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ORIGINAL ARTICLE

Secular change of interdependencies in the clusters of the Japanese motor vehicle industry: a case study in the Tokai region

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Abstract

The Tokai region, including the prefectures of Aichi, Shizuoka, Mie, Gifu, and Shiga, in the center of Japan's largest island, Honshu, houses clusters of the motor vehicle industry (MVI) and accounts for more than 50% of the domestic value from the MVI's manufactured goods shipments. The subcontracted factories in the MVI tend to locate their main hub close to the assembly factories, creating large supply-chain structures with wide transactions. Since the 1990s, new automotive assembly factories and subcontracted factories have been built outside Aichi, in the Kyushu and Tohoku regions. This may have had an influence on local industries and economy. This study applies the hypothetical extraction method to the Tokai region using the Chubu-region multi-regional input–output tables to understand the secular changes of interdependencies in the MVI as each prefecture in the Tokai region has automotive assembly factories. The study shows that the Aichi MVI has strengthened its ties with industries in other prefectures in the Tokai region and elsewhere because the rate of growth for Aichi dropped from 2005 to 2010. Still, other prefecture rates rose, thus expanding its supply-chain structure throughout Japan more than before. In addition, the study shows that the Shizuoka MVI has increased business relationships not only within its region but also with Aichi. These results highlight that the industrial linkage between the Aichi MVI and the Shizuoka MVI has deepened. However, the results show that the supply-chain structures of the Mie, Gifu, and Shiga MVI have remained inside of their respective regions.

Keywords Hypothetical extraction method · Linkage analysis · Clusters of Japanese motor vehicle industry · Secular change of interdependencies · Chubu-region multi-regional input–output table

JEL Classification C63 · C67 · D57 · R15

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Introduction

The motor vehicle industry (MVI)[1] accounts for approximately 20% of the domestic value of manufactured goods shipments (VMGS)[2] in Japan. The subcontracted factories in the MVI tend to locate their main hub close to the assembly factories, creating large supply-chain structures with wide transactions.

Toyota Motor Corporation (Toyota) has several assemblies and parts manufacturing plants in the Tokai region,[3] especially in Aichi, its place of origin.[4] Additionally, Suzuki Motor Corporation (Suzuki) has its main plant in Shizuoka, where the company was founded.

The MVI clusters in the Tokai region contribute to over 50% of the Japanese VMGS, meaning that the Tokai region has several MVI agglomerations and is the largest cluster in Japan.

Since the 1990s, however, for regional economic revitalization, and due to labor shortages and disaster risks, the TOYOTA group began building automotive assembly factories outside Aichi, in the Kyushu[5] and Tohoku[6] regions. As the subcontracted factories tend to locate their main hub close to the assembly factories, the clustering patterns of the MVI have been changing through large supply-chain structures with national transactions. These changes may have had an influence on local industries and economy in the Tokai region.

Additionally, companies that had never transacted with the MVI have entered the automobile market as suppliers because of hybrid vehicles sold in Japan and other countries. There has been a steady increase in the demand for electric automotive parts, such as lithium-ion batteries, electric motors, car navigation systems, onboard cameras, automatic braking devices, and automatic operation functions. This has caused structural changes to the supply chains in Japan.

Several automotive assembly factories for passenger motor cars operate in the Tokai region, with different production capacities. To clarify the differences using the Chubu-region input–output tables (Chubu-region I–O tables),[7] a location quotient (LQ) is an appropriate method that provides a single measure for analyzing industry concentration and specialization in a region. The LQ is calculated as:

[1] Passenger motor cars, trucks, buses and miscellaneous cars, and motor vehicle parts and accessories are included.

[2] Ministry of Economy, Trade and Industry (2020).

[3] The Tokai region, in the center of the largest island Honshu in Japan's four main islands; Hokkaido, Honshu, Shikoku and Kyushu. It consists of five prefectures: Aichi, Shizuoka, Mie, Gifu, and Shiga. There are 47 prefectures in Japan.

[4] Toyota Motor Corporation, Japanese facilities.

[5] The Kyushu region is the third largest island and the most southerly of the four largest islands.

[6] The Tohoku region consists of the northeastern portion of Honshu.

[7] Chubu Region Institute for Social and Economic Research (2013, 2014). The Chubu-region I−O table as prepared by the Chubu Region Institute for Social and Economic Research based on government regional I−O tables using the same methods is available for four points in time: 1995, 2000, 2005, and 2010. It is prepared every 5 years the same way as government regional I−O tables. This is the only published multi-regional I−O table available for the Tokai region. The latest one for 2015 will be published in 2023 (Kimura (2021)).

Table 1 LQ of the MVI in the Tokai region

	Aichi	Shizuoka	Mie	Gifu	Shiga
1995CY	4.25[c]	2.58[b]	1.95[a]	0.58	0.96
2000CY	4.69[c]	2.78[b]	2.31[b]	0.57	1.36[a]
2005CY	4.13[c]	2.71[b]	2.23[b]	1.17[a]	1.27[a]
2010CY	3.98[c]	2.79[b]	3.10[c]	1.16[a]	1.41[a]

Source: Chubu-region multi-regional input–output tables; [a]$1 \leq LQ < 2$; [b]$2 \leq LQ < 3$; [c]$3 \leq LQ$

LQ location quotient, *MVI* motor vehicle industry

$$\text{Location Quotient} = \frac{\text{The ratio of an industry's share in regional production output}}{\text{The ratio of an industry's share in domestic production output}}$$

If the LQ is greater than one, then that industry is more concentrated in the region than in the nation.

Table 1 indicates the LQ of the MVI for each prefecture in the Tokai region from 1995 to 2010, with all LQs witnessing a relative increase. When the LQs greater than one are arranged in descending order, all prefectures in the Tokai region show a high concentration of the MVI: 3.98 for Aichi, 3.10 for Mie, 2.79 for Shizuoka, 1.41 for Shiga, and 1.16 for Gifu in 2010.

Since the MVI has a large supply-chain structure with wide transactions and several subcontracted factories, changes in the environment surrounding the Japanese MVI have also affected many suppliers in the Tokai region. This implies that the MVI cluster has an influence on local industries and the economy in the Tokai region more than before.

Table 2 shows total output (MVI output in particular) and MVI output to total output ratio in each prefecture of the Tokai region, other regions outside the Tokai region, and the country. The trend in the ratio of the MVI's output to total output from 1995 to 2010 is as follows: 17–20% for Aichi, 10–14% for Shizuoka, 8–15% for Mie, 2–6% for Gifu, and 4–7% for Shiga.

The MVI is one of the main export industries in Japan because half of its production volume is exported.[8] After the collapse of the global investment bank Lehman Brothers and the ensuing global financial crisis, the MVI's domestic production output was valued at 44,125 billion yen in 2010, approximately 3,200 billion yen less than its value output in 2005 (Table 2). However, the ratio of total MVI output to domestic production output increased from 4.87% in 2005 to 4.93% in 2010, which means the Japanese MVI has been growing significantly in the national economy.

The hypothetical extraction method (HEM) was applied to the Tokai region using the Chubu-region I–O tables to understand the secular changes of interdependencies in the MVI cluster.

The rest of this paper is organized as follows. "Hypothetical extracted method" explains the analytical procedures of the HEM. "Analytical procedures" describes

[8] Japan Automobile Manufacturers Association, Active matrix database system.

Table 2 Ratio of MVI output to total industrial output in different regions

Billion¥	Total industrial output						
	Tokai region					Regions other than Tokai	Japan
	Aichi	Shizuoka	Mie	Gifu	Shiga		
1995CY	69,670	32,491	14,576	13,581	11,251	795,532	937,101
2000CY	71,777	33,441	16,006	13,667	11,584	812,411	958,886
2005CY	79,071	34,167	17,861	14,029	11,644	815,243	972,015
2010CY	69,779	32,176	17,097	12,677	11,406	751,199	894,334
Billion¥	Output of MVI						
	Tokai region					Regions other than Tokai	Japan
	Aichi	Shizuoka	Mie	Gifu	Shiga		
1995CY	11,671	3310	1122	311	426	20,124	36,964
2000CY	13,073	3611	1440	302	612	18,238	37,276
2005CY	15,903	4510	1944	802	721	23,486	47,366
2010CY	13,708	4428	2617	726	792	21,854	44,125
%	Ratio of MVI output to total industrial output						
	Tokai region					Regions other than Tokai	Japan
	Aichi	Shizuoka	Mie	Gifu	Shiga		
1995CY	16.75%	10.19%	7.70%	2.29%	3.79%	2.53%	3.94%
2000CY	18.21%	10.80%	9.00%	2.21%	5.28%	2.24%	3.89%
2005CY	20.11%	13.20%	10.88%	5.71%	6.19%	2.88%	4.87%
2010CY	19.65%	13.76%	15.30%	5.72%	6.94%	2.91%	4.93%

Source: Chubu-region multi-regional input–output tables

MVI motor vehicle industry

the results for each prefecture in the Tokai region. Finally, "Discussion" discusses the conclusions.

Hypothetical extracted method

Pilot studies

Initially proposed by Paelinck et al. (1965) and updated by Strassert (1968), Meller and Márfan (1981), Cella (1984), and Clements (1990), HEM was studied extensively and summarized by Miller and Lahr (2001). A specific industry is extracted from the I–O table as if it was not operational in the HEM. Thus, the difference between the HEM's output and actual output makes it possible to understand its economic impact.

Since Paelinck et al. (1965) proposed the HEM, many studies have applied the HEM to understand the impacts of natural disasters. In Japan, Yonemoto and Kanno (2012) presented the effects of the Fukushima nuclear power plant accident caused by the Great East Japan Earthquake on the import–export structure. Nozaki (2017) studied the economic impacts of production and infrastructure shocks related to natural disasters. Shibusawa and Yonemitsu (2021) also evaluated the Kyushu region's economic impact and resilience of flood damage.

In addition, the HEM has been applied to some specific industries: water (Duarte et al. 2002), agriculture (Cai and Leung 2004), real-estate (Song et al. 2006a), and construction (Song et al. 2006b), to name but a few.

Concerning MVI, Dietzenbacher et al. (2019) applied the HEM using the World Input–Output Database 2014 to the MVI in China, the US, and Germany, to estimate the impact of an increase in the imports of substitutes on each country. Shibusawa and Nakayama (2021) also applied the HEM using Japan and Aichi I–O tables to evaluate the impact of reduced production of conventional vehicles on national and regional economies by producing eco-friendly vehicles.

However, little research has been conducted to understand secular change using certain points in time with I–O tables using the HEM.

Analytical procedures

This analysis could be explained by premising the regional I–O model:

$$\mathbf{x} = [\mathbf{I} - \mathbf{A}]^{-1}\mathbf{f}$$

Here, $\mathbf{x}$ is an output vector, $\mathbf{A}$ is an input coefficient matrix, $\mathbf{f}$ is a final demand vector, and $\mathbf{I}$ is an identity matrix.

Following Miller and Blair (2009), MVI is extracted in this study to replace rows and columns in MVI's input coefficient matrix with 0, which represents $\bar{\mathbf{A}}_{(car)}$ ($\boldsymbol{n}$ industrial sectors):

$$\bar{\mathbf{A}}_{(car)} = \begin{bmatrix} a_{11} & a_{12} & \cdots & 0 & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & 0 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 & \cdots & a_{nn} \end{bmatrix}$$

This means that sales (forward linkage effect) and purchases (backward linkage effect) by the MVI have not occurred.

Additionally, the final demands and exports of the target regions are replaced with 0, so that the final demands are represented by $\bar{\mathbf{f}}_{(car)}$ ($\boldsymbol{n}$ industrial sectors):

$$\bar{\mathbf{f}}_{(\mathrm{car})} = \begin{bmatrix} f_1 \\ \vdots \\ 0 \\ \vdots \\ f_n \end{bmatrix}$$

When extracting the MVI, its output $\bar{\mathbf{x}}_{(car)}$ is as follows:

$$\bar{\mathbf{x}}_{(car)} = [\mathbf{I} - \bar{\mathbf{A}}_{(car)}]^{-1} \bar{\mathbf{f}}_{(car)}$$

If the MVI is extracted, the lost output $\mathbf{T}_{(car)}$ with the vector $\mathbf{i}'$ is calculated according to the following equation:

$$\mathbf{T}_{(car)} = \mathbf{i}' \bar{\mathbf{x}}_{(car)} - \mathbf{i}' x$$

In this study, normalization through division by total gross output $\mathbf{i}'\mathbf{x}$ and multiplication by 100 produces an estimate of the percentage decrease in total economic activity:

$$\bar{\mathbf{T}}_{(car)} = 100 \left[\mathbf{i}' \bar{\mathbf{x}}_{(car)} - \mathbf{i}'\mathbf{x}\right] / \mathbf{i}'\mathbf{x}$$

This study uses the multi-regional I–O table instead of the regional I–O table to analyze the case where MVI in a specific region is extracted. In the extraction process, in the input coefficient matrix after deducting imported goods, the row and column values indicating the activity of MVI in a specific region and the corresponding final demand values are all set to 0. In this case, since the impact of MVI on other industries is compared over time for each region, the standardization ratio using $\mathbf{i}'\mathbf{x}$ excluding the extracted production value of MVI is shown as the respective reduction rate.

In case of the activity of MVI in a specific region extracted from the multi-regional I–O table, the demand of MVI in the extracted region could be replaced by the production activity of MVI in other regions.

The HEM considers the hypothetical situation where a certain industry is no longer operational by I–O table. When applying the HEM to national I–O tables, it is assumed that imports will cover the missing original inputs after extraction (Cai and Leung 2004).

While applying the HEM to national multi-regional I–O tables, it is assumed that the missing original inputs in the extracted region will be replaced by interregional transactions from the remaining regions. In Nozaki's (2017) study, the input coefficient matrix is set on the assumption that the production decrease due to the natural disaster in a specific region will be covered by other regions that have not been damaged by the natural disaster.

While applying the HEM to global multi-regional I–O tables, the assumption is that the extracted inputs in specific countries will be supplied from other countries. Dietzenbacher et al. (2019) compared the analysis results of conventional HEM with the analysis results of the modified HEM, assuming that the extracted MVI in China, the US, and Germany will be replaced in other countries. The

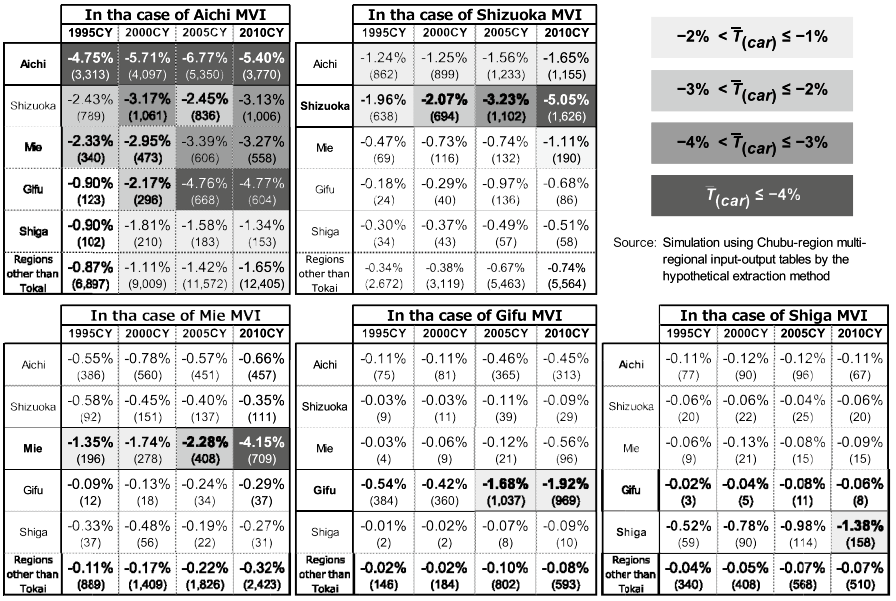

Fig. 1 Rate ($\bar{T}_{(car)}$) of decrease in output (diminution billion ¥ in parentheses); *MVI* motor vehicle industry

former analysis result has a lower production value in all three countries than the later analysis result. The production value of other countries increases due to their alternative production. However, the analysis results highly depend on the assumption of substitution rates by the MVI in other countries.

Meanwhile, this study investigated the MVI in the Tokai region to understand the secular changes of interdependencies in the MVI cluster. The MVI in Japan has a large supply-chain structure with wide transactions and several subcontracted factories. Each automaker has a multi-layered production structure as a regional industrial cluster (Ishiro 2007), and they have strict standards for different quality and safety, making it difficult to procure alternative parts from cooperating parts affiliates of other companies in the short term. The purpose of this study is to read these impact changes.

Furthermore, as Dietzenbacher et al. (2019) point out, if the assumption of substitution rates in other regions affects the analysis results, it is difficult to interpret the factors. The reason is that the change in production value in the analysis results is a mixture of two factors: changes in the supply chain of the MVI or the substitution rates in other regions.

Considering the above, in this study, it is not assumed that the extracted demand of the MVI in a specific area will be replaced by the import/export of other regions. The effect of replacing the extracted demand with the demand of other regions on the analysis results will be the subject of future research.

Results

This section shows the results for each prefecture in the Tokai region and other regions based on the Chubu-region I–O tables for four points in time from 1995 to 2010. Figure 1 indicates the rate of decrease in output excluding the extracted MVI output in each prefecture of the Tokai region using the HEM.

Impact of the Aichi motor vehicle industry

For the case of "Aichi MVI using the HEM," the rate of decrease for Aichi remains high at about -5% to -7% (about 3 trillion to 5 trillion yen of the reduced output) for four points in time: 1995, 2000, 2005, and 2010. The rate of decrease for the other prefectures in the Tokai region in 2010 are as follows: −4.77% (604 billion yen of the reduced output) for Gifu, −3.27% (558 billion yen of the reduced output) for Mie, −3.13% (1.6 trillion yen of the reduced output) for Shizuoka, and −1.34% (153 billion yen of the reduced output) for Shiga. In particular, the rate of decrease for Gifu jumped significantly from −0.90% in 1995 to −4.77% in 2010. The rate of decrease for each prefecture in the Tokai region has a relatively increasing trend since 1995. These results indicate that the interrelations between the Aichi MVI and the industries in Gifu, Mie, and Shizuoka have intensified.

The rate of decrease for regions other than Tokai is −0.87% (6.9 trillion yen of the reduced output) in 1995, −1.11% (9.0 trillion yen of the reduced output) in 2000, −1.42% (11.6 trillion yen of the reduced output) in 2005 and −1.65% (12.4 trillion yen of the reduced output) in 2010, which shows a relative increasing trend. Therefore, the interrelations between the Aichi MVI and the industries in regions other than Tokai have also intensified.

Moreover, the extracted output of the Aichi MVI in 2010, 13.7 trillion yen, is less than the output in 2005, 15.9 trillion yen, and the extracted output in 2010 is reduced by 13.80% (2.2 trillion yen) from 2005. Thus, the rate of decrease for Aichi dropped from −6.77% in 2005 to −5.40% in 2010; however, those of other prefectures rose. This also suggests that interregional transactions by Aichi MVI have been widespread not only with the Tokai region but also nationwide.

Impact of the Shizuoka motor vehicle industry

For the case of "Shizuoka MVI using the HEM," the rate of decrease for Shizuoka has been increasing from about −2% to −5% (about 0.6 trillion to 1.6 trillion yen of the reduced output) for four points in time: 1995, 2000, 2005, and 2010. The extracted output of Shizuoka MVI was about 1.4 times (4.5 trillion yen) in 2005 and about 1.3 times (4.4 trillion yen) in 2010 compared to 1995 (3.3 trillion yen). Meanwhile, the reduced output in Shizuoka was about 1.7 times (1.1 trillion yen) in 2005 and about 2.5 times (1.6 trillion yen) in 2010 compared to 1995 (0.6 trillion yen). The extracted outputs in 2005 and in 2010

are almost the same, but the reduced output in 2010 is over 0.5 trillion yen more than in 2005. Thus, the Shizuoka MVI has extended its business relationship to other industries in Shizuoka.

The rates of decrease for other prefectures in the Tokai region in 2010 are as follows: −1.65% (1.2 trillion yen of the reduced output) for Aichi, −1.11% (190 billion yen of the reduced output) for Mie, −0.68% (86 billion yen of the reduced output) for Gifu, and −0.51% (58 billion yen of the reduced output) for Shiga. These results indicate that the interrelations between the Shizuoka MVI and the industries in Aichi and Mie have intensified.

In addition, the rate of decrease for Aichi increased from −0.25% in 2000 to −1.56% in 2005 and −1.65% in 2010. Similar to Aichi, the rate of decrease for Shizuoka is also relatively high, the interrelation of industrial linkage between the Aichi MVI and the Shizuoka MVI has intensified.

The rate of decrease for regions other than Tokai is −0.34% (2.6 trillion yen of the reduced output) in 1995, −0.38% (3.1 trillion yen of the reduced output) in 2000, −0.67% (5.5 trillion yen of the reduced output) in 2005 and −0.74% (5.6 trillion yen of the reduced output) in 2010, which shows relative increasing trend albeit weak compared to the trends for Aichi and Gifu.

Impact of the Mie, Gifu, and Shiga motor vehicle industry

For the case of "Mie MVI using the HEM," the rate of decrease for Mie has been growing significantly; particularly, the rate of decrease jumped significantly from −1.35% (196 billion yen of the reduced output) in 1995 to −4.15% (709 billion yen of the reduced output) in 2010. The result indicates that Mie MVI has extended its business relationship to other industries in Mie.

For the case of "Gifu MVI using the HEM," the rate of decrease for Gifu has been growing; the rate of decrease increased from −0.54% (384 billion yen of the reduced output) in 1995 to −1.92% (969 billion yen of the reduced output) in 2010. The result indicates that Gifu MVI has extended its business relationship to other industries in Gifu.

For the case of "Shiga MVI using the HEM," the rate of decrease for Shiga has been growing; the rate of decrease increased from −0.52% (59 billion yen of the reduced output) in 1995 to −1.38% (158 billion yen of the reduced output) in 2010. The result indicates that Shiga MVI has extended its business relationship to other industries in Shiga.

In the case of Mie, Gifu, and Shiga, the rate of decrease for regions other than Mie or Gifu or Shiga has a relative increasing trend albeit weak compared to the trends in their own area. Particularly, in the case of Shiga, the rate of decrease for regions other than Shiga is relatively small.

Therefore, Mie, Gifu, and Shiga MVI have extended their business relationship to other industries in their area.

Discussion

In this study, the HEM was applied to each prefecture in the Tokai region that consists of five prefectures, Aichi, Shizuoka, Mie, Gifu, and Shiga, using the Chubu-region I–O tables to understand the secular change of interdependencies in the MVI clusters.

The Aichi MVI has strengthened its ties with industries in other prefectures in the Tokai region. In addition, the Aichi MVI has extended its clusters to industries in regions other than Tokai. Thus, the large supply-chain structures of the Aichi MVI have been expanding throughout Japan. It is evident from these results that Aichi MVI has supported industries all over Japan.

Furthermore, the Shizuoka MVI has increased business relationships within its region, Aichi, and Mie, which have large supply-chain structures in the MVI.

In particular, the interrelation of industrial linkage between the Aichi MVI and the Shizuoka MVI has deepened with the strengthening of ties between the two industries. This is because the reduced output in Aichi in the case of "Shizuoka MVI using the HEM" and the reduced output in Shizuoka in the case of "Aichi MVI using the HEM" are over 1 trillion yen each.

Meanwhile, for Mie, Gifu, and Shiga, their supply-chain structures have remained inside their regions.

Although each prefecture in the Tokai region has automotive assembly factories, each prefecture has different interdependences in the MVI creating large supply-chain structures with wide transactions and several subcontracted factories. Additionally, the changes in the environment surrounding the MVI, such as construction of new factories in different regions, new supplier entries from other industries, etc., have also affected the supply-chain structures. The results of this study clearly demonstrate that the Aichi MVI has much more influence on industries and economy not only in the Tokai region but also in regions other than Tokai. The Shizuoka MVI has increased business relationships within its region, Aichi, and Mie. Aichi and Shizuoka prefectures particularly have interrelations of industrial linkage with each other more than before. It may depend on their economic condition, but there is little doubt about the interrelations that are apparent from this study.

As not only the MVI but also other industries have some interdependencies in their supply-chain structures, this study can be applied to establish cooperation between prefectures to promote the local industry in some regions. In most cases, Japanese regional promotions for industries are undertaken by the national and the local governments. However, some industries have their ties with other regions, as in the case of Aichi and Shizuoka. In these cases, regional promotions by the local government in Aichi and Shizuoka are much more effective than those by only one local government. Moreover, it would be possible to share the promotion cost according to the HEM's effectiveness, especially during a recession, to protect their industries and economy using an economized budget.

In this study, the HEM was applied to each prefecture in the Tokai region using the Chubu-region I–O tables to understand the secular change of

interdependencies in the MVI clusters. However, some automotive assembly factories have been built outside the Tokai region due to regional economic revitalization, labor shortages, or disaster risks. Future studies of the HEM should be conducted for other regions. One limitation for future studies is that the multi-regional I–O tables for these regions do not exist or would not be disclosed. It is hoped that the outcome of the present study would be of some use for enhancing the utility of multi-regional I–O tables.

Furthermore, with the overseas location of automobile assembly factories, it is necessary to consider the global supply chain in the MVI, such as the overseas expansion of the subcontracted factories. The delay in procuring automobile parts produced overseas due to the spread of the COVID-19 infection has caused a situation in which automobile assembly factories in Japan and overseas are shut down. To understand the interdependence between the Japanese MVI and the world in international transactions, it is also necessary to analyze the international I–O tables for future studies.

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Data availability Data for the analysis were collected from various sources. Information on each source is available in the references section and cited in the main text, where appropriate.

Code availability Not applicable.

Declarations

Conflict of interest The author has no relevant financial or non-financial interests to disclose.

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Consent to participate Not applicable.

Consent for publication Not applicable.

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