf{h}_i^{\mathsf{T}} \cdot \mathbf{n}_j = 0 \tag{7}$$

but this can be satisfied by setting the entries (noted in lower cases) as follows.

$$n_{ic} = \begin{cases} 0 & s_{ic} < 0 \\ s_{ic} & s_{ic} \geq 0 \end{cases} \qquad h_{ic} = \begin{cases} 0 & s_{ic} \geq 0 \\ -s_{ic} & s_{ic} < 0 \end{cases} \tag{8}$$

Note that even in the case that we have inflows and outflows including cross-hauling in some region, we may redefine them using (8) to have one without.

Under condition (7), there will be $R - 1$ independent equations and at most $(2R^2 - 1 + (-1)^R)/8$ unknowns in this case.[5] The number of independent equations and the unknowns will necessarily coincide only when $R \leq 3$. This feature is also mentioned in Begg (1985). Hence, we can now estimate cross-regional trades with and without cross-hauling for the three-region models in this framework. We will accordingly compare the propagation effects later.

3 Estimation of gravity parameters

3.1 Distances between regions

We use the nine-region multiregional table of Japan to estimate the gravity parameters for Eq. (9) below. Prior to carrying out the regression, we ought to have the distances between regions, that is, d_{ij} for all regions i and j. In this study, we use the population-weighted distances as described below.

Let $k \in U_i$ be a city in region i with population p_k. Likewise, let $l \in U_j$ be a city in region j with population p_l. The distance between city k and l is d_{kl}. We define the population-weighted distance d_{ij} between region i and j as follows:

[5] The proof is standard and is therefore omitted.

Table 1 Population-weighted distances (day)

Region	1	2	3	4	5	6	7	8
1 Hokkaido								
2 Tohoku	0.68							
3 Kanto	0.84	0.17						
4 Chubu	0.99	0.33	0.16					
5 Kinki	1.09	0.43	0.29	0.13				
6 Chugoku	1.22	0.56	0.42	0.26	0.16			
7 Shikoku	1.28	0.62	0.48	0.33	0.19	0.13		
8 Kyushu	1.40	0.75	0.60	0.45	0.33	0.14	0.31	
9 Okinawa	3.25	2.60	2.45	2.30	2.18	2.05	2.16	1.86

$$d_{ij} = \sum_{l \in U_j} \sum_{k \in U_i} \frac{p_k \, p_l}{\sum_{l \in U_j} \sum_{k \in U_i} p_k \, p_l} d_{kl} \tag{9}$$

Table 1 shows the distances measured in days across the nine regions according to the configuration of the regions in the multiregional table. We measured these distances by referencing the top three largest population cities in each region with road transportation distances using an in-car navigation system between the representative locations for which we assigned municipal offices.

3.2 Gravity parameters

Gravity parameters γ and δ of Eq. (6) are estimated using log-linear regressions for each sector. We used the 2005 nine-region MRIO data for Japan (METI 2010) and the corresponding distance table as shown in Table 1. In the regression, we excluded Okinawa, as this region is peculiar in terms of distances while transactions are relatively small in scale. The results are shown in Table 2.[6] There are 53 sectors total while the table excludes three sectors with unobserved trades, namely, rental housing, public service, and others. We consider the observations for eight regions, and for each region, the observations are given by a combination of the number of regions sans the origin and a pair of regions (${}_7C_2$); as such, the total number of observations is $8 \times {}_7C_2 = 168$ (ad extremum).

The estimates are fairly satisfactory, except for some sectors presenting signs opposite to the expected direction. For Coal oil and natural gas, a very small sample size representing the fact that domestic production and thus transactions are nearly absent, or, if any, being very specific. Similarly, parameters on the distance variables for office and service machinery, and other automobiles sectors may have been affected by specific factory locations. On the other hand, water and waste processing is well preferred in an underpopulated region; hence, the parameter on the demand variable should have a negative sign.

[6] We checked the robustness of the ordinary specification of the gravity model in the Appendix.

Table 2 Estimation of gravity parameters for each sector

Sectors ($c \in C$)	γ	$-\delta$	R^2	N
Agriculture, fishery, and forestry	0.949 (13.11)***	1.208 (15.79)***	0.694	168
Mining	0.386 (2.02)**	1.058 (5.30)***	0.318	168
Coal oil and natural gas	1.691 (3.06)**	−6.824 (−5.14)***	0.732	9
Food and beverages	0.828 (27.06)***	0.915 (21.21)***	0.892	168
Textile industry products	0.662 (13.92)***	0.211 (2.51)**	0.700	150
Apparel and textile products	1.163 (15.91)***	0.583 (5.78)***	0.692	168
Lumber and furniture	1.296 (21.13)***	0.782 (10.72)***	0.814	168
Pulp and paper	1.140 (18.31)***	0.858 (11.00)***	0.787	168
Printing and binding	1.047 (12.61)***	1.023 (7.34)***	0.612	168
Basic chemical products	0.566 (10.04)***	0.910 (8.35)***	0.717	162
Synthetic resin	0.747 (23.14)***	0.374 (4.61)***	0.863	147
Final chemical products	0.649 (19.39)***	0.446 (6.67)***	0.781	168
Pharmaceutical products	0.495 (12.78)***	0.205 (3.37)***	0.592	168
Petroleum and coal products	0.835 (6.21)***	1.703 (8.14)***	0.534	168
Plastic products	0.499 (16.55)***	0.848 (12.77)***	0.797	168
Ceramic and clay products	1.016 (14.79)***	0.958 (10.52)***	0.757	168
Iron and steel	0.634 (14.72)***	0.759 (7.34)***	0.727	168
Nonferrous metal	0.745 (16.46)***	0.504 (4.79)***	0.743	168
Metal products	0.699 (13.02)***	0.847 (9.05)	0.710	162
General machinery	0.643 (22.98)***	0.126 (2.07)**	0.827	168
Office and service machinery	0.608 (12.01)***	−0.047 (−0.33)	0.531	141
Industrial electrical equip.	0.751 (22.53)***	0.505 (7.38)***	0.820	162
Other electrical machinery	0.920 (22.18)***	−0.072 (−0.92)	0.783	162
Consumer electric equip.	0.589 (13.15)***	0.088 (0.93)	0.588	150
Telecommunication equip.	0.721 (19.16)***	0.275 (3.88)***	0.744	168
Computers and related devices	0.926 (6.28)***	0.192 (0.80)	0.281	112
Electronic components	0.763 (15.36)***	0.083 (0.63)	0.654	168
Passenger cars	0.634 (25.92)***	0.073 (1.41)	0.865	126
Other automobiles	0.170 (4.18)***	−0.198 (−1.69)*	0.095	136
Auto parts and accessories	0.667 (20.34)***	0.431 (3.13)***	0.775	162
Other transportation equip.	0.705 (10.42)***	0.675 (6.48)***	0.528	168
Precision machinery	0.779 (15.75)***	0.319 (3.79)***	0.658	168
Other manufactured products	0.866 (16.65)***	0.335 (3.79)***	0.684	168
Renewables recovery	0.540 (4.69)***	0.812 (3.55)***	0.378	156
Construction	0.630 (7.39)***	0.446 (4.16)***	0.350	168
Electric power	2.121 (10.82)***	1.247 (5.62)***	0.590	162
Gas and heat supply	0.330 (4.90)***	0.712 (5.30)***	0.352	162
Water and waste processing	−0.214 (−2.37)**	0.815 (7.09)***	0.365	151
Commerce	0.547 (32.66)***	0.966 (31.75)***	0.932	168

Table 2 continued

Sectors ($c \in C$)	γ	$-\delta$	R^2	N
Finance and insurance	0.892 (11.34)***	−0.295 (−2.62)***	0.433	168
Real estate	0.402 (3.57)***	1.077 (6.07)***	0.261	168
Transportation	0.938 (25.53)***	0.858 (15.60)***	0.892	168
Other communications	0.881 (15.80)***	1.087 (12.69)***	0.762	168
Information services	1.103 (13.97)***	1.108 (7.00)***	0.667	151
Education and research	0.934 (15.68)***	0.685 (8.35)***	0.744	168
Health care and social security	2.318 (20.25)***	2.129 (17.72)***	0.862	157
Advertising	0.530 (12.72)***	2.208 (23.87)***	0.838	168
Rental and leasing services	0.352 (11.53)***	0.810 (14.86)***	0.735	168
Other office services	0.663 (13.10)***	1.028 (12.53)***	0.715	168
Consumer service	1.067 (15.89)***	1.834 (18.63)***	0.820	168

Numbers in parentheses are the value of the t statistics *** Significance at 1 % level, ** at 5 %, and * at 10 %

4 Application

4.1 Multiregional table for Aichi

For our empirical study, we use MRIO analysis to estimate industrial waste and final landfill resulting from the change in consumption patterns of Nagoya citizens. Specifically, we investigate how much final landfill is propagated owing to a 10 % proportional increase in the final demand bundle of Nagoya.[7] For this purpose, we first prepare a three-region multiregional table for Nagoya (region 1), the rest of Aich (region 2), and the rest of Japan (region 3) by partitioning the available biregional table between Aichi (regions 1 and 2) and the rest of Japan (region 3). Then, we use the wastes disposal table for different regions by different types of wastes in order to calculate the change in total landfill of industrial wastes during our sample period in Nagoya. Thus, we use the change in the exogenous final demand in Nagoya (region 1) and calculate the regional propagation effects using Eqs. (11) and (12).

In partitioning Aichi's table (APG 2010), we use Nagoya's share of production for the control total in each sector, while we use the same input coefficient matrix for both regions.[8] For the final demand, we use the value-added (row) vector for nonhousehold expenses; for households we divided in proportion to the number of households; for government expenses we divided in proportion to the expenses of local governments. For fixed capital formation, we use the national capital coefficients with respect to the final output. As for imports and exports, we use the survey data for Nagoya.

Cross-regional trades are estimated using the model described earlier, with gravity ratios estimated by the population-weighted distances among three-regions, namely,

[7] Nagoya is the largest city in Aichi prefecture and the fourth-largest city in Japan.

[8] With regard to the following discussion, we compile our data using published statistics, namely, MIAC (2009), APG (2010), MAFF (2005), MIAC (2005), MIAC (2006), METI (2004), and METI (2005).

$d_{12} = d_{21} = 0.028$ [day], $d_{23} = d_{32} = 0.345$ [day], and $d_{13} = d_{31} = 0.347$ [day]. As mentioned earlier, we naturally prepare two tables, that is, with and without cross-hauling, since there are just three-regions. As for the sectors that do not have cross-hauling in the biregional table, we assume to not have cross-hauling in the partitioned table also.

4.2 Multiregional analysis

Here, we describe the authentic demand-pull type of the multiregional framework we use for our empirical analysis. Let $\hat{\mathbf{T}}_{ij}$ be the diagonalized inflow coefficient matrix from i to j such that

$$\mathbf{t}_{ij} = \hat{\mathbf{T}}_{ij}\left[\mathbf{A}_j\mathbf{x}_j + \mathbf{f}_j\right]$$

The physical balance in region i, as described by Eqs. (2) and (3), can be rewritten as follows:

$$\mathbf{x}_i = \left[\mathbf{I} - \hat{\mathbf{M}}_i\right]\left[\mathbf{A}_i\mathbf{x}_i + \mathbf{f}_i\right] + \mathbf{e}_i + \sum_{j \neq i}^{R}\left[\hat{\mathbf{T}}_{ij}\left[\mathbf{A}_j\mathbf{x}_j + \mathbf{f}_j\right] - \hat{\mathbf{T}}_{ji}\left[\mathbf{A}_i\mathbf{x}_i + \mathbf{f}_i\right]\right]$$

where $\hat{\mathbf{M}}_i$ is the diagonalized import coefficient matrix in i. This will be summarized in the following basic equation for multiregional analysis.

$$\boldsymbol{x} = [\boldsymbol{I} - \boldsymbol{M} - \boldsymbol{T}]\left[\boldsymbol{A}\boldsymbol{x} + \boldsymbol{f}\right] + \boldsymbol{e} \tag{10}$$

Note that the bold-italicized characters indicate that they are either R dimensional vectors of C dimensional vectors or $R \times R$ dimensional matrices of $C \times C$ dimensional matrices. For the three-region case this reads,

$$\boldsymbol{M} = \begin{pmatrix} \hat{\mathbf{M}}_1 & & \\ & \hat{\mathbf{M}}_2 & \\ & & \hat{\mathbf{M}}_3 \end{pmatrix}, \quad \boldsymbol{A} = \begin{pmatrix} \mathbf{A}_1 & & \\ & \mathbf{A}_2 & \\ & & \mathbf{A}_3 \end{pmatrix}, \quad \boldsymbol{x} = \begin{pmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \mathbf{x}_3 \end{pmatrix}, \quad \boldsymbol{f} = \begin{pmatrix} \mathbf{f}_1 \\ \mathbf{f}_2 \\ \mathbf{f}_3 \end{pmatrix}$$

$$\boldsymbol{T} = \begin{pmatrix} \hat{\mathbf{T}}_{21} + \hat{\mathbf{T}}_{31} & -\hat{\mathbf{T}}_{12} & -\hat{\mathbf{T}}_{13} \\ -\hat{\mathbf{T}}_{21} & \hat{\mathbf{T}}_{12} + \hat{\mathbf{T}}_{32} & -\hat{\mathbf{T}}_{23} \\ -\hat{\mathbf{T}}_{31} & -\hat{\mathbf{T}}_{32} & \hat{\mathbf{T}}_{13} + \hat{\mathbf{T}}_{23} \end{pmatrix}, \quad \boldsymbol{e} = \begin{pmatrix} \mathbf{e}_1 \\ \mathbf{e}_2 \\ \mathbf{e}_3 \end{pmatrix}$$

According to formula (10), the propagation effect $\Delta\boldsymbol{x}$, initiated by change in the regional final demand $\Delta\boldsymbol{f}$, can be assessed as follows:

$$\Delta\boldsymbol{x} = [\boldsymbol{I} - [\boldsymbol{I} - \boldsymbol{M} - \boldsymbol{T}]\,\boldsymbol{A}]^{-1}\,[\boldsymbol{I} - \boldsymbol{M} - \boldsymbol{T}]\,\Delta\boldsymbol{f} \tag{11}$$

Moreover, we can use $RC \times R$ regional disposal coefficient matrix $\boldsymbol{G}$ that designates disposal from C industries spanned in R regions, in order to estimate regional disposal propagation W as given below.

$$\Delta W = \boldsymbol{G}\Delta\boldsymbol{x} \tag{12}$$

Exogenous change of the final consumption is the 10 % of Nagoya's household consumption in 2005, obtained from APG (2005a). For sectoral waste generation and final landfill data, we use Aichi's municipal survey (APG 2005b). As for region 3, we use the national data (MOE 2010). In Table 3, we summarize the final exogenous variation in consumption, regional propagation effects considering cross-hauling, and the associated regional waste generation coefficients.

4.3 Results

We observe the waste generation coefficients being relatively large in region 3. By assuming an increase of about JPY 107 billion in overall production in region 1, the propagation effect spreads approximately in the order of JPY 113 billion, 18 billion, and 40 billion in regions 1, 2, and 3, respectively, while wastes generated per unit propagation (averaged waste generation coefficient) ranges from double in region 2 and considerably more than three times in region 3, compared to those in region 1.

Table 4 shows the breakdown of the overall effects on waste generation and final landfill, upon which the regional characteristics reflect. In region 1, the largest factor of generated waste is rubble and it is also the largest factor for final landfill ; it is mainly the construction sector that generates rubble. In region 2, on the other hand, the largest factor of generated waste is manure while rubble is the largest factor for landfill. A large part of waste and landfill is generated by sewage in region 3, where the water sector's coefficient is large. Notice that Nagoya is a large domestic importer of agriculture and food so that these sectors are propagated outside of Nagoya, and because of the large generation coefficient in these sectors, there is large manure generation outside of Nagoya. Nevertheless, they are effectively re-utilized in the corresponding region.

Finally, in Table 5, we compare the propagation effects, as well as the landfill abatement effects, with and without cross-hauling. The exogenous change in the final demand, as mentioned earlier, is an increase of about JPY 107 billion in total. The propagation effects are essentially identical in terms of total propagation (JPY 171 billion) in both cases, while its distribution among regions differs in the two cases. That is, propagation in region 1 is greater without cross-hauling while that in region 3 is less in the same case. As the inner propagation (region 1) is greater than outside regions in both cases and as waste and landfill coefficients are smaller inside and greater outside, differences in the regional propagations will not enhance the differences in the final landfill, but we may still observe differences. This study shows that unless cross-hauling is used, there exists the risk of underestimating final landfill.

5 Concluding remarks

In this paper, we proposed a nonsurvey method for estimating multiregional trades without eliminating cross-hauling, when a national biregional input–output table is available. Domestic outflows are assigned by interpolating the biregional trades on the basis of the gravity ratio between the origin and the destinations, with parameters estimated from a detailed survey on multiregional trades. The method is then applied to evaluate cross-regional industrial waste and final landfill propagation. We compiled

Table 3 Exogenous change Δf [MJPY], propagation effects Δx [MJPY], and waste generation coefficients G [Ton/MJPY]

Sectors	Region 1			Region 2		Region 3	
	Δf_1	Δx_1	G_1	Δx_2	G_2	Δx_3	G_3
Agriculture	634	25	2.29	582	6.47	1,315	8.52
Mining	−26	1	2.78	10	1.40	155	13.92
Construction	12,815	12,378	1.22	1,676	1.37	540	1.21
Food	4,138	1,738	0.21	113	0.16	3,897	0.42
Drinks and feeds	1,860	91	0.81	499	0.09	1,920	0.27
Textiles	60	94	0.54	24	0.52	61	0.44
Clothing	833	61	0.09	6	0.08	158	0.05
Timber	25	142	0.49	23	0.27	191	0.62
Furniture	141	118	0.06	14	0.07	194	0.11
Pulp and paper	68	189	1.58	335	1.56	914	4.49
Publishing and print	23	471	0.21	48	0.19	585	0.17
Chemical products	648	436	1.10	546	0.33	2,492	0.61
Oil and coal products	1,158	35	0.00	168	0.15	2,532	0.10
Plastic products	173	147	0.08	352	0.06	1,066	0.11
Rubber products	84	30	0.11	50	0.20	252	0.11
Leather products	228	2	0.00	3	0.00	136	0.14
Ceramic soil products	92	129	0.76	257	0.77	816	1.39
Iron and steel	58	260	0.47	372	1.69	2,268	1.71
Nonferrous products	16	137	0.81	126	0.14	508	0.49
Metal products	155	604	0.29	261	0.21	1,376	0.19
General machinery	2,372	2,565	0.10	442	0.07	204	0.06
Electric machinery	4,116	386	0.10	2,275	0.05	2,255	0.09
Cars and trucks	2,575	788	0.11	2,850	0.14	1, 057	0.07
Precision machinery	578	172	0.00	20	0.02	402	0.06
Other products	672	157	0.25	88	0.21	634	0.12
Electric power	902	950	0.02	505	0.97	1,344	0.63
Gas and heat	280	505	0.02	13	0.12	50	0.06
Water	237	614	0.05	31	1.66	153	19.08
Transportation	3,171	4,142	0.02	659	0.02	3,515	0.01
Commerce	13,022	17,273	0.03	298	0.04	1,837	0.02
Services	39,534	50,127	0.02	1,596	0.02	4,981	0.01
Unclassified	16,281	18,199	0.00	3,596	0.00	2,618	0.00
Total	106,920	112,965		17,840		40,425	

three-region MRIO tables, including Nagoya, with and without cross-hauling by partitioning the biregional table of Aichi that includes Nagoya, and the rest of Japan. Although the propagation effects in monetary terms for the two cases (with and without cross-hauling) coincide in total, they have different distributions among regions such that different regional characteristics of industrial waste processing lead to differ-

Table 4 Overall effects in industrial wastes ΔW [Ton]

	Region 1		Region 2		Region 3	
	Generated	Landfill	Generated	Landfill	Generated	Landfill
Ash	71	35	73	30	172	32
Sewage	3,782	386	1,188	75	13,480	674
Oil/fat	286	13	62	3	241	7
Acid	47	4	15	1	263	19
Alkaline	317	10	58	2	166	14
Plastic	819	241	146	39	396	128
Paper	234	17	92	8	144	9
Wood	575	66	85	10	181	14
Fiber	9	0	2	1	2	0
Residue	155	12	28	2	515	18
Rubber	6	6	2	1	4	2
Metal	1,092	65	513	11	707	40
Glass	297	71	93	19	327	108
Tailing	172	15	576	22	2,263	197
Rubble	11,372	845	1,780	136	690	33
Manure	58	0	3,771	0	11,158	167
Carcass	0	0	0	0	25	4
Dust	108	9	522	61	1,532	241
Total	19,399	1,794	9,004	421	32,268	1,707

Table 5 Comparison of propagation effects with and without cross-hauling

	Exogenous Δf [MJPY]	With cross-hauling		Without cross-hauling	
		Propagation Δx [MJPY]	Landfill ΔW [ton]	Propagation Δx [MJPY]	Landfill ΔW [ton]
Region 1	106,920	112,965	1,794	122,352	2,012
Region 2	0	17,840	421	22,780	526
Region 3	0	40,425	1,707	25,806	1,062
Total	106,920	171,230	3,923	170,938	3,600

ences in assessing the overall landfill abatement, initiated by an artificial consumption boost in Nagoya.

6 Appendix

Here, we try an alternative specification for the gravity model and see how much of the result is affected. In particular, we estimate the parameters for the following model:

$$\ln t_{ij} = \alpha_2 + \beta_2 \ln y_i + \gamma_2 \ln y_j + \delta_2 \ln d_{ij} + \eta \ln v_j + u_{ij}$$

Notice that the model now includes v_j, per-capita GVA (gross valued added) in region j, which we intend to represent the affluence characteristics of the demand in the region.

The result is shown in Table 6, where we observe that the demand and distance parameters, γ and δ, and the corresponding significances as well, are not too far from the original ones shown in Table 2. Further, in Table 7, we show the propagation effects via the alternative model (shown with prime) in comparison with those of the original model, presented in Table 3. The numbers are very similar, so we proceed to use the simple ordinary gravity specification.

Table 6 Alternative gravity parameters estimation

Sectors ($c \in C$)	γ_2	$-\delta_2$	η	R^2
Agriculture, fishery, and forestry	0.761***	1.072***	1.857***	0.73
Mining	−0.240	1.138***	5.638***	0.43
Coal oil and natural gas	−1.610*	−5.168***	16.475***	0.93
Food and beverages	0.773***	0.900***	0.532*	0.89
Textile industry products	0.510	0.283***	1.904***	0.74
Apparel and textile products	1.409***	0.591***	−1.976***	0.70
Lumber and furniture	1.384***	0.788***	−0.662	0.81
Pulp and paper	0.946***	0.853***	1.453***	0.79
Printing and binding	0.660***	0.974***	4.037***	0.65
Basic chemical products	0.389***	1.013***	1.711**	0.71
Synthetic resin	0.825***	0.322***	−1.119**	0.87
Final chemical products	0.791***	0.434***	−1.644***	0.80
Pharmaceutical products	0.428***	0.206***	0.695*	0.60
Petroleum and coal products	0.973***	1.691***	−1.153	0.53
Plastic products	0.447***	0.846***	0.848**	0.80
Ceramic and clay products	1.129***	0.964***	−1.029*	0.76
Iron and steel	0.574***	0.759***	1.056*	0.73
Nonferrous metal	0.631***	0.530***	2.189***	0.77
Metal products	0.706***	0.848	−0.081	0.71
General machinery	0.615***	0.135**	0.407	0.83
Office and service machinery	0.485***	−0.044	2.705***	0.56
Industrial electrical equip.	0.644***	0.487***	1.869***	0.85
Other electrical machinery	0.903***	−0.067	0.191	0.78
Consumer electric equip.	0.647	0.078	−0.721	0.59
Telecommunication equip.	0.765***	0.276***	−0.490	0.74
Computers and related devices	0.552**	0.178	3.863**	0.31
Electronic components	0.650***	0.090	2.816***	0.70

Table 6 continued

Sectors ($c \in C$)	γ_2	$-\delta_2$	η	R^2
Passenger cars	0.639***	0.073	−0.077	0.86
Other automobiles	0.009	−0.161	2.442**	0.11
Auto parts and accessories	0.691***	0.439***	−1.019	0.78
Other transportation equip.	0.599***	0.653***	1.084	0.53
Precision machinery	0.935***	0.325***	−1.654***	0.68
Other manufactured products	0.912***	0.337***	−0.505	0.68
Renewables recovery	0.054	0.870***	6.032***	0.40
Construction	0.951***	0.475***	−2.569***	0.40
Electric power	0.831***	1.254***	9.810***	0.72
Gas and heat supply	0.394***	0.722***	−0.869	0.36
Water and waste processing	0.085	0.828***	−2.482***	0.43
Commerce	0.540***	0.964***	0.078	0.93
Finance and insurance	1.030***	−0.294***	−1.194	0.45
Real estate	0.870***	1.160***	−4.496***	0.31
Transportation	0.977***	0.860***	−0.339	0.89
Other communications	0.735***	1.077***	1.313**	0.77
Information services	0.749***	1.061***	4.094***	0.68
Education and research	0.906***	0.686***	0.248	0.74
Health care and social security	1.857***	2.080***	3.229***	0.87
Advertising	0.625***	2.232***	−1.361**	0.84
Rental and leasing services	0.214***	0.793***	1.618***	0.77
Other office services	0.761***	1.041***	−1.015*	0.72
Consumer service	0.826	1.793***	2.321***	0.83

Table 7 Regional propagation effects with alternative specifications

	Region 1		Region 2		Region 3	
	Δx_1	$\Delta x'_1$	Δx_2	$\Delta x'_2$	Δx_3	$\Delta x'_3$
Agriculture	25	24	582	556	1,315	1,381
Mining	1	2	10	10	155	149
Construction	12,378	12,391	1,676	1,670	540	534
Food	1,738	1,210	113	151	3,897	4,371
Drinks and feeds	91	87	499	500	1,920	1,927
Textiles	94	107	24	19	61	50
Clothing	61	125	6	2	158	97
Timber	142	166	23	21	191	171
Furniture	118	144	14	11	194	171
Pulp and paper	189	126	335	105	914	1,200
Publishing and print	471	215	48	60	585	821
Chemical products	436	428	546	530	2,492	2,520

Table 7 continued

	Region 1		Region 2		Region 3	
	Δx_1	$\Delta x'_1$	Δx_2	$\Delta x'_2$	Δx_3	$\Delta x'_3$
Oil and coal products	35	36	168	167	2,532	2,537
Plastic products	147	651	352	394	1,066	531
Rubber products	30	66	50	41	252	226
Leather products	2	18	3	2	136	121
Ceramic soil products	129	260	257	248	816	694
Iron and steel	260	1,199	372	465	2,268	1,125
Nonferrous products	137	146	126	90	508	524
Metal products	604	640	261	234	1,376	1,368
General machinery	2,565	2,573	442	434	204	201
Electric machinery	386	823	2,275	1,599	2,255	2,520
Cars and trucks	788	281	2,850	2,497	1,057	1,919
Precision machinery	172	264	20	4	402	323
Other products	157	256	88	69	634	557
Electric power	950	964	505	498	1,344	1,336
Gas and heat	505	508	13	13	50	49
Water	614	616	31	28	153	153
Transportation	4,142	4,323	659	632	3,515	3,363
Commerce	17,273	17,254	298	258	1,837	1,895
Services	50,127	50,225	1,596	1,512	4,981	5,001
Unclassified	18,199	18,239	3,596	3,572	2,618	2,609
Total	112,965	114,368	17,840	16,396	40,425	40,443

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