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The Automotive Value Chain in Thailand

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Abstract: *A country's participation in global value chains (GVCs) is increasingly becoming important as a strategy for economic development. However, participation in GVCs alone is not sufficient. Industrial deepening – or the formation of backward linkages by creating robust supplier bases – is necessary to sustain economic growth. This paper explores how the automotive value chain has evolved in Thailand since the 1990s. Trade in value-added analysis is applied to the Organisation for Economic Cooperation and Development's Inter-Country Input-Output data. Moreover, the concept of value chain mapping is introduced to illustrate upstream and downstream transactions of goods and services along the value chain. Results show that international linkages were strengthened because of the expanding production networks in Southeast Asia. On the other hand, domestic linkages and domestic content started to decline after a certain point. These results suggest that the benefits of specialisation and exchange have outweighed those of agglomeration in recent decades.*

Keywords: value chain mapping, trade in value added, automotive value chain
JEL Classification: D57, F14, O53

1. Introduction

A country's participation in global value chains (GVCs) has become increasingly important as a strategy for economic development. Unlike in the past, today's developing countries can take part in the GVCs of sophisticated products by specialising in a niche segment in a value chain. Such phenomena have occurred due to the rapid drop in trade and communication costs, spurred by trade liberalisation, technology, and infrastructure development.

However, mere participation in GVCs is not sufficient. To sustain economic growth, there ought to be structural transformation – particularly, industrial deepening, which is defined as the formation of backward linkages by creating a robust supplier base (ADB, 2013) – especially for industries with significant agglomeration economies such as the automobile industry.

The advantages of industrial deepening are multi-faceted. First, industrial deepening induces the participation of local suppliers in GVCs, which will increase the share of domestic value added contained in the products and will improve the balance of payments. Second, the development of a local supplier base will bring about the benefits of agglomeration and increase the competitiveness of downstream industries by delivering parts and components at lower costs and shorter time, and with more flexibility. Third, the backward linkage – one that is established between local suppliers and multinational firms – is an important channel of technology transfer from multinational firms to local suppliers (Javocik, 2004; Blalock and Gerlten, 2007). Finally, industrial deepening can upgrade and diversify the industrial structure by stimulating the development of upstream industries in sequence, from

parts and component suppliers to materials and machinery manufacturers (Hirschman, 1958).

When it comes to policy measures that stimulate the development of upstream industries, current development literature that focuses on engagement in GVCs tends to emphasise the importance of access to cheaper or higher-quality imported inputs. Thus, any trade protection measures that protect the local suppliers of intermediate inputs at the cost of production efficiency would not be recommended as an effective policy option (OECD, 2013).[1] Moreover, such protective measures have become increasingly difficult to implement as a result of trade liberalisation in recent decades. In particular, the local content requirement (LCR) – extensively used to protect local suppliers during the era of import substitution – was prohibited by the World Trade Organization's Agreement on Trade-Related Investment Measures.

Despite the increasing difficulty of policy intervention, there are critical factors that still affect local procurement. In particular, the benefits of agglomeration are critical in local suppliers' development. In the automotive industry, for instance, spatial proximity between local suppliers and assemblers not only saves costs in the transport of heavy and bulky components, but also facilitates just-in-time production and delivery so as to reduce lead-time and inventories.[2] It could therefore be possible that local procurement will increase, despite the lack of policy intervention.

[1] An industry with a high share of imported inputs displays, on average, higher productivity in the OECD countries, because foreign inputs embody more productive technology, and resources are re-allocated more efficiently. In particular, increased productivity results from: (1) A price effect: increased intermediate imports result in stronger competition and therefore lower prices for inputs; (2) A supply effect: increased imports enhance the variety of inputs available; (3) A productivity effect: new intermediate inputs may spur innovation in the final goods sector by enhancing access to knowledge (OECD, 2013).

[2] There are several sources of agglomeration economies that include input sharing, knowledge spillovers, and labour market pooling (Marshall, 1920; Rosenthal and Strange, 2004). The other benefit of industrial agglomeration is an increase in the share of domestic procurement, which reduces the impact of exchange rate fluctuations on local production costs.

On the other hand, the declining trade and transportation costs have increased the benefits of specialisation and exchange, reaping significant gains from international trade. For instance, some types of automotive parts – with the most notable example being a wire harness – are quite labour intensive, so that it would be more efficient to procure these parts from low-income countries.[3]

Manufacturing key components such as an engine or a transmission involves a large fixed cost and requires a well-established local supplier base; thus, it would be more efficient to source from an existing production base.[4]

In summary, there are two forces that work in opposite directions. One is the benefit of agglomeration, which encourages local supplier development and strengthens domestic linkages. The other is the benefit of specialisation and exchange, which promotes trade and strengthens international linkages. It is therefore a matter of empirical evidence to demonstrate which type of linkage – domestic or international – has been strengthened during the course of the automotive industry's development.

Against the above backdrop, this study focuses on the automotive value chain in Thailand.

The Thai automotive industry, which includes auto parts manufacturing, has developed rapidly since the end of the 1980s. Concurrently, the automotive industry's value chain has been increasingly internationalised by trade liberalisation and regional integration efforts since the early 1990s. In this paper's review of the evolution of the

[3] For instance, Yazaki and Toyota Boshoku in Thailand have relocated manufacturing facilities of a wiring harness and an automotive sheet cover to Cambodia and Laos respectively, and started sourcing from these countries.

[4] It is well known that after Toyota participated in the Brand-to-Brand Complementation Scheme in 1989, it established a complementary supply system in Southeast Asia, where manufacturing bases in the respective countries procure key components from specific countries, such as diesel engines from Thailand, gasoline engines from Indonesia, transmissions from the Philippines, and steering components from Malaysia.

automotive value chain in Thailand, particular focus will thus be given on the changes in domestic as well as international linkage structures.

Two sets of international input-output data – the Institute of Developing Economies (IDE-JETRO's) Asian Input-Output Tables for 1990, 1995, 2000, and 2005; and the Organization for Economic Cooperation and Development's Inter-Country Input-Output (OECD's ICIO) tables for 1995 and 2011[5] – will be used to measure the share of domestic procurement and to conduct the trade in value added analysis. Note that trade in value added accounts for double counting implicit in the gross flow of trade, so as to measure the flow of value added in the trade of goods or services.

This paper's other purpose is to introduce a simple method of value chain mapping using international input-output data, specifically the OECD's ICIO tables for 1995 and 2001. International input-output data have been used in recent years to calculate some GVC-related indices and to decompose gross trade data (Hummels, Ishii, and Yi, 2001; Daudin, Rifflart, and Schweisguth, 2011; Johnson and Noguera, 2012; Koopman, Wang, and Wei, 2014).

On the other hand, there has never been yet any attempt to use the international input-output data for value chain mapping. While the value chain mapping is an indispensable part of the value chain analysis, a major drawback of current value chain analyses lies in the lack of objective or quantitative data.[6] As shown below, the value chain mapping using the international input-output data will fill this void and

[5] The OECD's inter-country tables are available for 1995, 2000, 2005, 2008, 2009, 2010, and 2011, from which the oldest and newest tables are used in this study.

[6] Frederick (2014) pointed out this problem, referring to the advantage of using input-output data, and asserted that 'the analysis and policy recommendations provided in GVC studies are often based on qualitative data and are therefore subjective. Policy makers need to have concrete evidence to support the decision-making process in order to justify investments and widespread policy changes.'

provide objective information regarding the transactions of goods and services along the value chain.

This paper is organised as follows: The next section outlines the history of the Thai automotive industry, including the transition of industrial policies since the 1960s. Then, this paper examines the result of the analysis on trade in value added and introduces the value chain mapping method to complement the said analyses. Finally, the paper concludes with a summary of the findings.

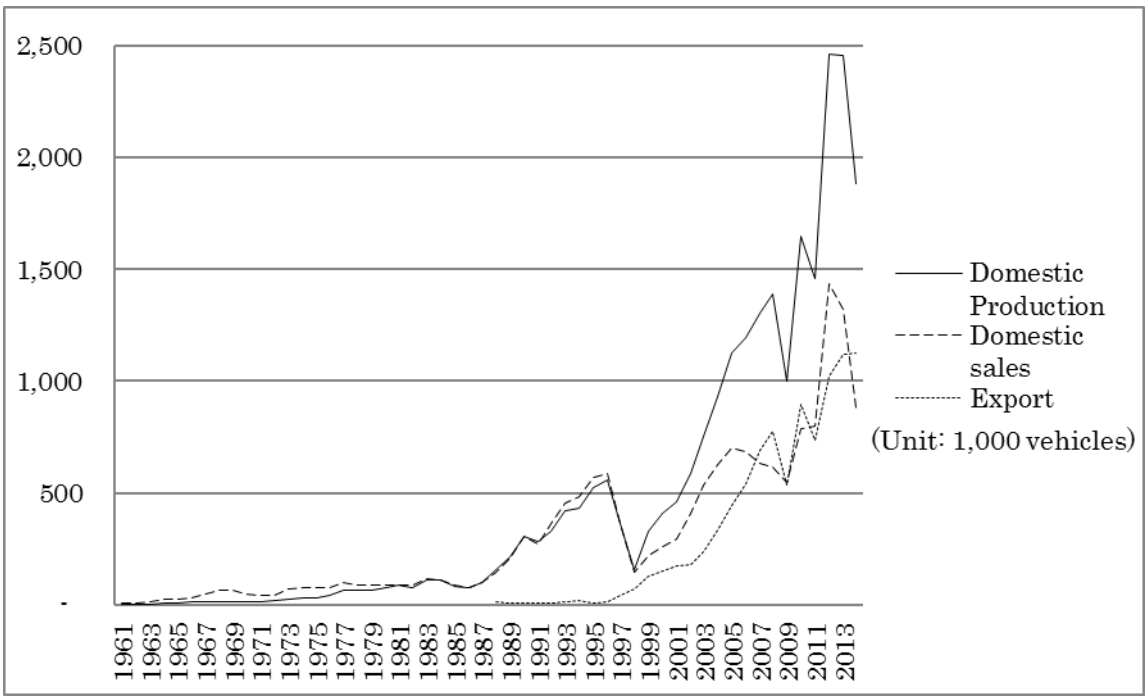
2. The Automotive Industry in Thailand

2.1. Outline of the Thai automotive industry

Figure 1 shows the domestic production of the Thai automotive industry in 1961-2014. Thailand's automotive production started to increase rapidly at the end of the 1980s, although it plummeted temporarily during the Asian Crisis in 1997-1998, the Global Financial Crisis in 2009, the flooding in 2011, and the political conflict in 2014.

The exportation of complete vehicles started in 1988, but it was the Asian Crisis that triggered the rapid growth of vehicle exports (Figure 1). Consequently, the Thai automotive industry has become quite export-driven, wherein its share of total exports has exceeded 50% in recent years. It is particularly competitive in commercial vehicle exports and Thailand has in fact come to be known as the production hub of 1-ton pickup trucks. In 2012, motor vehicle production reached 2.46 million units (with exports of 1.02 million vehicles), making Thailand the 9th largest automotive manufacturer in the world.

Figure 1. Domestic Production, Domestic Sales, and Exports of Automobiles in Thailand (1961-2014)

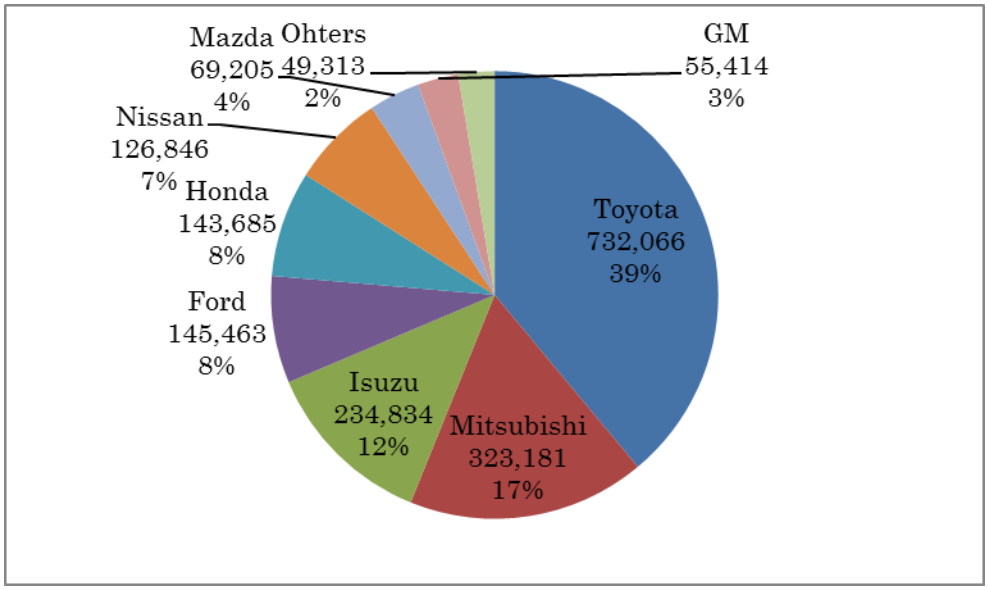


Source: Author's calculation based on Thailand Automotive Club, Federation of Thai Industries.

Figures 2 and 3 respectively show the domestic production and market shares of automotive manufacturers in Thailand in 2014. Japanese companies dominated the Thai automotive industry as the former accounted for 88.6% and 87.5% of Thailand's domestic production and domestic market, respectively. In particular, Toyota's share stood at close to 40% for both domestic production and market shares.

Figure 2. Shares of Automobile Production in Thailand, 2014

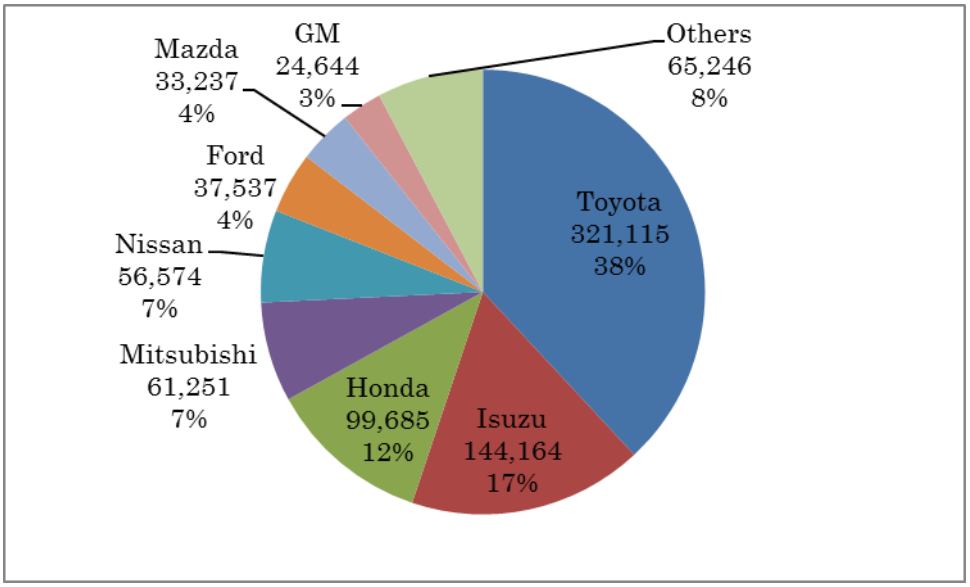
(total production = 1,880,007 vehicles)



Source: Fourin (2015).

Figure 3. Shares of Automobile Sales in Thailand, 2014

(total sales = 843,453 vehicles)



Source: Fourin (2015).

Mitsubishi and Ford had a relatively high production share, while Isuzu and Honda had high numbers in terms of domestic market share. These reflect the differences in the dependency on foreign markets: The former set of companies had a higher dependency on exports than did the latter.

2.2. Automotive industry policy

The automotive industry policy regimes in Thailand can be categorised into five periods:

1) Initial stage of import substation (1960-1968)
2) Localisation and acceleration of LCR (1969-1990)
3) Trade liberalisation and export promotion (1991-1996)
4) The Asian Crisis and recovery (1997-1999)
5) Automotive manufacturing hub in East Asia (2000-)

The import substation policy was introduced in Thailand in the 1960s, while the complete knock-down vehicle production was started by Ford in 1961. After the Automotive Development Committee was established in 1969, such import substitution policy was extended to automotive parts and components, and the LCR was introduced in 1975. Since then, the local content has increased in accordance with the government's policy directions. For instance, the LCR for a pickup truck with a diesel engine was initially set at 20%, but increased to 72% in 1994 (Natsuda and Thoburn, 2012).

In the 1990s, the policy orientation changed dramatically. The import substitution policy was replaced by the trade liberalisation and export promotion policy. In 1991, the government allowed the importation of complete vehicles (with engines of less

than 2300 cc) and reduced the tariff on imported vehicles. It also allowed the development of new assembly factories and dropped the restriction on the number of vehicle models. In 1994, it decided to grant a tax incentive to automotive-exporting firms.

Another turning point in the automotive industry's policy direction came after the Asian Crisis in 1997. To help local firms that were in financial straits, the government allowed a majority equity holding by foreign firms. Moreover, in 2000, the government decided to abolish the LCR, which was already prohibited by the World Trade Organization's Agreement on Trade-Related Investment Measures.

During the Thaksin administration, which started in 2001, the automotive industry was positioned as a strategic industry. Similar to the 1-ton pickup trucks of prior years, the eco-car project was formalised as a way to cultivate the export market. After the 2000s, the Thai automotive industry grew rapidly as the 'Detroit of Asia,' particularly driven by exports of its 1-ton pickup trucks.

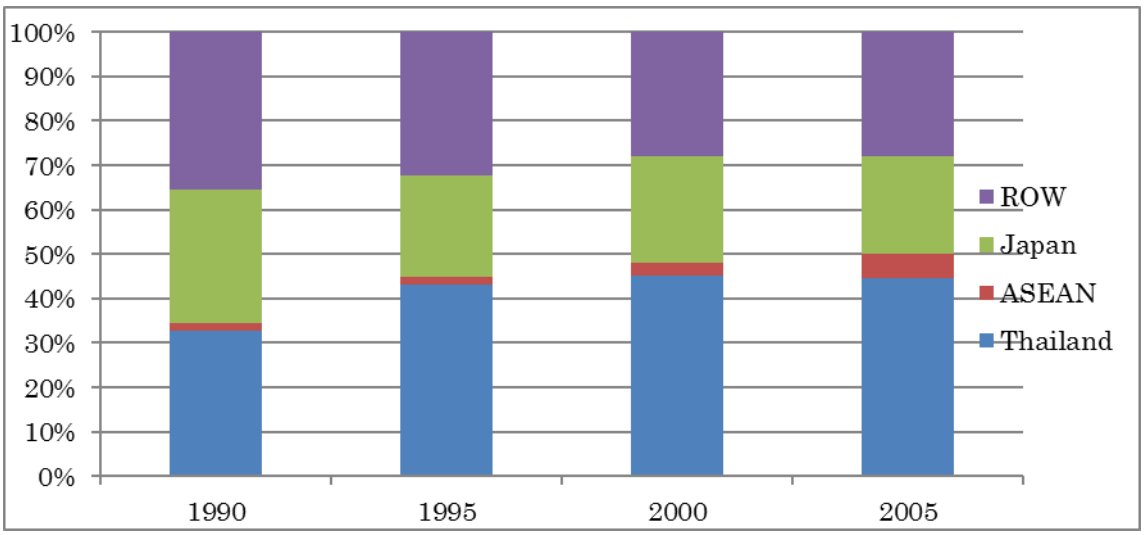
3. Empirical Results

3.1. Procurement of intermediate inputs (1990-2005)

Figure 4 indicates the percentage share of intermediate inputs (i.e. parts, components, materials, and services) used in the Thai automotive industry. The share of domestic procurement increased from 32.6% to 45.2% in 1990-2000, but declined slightly (44.6%) in 2005. It should be noted here that the share of domestic procurement continued to rise until the LCR was abolished in 2000.[7,8]

[7] The share of domestic procurement in terms of value added content can be calculated using a method similar to trade in value added and called the 'share of domestic procurement in total

Figure 4. Procurement of Intermediate Inputs by the Automobile Industry in Thailand (1990-2005)



Source: Calculated from the Asian input-output tables (IDE).

The share of procurement from the Association of Southeast Asian Nations (ASEAN) countries continued to rise from less than 2% to more than 5% in 1990-2005, whereas the share from Japan and the Rest of the World (ROW) declined significantly. This implies that there was a significant shift in the source countries for parts and components, especially from Japan to the ASEAN countries.

What factors affected the shift in the source countries? Why did the local content continue to increase until 2000? Why did the share of the ASEAN countries increase? In terms of the industrial policy, the following factors appear to be important:

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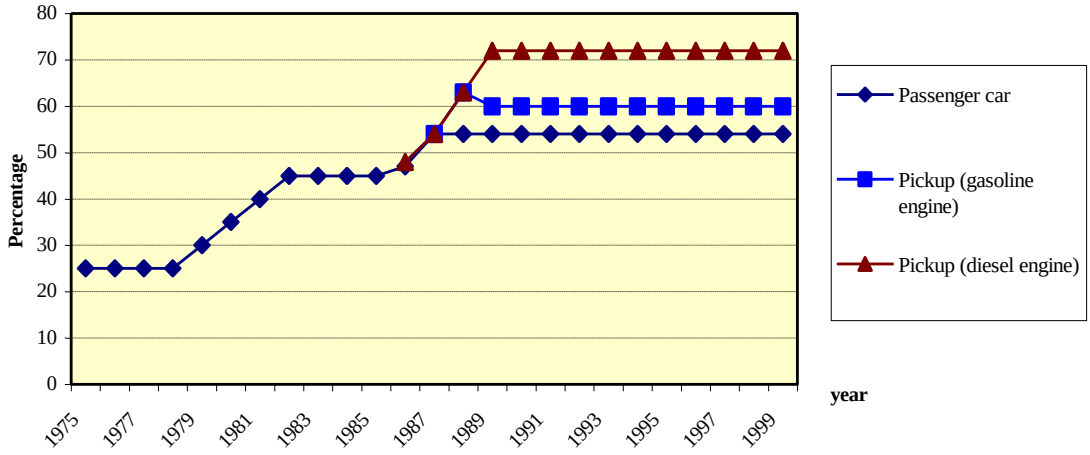
measure' (Kuroiwa, 2015). Since the total measure takes into account the leakage of value added that occurs through the import of intermediate inputs in an upstream production process, it represents more precisely the true dependency on domestic inputs. The share of domestic procurement in total measure was 6.6% in 1990, 24.3% in 1995, 35.2% in 2000, and 32.2% in 2005. This shows a similar trend to domestic procurement, but with greater fluctuations.

[8] Baba (2005) examined the trend of domestic procurement of the automobile industry in the ASEAN 4 countries (i.e. Thailand, Malaysia, Indonesia, and the Philippines as a whole) since 1975. He found that the share of domestic procurement increased slightly (43.5%-45.6%) from 1975 to 1990. It started to increase rapidly (45.8%-50.8%) in the early 1990s (1990-1995). The number of auto parts suppliers in Thailand increased sharply after the mid-1980s. These facts suggest that auto parts industry in Southeast Asia started to develop significantly during this period.

1) Local content requirement (LCR)

Since the LCR was introduced in 1975, the level of local content imposed by the government continued to increase until the end of the 1980s (Figure 5). The LCR was retained until it was abolished in 2000.

Figure 5. Local Content Requirement of in Automobile Assembly (1975-1999)



Source: Wattanasiritham (2000), Figure 2.1, p. 23.

The LCR policy raised the cost of automotive parts and components, thus reducing production efficiency. However, it was effective in engaging local suppliers in the automotive value chain.[9] At the same time, many foreign parts suppliers – particularly the Japanese suppliers – made investments to comply with the assemblers' requests. Table 1 shows that the number of Japanese investors started to increase rapidly in the mid-1980s.

[9] Some successful local firms, such as Thai Summit Group, received substantial benefits from the LCR policy. Starting as small enterprises during the LCR regime, these firms not only had their customers but also received technical advice and support from the assemblers. Today, with annual sales of USD 2 billion, Thai Summit Group has more than 40 subsidiary companies and produce a variety of automotive parts including car bodies; interior/exterior parts; wire harness; chassis; machine, forging and die casting; and tooling.

Table 1. Ownership Types and Periods of Establishment in Thailand

	-1960	1961-75	1976-85	1986-99	2000-14
Thai firms	8	69	97	297	102
Foreign firms	0	14	6	163	55
(Japanese firms)	0	9	4	115	33
Joint Venture	4	22	18	123	35
Unknown	11	56	71	302	197
Total	23	161	192	885	389

Source: Calculated from Thailand Automotive Industry Directory 2014.

Note that the number of Thai firms, which outnumbered foreign firms and joint ventures, grew substantially in 1986-1999. Table 2 reveals that the types of parts produced in Thailand also increased during the same period. In particular, the number of technologically sophisticated parts such as engine parts grew due to the LCR that was imposed on engine parts in 1989-1998.[10]

[10] The engine manufacturers had to increase local content every year from 20% in 1989 to 70% in 1998. More specifically, engine manufactures had to procure locally cylinder blocks from 1994, connecting rods and camshaft from 1996, cylinder head from 1997, and crank shaft from 1998 (Techakanont, 2011).

Table 2. Types of Parts by Periods of Establishment in Thailand

	-1960	1961-75	1976-85	1986-99	2000-14
Engine	9	58	51	253	89
Drive train	1	7	11	52	29
Suspension / steering / wheel & tire	4	22	40	110	48
Axle/brake/body control,	1	19	28	125	53
Body and exterior	4	35	47	170	78
Interior	1	15	23	94	49
Climate control	3	11	22	68	25
Driving support & security	0	2	6	22	7
Electronic/electrical parts	1	11	17	95	26
Small/general parts	4	39	52	199	77
Categories by production process	3	41	61	260	124
Motorcycle parts	5	44	67	263	94
Automobile assembly	4	8	1	18	9
Agricultural machinery and other transport machinery	3	16	22	44	29
Chemical, oil, lubricant, paint, etc.	2	18	17	61	25
Accessories	0	13	16	61	28
Service (trading, logistics, trade show, training, etc.)	6	35	32	154	107
Machine tools, jigs and fixtures, moulds and dies, etc.	1	9	19	68	36
TOTAL	52	403	532	2117	933

Notes:
1. The Thailand Automotive Directory includes parts of other transport machinery, such as motor cycles and agricultural machinery.
2. The number of types of parts is greater than the number of establishments, because each establishment (or plant) usually produces more than one type of parts.
Source: Calculated from Thailand Automotive Industry Directory 2014.

2) Agglomeration benefits

Since the early 1990s, sales competition has become tougher after the automotive industry was liberalised (e.g. through import liberalisation of complete vehicles, tariff reductions, and removal of barriers to market entry). It then became necessary for automotive assemblers to reduce costs and increase their market competitiveness. Since many automotive parts and components are heavy and bulky, the option of procuring these locally would mean reduced transport costs and facilitate just-in-time production and delivery of automotive parts.

Thus, faced now with stiff competition, assemblers needed to turn more to local procurement not to meet the LCR, but to improve their market competitiveness.[11] As shown in Table 1, the number of newly created establishments reached its peak in

[11] Another important reason for local procurement is that labour costs in Thailand are lower than in Japan. Moreover, the appreciation of the Japanese yen (1985), as well as the depreciation of the Thai baht after the Asian Crisis (1997) increased the cost competitiveness of the local suppliers in Thailand.

1985-1999, when market competition became tough due to trade and investment liberalisation in Thailand.

3) Expansion of vehicle production

Because of scale economies in production, there is a certain threshold in the production volume of automotive parts where the cost of local production would become lower than their imported counterparts that always incur trade and transport costs. When this happens, a rapid growth in vehicle production would then increase the demand for inputs and encourage the setup of domestic suppliers.[12] As Figure 1 shows, the Thai automotive production has grown rapidly since the end of the 1980s, which was then met with a concomitant and significant rise in the number of automotive parts suppliers as well.

4) Formation of automotive supply chains in Southeast Asia

Businesses' preference to source parts and components from ASEAN countries has also increased since the early 1990s (Figure 4), thanks to the implementation of regional cooperation schemes – e.g. Brand-to-Brand Complementation scheme, ASEAN Industrial Cooperation scheme, and ASEAN Free Trade Area – that removed trade barriers for automotive parts in the region. Also, multinational firms – particularly the Japanese firms – that had already established supplier bases in other ASEAN countries started to procure key components such as engines, steering components, and transmissions from other ASEAN countries by using these regional frameworks.

[12] In spatial economics, this effect is called the 'backward linkage effect', while the agglomeration benefits described above is related to the 'forward linkage effect' (Fujita, Krugman, and Venables, 1999).

As discussed earlier, specialisation and exchange can promote trade and strengthen international linkages. In Southeast Asia, these were accelerated by regional integration efforts among ASEAN countries

3.2. The structure of vertical specialisation (1995-2011)

This section analyses the trade in value added using the OECD inter-country input-output tables for 1995 and 2011. First, the vertical specialisation (VS) index is calculated to define the structure of vertical trade in the Thai automotive sector.

3.2.1 The VS share

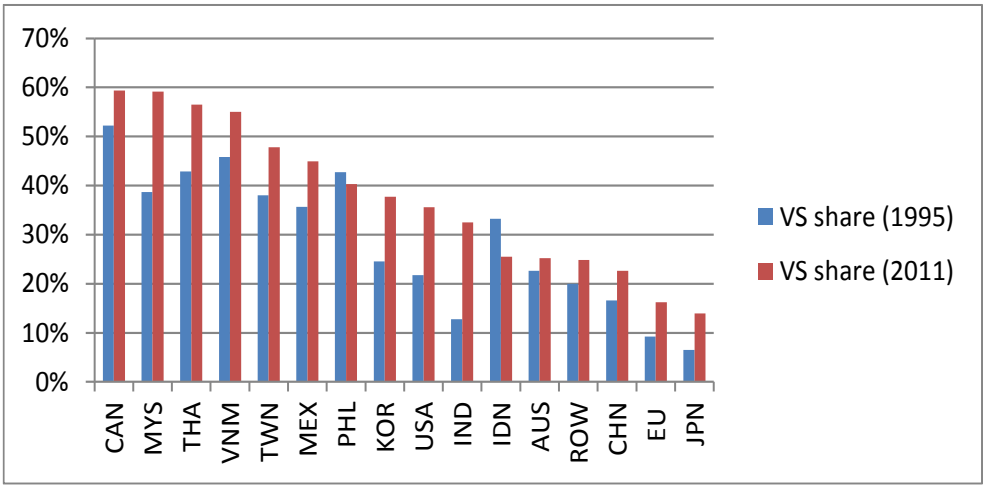
The VS share represents the percentage share of foreign content embodied in exports – i.e. the share of value added that is induced by exports, but accrues to foreign countries (for details on the method, see Appendix 1).[13] Therefore, the VS share indicates the true dependency on foreign inputs in exports. Its value tends to increase as the share of value added exports in gross exports decreases.[14]

Figure 6 shows the VS share of the automotive sector in 21 countries or regions. As in many other countries (except the Philippines and Indonesia), the VS share of the Thai automotive sector increased significantly in 1995-2011. This suggests that as the Thai automotive sector becomes more integrated into GVCs, it increases (decreases) its dependency on foreign (domestic) inputs.

[13] It is worth noting that, although the VS share by definition indicates the foreign content of exports, the same numerical value applies to the foreign content of other final demand components such as consumption, investment, and government consumption. This is due to the assumption in an input-output model that the input structure is the same regardless of the final demand item.

[14] It holds that gross exports = value added exports + VS (foreign content) + domestic content in intermediate exports that finally returns home (Koopman et al., 2014)

Figure 6. VS Share (%) of 16 Countries or Regions: Automotive Sector (1995, 2001)[a]



[a] The original OECD ICIO table contains 62 countries or regions but these are aggregated into 21 countries or regions for this study, among which only 16 have a motor vehicle assembly industry.

Note: VS stands for vertical specialisation.

Source: Calculated from the ICIO tables (OECD).

The ASEAN countries such as Malaysia, Thailand, and Viet Nam have relatively high VS shares in their automotive industry. Canada and Mexico – member countries of the North American Free Trade Agreement – also have high VS shares. These findings indicate that small and open economies actively involved in regional integration tend to have high VS shares.

On the other hand, larger economies such as Japan, the European Union, and China have relatively low VS shares. It should be noted, however, that the United States – a very large economy and a member country of the North American Free Trade Agreement – has a higher VS share than, for example, India or Indonesia.

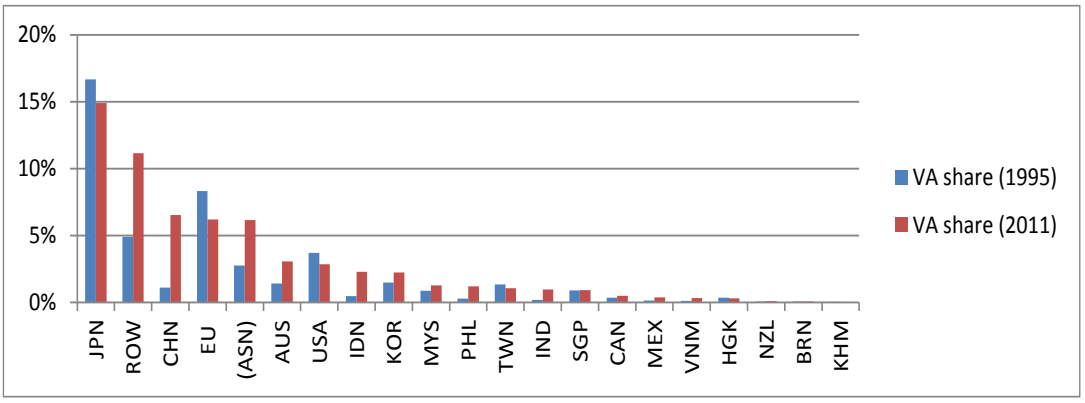
In the next section, the foreign content of Thai automotive exports is broken down further into various elements by country of origin and by industry of origin, to show

how the Thai automotive's value chain was established in association with other countries.

3.2.2 Decomposition of the VS share

Figure 7 shows the share of foreign content in Thailand's automotive exports by country of origin. Japan's content is the largest among all the countries, indicating that the Thai automotive industry is dominated by Japanese companies. However, Japan's share declined sharply in 1995-2011. Other developed countries such as the European Union and the United States also had a drop in their shares.

Figure 7. Share (%) of Foreign Content by Country of Origin: Automotive Sector in Thailand (1995, 2001)



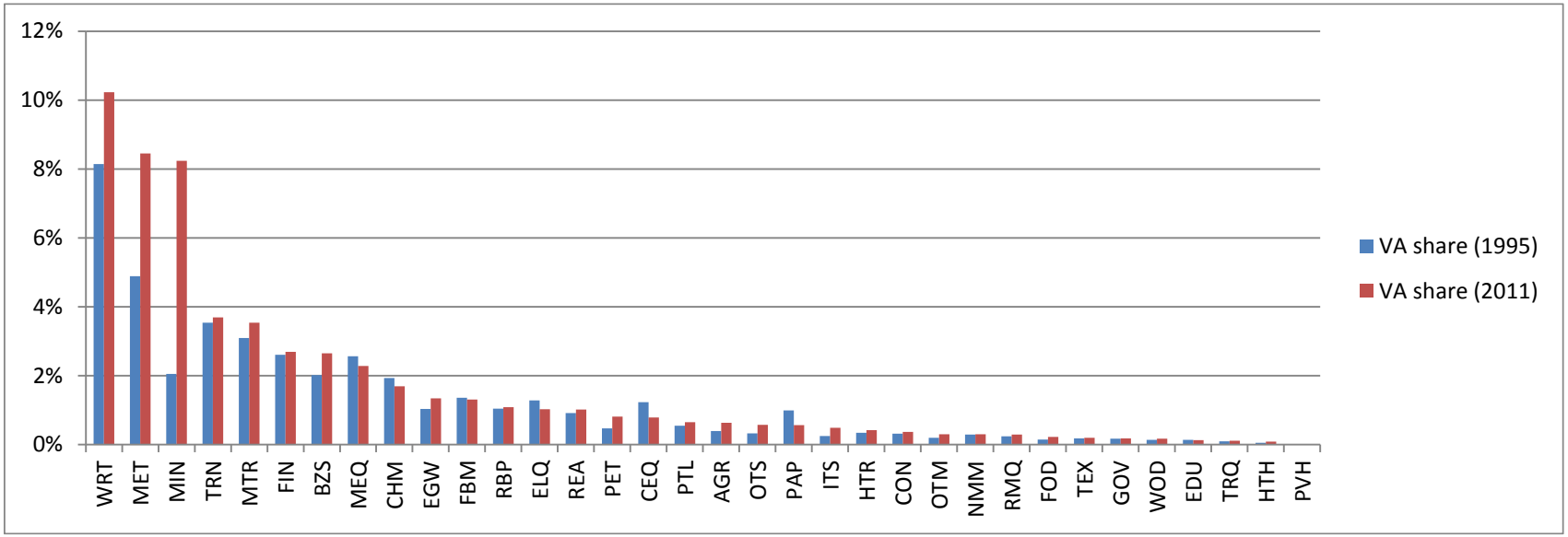
Note: ASN stands for ASEAN countries.
Source: Calculated from the ICIO tables (OECD).

On the other hand, developing countries demonstrate the opposite trend. In particular, Southeast Asian countries as well as China increased their shares significantly. That of the ASEAN countries as a whole rose from 2.8% in 1995 to 6.2% in 2011.

Figure 8 presents the share of foreign content, this time by industry of origin, in Thai automotive exports. Wholesale and retail trade has the highest share (10.2% in

2011). Services such as transportation, financial intermediation, research and development, and other business activities also show high shares.

Figure 8. Share (%) of Foreign Content by Industry of Origin: Thai Automotive Industry (1995, 2001)



Note: For the sector classification, see Appendix 2.
Source: Calculated from the ICIO tables (OECD).

These results suggest that a great amount of imported service value added is involved in Thai automotive exports.[15] In the manufacturing sector, the share of basic metals and mining increased rapidly and even exceeded 8% in 2011. As will be discussed later in this paper, there is a higher dependency on basic metals, which reflects the weak production capacity of the domestic metal industry in Thailand.[16]

To further investigate the complementary relationship between foreign and domestic inputs, the share of domestic content is examined, this time by industry of origin (Figure 9).

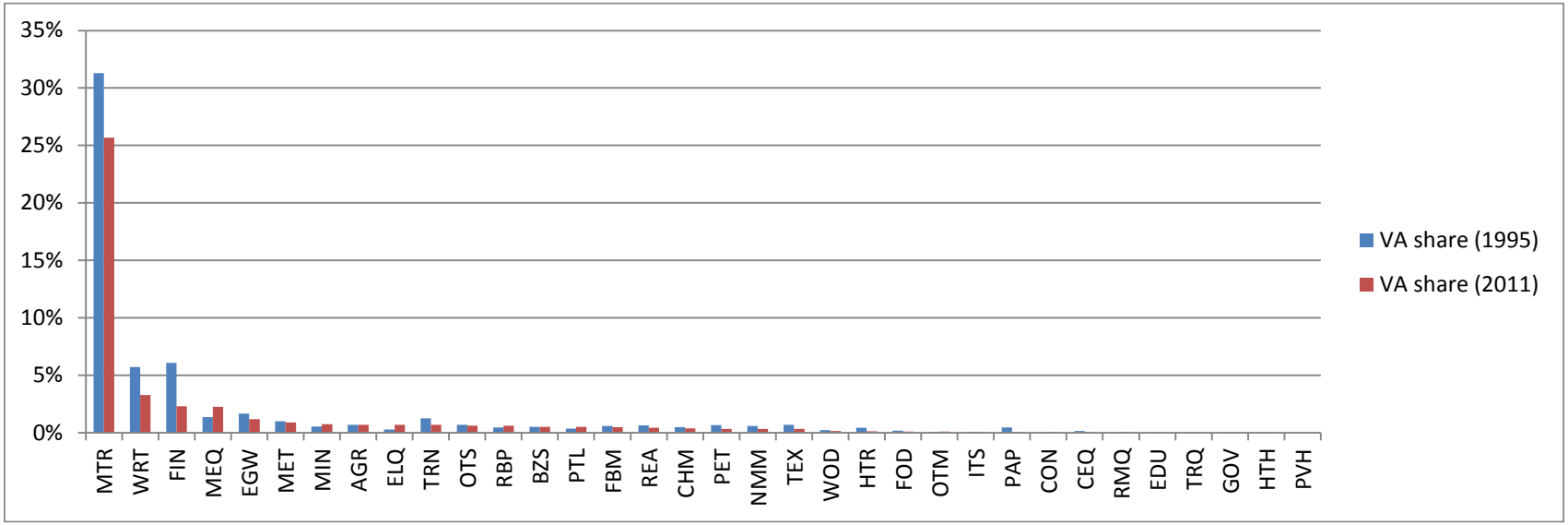
Here, one sees that motor vehicles have a strikingly high domestic content share when compared to their foreign content. In 2011, the domestic content share of motor vehicles was as high as 25.7%, while its foreign content was only at 3.5%. This is a remarkable achievement in the Thai automotive industry's localisation efforts.

On the other hand, the domestic content's share of basic metals was very low (0.9% in 2011), reflecting the weak production capacity of the Thai metal industry. Note that, as shown in Figure 8, the Thai automotive industry is heavily dependent on imported basic metals.

[15] The share of foreign service value added contained in Thai automotive exports was 20.6% and 24.8% in 1995 and 2011, respectively.

[16] Note that another important material for motor vehicles industry – i.e. chemical and chemical products – has relatively low foreign content in Figure 7. This reflects the fact that chemical products are more self-sufficient in Thailand.

Figure 9. Share (%) of Domestic Content by Industry of Origin: Thai Automotive Industry (1995, 2001)



Note: For the sector classification, see Appendix 2.
Source: Calculated from the ICIO tables (OECD).

Finally, similar to the findings in terms of foreign content, service sectors such as wholesale and retail trade and financial intermediaries have one of the highest domestic content shares among the sector classifications.[17] Note that the service content becomes even higher when measured in value added terms. For one, the share of value added contained in services is higher than in manufactured goods. Also, service is used as input for manufactured goods; thus, a substantial amount of service content is traded indirectly through manufacturing trade.

3.3. Mapping the value chain

In the previous section, the structure of the Thai automotive value chain was examined using the trade in value added method. Results showed how value added is generated by country of origin and sector of origin. However, it would be more illustrative if these data are combined together and used to demonstrate how value added is generated across borders throughout the entire manufacturing processes.

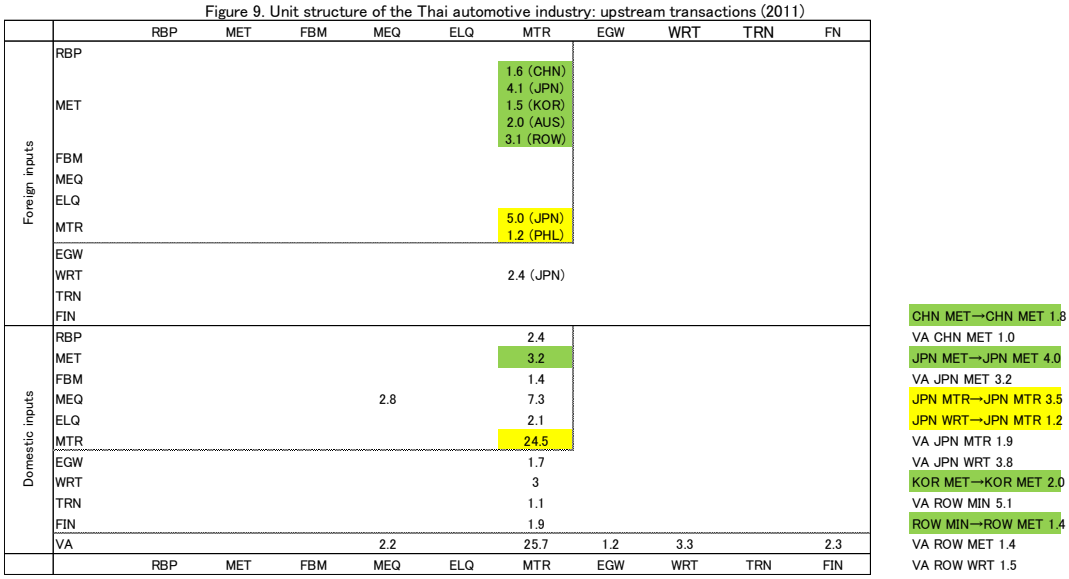
Upstream value chain mapping provides information on the generation of value added as well as inter-industry transactions of goods and services that are induced by a unit of final demand for specific goods or services. On the other hand, downstream mapping provides information regarding the inter-industry transactions as well as final demand components that are induced by a unit of primary inputs for specific goods or services.

[17] The share of domestic service value added (as a whole) contained in Thai automotive exports for 1995 and 2011 was 17.5% and 9.8%, respectively.

3.3.1. Upstream transactions

Figure 10 shows the unit structure of the Thai automotive industry in 2011. The unit structure analysis indicates the intermediate transactions of goods and services, as well as the value added generated in the respective sectors that are induced by a unit of motor vehicle final demand in Thailand (for the methodology, see Appendix 3).[18]

Figure 10. Unit Structure of the Thai Automotive Industry: Upstream Transactions (2011)



Note: For the sector classification, see Appendix 2.
Source: Calculated from the ICIO tables (OECD).

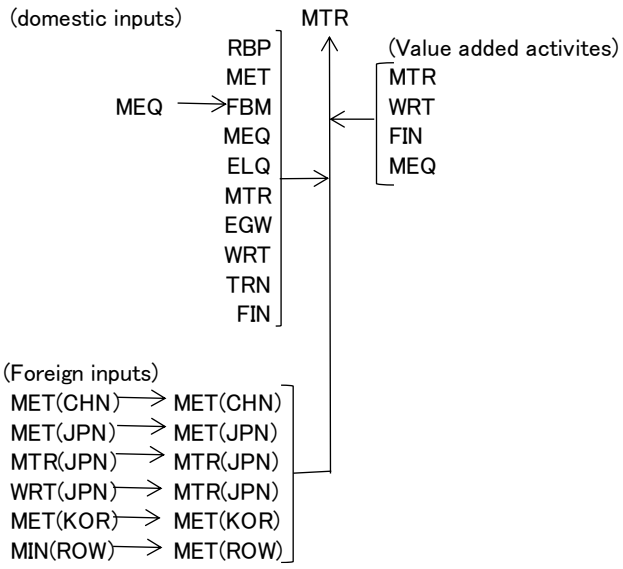
The figure presents the unit structure of motor vehicles when 100 units of final demand are given to the motor vehicle industry in Thailand. Note that one unit is actually normalised to 100 units, and only induced transactions and value added that exceed one unit – i.e. only those transactions exceeding 1% of the original final demand – appear in the figure.[19]

[18] It should be noted that the automotive industry is actually composed of complete vehicles, and parts and components industries, but both are categorised under the same motor vehicle (MTR) industry in the ICIO data.

[19] The percentage shares of all transactions recorded in Figures 10 and 12 [=100 X (all intermediate transactions and value added (final demand) that appear in Figures 10 and 12) / (all the intermediate transactions and value added induced by a unit of automobile final demand)] are

Results show that 25.7 units of value added were generated by the Thai motor vehicle sector, and 24.5 units of motor vehicle outputs were used as intermediate inputs for its own sector. Similarly, five units of Japanese motor vehicles inputs and 1.2 units of Philippine motor vehicles inputs were used in Thai motor vehicles. In addition, basic metals, which include iron and steel – main materials for motor vehicles – were provided by Japan (4.1 units), Australia (2 units), China (1.6 units), Korea (1.5 units), and the ROW (3.1 units) as well as Thailand (3.2 units).

Figure 11. The Flow of Upstream Transactions: Automotive Sector in Thailand (2011)



Note: For the sector classification, see Appendix 2.
Source: Calculated from the ICIO tables (OECD).

as follows: Figure 10: intermediate transactions 37.2%, value added 52.6%; Figure 12: intermediate transactions 57.0%, final demand 71.1%. Therefore, although the numbers of transactions that appear in Figure 10 and 12 are small, their shares are significantly high.

However, as shown in Figure 10, repercussion effects are concentrated in a relatively small number of sectors (such as motor vehicles in domestic industries and basic metals in foreign industries). Although the Thai motor vehicle industry had large inputs from other domestic sectors – example, 7.3 units from machinery and equipment and 2.4 units from rubber and plastic – the repercussion effects had not spread widely, and more than one unit of value added was generated only in the wholesale and retail trade (3.3 units), financial intermediaries (2.3 units), machinery and equipment (2.2 units), electricity, gas, and water supply (1.2 units).

The description on the right hand side of Figure 10 indicates transactions that occurred outside Thailand. Large intra-industry transactions occurred in motor vehicles in Japan (3.5 units) and basic metals in Japan (4.0 units), Korea (2.0 units), and China (1.8 units). The ROW has large inter-industry transactions (1.4 units) from minerals to basic metal.[20] Note that value added was also generated abroad incidental to these transactions.

Finally, the above transactions – except for the magnitude of transactions – are illustrated again in Figure 11 in a manner similar to value chain mapping, with arrows indicating the direction of the transactions. The value chain of the automotive sector is straightforward and simple. Repercussion effects of motor vehicles were concentrated on those in Thailand and Japan, as well as basic metals from Thailand, Japan, Australia, China, and Korea. Moreover, material industries (i.e. fabricated metal products, rubber and plastic products), machinery industries (machinery and equipment, electrical machinery), and services industries (wholesale and retail trade,

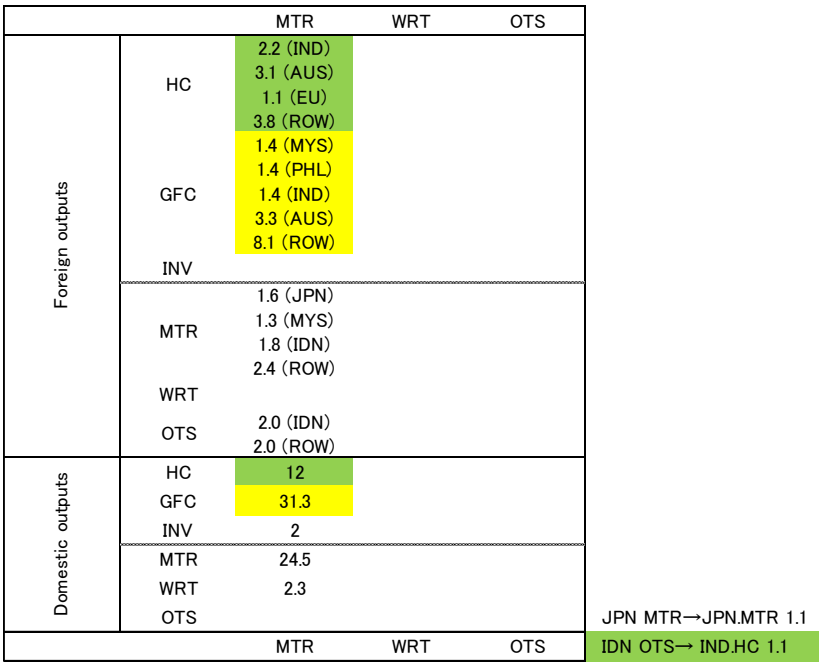
[20] Major producers of iron ore such as Brazil and Russia are included in the ROW. They provide materials for iron and steel industry, which constitute an important segment of the basic metal industry.

financial intermediation, transportation) constituted major domestic inputs for motor vehicle industries.

3.3.2. Downstream transactions

Since the automotive industry – in particular, the manufacture of complete vehicles – is close to the final market in the supply chain, it is expected that downstream transactions of motor vehicles are relatively short. Figure 12 shows that downstream transactions of goods and services induced by 100 units of motor vehicle primary inputs in Thailand are concentrated in the motor vehicle industry, without significant repercussions on the other sectors (except for wholesale and retail trade).

Figure 12. Unit Structure of the Thai Automotive Industry: Downstream Transactions (2011)



Note: For the sector classification, see Appendix 2.
Source: Calculated from the ICIO tables (OECD).

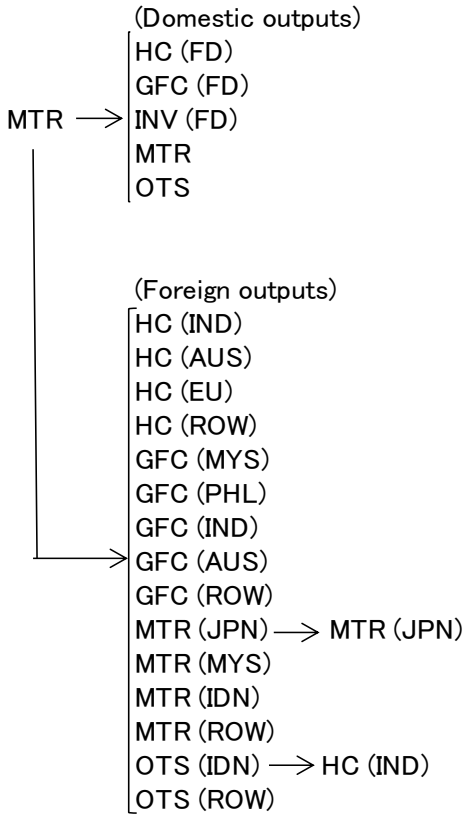
Figure 12 shows that 24.5 units of motor vehicles are used as intermediate inputs by its own sector, but the largest domestic transactions occurred in gross fixed capital formation (31.3 units) and household consumption (12 units).[21] In foreign markets, motor vehicles were used as intermediate inputs and distributed to the motor vehicle industries in Indonesia (1.8 units), Japan (1.6 units), Malaysia (1.3 units), and the ROW (2.4 units). However, a greater portion of their products was used for capital formation in Australia (3.3 units), Malaysia (1.4 units), the Philippines (1.4 units), India (1.4 units) and the ROW (8.1 units), as well as for household consumption in Australia (3.1 units), India (2.2 units), the European Union (1.1 units), and the ROW (3.8 units).

Regarding transactions outside Thailand, only two transactions exceeded one unit, one of which was intra-industry transactions by the motor vehicle industry in Japan (1.1 units). The other transaction was the household consumption in Indonesia (1.1 units) caused by other community, social, and personal services.

Figure 13 illustrates the flow of downstream transactions. Reflecting the nature of the motor vehicle industry, the downstream supply chain of the motor vehicle industry is short. A large portion of motor vehicle outputs are used either for intermediate inputs for its own sector, or for household consumption, or capital formation in both the foreign and domestic markets.

[21] As discussed above, the production share of commercial vehicles (in particular, 1-ton pickup trucks) is very high in Thailand. The share of 1-ton pickup trucks in 2014 was 53%. Therefore, Thailand has a relatively high share of motor vehicles used for capital formation.

Figure 13. The Flow of Downstream Transactions: Automotive Sector in Thailand (2011)



Note: For the sector classification, see Appendix 2.

Source: Calculated from the ICIO tables (OECD).

4. Conclusion

In the Thai automotive industry, the share of domestic procurement of intermediate inputs continued to rise over the periods 1990-1995 and 1995-2000, but declined slightly in 2000-2005 (see also Footnote 8). Moreover, trade in value added analysis indicates that the domestic (foreign) content of Thai automotive exports decreased (increased) in 1995-2011. These results suggest that dependency on domestic procurement initially increased but started to decline at a certain point during these periods. Although more detailed analysis is necessary, the abolition of the

LCR in 2000 – as well as trade liberalisation and regional integration efforts after the early 1990s – might have affected the trend in domestic procurement.

Also, as shown in Figure 1, automotive exports have increased dramatically since the end of the 1990s. International markets require higher product quality, and this might have raised the demand for imported inputs and the dependency on foreign content.

Meanwhile, the decomposition analysis of foreign content shows that Japan's content was the largest among all the countries, but its share declined in 1995-2011. On the other hand, shares of Southeast Asian countries as well as China climbed significantly. These results indicate that inputs from Japan have been replaced by those from the neighbouring Southeast Asian countries.

In sum, one sees that international linkages were strengthened as a result of the expanding production networks in Southeast Asia. On the other hand, domestic linkages started to decline after a certain point. These results suggest that the benefits of specialisation and exchange might have outweighed those of agglomeration, especially in recent decades, although a portion of business functions and industrial activities – such as research and development, design, logistics, and regional headquarters functions, or production of specialized parts and components – have been increasingly concentrated in such countries as Thailand.

The decomposition analysis shows that a great amount of service value added was contained in Thai automotive exports: they also have high foreign content of basic metals, while domestic content was high in motor vehicle.

The unit structure analysis provides information regarding the flow of value added as well as goods and services used to produce a unit of motor vehicles. Then

value chain mapping was performed using the information provided by the unit structure analysis.

The unit structure analysis shows that the Thai automotive industry achieved high self-sufficiency in automotive inputs but had high dependency on basic metals imported from Japan and other countries. On the other hand, the downstream transactions of the motor vehicle industry were short. A portion of the motor vehicle output was used as intermediate inputs by its own sector, but a greater portion was tapped for either household consumption or capital formation in both the domestic and foreign markets.

This paper demonstrated that trade in value added analysis, along with the newly introduced value chain mapping method, is helpful in tracing the flow of goods and services in a value chain. However, there are some limitations with the current methodology. First, it is necessary to use more disaggregated data (which have a greater number of sector classifications) when conducting more detailed analysis. Second, the current input-output data has industry activity-based sector classification, while conventional value chain analysis should focus on business functions (research and development, design, production, marketing, logistics, distribution, etc.) as the unit of analysis. Finally, it is important to extend the method used in this study to other countries or sectors, so that the validity of the method can be tested for replicability.

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Appendix 1: Calculation of the VS Share Index

The vertical specialisation (VS) share represents the percentage share of foreign content embodied in exports – i.e. the share of value added that is induced by exports but accrues to foreign countries. The methodology was originally developed by Hummels, Ishi, and Yi (2001) and was introduced into the analysis of trade in value added by Koopmans, Wang, and Wei (2014).

Using the notations in Appendix 2, the VS share is calculated as $VS_j^s = 100 \text{ X } \sum_{r \neq s}^{m} \sum_{i=1}^{n} \mathbf{V}(\mathbf{c})_i^r \mathbf{L}_{ij}^{rs}$, where VS_j^s represents the share of foreign content contained in the exports of sector *j* in country *s*. Here, the VS share is expressed in percentage terms, so that it can take a range of 0 to 100.

Moreover, VS_j^s is decomposed as follows:

(1) Share of foreign content by country of origin:

$$VS_j^{rs} = 100 \text{ X} \sum_{i=1}^{n} \mathbf{V}(\mathbf{c})_i^r \mathbf{L}_{ij}^{rs}$$

where VS_j^{rs} represents the share of foreign content of country *r* contained in the exports of sector *j* in country *s*.

(2) Share of foreign content by sector of origin:

$$VS_{ij}^{s} = 100 \text{ X} \sum_{r \neq s}^{m} \mathbf{V}(\mathbf{c})_i^r \mathbf{L}_{ij}^{rs}$$

where VS_{ij}^{s} represents the share of foreign content of sector *i* contained in the exports of sector *j* in country *s*.

Similarly, the share of domestic content by sector origin is calculated as:

$$VS_{ij}^{s(d)} = 100 \text{ X } \mathbf{V}(\mathbf{c})_i^s \mathbf{L}_{ij}^{ss}$$

where $VS_{ij}^{s(d)}$ represents the share of domestic content of sector *i* contained in the exports of sector *j* in country *s*.

Appendix 2: Sector Classification of the OECD ICIO Tables

AGR	Agriculture, hunting, forestry and fishing
MIN	Mining and quarrying
FOD	Food products, beverages and tobacco
TEX	Textiles, textile products, leather and footwear
WOD	Wood and products of wood and cork
PAP	Pulp, paper, paper products, printing and publishing
PET	Coke, refined petroleum products and nuclear fuel
CHN	Chemicals and Chemical products
RBP	Rubber and plastic products
NMM	Other non-metallic mineral products
MET	Basic metals
SFBM	Fabricated metal products
MEQ	Machinery and equipment, nec
CEO	Computer, Electronic and optical equipment
ELQ	Electrical machinery and apparatus, nec
MTR	Motor vehicles, trailers and semi-trailers
TRQ	Other transport equipment
OTM	Manufacturing nec; recycling
EGW	Electricity, gas and water supply
CON	Construction
WRT	Wholesale and retail trade; repairs
HTR	Hotels and restaurants
TRN	Transport and storage
PTL	Post and telecommunications
FIN	Financial intermediation
REA	Real estate activities
RMQ	Renting of machinery and equipment
ITS	Computer and related activities
BZS	research and development, and other business activities
GOV	Public admin. and defence; compulsory social security
EDU	Education
HTH	Health and social work
OTS	Other community, social and personal services
PUH	Private households with employed persons
HC	Household consumption
NPI	Non-profit institution serving household
GGF	General government final consumption
GFC	Gross fixed capital formation
INV	Changes in inventories
CON	Direct purchase abroad by residents
DISC	Discrepancies
VA	Value added
CT	Output at basic prices

Source: The ICIO tables (OECD).

Appendix 3: Method for Mapping Value Chains

1) Upstream Transactions

This section introduces the method for the structural analysis, which was originally developed by Ozaki (1980) for a single country input-output model. Here, it is extended to a multi-country model so that cross-border transactions of goods and services can be traced inside the model. Moreover, induced value added is calculated to trace sequences of value adding activities.

Using an input coefficient matrix, the accounting identity on the output side (i.e. the equality between total output and intermediate inputs plus final demand) can be expressed as

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} \qquad (1)$$

where

$$\mathbf{x} = \begin{bmatrix} \mathbf{x}^1 \\ \vdots \\ \mathbf{x}^r \\ \vdots \\ \mathbf{x}^m \end{bmatrix}$$

is the vector of total output ($\mathbf{x}^r$ is country r's *n x 1* vector of output: *m* and *n* respectively represent the number of countries and sectors).

$$\mathbf{A} = \begin{bmatrix} \mathbf{A}^{11} & \cdots & \mathbf{A}^{1s} & \cdots & \mathbf{A}^{1m} \\ \vdots & & \vdots & & \vdots \\ \mathbf{A}^{r1} & \cdots & \mathbf{A}^{rs} & \cdots & \mathbf{A}^{rm} \\ \vdots & & \vdots & & \vdots \\ \mathbf{A}^{m1} & \cdots & \mathbf{A}^{ms} & \cdots & \mathbf{A}^{mm} \end{bmatrix}$$

is the multi-country input coefficient matrix ($\mathbf{A}^{rs}$ is an $n \times n$ sub-matrix that indicates the ratios of intermediate inputs provided by industries in country r to industries in country *s* relative to the industrial outputs in country *s*).

$$\mathbf{f} = \begin{bmatrix} \mathbf{f}^1 \\ \vdots \\ \mathbf{f}^r \\ \vdots \\ \mathbf{f}^m \end{bmatrix}$$

is the vector of final demand ($\mathbf{f}^r$ is country r's *n x 1* vector of final demand).

Solving the equation (1) for X yields

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{L}\mathbf{f} \qquad (2)$$

where

$$\mathbf{I} = \begin{bmatrix} \mathbf{I} & \cdots & \mathbf{O} & \cdots & \mathbf{O} \\ \vdots & \ddots & \vdots & & \vdots \\ \mathbf{O} & \cdots & \mathbf{I} & \cdots & \mathbf{O} \\ \vdots & & \vdots & \ddots & \vdots \\ \mathbf{O} & \cdots & \mathbf{O} & \cdots & \mathbf{I} \end{bmatrix}$$

is the identity matrix (a sub-matrix $\mathbf{I}$ is an $n \times n$ identity matrix and $\mathbf{O}$ represents an $n \times n$ matrix of zeros)

$$\mathbf{L} = \begin{bmatrix} \mathbf{L}^{11} & \cdots & \mathbf{L}^{1s} & \cdots & \mathbf{L}^{1m} \\ \vdots & & \vdots & & \vdots \\ \mathbf{L}^{r1} & \cdots & \mathbf{L}^{rs} & \cdots & \mathbf{L}^{rm} \\ \vdots & & \vdots & & \vdots \\ \mathbf{L}^{m1} & \cdots & \mathbf{L}^{ms} & \cdots & \mathbf{L}^{mm} \end{bmatrix}$$

is the multi-country Leontief Inverse matrix ($\mathbf{L}^{rs}$ is an $n \times n$ Leontief Inverse sub-matrix).

Then, differentiating each element in **x** in the equation (2) with regard to each element in ***f*** yields

$$l_{ij}^{rs} = \frac{\Delta \mathbf{x}_i^r}{\Delta \mathbf{f}_j^s} \qquad (3)$$

That is to say, the *ij* element in the sub-matrix *rs* in the Leontief Inverse indicates the output of sector *i* in country *r* that is induced directly or indirectly by one unit of final demand of sector *j* in country *s*. Thus, a column vector of, say, sector *j* in country *s* reveals the output of all the sectors (i.e. sector 1 through sector *n*) in all the countries (i.e. country 1 through country *m*) that is induced by a unit of final demand (for sector *j* in country *s*) as shown below:

$$\mathbf{l}_{\bar{j}}^{\bar{s}} = \left[l_{1j}^{1s}, \cdots l_{nj}^{1s}, \cdots l_{1j}^{rs}, \cdots l_{nj}^{rs}, \cdots l_{1j}^{ms}, \cdots l_{nj}^{ms}\right]'$$

$$= \left[\frac{\Delta \mathbf{x}_1^1}{\Delta \mathbf{f}_j^s}, \cdots \frac{\Delta \mathbf{x}_n^1}{\Delta \mathbf{f}_j^s}, \cdots \frac{\Delta \mathbf{x}_1^r}{\Delta \mathbf{f}_j^s}, \cdots \frac{\Delta \mathbf{x}_n^r}{\Delta \mathbf{f}_j^s}, \cdots \frac{\Delta \mathbf{x}_1^m}{\partial \Delta \mathbf{f}_j^s}, \cdots \frac{\Delta \mathbf{x}_n^m}{\Delta \mathbf{f}_j^s}\right]'. \qquad (4)$$

Then, the unit structure for the upstream value chain can be obtained by post-multiplying **A** by the diagonal matrix of column vector $\mathbf{l}_{\bar{j}}^{\bar{s}}$.

$$\mathbf{U}_{\bar{j}}^{\bar{s}} = \mathbf{A}\hat{\mathbf{L}}_{\bar{j}}^{\bar{s}}$$

$$= \begin{bmatrix} \mathbf{A}^{11} & \cdots & \mathbf{A}^{1s} & \cdots & \mathbf{A}^{1m} \\ \vdots & & \vdots & & \vdots \\ \mathbf{A}^{r1} & \cdots & \mathbf{A}^{rs} & \cdots & \mathbf{A}^{rm} \\ \vdots & & \vdots & & \vdots \\ \mathbf{A}^{m1} & \cdots & \mathbf{A}^{ms} & \cdots & \mathbf{A}^{mm} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{L}}_{\bar{j}}^{\bar{s}\,1} & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & & \vdots \\ 0 & \cdots & \hat{\mathbf{L}}_{\bar{j}}^{\bar{s}\,r} & \cdots & 0 \\ \vdots & & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \hat{\mathbf{L}}_{\bar{j}}^{\bar{s}\,m} \end{bmatrix}, \qquad (5)$$

where $\hat{\mathbf{L}}_{\bar{j}}^{\bar{s}}$ is the diagonal matrix of column vector $\mathbf{l}_{\bar{j}}^{\bar{s}}$.

Analogously, induced value added is calculated by post-multiplying the row vector of the value added coefficients by $\hat{\mathbf{L}}_{\bar{j}}^{\bar{s}}$.

$$\mathbf{v}_{\bar{j}}^{\bar{s}\prime} = \mathbf{v}(\mathbf{c})'\hat{\mathbf{L}}_{\bar{j}}^{\bar{s}}$$

$$= \left[\mathbf{v}(\mathbf{c})^{1\prime} \quad \cdots \quad \mathbf{v}(\mathbf{c})^{r\prime} \quad \cdots \quad \mathbf{v}(\mathbf{c})^{m\prime}\right] \begin{bmatrix} \hat{\mathbf{L}}_{\bar{j}}^{\bar{s}\,1} & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & & \vdots \\ 0 & \cdots & \hat{\mathbf{L}}_{\bar{j}}^{\bar{s}\,r} & \cdots & 0 \\ \vdots & & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \hat{\mathbf{L}}_{\bar{j}}^{\bar{s}\,m} \end{bmatrix} \qquad (6)$$

where

$$\mathbf{v}(\mathbf{c}) = \begin{bmatrix} \mathbf{v}(\mathbf{c})^1 \\ \vdots \\ \mathbf{v}(\mathbf{c})^r \\ \vdots \\ \mathbf{v}(\mathbf{c})^m \end{bmatrix}$$

is a column vector of the value added coefficients ($\mathbf{v}(\mathbf{c})^r$ is country r's $n \times 1$ vector of the value added coefficients).

2) Downstream Transactions

Regarding downstream transactions, this paper proposes to use the Ghosh Inverse (Ghosh, 1958) as an alternative to the Leontief Inverse, and to apply the analytical method analogous to the upstream transactions, as shown below.[22]

Using an allocation coefficient matrix, the accounting identity on the input side (i.e. the equality between total inputs and intermediate inputs plus value added) is expressed as

$$\mathbf{x}' = \mathbf{x}'\mathbf{B} + \mathbf{v}' \qquad (7)$$

where

$$\mathbf{B} = \begin{bmatrix} \mathbf{B}^{11} & \cdots & \mathbf{B}^{1s} & \cdots & \mathbf{B}^{1m} \\ \vdots & & \vdots & & \vdots \\ \mathbf{B}^{r1} & \cdots & \mathbf{B}^{rs} & \cdots & \mathbf{B}^{rm} \\ \vdots & & \vdots & & \vdots \\ \mathbf{B}^{m1} & \cdots & \mathbf{B}^{ms} & \cdots & \mathbf{B}^{mm} \end{bmatrix}$$

is the multi-country output coefficient matrix ($\mathbf{B}^{rs}$ is an $n \times n$ sub-matrix that indicates the ratio of intermediate outputs distributed from industries in country r to industries in country s relative to the industrial outputs in country *r*).

[22] Ozaki's method, which uses the Leontief Inverse for the structural analysis of input structure, cannot be used for the analysis of output structure. Therefore, it is necessary for us to use the Ghosh Inverse, which assumes a fixed output coefficient matrix.

$$\mathbf{v} = \begin{bmatrix} \mathbf{v}^1 \\ \vdots \\ \mathbf{v}^r \\ \vdots \\ \mathbf{v}^m \end{bmatrix}$$ is the vector of value added ($\mathbf{v}^r$ is country r's *n x 1* vector of value added).

Solving the equation (7) for **x'** gives

$$\mathbf{x}' = \mathbf{v}'(\mathbf{I} - \mathbf{B})^{-1} = \mathbf{v}'\mathbf{G} \qquad (8)$$

where

$$\mathbf{G} = \begin{bmatrix} \mathbf{G}^{11} & \cdots & \mathbf{G}^{1s} & \cdots & \mathbf{G}^{1m} \\ \vdots & & \vdots & & \vdots \\ \mathbf{G}^{r1} & \cdots & \mathbf{G}^{rs} & \cdots & \mathbf{G}^{rm} \\ \vdots & & \vdots & & \vdots \\ \mathbf{G}^{m1} & \cdots & \mathbf{G}^{ms} & \cdots & \mathbf{G}^{mm} \end{bmatrix}$$ is the multi-country Ghosh Inverse matrix ($\mathbf{G}^{rs}$ is an $n \times n$ Ghosh Inverse sub-matrix).

Then, differentiating each element in ***x*** in the equation (8) with regard to each element in ***v*** yields

$$g_{ij}^{rs} = \frac{\Delta \mathbf{x}_j^s}{\Delta \mathbf{v}_i^r} . \qquad (9)$$

It should be noted that, contrary to the equation (3), g_{ij}^{rs} represents the output of sector *j* in country *s* that is induced directly or indirectly by one unit of primary inputs in sector *i* in country *r*. Therefore, the row vector of sector *i* in country *r* reveals the output of all the sectors in all the countries that is induced by sector *i* in country *r*:

$$\mathbf{g}_i^r = [g_{i1}^{r1}, \cdots g_{in}^{r1}, \cdots g_{i1}^{rs}, \cdots g_{in}^{rs}, \cdots g_{i1}^{rm}, \cdots g_{in}^{rm}]$$

$$= \left[\frac{\Delta \mathbf{x}_1^1}{\Delta \mathbf{v}_i^r}, \cdots \frac{\Delta \mathbf{x}_n^1}{\Delta \mathbf{v}_i^r}, \cdots \frac{\Delta \mathbf{x}_1^s}{\Delta \mathbf{v}_i^r}, \cdots \frac{\Delta \mathbf{x}_n^s}{\Delta \mathbf{v}_i^r}, \cdots \frac{\Delta \mathbf{x}_1^m}{\Delta \mathbf{v}_i^r}, \cdots \frac{\Delta \mathbf{x}_n^m}{\Delta \mathbf{v}_i^r}\right] \qquad (10)$$

Then, the unit structure for the downstream transactions can be obtained by pre-multiplying **B** by the diagonal matrix of row vector $\mathbf{g}_i^r$.

$$\mathbf{D}_i^r = \widehat{\mathbf{G}}_i^r \mathbf{B}$$

$$= \begin{bmatrix} \widehat{\mathbf{G}}_{\bar{i}}^{\bar{r}1} & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & & \vdots \\ 0 & \cdots & \widehat{\mathbf{G}}_{\bar{i}}^{\bar{r}s} & \cdots & 0 \\ \vdots & & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \widehat{\mathbf{G}}_{\bar{i}}^{\bar{r}m} \end{bmatrix} \begin{bmatrix} \mathbf{B}^{11} & \cdots & \mathbf{B}^{1s} & \cdots & \mathbf{B}^{1m} \\ \vdots & & \vdots & & \vdots \\ \mathbf{B}^{r1} & \cdots & \mathbf{B}^{rs} & \cdots & \mathbf{B}^{rm} \\ \vdots & & \vdots & & \vdots \\ \mathbf{B}^{m1} & \cdots & \mathbf{B}^{ms} & \cdots & \mathbf{B}^{mm} \end{bmatrix} \quad (11)$$

where $\widehat{\mathbf{G}}_{\bar{i}}^{\bar{r}}$ is the diagonal matrix of row vector $\mathbf{g}_{\bar{i}}^{\bar{r}}$.

Analogous to Equation (6), the induced final demand is calculated as

$$\mathbf{F}_{\bar{i}}^{\bar{r}} = \widehat{\mathbf{G}}_{\bar{i}}^{\bar{r}} \mathbf{F}(\mathbf{c})$$

$$= \begin{bmatrix} \widehat{\mathbf{G}}_{\bar{i}}^{\bar{r}1} & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & & \vdots \\ 0 & \cdots & \widehat{\mathbf{G}}_{\bar{i}}^{\bar{r}s} & \cdots & 0 \\ \vdots & & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \widehat{\mathbf{G}}_{\bar{i}}^{\bar{r}m} \end{bmatrix} \begin{bmatrix} \mathbf{F}(\mathbf{c})^1 \\ \vdots \\ \mathbf{F}(\mathbf{c})^s \\ \vdots \\ \mathbf{F}(\mathbf{c})^m \end{bmatrix} \quad (12)$$

where

$$\mathbf{F}(\mathbf{c}) = \begin{bmatrix} \mathbf{F}(\mathbf{c})^1 \\ \vdots \\ \mathbf{F}(\mathbf{c})^s \\ \vdots \\ \mathbf{F}(\mathbf{c})^m \end{bmatrix}:$$

is the matrix of the final demand coefficient [23] ($\mathbf{F}(\mathbf{c})^r$ is country r 's $n \times 6$ sub-matrix of the final demand coefficients).[24]

[23] A final demand coefficient is the ratio of final demand to total output.

[24] The reason why the final demand matrix for each country has 6 X m columns is that in the ICIO tables, the distribution of goods and services for final consumption is divided into m destination countries and six final demand columns (i.e. household consumption, non-profit institutions serving households, general government final consumption, gross fixed capital formation, changes in inventories, and direct purchases abroad by residents) for each destination country.

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