Preparation of Inter-Prefectural Input-Output Tables 2011 and 2015 with Gravity Model

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1. Introduction

This research aims to create multi input-output table (MRIO) for all 47 prefectures of Japan using the regional input-output tables published by each prefecture. The regionalization of national input-output tables has been a topic of significant interest in regional economics for decades. This study draws upon the extensive body of work in this field, particularly the comprehensive review conducted by Szabó (2015), who examined various methods for estimating regional and interregional input-output tables.

It is well known that regional economies have a higher degree of interdependence with other regions compared to national economies. The induced effects in a regional economy stimulate production in other regions, which in turn re-stimulates production in the original region. To analyze these inter-regional spillover effects, an inter-regional input-output table is necessary. Inter-prefectural input-output tables for all 47 prefectures have been created by Miyagi et al. (2003), Ishikawa et al. (2004), Hitomi et al. (2008), and Ogiwara (2011).

Regional input-output tables are highly applicable tools for analyzing regional economies. In Japan, the Research Institute of Economy, Trade and Industry (RIETI) has published the "2005 Prefectural Input-Output Tables" and the "2011 Prefectural Input-Output Tables". These prefectural input-output tables differ in their creation methods, with the 2011 tables being particularly precise due to the creation of headquarters sections and the use of census data for complementing information.

Classification of Regionalization Methods

Drawing from the survey by Szabó (2015), we can classify regionalization methods into three broad categories:

1. Survey methods: These involve collecting primary data from firms and are considered the most accurate but are also the most time-consuming and expensive.

2. Non-survey methods: These techniques use national input-output tables and limited regional data to estimate regional tables. They are cost-effective but may lack accuracy.
3. Hybrid methods: These combine elements of both survey and non-survey approaches, aiming to balance accuracy and cost-effectiveness.

Additionally, methods can be classified based on their spatial focus:

1. Single-region methods: These focus on estimating input-output relationships for a single region.
2. Multi-region or interregional methods: These aim to capture economic relationships between multiple regions.

This paper aims to create an inter-regional input-output table using a method that is as simple as possible, differing from the RIETI method. We focus on non-survey methods, given the frequent lack of detailed regional data. This is because when creating an inter-municipal input-output table at an administrative level smaller than prefectures, it is impossible to complement data for 1,718 municipalities, and a purely theoretical model-based estimation becomes necessary.

Non-Survey Methods

Among the non-survey techniques, the most common include:

- Location Quotient (LQ) Methods:
  - Simple Location Quotient (SLQ)
  - Cross-Industry Location Quotient (CILQ)
  - Flegg's Location Quotient (FLQ)
  - Augmented FLQ (AFLQ)
- Commodity Balance Method
- Gravity Models
- Mathematical Programming Models
- Bi-proportional Methods (e.g., RAS method)

In this study, we employ a gravity model, adding only distance data between prefectural capitals to the regional input-output tables created for each prefecture, to create an input-output table for all 47 prefectures.

The gravity model, based on the law of gravity in physics, assumes that the trade volume between two regions is proportional to their respective economic sizes and inversely proportional to the distance between them. This model is very effective in estimating economic interactions between regions with limited data and is easily adaptable to actual economic activity patterns. In particular, this study develops a model that can be applied even when additional data is difficult to obtain, unlike the "2011 Inter-Prefectural Input-Output Table".

Empirical studies have shown that among the Location Quotient methods, FLQ generally outperforms others in terms of accuracy. However, for our purpose of creating a comprehensive inter-prefectural table, the gravity model offers several advantages:

1. Minimal data requirements: When estimating inter-regional trade volumes, estimates can be made with only basic data on regional economic size and physical distance, eliminating the need for extensive statistical data.
2. Natural capture of inter-regional interactions: It incorporates the basic intuition that trade volume decreases as physical distance increases.
3. Extensible model: The gravity model can define the impact of distance as an arbitrary exponential function, allowing for more realistic estimation of inter-regional trade volumes.

Due to these advantages, this study adopts the gravity model to estimate the inter-prefectural input-output table. Also, with future extensions in mind, the model is designed to estimate the degree of distance influence (using an arbitrary exponent rather than limiting to the square of distance) as a parameter of the gravity model. This flexibility is expected to be effective when estimating inter-municipal input-output tables in the future.

This research applies the same estimation method (gravity model) to two different years, 2011 and 2015. This allows for direct comparison between the economic situation including the impact of the earthquake and the normal situation after recovery from the earthquake. While it is difficult to compare data estimated by different methods, using the same model enables quantitative analysis of changes in economic transactions and dependence on distance.

In particular, it becomes possible to accurately grasp the impact of the earthquake on the Japanese economy, identify which prefectures were more significantly affected, and quantitatively measure the progress of subsequent recovery. Based on the estimation results of the gravity model, it is expected that regions with strong economic linkages and those where transactions decreased due to the earthquake's impact can be identified, contributing to future regional economic policies.

2. Model and Data

Input-output tables comprehensively capture the input and output for each production sector (Figure 1). The input for each production sector is described in the column direction, and the input for sector 1 is represented as $X_1 = x_{11} + x_{12} + \ldots + x_{1n} + V_1$. Here, X_1 is the total production value of sector 1, x_{1n} is the intermediate input amount from sector n to sector 1, and V_1 is the value added amount of sector 1. In input-output tables, the output of each sector is described in the row direction. The output of sector 1 is $X_1 = x_{11} + x_{21} + \ldots + x_{n1} + F_1 + E_1 - M_1$, where x_{n1} is the intermediate input from sector 1 to sector n, F_1 is final demand, E_1 is exports, and M_1 is imports. Final demand includes household consumption, corporate consumption, government consumption, fixed capital formation (private and public), and inventory changes. In this paper, we analyze by dividing final demand into two categories: fiscal-related final demand and private final demand, without distinguishing between consumption and investment. The competitive import-type input-output table in Figure 1 includes a certain degree of imported goods in both intermediate inputs and final demand, which are deducted in a lump sum. However, in reality, the import rates for each sector are not the same, and the import rates in final demand also differ.

Therefore, a non-competitive import-type input-output table that separates domestic output and imports is sometimes used. Although the non-competitive import type has issues with the stability of the input coefficient matrix representing technological relationships in production, it can more precisely estimate the economic ripple effects due to final demand, including effects that spread within the region and effects that induce imports. In the non-competitive import-type input-output table, the row direction is divided into domestic goods and imported goods. Here, xd_{nn} represents the input-output relationship within the region, and xm_{nn} represents the input-output relationship of imported goods. Since imports are not included in the domestic goods sector's intermediate inputs and final demand sectors (domestic demand), there is no need to deduct them there. All intermediate inputs and domestic demand in the imported goods sector are imports, so deducting the import amount results in zero.

Prefectural input-output tables are generally created every five years, and we used the regional input-output tables for 2011 and 2015, which are available for all prefectures, to create the 47 prefectural input-output table. To align the number of sectors, we used the medium classification table, which usually consists of about 100 sectors, and integrated them into 77 sectors. For some tables where medium classification tables do not exist, we divided sectors to align them with 77 sectors, keeping as many sectors as possible.

Special processing is required for Tokyo and Okinawa when aligning prefectural input-output tables to common sectors. For Tokyo, a non-competitive import-type regional table format is used with the headquarters sector separated. Therefore, for Tokyo, we aggregated each sector for endogenous sectors and final demand sectors. For Okinawa, only up to 35 sector tables are published. Therefore, we integrated the national version of the input-output table into 77 sectors, created a proportional distribution for endogenous sectors and each final demand item, and expanded 35 sectors to 77 sectors.

Using these 77-sector input-output tables for 47 prefectures, we made preparations to create an inter-prefectural input-output table. Specifically, to enable estimation of inter-regional endogenous sectors and final demand items by multiplying trade coefficients, we placed 77*77 endogenous sectors for each region diagonally in a 3619*3619 matrix for 47 regions and 77 sectors for endogenous sectors. For final demand items, we diagonally placed private consumption (CP), government consumption (CG), private investment (IP), and government investment (IG) in 77 sectors in a 3619 * 47 matrix. Regarding the handling of exports and imports, we adopt a non-competitive import type, adding one row and one column for Rest of the World (ROW). Therefore, the intermediate input matrix becomes 3620 rows * 3620 columns, and each domestic demand item becomes 3620 rows * 48 columns.

In this study, we apply the same estimation method (gravity model) to two different years, 2011 and 2015. This allows for direct comparison between the economic situation including the impact of the earthquake and the normal situation after recovery from the earthquake. While it is difficult to compare data estimated by different methods, using the same model enables quantitative analysis of changes in economic transactions and dependence on distance.

In particular, it becomes possible to accurately grasp the impact of the earthquake on the Japanese economy, identify which prefectures were more significantly affected, and quantitatively measure the progress of subsequent recovery. Based on the estimation results of the gravity model, it is expected that regions with strong economic linkages and those where transactions decreased due to the earthquake's impact can be identified, contributing to future regional economic policies.

This study estimates the economic trade volume between prefectures based on the 2011 and 2015 inter-prefectural input-output tables using a gravity model. The gravity model, applying the law of gravity from physics, assumes that economic transactions between two regions are proportional to the economic size of each region and inversely proportional to the distance between them. This model allows for relatively reliable estimates even with limited data, making it applicable to more detailed analysis at the municipal level.

The basic equation of the gravity model is expressed as follows:

$$Tij = G * (Ei * Fj) / (Dij\^{}y)$$

- Tij is the trade volume from region i to region j.
- Ei is the economic size of region i (production value based on the export vector).
- Fj is the economic size of region j (demand value based on the import vector).
- Dij is the physical distance between regions.
- G is the gravitational constant (an estimated parameter).
- y is the degree of dependence on distance (estimated as an arbitrary exponent).

In this study, to accurately reflect the impact of the earthquake and normal economic conditions, we use an arbitrary exponent y instead of the square of distance, allowing for more realistic estimation. By applying the same model to data from 2011 and 2015, we can quantitatively compare the differences in economic activities between the two years.

3. Procedure for Creating Inter-Prefectural Input-Output Tables

This study creates inter-prefectural input-output tables using the gravity model, keeping in mind its applicability to creating inter-municipal input-output tables. While there are many studies on creating input-output tables using the gravity model, the theory itself is established, and there is no significant difference in the model itself between studies. Rather, the ambiguity often lies in the preprocessing of dividing and adjusting exports and imports.

3.1 Integration and Adjustment of Prefectural Input-Output Tables

Let's actually estimate the inter-prefectural input-output table using Japan's prefectural input-output tables. The following estimation is done manually in Excel. Understand this preparatory work.

First, integrate the regional tables (medium classification) of 47 prefectures into 77 common sectors. For tables with fewer sectors that need to be divided, simply divide them with the same values. Then, for regions where exports and outflows, imports and inflows are not divided but integrated, use the average export: outflow ratio and import: inflow ratio by industry sector of other regions to divide them.

Next, adjust the outflows and inflows. Explicitly showing this procedure is the most original part of this study. First, sum up the outflows and inflows for each sector in each region. The sum of outflows and inflows for each sector needs to match. This is because what is exported from one region is imported by another region. However, in reality, there are discrepancies in the total of outflows and inflows by sector, so this difference needs to be adjusted. Generally, in regional input-output tables, the outflow figures are considered to be more accurate than the inflow figures. This is because it's easier to understand where products and services are sold, but harder to grasp where they are sourced from. Therefore, we will align the total of outflows and inflows for each sector using the following three rules:

(1) If the outflow amount is smaller than the absolute value of the inflow amount, reduce the absolute value of the inflow amount and add it back to imports.

(2) If the outflow amount is larger than the absolute value of the inflow amount, add the import amount to the inflow amount, but it cannot exceed the original import-inflow amount. This is because if it becomes larger, there is a possibility of becoming negative when deducted from intermediate transactions or final demand. Except for values that are originally recorded as negative in the regional input-output table, the processing must be done so that it does not become negative.

(3) In cases where the gap between the total outflow and inflow by sector cannot be fully filled in both cases (1) and (2), use an error term to adjust the outflow amount.

This completes the adjustment of the outflow and inflow values for each sector in the total of the intermediate input matrix and domestic demand, prioritizing the outflow values while ensuring that imports and inflows do not exceed intermediate inputs and domestic demand. Next, divide the outflows and inflows into the intermediate input matrix and the four domestic demand sectors: private consumption, government consumption, private investment, and government investment. An important point here is that adjustments need to be made so that the inflows do not become negative when deducted from intermediate inputs and domestic demand in each region.

Therefore, initially divide the inflows according to the ratio of the sum of the intermediate input matrix and the sum of each domestic demand item in the row direction of the output amount. This allows for processing that does not result in negative values. Although this processing may seem simplistic, it is based on the assumption that a certain ratio of goods produced in other regions is used whether it's for intermediate input or final demand, similar to the calculation of induced effects using the domestication ratio in competitive import-type input-output tables.

Next, calculate the total of inflow amounts for each sector in the intermediate input matrix and each domestic demand item, and divide the outflow amount according to this ratio. At this time, the total of outflows and inflows for each region will not match, but the total of outflows and inflows for each sector across all regions will match. By dividing in this way, five 3620-row vertical vectors are created for both outflows and exports, and inflows and imports, for intermediate inputs, private consumption, government consumption, private investment, and government investment. Let's call these E1–5 and N1–5 respectively.

3.2 Division and Adjustment of Outflows/Exports and Inflows/Imports

An important step in this research is the division of "outflows" and "exports", and "inflows" and "imports" in inter-prefectural transactions. After this division, to grasp the economic activities of each prefecture in detail, outflows and inflows are divided into intermediate inputs, private consumption, government consumption, private investment, and government investment. Furthermore, adjustments are made to balance outflows and inflows for each sector, and error terms are applied to improve the accuracy of the estimation.

Procedure for dividing outflows/exports:

1. To divide the outflow and export amounts for each prefecture, proportionally distribute the total transaction amount of each industrial sector in each prefecture based on the sum of intermediate inputs and domestic demand.
   - Sum of intermediate inputs: Total value based on inter-industry transactions (inter-sector transactions) within each prefecture.
   - Sum of domestic demand: Total of four domestic demand items - private consumption, government consumption, private investment, and government investment.
2. When exports are divided according to the ratio of intermediate inputs and domestic demand, use the following formula for division:

   Export ratio = Sum of intermediate inputs/(Sum of intermediate inputs + Sum of domestic demand)

3. Calculate the sum of intermediate inputs and the sum of domestic demand, and based on this, divide outflows and exports for each sector.
4. After appropriately dividing the outflow and export amounts, organize the data by industrial sector for each prefecture.

Next, proportionally distribute the outflow amount to intermediate inputs, private consumption, government consumption, private investment, and government investment.

- Intermediate inputs: To what extent each prefecture provides goods and services to other prefectures in inter-industry transactions.
- Private consumption: The proportion of outflows in private consumption between prefectures.
- Government consumption: The proportion of outflows in government expenditure between prefectures.
- Private investment: The proportion of outflows in private investment between prefectures.
- Government investment: The proportion of outflows in government investment between prefectures.

To distribute the outflow amount to these four items, allocate the total outflow amount in proportion to the total amount of each item:

Outflow for each item = (Total of each item/Overall total) * Total outflow

This allocates the outflow amount of each prefecture appropriately to intermediate inputs and domestic demand.

Procedure for dividing inflows/imports:

The division of inflows and imports follows a similar procedure to outflows/exports.

1. Divide the inflow amount of each prefecture proportionally between intermediate inputs and domestic demand. Use the following formula to calculate the import amount:

   Import ratio = Sum of intermediate inputs/(Sum of intermediate inputs + Sum of domestic demand)
2. Calculate for each prefecture and divide inflows and imports based on this.
3. Next, divide the inflow amount into intermediate inputs, private consumption, government consumption, private investment, and government investment. Calculate

the ratio of each item to intermediate inputs and domestic demand, and use the following formula to distribute the inflow amount to each item:
Inflow for each item = (Total of each item/Overall total) * Total inflow amount

This allocates the inflow amount to intermediate inputs and domestic demand for each prefecture, reflecting the transaction relationships appropriately.

Adjustment of each industrial sector and creation of error terms:

1. Balance of outflows and inflows for each industrial sector: Outflows and inflows need to be balanced for each industrial sector. In other words, the total amount of outflows should match the total amount of inflows, as goods produced in one region are consumed in other regions. However, discrepancies may occur due to data inconsistencies or calculation processes. To correct these discrepancies, adjustments are made so that the sum of outflows and inflows for each industrial sector becomes zero. When discrepancies occur, the following two approaches are taken:
   - If outflows are smaller than inflows: Decrease the inflow amount and adjust. The adjusted amount can be added to the import amount.
   - If outflows are larger than inflows: Decrease the import amount and add to the inflow amount. However, adjustments are made within the range that does not exceed the original import-inflow amount.
2. Creation of error terms: Even after adjustments, the total of outflows and inflows may not match perfectly. In this case, error terms are introduced to maintain balance. Error terms are used as correction values to make the total of outflows and inflows zero.
   - Error terms can be distributed equally among sectors or applied more heavily to specific sectors. The method of applying error terms is determined considering the accuracy of the data and the characteristics of each industrial sector.

3.3 Procedure for Modifying to Non-Competitive Import Type Input-Output Table: Adding Rest of the World (ROW)

Next, add the overseas sector (Rest of the World, ROW) to the intermediate input and final demand sectors. The intermediate input sector is 3619*3619 for 47 regions * 77 sectors. Add input from ROW (imports) to the bottom row and output to ROW (exports) to the rightmost column. To do this, use the already estimated exports (1 column with positive values) and imports (1 column with negative values). For exports, simply divide by the ratio of the total intermediate input to the total domestic demand for each region and sector. For the intermediate input matrix, add ROW to the rightmost column. As a result, it becomes a 3619*3620 matrix.

Domestic demand is classified into four items: private consumption, government consumption, private consumption (equipment investment and housing investment out of gross fixed capital formation), and government investment (public out of gross fixed capital formation), with inventory changes included in the error term. Each domestic demand item is a 3619*1 vector, but this is expanded to 47 regions. To expand it to a 3619*47 matrix, create a matrix with domestic demand items for 77 sectors in each region and zeros in other regions. The part with zeros represents inter-regional trade of domestic demand items, which will be estimated later. As a result, four 3619*48 matrices are created.

For imports, first divide by the total of intermediate inputs and domestic demand. For intermediate inputs, proportionally distribute to each region and sector (47*77) in the row direction and sum up (decreasing as negative values are added), and sum up as positive values in the bottom row. This is the process of deducting the summed imported goods and describing them separately. As a result, a 3620*3620 matrix is created. The same is done for domestic demand, with four demand items having 47 columns (regions) and 47*77 rows (regions and sectors), so the same proportional negative processing is done, and one row is added at the bottom to sum up the input from ROW. As a result, four 3620*48 matrices are created. For transactions within ROW, this study inputs zero. This is based on the assumption that spillover effects from transactions within ROW are not considered. The above processing was done using Excel.

Finally, estimate inter-regional trade. Currently, we have an intermediate input matrix (3620*3620), four matrices for private consumption, government consumption, private investment, and government consumption (3620*48 each), positive outflows divided by sector according to the ratio of intermediate input total: private consumption total: government consumption total: private investment total: private consumption total (five 3620*1), similarly processed negative inflows (five 3620*1), and a distance matrix between 47 regions (47*47 with zeros on the diagonal). Using these data, we calculate inter-regional trade using the gravity model.

First, estimate inter-regional trade using the intermediate input matrix (3620*3620 with 77*77 intra-regional sectors diagonally arranged for 47 regions, plus one row and one column for ROW), the outflow vector (3620*1), the inflow vector (3620*1), and the inter-regional distance matrix (47*47 with zeros on the diagonal). Let AX be the 3620 row 3620 column intermediate input matrix with ROW, CP be the private consumption matrix, CG be the government consumption matrix, IP be the private investment matrix, and IG be the government investment matrix, each with 3620 rows and 48 columns including ROW. Let E1, E2, E3, E4, E5 be the outflow vectors, N1, N2, N3, N4, N5 be the inflow vectors (negative values), and D be the distance matrix. Use the reference Python estimation program to perform the calculations. Label the output matrices with T at the beginning, as TAX, TCP, TCG, TIP, TIG.

Through these steps, a non-competitive import type 47 inter-prefectural input-output table is created. This method can also be applied to creating municipal-level input-output tables and is effective in estimating inter-regional economic transactions even under strict data constraints.

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To illustrate the structure of the non-competitive import type inter-regional input-output table we've created, let's consider a simplified example. Figure 1 shows the matrix structure of a non-competitive import type inter-regional input-output table for three regions and two sectors.

In Figure 1, we can observe the following key components:

1. Intermediate Transactions: The upper-left 6 * 6 matrix (outlined in bold) represents the intermediate transactions between sectors and regions. Each 2 * 2 block on the diagonal (A11, A22, A33) shows intra-regional transactions, while off-diagonal blocks (A12, A13, A21, A23, A31, A32) represent inter-regional transactions.
2. Final Demand: The upper-right part of the matrix shows the final demand for each region (F1, F2, F3) and exports (E).
3. Value Added: The lower-left part of the matrix represents the value added in each region (V1, V2, V3).
4. Imports: The bottom row (M) shows imports for each sector in each region and for final demand.
5. Rest of the World (ROW): The rightmost column and bottom row represent transactions with ROW, consistent with our addition of the ROW sector in the procedure described earlier.

Figure 1. Structure of a Non-Competitive Import Type Inter-Regional Input-Output Table (3 Regions, 2 Sectors)

		Region 1		Region 2		Region 3		ROW	Domestic Demand				Output
		Sector 1	Sector 2	Sector 1	Sector 2	Sector 1	Sector 2		R1	R2	R3	ROW	
Region 1	Sector 1	x_{11}^{11}	x_{21}^{11}	x_{11}^{21}	x_{21}^{21}	x_{11}^{31}	x_{21}^{31}	$E1_1^1$	F_1^{11}	F_1^{12}	F_1^{13}	$E2_1^1$	X_1^1
	Sector2	x_{12}^{11}	x_{22}^{11}	x_{12}^{21}	x_{22}^{21}	x_{12}^{31}	x_{22}^{31}	$E1_2^1$	F_2^{11}	F_2^{12}	F_2^{13}	$E2_2^1$	X_2^1
Region 2	Sector 1	x_{11}^{12}	x_{21}^{12}	x_{11}^{22}	x_{21}^{22}	x_{11}^{32}	x_{21}^{32}	$E1_1^2$	F_1^{21}	F_1^{22}	F_1^{23}	$E2_1^2$	X_1^1
	Sector 2	x_{12}^{12}	x_{22}^{12}	x_{12}^{22}	x_{22}^{22}	x_{12}^{32}	x_{22}^{32}	$E1_2^2$	F_2^{21}	F_2^{22}	F_2^{23}	$E2_2^2$	X_2^1
Region 3	Sector 1	x_{11}^{13}	x_{21}^{13}	x_{11}^{23}	x_{21}^{23}	x_{11}^{33}	x_{21}^{33}	$E1_1^3$	F_1^{31}	F_1^{32}	F_1^{33}	$E2_1^3$	X_1^1
	Sector 2	x_{12}^{13}	x_{22}^{13}	x_{12}^{23}	x_{22}^{23}	x_{12}^{33}	x_{22}^{33}	$E1_2^3$	F_2^{31}	F_2^{32}	F_2^{33}	$E2_2^3$	X_2^1
ROW		$M1_1^1$	$M1_2^1$	$M1_1^2$	$M1_2^2$	$M1_1^3$	$M1_2^3$	0	$M2^1$	$M2^2$	$M2^3$	0	
Added Value		V_1^1	V_2^1	V_1^2	V_2^2	V_1^3	V_2^3						
Input		X_1^1	X_2^1	X_1^2	X_2^2	X_1^3	X_2^3						

Source: Created by author.

This structure aligns with our methodology of creating a non-competitive import type table.

By separating imports (M) and exports (E), we can more accurately represent the flow of goods and services between regions and with the rest of the world. This is particularly important for our analysis, as it allows us to:

1. Distinguish between intra-regional, inter-regional, and international trade flows.
2. More precisely estimate the economic ripple effects due to final demand, including effects that spread within the region and effects that induce imports.
3. Reflect the reality that import rates for each sector are not the same, and import rates in final demand also differ.

The structure shown in Figure 1 is a simplified version of our 47-prefecture, 77-sector model. In our full model, the intermediate transactions matrix expands to 3619*3619 (47 regions*77 sectors), with the final demand, value added, and import/export sections scaling accordingly.

This matrix structure forms the foundation for our subsequent analysis using the gravity model to estimate inter-regional trade flows. By populating this matrix with our estimated data, we can create a comprehensive picture of the economic interactions between Japan's prefectures and their relationships with the global economy.

4. Estimation of Trade Parts: Two Sections of Intermediate Inputs, Private Consumption, Government Consumption, Private Investment, and Government Investment

In the inter-prefectural input-output table, the estimation of trade parts is very important. In this study, we estimate trade between prefectures and ROW (Rest of the World) using the gravity model, revealing the transaction relationships for each industrial sector in each prefecture. The trade part is broadly divided into two sections for estimation.

1. Intermediate inputs: Estimate transactions related to intermediate goods purchased by industrial sectors in each prefecture from other prefectures and ROW.
2. Private consumption/Government consumption/Private investment/Government investment: Estimate transactions related to consumption and investment in final demand.

4.1 Estimation of Intermediate Input Section

Transactions in intermediate inputs depend on the intermediate goods purchased by industrial sectors in each prefecture from other prefectures and ROW. Intermediate goods are raw materials and parts used in the production activities of other industrial sectors. The estimation of the intermediate input part is particularly important for understanding the details of inter-industry transactions.

Step 1: Division of Exports and Imports in Intermediate Inputs

Divide the exports and outflows in intermediate inputs for each prefecture based on the values in the existing intermediate input matrix.

- Intermediate input exports represent intermediate goods provided from prefectures to foreign countries and are added to the column of the intermediate input matrix along with outflows.
- Intermediate input outflows represent intermediate goods provided to other domestic prefectures and are placed in parts of the intermediate input matrix other than the diagonal blocks.

Similarly, imports and inflows are added to the rows of the intermediate input matrix.

- Intermediate input imports are intermediate goods supplied from ROW to industrial sectors in each prefecture, which are added to the bottom row.
- Intermediate input inflows are transactions from other domestic prefectures, which are added to appropriate places in the intermediate input matrix.

This explicitly shows the intermediate goods purchased by industrial sectors in each prefecture from other prefectures and ROW.

Step 2: Estimation Using the Gravity Model

The transaction volume between prefectures in intermediate inputs is estimated using the gravity model. The gravity model uses the economic scale of each prefecture (total amount of intermediate inputs) and the distance between prefectures to estimate the transaction volume.

The equation for the gravity model is as follows:

Tij = G * (Ei * Fj) / (Dij^y)

- Tij: Volume of intermediate goods trade from prefecture i to j
- Ei: Outflow amount based on intermediate inputs of prefecture i
- Fj: Inflow amount based on intermediate inputs of prefecture j
- Dij: Physical distance between prefectures
- G, y: Model parameters to be estimated (gravitational constant and degree of dependence on distance)

Using this model, we estimate how much intermediate goods are traded between each prefecture or with ROW. The final results are recorded in a matrix as TAX, explicitly showing intermediate goods transactions between prefectures and with ROW.

4. 2　Estimation of Final Demand Section (Private Consumption, Government Consumption, Private Investment and Government Investment)

In the final demand section, we estimate trade related to private consumption, government consumption, private investment, and government investment. These items are related to the final use of goods and services by industries and form important demand elements of the regional economy.

Step 1: Division of Exports and Outflows in Final Demand Items

For final demand as well, divide outflows and exports through the following process:

- Exports represent private consumption or government consumption for foreign countries and are added to the bottom column of the private consumption or government consumption matrix as the part from ROW.
- Outflows represent final consumption or investment for other prefectures and are placed in appropriate rows of the existing private consumption, government consumption, private investment, and government investment matrices.

Similarly, based on the inflow and import data, add to the row direction for each final demand item.

Step 2: Division into Each Item

Next, divide the exported and outflowed amounts into each final demand item (private consumption, government consumption, private investment, government investment). These are divided based on the proportion of consumption and investment in each prefecture.

- Private consumption: Calculate the ratio of exports and outflows to inter-prefectural personal consumption and add to the private consumption matrix.
- Government consumption: Perform similar division for government expenditure in each prefecture.
- Private investment: Divide the export and outflow amounts based on inter-prefectural private investment.
- Government investment: Similarly divide targeting inter-prefectural government investment.

Step 3: Estimation Using the Gravity Model

For each final demand item (private consumption, government consumption, private investment, government investment), estimation is performed using the gravity model, similar to intermediate inputs. The transaction volume related to final consumption or investment between each prefecture and ROW is estimated using the following equation:

Tij_FD = G_FD * (Ci * Dj) / (Dij^y_FD)

- Tij_FD: Transaction volume based on final demand items from prefecture i to j
- Ci: Outflow amount based on final demand of prefecture i

- Dj: Inflow amount based on final demand of prefecture j
- Dij: Distance between prefectures
- G_FD, y_FD: Estimated parameters for final demand items

This estimates the transaction volume of final demand items between each prefecture and ROW. Based on the estimated values for each item, matrices TCP (private consumption), TCG (government consumption), TIP (private investment), and TIG (government investment) are constructed.

4. 3 Estimation of Gravity Model Parameters

The estimation of gravity model parameters (G, y, G_FD, y_FD) is performed using the nonlinear least squares method. This method adjusts the parameters to minimize the sum of squares of the differences between actual transaction volumes and estimated transaction volumes.

The data used for estimation are as follows:

- Intermediate input matrix (AX): 3620 rows * 3620 columns including ROW
- Private consumption matrix (CP), government consumption matrix (CG), private investment matrix (IP), government investment matrix (IG): Each 3620 rows * 48 columns including ROW
- Outflow vectors (E1, E2, E3, E4, E5): Each 3620 rows * 1 column
- Inflow vectors (N1, N2, N3, N4, N5): Each 3620 rows * 1 column (negative values)
- Distance matrix (D): 47*47 (zeros on the diagonal)

The process of parameter estimation is as follows:

1. Set initial parameter values: Set initial values for G, y, G_FD, y_FD.
2. Calculate estimated transaction volumes: Use the set parameter values to estimate transaction volumes between each prefecture using the gravity model.
3. Calculate errors: Calculate the difference between actual transaction volumes and estimated transaction volumes, and find the sum of squares.
4. Adjust parameters: Adjust parameters to minimize the sum of squares of errors.
5. Convergence judgment: Repeat steps 2–4 until the error becomes sufficiently small or a certain number of iterations are performed.

Through this process, optimal parameter values are obtained. These parameters are used to estimate the final transaction volumes between prefectures.

4.4 Verification and Adjustment of Estimation Results

To ensure the validity of the estimation results, the following verifications and adjustments are performed:

1. Sector-wise balance check: Confirm that the total outflows and total inflows match for each industrial sector.
2. Region-wise balance check: Confirm that the total outflows and total inflows match for each prefecture.
3. Balance of transactions with ROW: Confirm that the total exports and total imports match.
4. Confirmation of anomalous values: Check for extremely large or small transaction volumes and make adjustments as necessary.
5. Consistency check with known data: Compare with published inter-prefectural transaction data and check for any significant discrepancies.

Through these verifications and adjustments, the final 47 inter-prefectural input-output table is completed. This method enables reasonable estimation of inter-regional economic transactions even under strict data constraints. Furthermore, the method developed in this research can be applied to creating input-output tables for more detailed regional divisions (e.g., at the municipal level), and is expected to contribute to the refinement of regional economic analysis.

5. Analysis of Regional Balance in 2011 and 2015

The analysis of regional balance derived from the inter-prefectural input-output tables for 2011 and 2015 provides significant insights into Japan's regional economic structure. Figures 2 and 3 illustrate the regional balance for 2011 and 2015 respectively, while Figure 4 offers a geographical analysis comparing the two years.

Both years show Tokyo maintaining substantially larger outflows and inflows compared to other prefectures, as clearly visible in Figures 2 and 3. This confirms Tokyo's central role in the Japanese economy. However, a slight reduction in scale was observed in 2015, potentially indicating a minor easing of this concentration. The geographical analysis in Figure 4 further emphasizes Tokyo's dominance and the slight changes between 2011 and 2015.

Osaka and Aichi prefectures follow Tokyo in terms of outflow and inflow scale, as evident from the bar heights in Figures 2 and 3. This reaffirms these regions as key economic centers. The 2015 data suggests a slight decrease in scale for these areas, possibly indicating a trend towards economic decentralization. Figure 4 visually represents this trend, showing subtle changes in the economic landscape of major urban areas.

Many rural prefectures continue to show higher inflows than outflows, as indicated by the negative balances (diagonal bars) in Figures 2 and 3. This highlights challenges in regional economic self-sufficiency. However, some prefectures showed improved balance in 2015, possibly reflecting the effects of regional economic policies or changes in industrial structure. The geographical representation in Figure 4 helps to identify these regional patterns more clearly.

Prefectures in the Tohoku region, particularly Miyagi and Fukushima, which were severely affected by the 2011 Great East Japan Earthquake, showed more stabilized outflow and inflow patterns in 2015. This is visible in the comparison between Figures 2 and 3, and more pronounced in the geographical analysis of Figure 4, suggesting progress in recovery efforts.

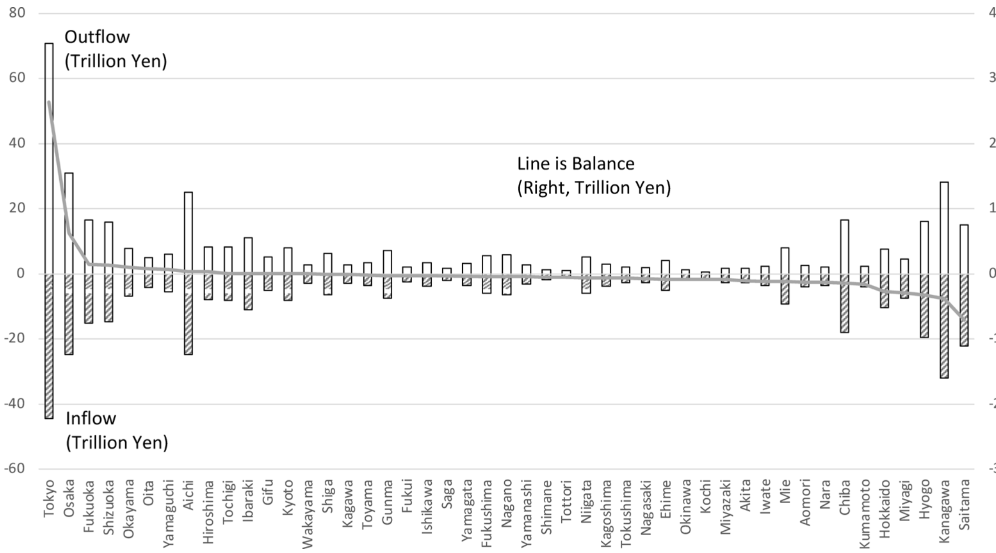
Prefectures with strong manufacturing sectors (e.g., Aichi, Shizuoka) or significant port functions (e.g., Kanagawa, Hyogo) maintained relatively high outflows in both years, as shown by the consistently tall positive bars in Figures 2 and 3. This confirms the importance of these industries to regional economies. Figure 4 helps to visualize the geographical distribution of these industrially strong prefectures.

The economic gap between major urban areas centered on Tokyo and rural regions showed no significant change from 2011 to 2015, as evident from the similar overall patterns in Figures 2 and 3. This indicates that addressing regional disparities remains a crucial policy challenge. The geographical analysis in Figure 4 starkly illustrates these persistent disparities across Japan.

Many prefectures showed slightly reduced scales of outflows and inflows in 2015 compared to 2011, as can be observed by comparing the bar heights in Figures 2 and 3. This potentially reflects changes in Japan's overall economic environment and demographic shifts. The subtle changes are more apparent in the geographical comparison provided by Figure 4.

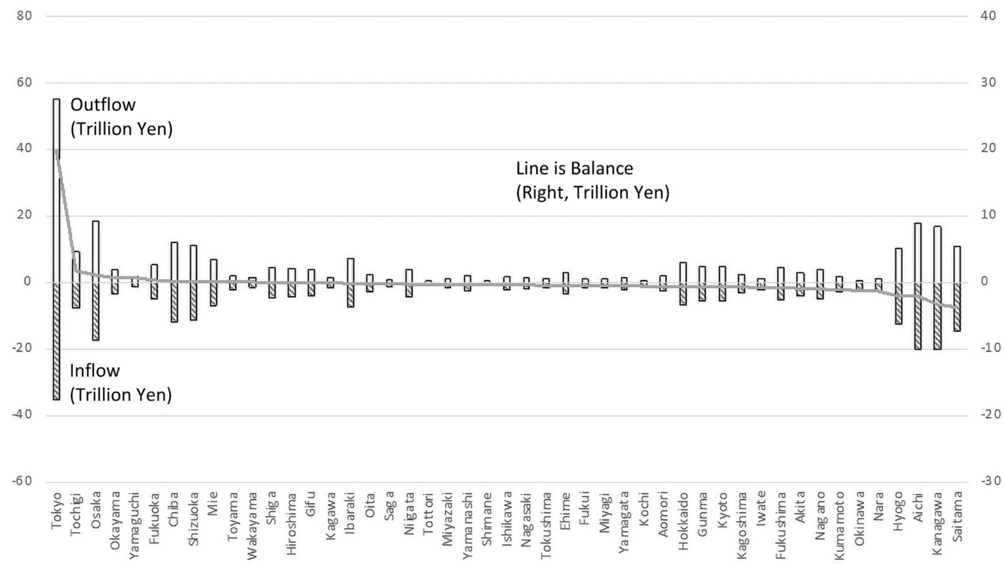
Throughout both years, the outflow and inflow patterns strongly reflected each prefecture's industrial structure and geographical characteristics, as consistently shown in Figures 2 and 3. This reaffirms the importance of these factors in shaping regional economic profiles. The geographical analysis in Figure 4 provides a clear visual representa-

Figure 2. Regional Balance in 2011



Source: Created by author.

Figure 3. Regional Balance in 2015

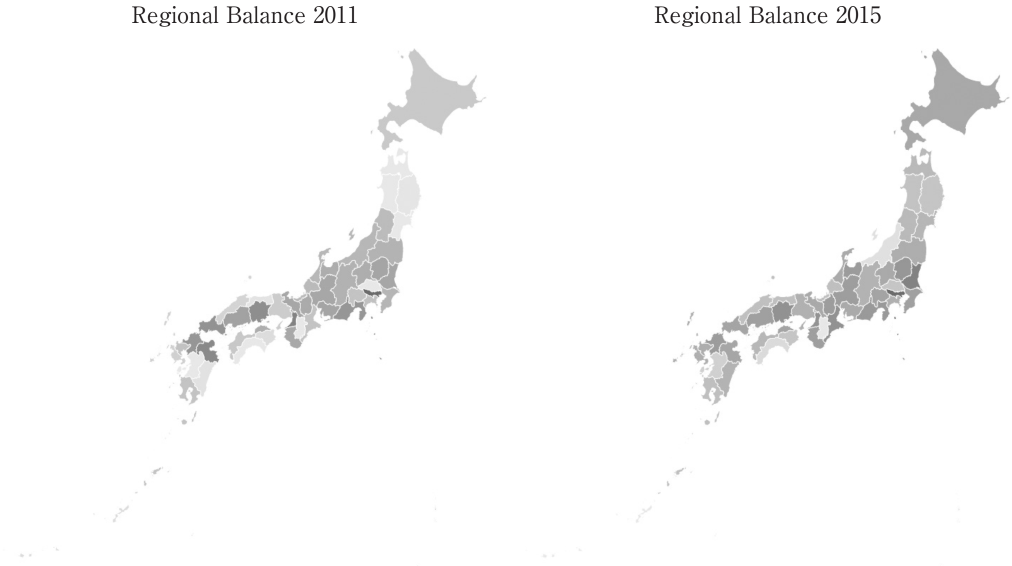


Source: Created by author.

tion of how these characteristics persist over time.

These findings, now visually supported by Figures 2, 3, and 4, provide valuable insights for formulating and evaluating regional economic policies. Particularly, the quantitative understanding of the strength and changes in inter-regional economic connections, as

Figure 4. Geographical Analysis between Regional Balance 2011 and 2015



Source: Created by author.

well as their geographical distribution, enables more effective consideration of regional development and industrial policies. The visual representations offer a powerful tool for policymakers and researchers to quickly grasp complex economic relationships and trends across Japan's prefectures.

Conclusion

This study created an inter-prefectural input-output table for Japan's 47 prefectures using a gravity model and analyzed the regional balance for 2011 and 2015. This methodology demonstrated the feasibility of reasonably estimating inter-regional economic transactions even with limited data.

Key conclusions include:

1. Effectiveness of the Methodology:
   The non-survey method using a gravity model proved effective in creating input-output tables, even in situations lacking detailed regional data. This suggests potential applications for municipal-level input-output table creation.
2. Tokyo-Centric Economic Structure:
   The analysis quantitatively demonstrated Tokyo's overwhelming centrality in the

Japanese economy. However, the 2015 data indicated a slight easing trend, suggesting subtle changes in the economic structure.

3. Persistence of Regional Disparities:
   Economic disparities between major urban areas and rural regions remain significant, reaffirming the importance of regional economic policies.
4. Importance of Industrial Structure and Geographical Factors:
   Outflow and inflow patterns for each prefecture strongly reflected its industrial structure and geographical characteristics, highlighting the importance of these factors in shaping regional economic profiles.
5. Earthquake Impact and Recovery:
   Changes from 2011 to 2015 reflected the recovery process from the Great East Japan Earthquake, with notable changes observed in the economic situations of Tohoku region prefectures.
6. Changing Economic Environment:
   The overall trend of reduced outflow and inflow scales observed in 2015 may reflect changes in Japan's overall economic environment and demographic shifts, presenting important considerations for future regional economic policies.

This study's methodology and results offer valuable tools for formulating and evaluating regional economic policies, as well as for future economic forecasting. Particularly, the quantitative understanding of inter-regional economic interdependencies enables more effective consideration of regional development and industrial policies.

Future research directions include analysis with more detailed industrial classifications, examination of long-term trends through time-series data accumulation, and the development of more comprehensive regional economic models incorporating international trade. Additionally, applying this methodology to create municipal-level input-output tables is expected to enable more precise regional economic analysis.

Note

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