Measuring the Nature of East Asia's Automobile Production Networks

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***Abstract*—The aim of this study is to explore the nature of East Asia's automobile production networks by means of social-network methods. In this paper, we have also developed a domination degree index (DDI) and domination intensity index (DII) to measure the dominating power of each East Asian country in the automobile networks. The results suggested that the networks of East Asia's automobile industry are expanding over time both in terms of the number of links in the network as well as the strength of those links. This result indicates that both export and import of automobile products in this region increase significantly over time. In addition, Japan has emerged as the main player, both in the case of auto parts and components (P&C) and final automobiles. The Republic of Korea has also emerged as the second most important player in East Asia's final automobile networks, while China has become the second most important player in East Asia's auto P&C networks. Even though Thailand is the third most important player in East Asia's automobile networks in both auto P&C and final automobiles, the analysis of this paper has suggested that there is a possibility for this country to overtake China and the Republic of Korea to become the second most important player in terms of both auto P&C and final automobiles. The dramatic changes in the development of Thailand's automobile industry as well as significant development in China's auto P&C have been made possible by the pivotal role played by Japan (on Thailand) and the Republic of Korea (on China) – all of which have stimulated the development of their subordinates' auto industry in a so-called "win-win situation".**

Keywords— *Globalisation, international production networks, automobile industry, parts and components, social network methods, East Asia.*

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1. Introduction

Integration of countries or regions into the worldwide exchange network is one of the significant phenomena of globalisation. In the East Asian region, increases in trade, particularly in terms of P&C among countries under the international production networks (IPNs), are one of the important factors behind world trade becoming more increasingly integrated now than ever before [1-3]. Accordingly, countries such as Vietnam, Thailand and the Philippines, which formerly were merely buyers of various final products, have become members of the global production network and are now engaged in the activity of import and export of P&C.

The rapid increase in integration network among countries in the East Asian region, particularly in high-technology industries such as the automobile industry, has led to trade networks in that industry becoming increasingly complex over time [4], [5]. This situation has led many researchers in the field of economics such as [6-10] to concentrate on the network of trade structure. In this paper, we developed summary indices that characterise that structure and the place of individual countries within them so as to facilitate discussion of the nature and development of such networks.

This paper is structured as follows: Section 2 discusses the basic concept of network. Sections 3 and 4 respectively discuss the data and research methodology of the paper. Section 5 discusses the findings from global-level, country-level and network domination analyses. Finally, Section 6 draws the conclusions.

2. The Basic Concept of Network

Compared to other disciplines, the study of networks took place earlier in the field of sociology and mathematics. Thereafter, it has been studied extensively in other areas such as biology, computer science and physics. In recent years, the study of networks has become very popular in economics [11]. As in other disciplines, in principle, a network consists of a set of nodes or vertices, and those nodes are normally connected by a set of links (A similar definition is used in [7-8]). Specifically, in international trade a "country" is considered to be a network node, while the monetary values of exports or imports are analogous to valued links.

Links between countries in a network can be either non-directed or directed, and may also be valued by weight or magnitude. In the case of non-directed relationships between nodes, these are conceptualised in terms of binary variables (i.e., $a_{ij} \in a_{ij} \in \{0,1\}$), where a_{ij} takes the value of one if a relationship exists between i and j; otherwise, it takes zero (This condition is the same for a_{ji}).

A drawback of the non-directed approach is that it does not distinguish between the link from i to j and that from j to i. In the case of a directed network, however, the relationships between two countries can be distinguished either from i to j and/or from j to i. For example, country i exports to country j and/or country j exports to country i. In this case, if $a_{ij}=1$, then there is a flow of information from i to j and at the same time we allow for $a_{ji}=0$ even if $a_{ij}=1$.

3. The Data

This paper uses international trade data published by the UN Comtrade due to advantages such as their accessibility, comparability across countries, as well as their comprehensive coverage of international production sliced trade. Nevertheless, data reported in that database are inconsistent and not reliable for direct use. Since analyses in this paper require consistency between the export flow and its corresponding imports for all partner pairs, we carried out a reconciliation of the original data by adopting the procedures of [12]. Commodities included under automobile P&C are SITC 7841 (chassis), SITC 7842 (bodies), and SITC 7849 (other parts and accessories for vehicles). Commodities under final automobiles comprise SITC 7223 (track-laying tractors), SITC 7224 (wheeled tractors), SITC 7810 (passenger vehicles), SITC 7821 (vehicles for the transport of goods or materials), SITC 7822 (special purpose vehicles), SITC 7831 (public service vehicles), and SITC 7832 (road tractors).

For product classification, we chose SITC Revision 2 due to the following reasons. Firstly, unlike the SITC Revision 1, SITC Revision 2 is detailed enough to distinguish traded P&C from finished products. It also has detailed commodity classification, particularly in the machinery and transport goods (SITC 7) [13-15]. Secondly, unlike the HS and SITC Revision 3, SITC Revision 2 provides the broadest country and period coverage [13], [16], thereby allowing one to analyse trade in final goods and P&C between 1990 and 2015.

The main focus of our study is the following East Asian countries: Japan, China, Republic of Korea, and ASEAN (i.e., Thailand, Indonesia, Malaysia, the Philippines, Singapore, and Vietnam). Nevertheless, to see the role of East Asia's automobile industry on other regions and vice versa, we include the North American Free Trade Agreement (NAFTA), European Union (EU), and the rest of the world (ROW) in our analysis.

4. Methodology

In this paper, we will use social network methods to measure and analyse the complexity of those networks at both global and country level in order to understand the nature of these networks and how they have evolved over the last 25 years. Consequently, to understand the nature of a dominance-dependence relationship in such interdependent complex networks, we have developed dominance indices to gauge the degree of domination among East Asian countries.

4.2 Global Level Analysis

The Global-level analysis provides measures of total network sizes. In the global-level analysis of the directed links, we will use both a binary and weighted approach when analysing the network's complexity. We have carried out these two analyses because both analyses could complement each other. In the binary approach, important trade links are assumed to either exist or not, while in the weighted analysis values will be given to those links. In both analyses, we only count trade flows that have previously been deemed important in the analysis by [17].

4.2.1 Binary network analysis (BNA)

BNA is an approach that measures the existence of a network using the binary approach. When two countries, say country *i* and country *j*, are connected by a link $\{i,j\}$, they are called adjacent. In the binary approach, the adjacency relation is quantified by the term $a_{ij}=1$, where the value of exports from country *i* to country *j* as a proportion of country *i*'s total exports is greater than or equal to a given threshold value. On the other hand, the non-adjacency one is quantified by $a_{ij}=0$, where the value of exports from country *i* to country *j* as a proportion of country *i*'s total exports is smaller than a given threshold value. The same rules will apply to a_{ji} but we only discuss here the case of a_{ij}. By using the adjacency matrix, one can calculate the total nodes' degree (i.e. the number of links that exist in a network) using the following formula:

$$B(G) = \sum_{i=1}^{N} \sum_{j=1}^{N} a_{ij} \quad (1)$$

where,

$B(G)$ = total nodes' degree

i = country i

j = country j (i.e., country i's trading partner)

N = total number of countries in the network.

In addition, by using the adjacency matrix one can provide some generalised descriptors of network connectivity, such as average degree and connectedness, as follows:

$$\overline{B(G)} = \frac{B(G)}{N} \quad (2)$$

where,

$\overline{B(G)}$ = average degree and the rest of variables are defined as in Eq. (1).

$$BConn = \frac{B(G)}{N^2} \quad (3)$$

where,

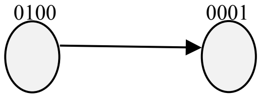
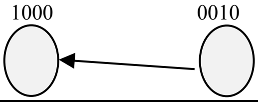
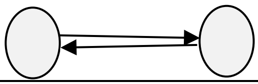
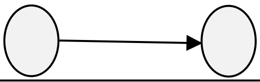
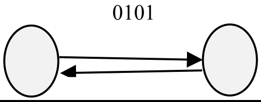
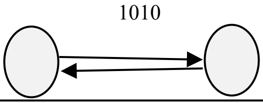
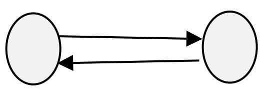
$BConn$ = connectedness and the rest of variables are defined as in Eq. (1).

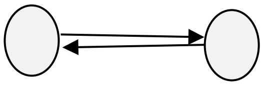
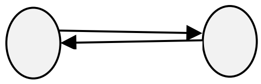
For example, there are six countries in a network and there exist 14 node degrees. Thus, $\overline{B(G)} = \frac{14}{6}\overline{B(G)} = \frac{14}{6}$ = 2.333. Meanwhile, connectedness measures the relative network connectivity. The values of connectedness ranged from zero to one. After multiplying by 100, the values ranged from 0 percent to 100 percent. Thus, $BConn = \frac{14}{36} = 0.389$ $BConn = \frac{14}{36} = 0.389$ or 38.9 percent. Different to previous studies (for example, [6] used either export or import data to identify the existence of a link between two countries. In other words, [6] looks at it from the perspective of either an exporter or importer), the directed links between a country and its partner(s) in our study are based on how important that country is to its partner(s) (In this study, we used both export and import data to identify such an important link from the perspective of both exporter and importer).

In this study, we are not using specifically the exact value of exports and imports when charting the structure of the network. We define a trade-link between country *i* and country *j* to be present if the value of exports from country *i* to country j as a proportion of country *i*'s total exports is greater than the 15 percent threshold. This is also the same for the case of imports as well as in the weighted analysis that will be discussed in Section 4.2.2. The advantage of using this approach is that it enables us to examine the structure and evolution of the trade network for different levels of trade. Examining how the structure of the network changes with the trade threshold used to define the presence of links also enables us to understand the sensitivity of various topological characteristics of the network to different trade magnitudes. Constructing the network for different thresholds enables us to incorporate both magnitude and network features in our analysis. Using threshold enables us to avoid working directly with valued-directed links even though implicitly this threshold embodies the values of the trade links in our data.

In this study, we use Piana's approach wherein we identify a trade link between country *i* and *j* to be present if the value of exports from country *i* to country j as a proportion of country i's total exports is greater than or equal to a given threshold value. In this study, we attribute the link to the exporter if the associated trade flow is important to either (or both) partner(s) rather than attribute the existence of a trade link to a country whenever it is important to that country. For example, we define a_{ij}=1 when the exports of country i are considered important by either country i or country j (i.e. country j is an important export market for country i or country i is an important source of imports for country j) rather than a_{ij}=1 when country i is important for country j. This is because we are able to distinguish the important links that exist based on their role of either as a market destination or input source or both. As shown in Table 1 below, there exist nine possible directed networks that can be created from the code, and some codes can envisage more than one existing link between two countries (we follow [4] to define those nine possible directed networks).

Table 1. Binary Values Based on the Countries' Relationship Code

Relationship code	a_{ij}	a_{ji}
0100 0001 	1	0
Code 0100 (0001). This code implies that a_{ij}=1 and a_{ji}=0. This is because the direction of exports is from country i to country j, wherein country j relies upon its partner (country i) as an import source. In this case, the link is only important for country j but not for country i.		
1000 0010 	0	1
Code 1000 (0010). This code shows that a_{ij}=0 and a_{ji}=1. In this case, the direction of export flow only exists from country j to country i, wherein country j relies upon country i as a market destination. Again, in this case, the link is only important for country j but not for country i.		
0011 1100 	1	1
Code 0011 (1100). This code indicates that both a_{ij} and a_{ji} are equal to 1. In this case, there exist two directions of export flow. One is from country i to country j, and the other is from country j to country i. In this relationship, country i relies upon country j, both as an import source and market. This link is only important for country i but not for country j.		
0110 1001 	1	0
Code 0110 (1001). This code implies that a_{ij}=1 and a_{ji}=0. The direction of export flow is only from country i to country j. In this relationship, country i relies upon its partner (i.e., country j) as a market destination, while its partner relies on her as an import source. In this case, this link is crucial to both parties.		
0101 	1	1
Code 0101. This code indicates that both a_{ij} and a_{ji} are equal to 1. In other words, this code envisages that there exist two directions of export flow. One is from country i to country j, and the other from country j to country i. In this relationship, country i and country j rely on each other as import sources, and this link is important to both parties.		
1010 	1	1
Code 1010. This code tells us that both a_{ij} and a_{ji} are equal to 1. In other words, there exist bilateral trade flows between these two countries. One is from country i to country j, and the other is from country j to country i. In this link, countries i and j rely on each other as import markets, and this link is important to both parties.		
1111 	1	1
Code 1111. This code also indicates that both a_{ij} and a_{ji} are equal to 1. In this respect, there exist two directions of export flow between countries i and j. One is from country i to country j, and the other is from country j to country i. In this relationship, countries i and j rely on each other in terms of both import source and market, and this link is important to both parties.		
0111 1101	1	1

		
Code 0111 (1101). This code indicates that both a_{ij} and a_{ji} are equal to 1, which also means that there exist two directions of export flow between countries *i* and *j*. One is from country *i* to country *j*, and the other is from country *j* to country *i*. In this relationship, however, country *i* relies on country *j* in terms of both import source and market, while country *j* relies on country *i* as an import source. This link is important to both parties.		
1011 1110 	1	1
Code 1011 (1110). This code implies that both a_{ij} and a_{ji} are equal to 1. In this case, there exist two directions of export flow. One is from country *i* to country *j*, and the other is from country *j* to country *i*. In this relationship, country *i* relies on country *j* in terms of both import source and market, while country *j* relies on country *i* as a market destination. This link is important to both parties.		

Note: (1) Arrows denote direction of trade flow.
*(2) *indicates that the country considers the link to be important.*
(3) Codes in parentheses refer to situations where the roles of the two countries are reversed.

4.2.2 Weighted network analysis (WNA)

The above binary network indices only measure the number of links while ignoring the volume as well as the distribution of those links. To overcome this deficiency, we used a weighted network analysis (WNA). WNA is defined as an approach that measures the existence of a network based on the value of exports (or imports). By using this approach, one can calculate the node strength in a network using the following formula:

$$W(G) = \sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij} \qquad (4)$$

where,

$W(G)$ = node strength

w_{ij} = weighted link

i = country *i*

j = country *j* (i.e., country *i*'s trading partner)

N = total number of countries in the network.

Again, in the weighted approach, by using the adjacency matrix one can also provide some generalised descriptors of network connectivity such as average strength $(\overline{W(G)}(\overline{W(G)}$ and weighted connectedness ($WConnWConn$) as follows:

$$\overline{W(G)} = \frac{W(G)}{N} \qquad (5)$$

where,

$\overline{B(G)}$ = average degree and the rest of variables are defined as in Eq. (4).

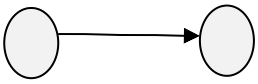
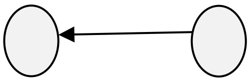
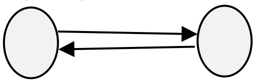
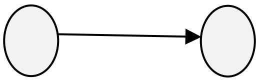
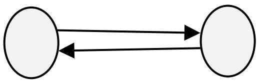
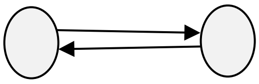
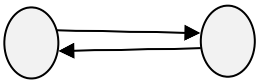
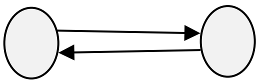
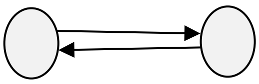
$$WConn = \frac{W(G)}{N^2} \qquad (6)$$

where,

$WConnWConn$ = weighted connectedness and the rest of variables are defined as in Eq. (4).

In this study, the weighted link is based on the type of relationship between two countries (see Table 2). This means that the relationship code would determine the existence of a directed link between two countries (as in the binary approach), while the strength of the link would be represented by the value of exports (or imports) between those two countries ([10] also used the value of exports as weighted). This export (import) values are only taken into account if there exist important links between two countries. Therefore, node strength [$W(G)W(G)$] is not necessarily equal to the total volume of trade in automobile. In this respect, some paired countries would have a reciprocal relationship, while others would not. Besides, the magnitude of the link in each pair would also be different.

Table 2. Weighted Values Based on the Countries' Relationship Code

Relationship code	w_{ij}	w_{ji}
(0100) (0001) 	X_{ij}	0
(1000) (0010) 	0	M_{ij}
(0011) (1100) 	X_{ij}	M_{ij}
(0110) (1001) 	X_{ij}	0
0101 	X_{ij}	M_{ij}
1010 	X_{ij}	M_{ij}
1111 	X_{ij}	M_{ij}
(0111) (1101) 	X_{ij}	M_{ij}
(1011) (1110) 	X_{ij}	M_{ij}

4.3 Specific-Country Analysis

In the above global-level analysis, we focus on the network as a whole and not on the nature of relationships for any specific country. In fact, conducting the analysis at the country-level will allow us to form a picture of the general structure of the network and its properties, such as: (1) the extent to which a country is integrated in a network; (2) who is the influential actor(s) in a network; (3) core-periphery relationships in a network. In this study, we use a node degree centrality index and node strength centrality index to understand the structure of East Asia's automobile networks.

4.3.1 Node degree centrality (NDC)

NDC refers to the number of ties a country has to other countries. In this respect, countries that have more ties would be characterised as influential and prominent as they may have multiple, alternative ways and resources to achieve their goals. Node degree centrality was proposed by [20] to measure the relevance or influence that a country has in a network based on its interaction or degree of connectedness ([21], [22]). This index is based on binary analysis, and the formula for this index may be given as follows:

$$NDC_i = \sum_{j=1}^{N} a_{ij} + a_{ji} \quad (7)$$

In this study, both a_{ij} and a_{ji} are equal to 1 when there exists a reciprocal relationship between country *i* and country *j*; for example, those with codes 0011, 0101, 1010, 1111, 0111 and 1011 (see Table 1). In contrast, a_{ij} would take the value of 0 when a_{ji}=1 or vice-versa when there exists a unidirectional relationship between country *i* and country *j*; for example, those with codes 0001, 0010 and 0110 (see Table 1).

By using NDC, we can also calculate the network density (ND) of a country using the following formula:

$$ND_i = \frac{NDC_i}{2(N-1)} \quad (8)$$

where *N* is the number of countries in the network, and ND is simply the fraction of links that are actually present out of all possible ones.

4.3.2 Node strength centrality (NSC)

We proceed with the weighted analysis since the binary one does not consider the difference between strong links and weak ones. In the weighted analysis, we use node strength centrality (NSC) index to calculate the strength of links between a country and its partner(s). NSC refers to the sum of weights of a country's direct ties to other countries. In this respect, countries with bigger weights would be characterised as influential and prominent as they may have multiple, alternative ways and resources to reach their goals. The formula for this index may be laid out as follows:

$$NSC_i = \sum_{j=1}^{N} w_{ij} + w_{ji} \quad (9)$$

In the weighted case, $w_{ij}=x_{ij}$ and $w_{ji}=x_{ji}$ when there exists a reciprocal relationship between country *i* and country *j*. Again, examples of this are those with codes 0011, 0101, 1010, 1111, 0111 and 1011 (see Table 2). In contrast, w_{ij} would take the value of 0 when $w_{ji}=x_{ji}$ or w_{ji} would take the value of 0 when $w_{ij}=x_{ij}$ and if there exists a unidirectional relationship between country *i* and country *j*; for example, those with codes 0001, 0010 and 0110 (see Table 2).

4.4 Network Domination by Country

After understanding the nature and complexity of East Asia's automobile networks, we then tried to investigate the dominating power of each country in the network by developing dominant indices, and to see how they evolved between 1990 and 2015. Again, we will use both binary and weighted approaches in these analyses.

4.4.1 Binary analysis

After considering the importance of each country in East Asia's automobile network, we are now interested in studying each country's domination over its partner(s) in the network. Figure 1 illustrates a sub-network that envisages the relationship between country *i* and its trading partners (viz. countries *j, k, l, m* and *n*), while country *p* (a member of the network) does not have any trade relationship with country *i*.

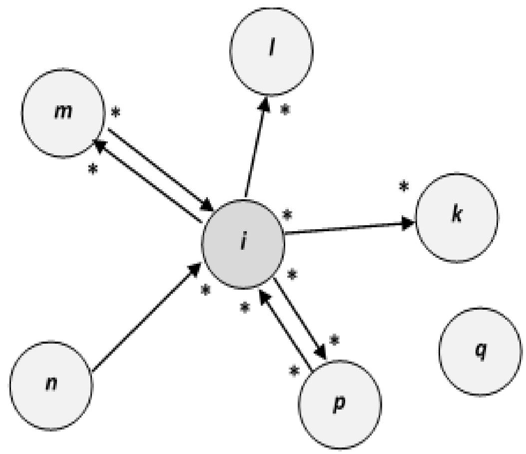


Figure 1. The Relationship between Country *i* and Its Partners in the Sub-Network

The relationship between country *i* and its partners in the sub-network is described as follows (The six concepts and definitions provided below are adapted from [17]):

1. For country i, the relationship with country k is important since the latter is a major market destination; at the same time, for

country k the relationship with country i is important as the latter is a major import source. In this unidirectional relationship, we can see that the same flow of goods is important for both parties, and there is integration between country i and country k. In this respect, one is able to recognise that there is no dominance-dependence relationship between i and k.

2. For country i, the relationship with country l is not important, whereas for country l the relationship with country i is important as the latter is a major import source. In this unidirectional relationship, one can observe that there is domination by country i of its trading partner (country l) as an exporter.

3. For country i, the relationship with country m is not important, whereas for country m the relationship with country i is important as the latter is a major import source and export destination. In this bidirectional relationship, we can see domination by country I of its trading partner (country m) as both exporter and importer.

4. For country i, the relationship with country n is important as the latter is a major import source, whereas for country n the relationship with country i is not important. In this unidirectional relationship, we can see the dependency of country ion its trading partner (country n) as an importer.

5. For both countries (i and p), their mutual relationship is important in terms of both import source and market destination. In this bidirectional relationship, we can see that the flow of goods is important for both parties and there exists a trade integration between country i and country p. In this respect, one can see that there is no dominance-dependence relationship between country i and country p.

6. There is no relationship between country i and country q. It means that there is no trade between these two countries.

In this study, we assume that country *i* would have dominant features if its partner(s) consider their relationship with her to be important (i.e., either as a major export destination or as a major import source); at the same time, country *i* does not consider any relationship with her partners to be important. Based on this assumption, we can calculate the dominant intensity power that country *i* has in its relationships with partners. To do so, we need to acquire information about: (1) the number of export (or import) links that tie country *i* and its partners; (2) the frequency that country *i*'s partner is concerned about its relationship with country *i* (the word "concerned" in this study means that it matters or important to a country); (3) the frequency that country *i* is concerned about the relationship with her partner; (4) the possible number of export (import) links that exists if all partners have export (import) links with country *i* (this is a situation where the relationship between country *i* and each of her partners is a_{ij}=1 for the export side and a_{ji}=1 for the import side) (which is equal to (N-1) (where N is the number of countries in the network).

Table 3 summarises the information regarding the relationship between country *i* and each of its trading partners.

Based on the second column in Table 3, we can see that country *i* has four export links with its partners in that sub-network, while the third column indicates three import links that tie country *i* and its partners. Therefore, the number of country *i*'s export (import) links, as a proportion of the number of possible export (import) links that would exist if all partners have export (import) transactions with country *i*, can be written as $\frac{a_{ij}}{N-1}\frac{a_{ij}}{N-1}$ for export side analysis and $\frac{a_{ji}}{N-1}$ $\frac{a_{ji}}{N-1}$ for import side analysis. Based on the fourth column in Table 3, we can see that the total score at which country *i* matters to its partners (ϕ_{ij}) is 6, while the fifth column shows that the total score at which country *i*'s partner matters to her (ϕ_{ji}) is 4. Therefore, the total frequency of links for which country *i* matters to its partner in terms of the total frequency of concern that both country *i* and its partner have in that sub-network can be written as follows: $\phi_{ij}/(\phi_{ij}+\phi_{ji})$.

Table 3. Information about Relationships between Country *i* and Its Partners

(1)	(2)	(3)	(4)	(5)
Country *i*'s partner	Number of export links that ties country *i* and its partners (a_{ij})	Number of import links that ties country *i* and its partners (a_{ji})	The frequency at which country *i*'s partner is concerned about its relationship with country *i* (ϕ_{ij})	The frequency at which country *i* is concerned about the relationship with her partner (ϕ_{ji})
k	1	0	1	1
l	1	0	1	0
m	1	1	2	0
n	0	1	0	1
p	1	1	2	2
q	0	0	0	0
	$\sum_{j=1}^{N} a_{ij} = 4$	$\sum_{j=1}^{N} a_{ji} = 3$	$\sum_{j=1}^{N} \varphi_{ij} = 6$	$\sum_{j=1}^{N} \varphi_{ji} = 4$

Based on the information above, we developed domination degree indices (from the export and import side) for country *i* as follows:

$$DDI_i^X = \left(\frac{\sum_{j=1}^{N} a_{ij}}{N-1}\right)\left(\frac{\sum_{j=1}^{N} \varphi_{ij}}{\sum_{j=1}^{N} \varphi_{ij} + \sum_{j=1}^{N} \varphi_{ji}}\right)$$

$$DDI_i^X = \left(\frac{\sum_{j=1}^{N} a_{ij}}{N-1}\right)\left(\frac{\sum_{j=1}^{N} \varphi_{ij}}{\sum_{j=1}^{N} \varphi_{ij} + \sum_{j=1}^{N} \varphi_{ji}}\right) \quad (10)$$

$$DDI_i^M = \left(\frac{\sum_{j=1}^{N} a_{ji}}{N-1}\right)\left(\frac{\sum_{j=1}^{N} \varphi_{ij}}{\sum_{j=1}^{N} \varphi_{ij} + \sum_{j=1}^{N} \varphi_{ji}}\right)$$

$$DDI_i^M = \left(\frac{\sum_{j=1}^{N} a_{ji}}{N-1}\right)\left(\frac{\sum_{j=1}^{N} \varphi_{ij}}{\sum_{j=1}^{N} \varphi_{ij} + \sum_{j=1}^{N} \varphi_{ji}}\right) \quad (11)$$

From Eq. (10) and Eq. (11), we can see that both indices consist of two ratios: (1) the number of export (import) links in relation to their total possible links; (2) the total number at which country *i* matters to its partner relative to the total frequency of concern that both country *i* and its partners have. The former ratio measures the export (import) intensity of country *i*, wherein the larger the ratio the greater the degree of country *i*'s export (import) intensity. Meanwhile, the second ratio measures how frequently country *i* dominates her trading partner(s) in each relationship it has in (1). And again, the more frequent country *i* dominates her partner in each link, the higher is her influence on that partner. A combination of these two factors is necessary for developing a solid domination index.

For example, Japan has eight important export links in auto P&C (export intensity = 8/11=0.72), and seven out of eight links matter to its partners (second ratio = 7/8=0.88). Therefore,

$$DDI_i^X = 0.72 \times 0.88 = 0.63$$

$$DDI_i^X = 0.72 \times 0.88 = 0.63.$$

In another case, only one out of eight links matters to its partners (second ratio = 1/8 = 0.12). Therefore,

$$DDI_i^X = 0.72 \times 0.12 = 0.09$$

$$DDI_i^X = 0.72 \times 0.12 = 0.09$$

wherein this figure is smaller than the previous one. Based on the above example, the information about both ratios is crucial to gauging a country's dominating power.

Both $DDI_i^X DDI_i^X$ and $DDI_i^M DDI_i^M$ are non-negative indices and have a value range from zero to one. From the export side, $DDI_i^X = 0 DDI_i^X = 0$, indicating that country *i* does not have any dominating power as an exporter in its relationship with partner(s), while $DDI_i^X = 1 DDI_i^X = 1$ indicates that country *i* has maximum dominating power as an exporter over its partners in the network (countries with the highest score in both (1) and (2) have the highest dominant power in the network compared) Meanwhile, from the import side, $DDI_i^M = 0 DDI_i^M = 0$ which indicates that country *i* does not have any dominating power as an importer in its relationship with partner(s), while $DDI_i^M = 1$ $DDI_i^M = 1$ indicates that country *i* has maximum dominating power as an importer over its partners in the network.

4.4.2 *Weighted analysis*

The above analysis used a binary approach at 15 percent threshold. As a compliment to the binary analysis, we then conducted a weighted analysis (in this weighted analysis we take into account all links that exist between country i and its partners). In this respect, we will conduct two types of analyses: (1) export side analysis (i.e., country i serves as an exporter, while its partner serves as an importer); (2) import side analysis (i.e., country i serves as an importer, while its partner serves as an exporter). Again, to calculate the dominating power using a weighted approach, we needed to acquire the following information:

- Export side analysis: (1) country *i* is considered as an important exporter by her partner(s) in the network (represented by the import share automobile of country *i*'s partner(s)); (2) country *i* considers her partner(s) to be an important importer in the network (represented by export share of automobile of country *i*); (3) export of country *i*'s auto P&C (final automobiles) compared to the global export of auto P&C (final automobiles). Information about (1) and (2) are summarised in columns 2 and 3 in Table 4, respectively.

- Import side analysis: (1) country *i* is considered as an important importer by her partner(s) in the network (represented by the export share automobile of country *i*'s partner(s)); (2) country *i* considers her partner(s) to be an important exporter in the network (represented by import share of automobile of country *i*); (3) import of country *i*'s auto P&C (final automobiles) compared to the global import of auto P&C (final automobiles). Information about (1) and (2) are summarised in columns 2 and 3 in Table 5, respectively.

Table 4. Information about Relationship between Country *i* and Its Partners Based on Export Side Analysis Using a Weighted Approach

Country *i*'s partner	Import share of automobile of country *i*'s partner	Export share of automobile of country *i*
k	$\frac{M_{ki}}{M_k^{tot}}$	$\frac{X_{ik}}{X_i^{tot}}$
l	$\frac{M_{li}}{M_l^{tot}}$	$\frac{X_{il}}{X_i^{tot}}$
m	$\frac{M_{mi}}{M_m^{tot}}$	$\frac{X_{im}}{X_i^{tot}}$
n	$\frac{M_{ni}}{M_n^{tot}}$	$\frac{X_{in}}{X_i^{tot}}$
p	$\frac{M_{pi}}{M_p^{tot}}$	$\frac{X_{ip}}{X_i^{tot}}$
q	$\frac{M_{qi}}{M_q^{tot}}$	$\frac{X_{iq}}{X_i^{tot}}$
Total	$\sum_{j=1}^{N} \frac{M_{ji}}{M_j^{tot}}$	$\sum_{j=1}^{N} \frac{X_{ij}}{X_i^{tot}}$

Table 5. Information about Relationship between Country *i* and Its Partners Based on Import Side Analysis Using Weighted Approach

Country *i*'s partner	Export share of automobile of country *i's* partner	Import share of automobile of country *i*
k	$\frac{X_{ki}}{X_k^{tot}}$	$\frac{M_{ik}}{M_i^{tot}}$
l	$\frac{X_{li}}{X_l^{tot}}$	$\frac{M_{il}}{M_i^{tot}}$
m	$\frac{X_{mi}}{X_m^{tot}}$	$\frac{M_{im}}{M_i^{tot}}$
n	$\frac{X_{ni}}{X_n^{tot}}$	$\frac{M_{in}}{M_i^{tot}}$
p	$\frac{X_{pi}}{X_p^{tot}}$	$\frac{M_{ip}}{M_i^{tot}}$
q	$\frac{X_{qi}}{X_q^{tot}}$	$\frac{M_{iq}}{M_i^{tot}}$
Total	$\sum_{j=1}^{N} \frac{X_{ji}}{X_j^{tot}}$	$\sum_{j=1}^{N} \frac{M_{ij}}{M_i^{tot}}$

Based on the information in Table 4, we developed a domination intensity index (DII) for country i as follows:

$$DII_i^X = \sum_{j=1}^{N} \frac{X_{ij}}{X_W}\left[\frac{\sum_{j=1}^{N}\frac{M_{ji}}{M_j^{tot}}}{\sum_{j=1}^{N}\frac{M_{ji}}{M_j^{tot}}+\sum_{j=1}^{N}\frac{X_{ij}}{X_i^{tot}}}\right]$$

$$DII_i^X = \sum_{j=1}^{N} \frac{X_{ij}}{X_W}\left[\frac{\sum_{j=1}^{N}\frac{M_{ji}}{M_j^{tot}}}{\sum_{j=1}^{N}\frac{M_{ji}}{M_j^{tot}}+\sum_{j=1}^{N}\frac{X_{ij}}{X_i^{tot}}}\right] \quad (12)$$

Since $\sum_{j=1}^{N}\frac{X_{ij}}{X_i^{tot}} = 1\sum_{j=1}^{N}\frac{X_{ij}}{X_i^{tot}} = 1$, we can write Eq. (12) as:

$$DII_i^X = \sum_{j=1}^{N} \frac{X_{ij}}{X_W}\left[\frac{\sum_{j=1}^{N}\frac{M_{ji}}{M_j^{tot}}}{\sum_{j=1}^{N}\frac{M_{ji}}{M_j^{tot}}+1}\right]$$

$$DII_i^X = \sum_{j=1}^{N} \frac{X_{ij}}{X_W}\left[\frac{\sum_{j=1}^{N}\frac{M_{ji}}{M_j^{tot}}}{\sum_{j=1}^{N}\frac{M_{ji}}{M_j^{tot}}+1}\right] \quad (13)$$

As we can see in Eq. (13), $DII_i^X DII_i^X$ comprises two ratios: (1) export of automobile from country i in terms of the global export of automobile; (2) total automobiles imported by country i's partner(s) from country i in terms of its partner(s)' total imports of automobiles respectively divided by the aforesaid ratio plus one. The former ratio measures the strength of country i's export of automobiles to its partner(s). Meanwhile, the second ratio measures the degree of dependency of country i's partner(s) towards country i as an input source. In this respect, the higher the ratio the greater the dominating powers of country i as an input source.

The$DII_i^X DII_i^X$index has a minimum value of zero which indicates that country i does not have any dominating power as an input source. Meanwhile, the higher the $DII_i^X DII_i^X$possessed by a country, the greater the dominating power as an input source that that country has.

$$DII_i^M = \sum_{j=1}^{N} \frac{M_{ij}}{M_W}\left[\frac{\sum_{j=1}^{N}\frac{X_{ji}}{X_j^{tot}}}{\sum_{j=1}^{N}\frac{X_{ji}}{X_j^{tot}}+\sum_{j=1}^{N}\frac{M_{ij}}{M_i^{tot}}}\right]$$

$$DII_i^M = \sum_{j=1}^{N} \frac{M_{ij}}{M_W}\left[\frac{\sum_{j=1}^{N}\frac{X_{ji}}{X_j^{tot}}}{\sum_{j=1}^{N}\frac{X_{ji}}{X_j^{tot}}+\sum_{j=1}^{N}\frac{M_{ij}}{M_i^{tot}}}\right] \quad (14)$$

Since $\sum_{j=1}^{N}\frac{M_{ij}}{M_i^{tot}} = 1\sum_{j=1}^{N}\frac{M_{ij}}{M_i^{tot}} = 1$, we can thus write Eq. (14) as:

$$DII_i^M = \sum_{j=1}^{N} \frac{M_{ij}}{M_W}\left[\frac{\sum_{j=1}^{N}\frac{X_{ji}}{X_j^{tot}}}{\sum_{j=1}^{N}\frac{X_{ji}}{X_j^{tot}}+1}\right]$$

$$DII_i^M = \sum_{j=1}^{N} \frac{M_{ij}}{M_W}\left[\frac{\sum_{j=1}^{N}\frac{X_{ji}}{X_j^{tot}}}{\sum_{j=1}^{N}\frac{X_{ji}}{X_j^{tot}}+1}\right] \quad (15)$$

In Eq. (15), we can see that $DII_i^M DII_i^M$ comprises two ratios: (1) import of country i's automobile in terms of the global import of automobile; (2) total automobile export of country i's partner(s) to country i in terms of its partner(s)' total exports of automobiles, respectively divided by the aforesaid ratio plus one. The former ratio measures the strength of country i's import of automobiles from its partner(s). Meanwhile, the second ratio measures the degree of dependency of country i's partner(s) on country i as a market destination. In this respect, the higher the ratio the greater the dominating power of country i as a market destination. The minimum value of $DII_i^M DII_i^M$ is zero which indicates that country i does not have any dominating power as a market destination. Moreover, as a market destination possessed by a country, dominating power increases when $DII_i^M DII_i^M$also increases.

5. Results

5.2 Global-Level Analysis

Tables 6 and 7 respectively show the pattern of network for auto P&C between 1990 and 2015 based on the binary network analysis and weighted network analysis. Columns 3-5 in Table 6 depict the values of total node degree, average degree and connectedness degree, while columns 3-5 in Table 7 depict the values of node strength, average strength, and weighted connectedness. Findings from the binary analysis show that, in general, the node degree, average degree and connectedness degree for auto P&C increased between 1990 and 2015. There are only 15 links of auto P&C for East Asian countries within the network in 1990 and 1995. In 2000, however, the number of links increased to 21 and then to 27 in 2015. At the same time, the values of connectedness also increased within that period. For instance, between 1990 and 2015, the degrees of connectedness increased from 10.4 percent to 18.8 percent. Results from the weighted analysis, as shown in Table 7, seem to be in tandem with the binary one. Based on Table 7, we can see that the node strength, average strength, and weighted strength increased consistently throughout the period under study. Between 1990 and 2015, the node strength went up from US$ 16.55 billion to US$ 116.17 billion, while the average strength and weighted connectedness increased from 1.380 to 9.681 and from 0.115 to 0.807 respectively. From both types of analysis above, we can conclude that not only does the number of links in the network of auto P&C expand, but so does the strength of the existence link (i.e., as represented by the summation of the export value of East Asia's auto P&C possessed by each existence links) over time. The increase in the number of links is due to the fact that a new country did not traditionally take part in the network, even though today it has actively taken part in the network.

Table 6. The Patterns of Nodes Degree, Average Degree, and Connectedness of Auto P&C Based on BNA between 1990 and 2015

Year	N	Total Node Degree $B(G)=\sum_{i=1}^{N}\sum_{j=1}^{N} a_{ij}$	Average Degree $\overline{B(G)}=\frac{B(G)}{N}$	Connectedness $BConn=\frac{B(G)}{N^2}$
1990	12	15	1.250	0.104
1995	12	15	1.250	0.104
2000	12	21	1.750	0.146
2005	12	24	2.000	0.167
2010	12	25	2.083	0.174
2015	12	27	2.250	0.188

Table 7. The Patterns of Nodes strength, Average strength, weighted connectedness of Auto P&C Based on WNA between 1990 and 2015

Year	N	Node Strength $W(G)=\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}$	Average Strength $\overline{W(G)}=\frac{W(G)}{N}$	Weighted Connectedness $WConn=\frac{W(G)}{N^2}$
1990	12	16.552	1.380	0.115
1995	12	22.165	1.847	0.154
2000	12	24.850	2.071	0.173
2005	12	42.297	3.525	0.294
2010	12	74.097	6.175	0.515
2015	12	116.172	9.681	0.807

Meanwhile, Tables 8 and 9 measure the patterns of networks for final automobiles between 1990 and 2015 based on a binary network analysis and a weighted network analysis, respectively. Columns 3-5 in Table 8 depict the values of node degree, average degree and connectedness degree, while columns 3-5 in Table 9 present the node strength, average strength, and weighted connectedness of final automobiles. Based on results from the binary analysis, we can say that the value of node degree, average degree and connectedness degree for final automobiles increased until the year 2000 and then decreased slightly in the years that followed. Between 1990 and 2000, the number of links for final automobiles increased from 20 to 26, while the connectedness degree increased from 13.9 percent to 18.1 percent. Since 2005, however, the number of links started to decline and fell to 21 in 2015, while the connectedness degree decreased from 18.1 percent to 14.6 percent in 2015. The decrease in the number of links after 2000 is due to the reduction in trade values of final automobiles between some countries; for example, trade between Japan and Thailand. In this respect, Thailand started to reduce its import of cars from Japan after that country (i.e. Thailand) emerged as the centre of production for Japanese cars.

Nonetheless, results from the weighted analysis are somewhat different from those of the binary one. Based on the third column in Table 9, it is obvious that the node strength increased consistently between 1990 and 2015. For instance, the node strength increased at an incredible pace from US$

67.53 billion in 1990 to US$ 276.11 billion in 2015. During the same period, average strength and weighted connectedness increased from 5.628 to 23.009 and from 0.469 to 1.917, respectively. From the above analyses, we can conclude that IPNs expanded over time. This is because, although the number of links decreased slightly after 2000, the strength of those links continues to intensify after that period.

Table 8. The Patterns of Nodes Degree, Average Degree, and Connectedness of Final Automobiles Based on BNA between 1990 and 2015

Year	N	Total Node Degree $B(G)=\sum_{i=1}^{N}\sum_{j=1}^{N} a_{ij}$	Average Degree $\overline{B(G)}=\frac{B(G)}{N}$	Connectedness $BConn=\frac{B(G)}{N^2}$
1990	12	20	1.667	0.139
1995	12	21	1.750	0.146
2000	12	26	2.167	0.181
2005	12	25	2.083	0.174
2010	12	22	1.833	0.153
2015	12	21	1.750	0.146

Table 9. The Patterns of Nodes Strength, Average Strength, and Weighted Connectedness of Final Automobiles Based on WNA between 1990 and 2015

Year	N	Node Strength $W(G)=\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}$	Average Strength $\overline{W(G)}=\frac{W(G)}{N}$	Weighted Connectedness $WConn=\frac{W(G)}{N^2}$
1990	12	67.531	5.628	0.469
1995	12	75.278	6.273	0.523
2000	12	118.054	9.838	0.820
2005	12	200.614	16.718	1.393
2010	12	238.735	19.895	1.658
2015	12	276.114	23.009	1.917

5.3 Country-Specific Analysis

5.3.1 Binary analysis

Tables 10 and 11 depict the node degree centrality (NDC) and node density (ND) for auto P&C in nine East Asian countries between 1990 and 2015. As illustrated in Table 10, Japan has the highest NDC (i.e., the number of trade links) as well as ND for each year under study when compared to other East Asian countries in auto P&C. Based on that table, Japan has a network density of more than 35 percent for each year, and reached a network density of 50 percent in 2000 and 2005. These figures imply that in terms of auto P&C, Japan is the most integrated country in the East Asian region and remains the main actor in East Asia's automobile industry (The main actors in the network are those with a high degree of centrality and are actively involved in relationships with other actors (countries), while the peripheries are those with a low degree of centrality and are less involved in relationships with other actors). This phenomenon is due to the rapid growth of outsourcing activities relating to Japanese auto parts following relocation of production abroad which gathered pace in the 1990s [18].

Table 10. The Patterns of East Asian Countries' NDC and ND for Auto P&C Based on Binary Analysis between 1990 and 2015

Country	1990		1995		2000		2005		2010		2015	
	NDC_i	ND_i	NDC_i	ND_i	NDC_i	ND_i	NDC_i	ND_i	NDC_i	ND_i	NDC_i	ND_i
CHI	1	0.045	4	0.182	5	0.227	6	0.273	6	0.273	6	0.273
IND	2	0.091	1	0.045	1	0.045	4	0.182	2	0.091	2	0.091
JPN	8	0.364	8	0.364	11	0.500	11	0.500	9	0.409	10	0.455
KOR	2	0.091	0	0	1	0.045	2	0.091	4	0.182	5	0.227
MAL	2	0.091	2	0.091	2	0.091	3	0.136	2	0.091	2	0.091
PHI	1	0.045	1	0.045	4	0.182	3	0.136	4	0.182	4	0.182
SIN	1	0.091	2	0.091	2	0.091	2	0.091	1	0.045	1	0.045
VN	0	0	0	0	2	0.091	3	0.136	3	0.136	3	0.136
THA	1	0.045	2	0.091	2	0.091	5	0.227	8	0.364	9	0.409

Note: The values of NDC_i and ND_i have been calculated using formulae $NDC_i=\sum_{j=1}^{N} a_{ij}+a_{ji}$ *and* $ND_i=\frac{NDC_i}{2(N-1)}$ *respectively*

In addition, Table 10 suggests that China has become the second main actor in the auto P&C trade for she has the second largest value of NDC and ND between 1995 and 2005. However, since 2010 China's position was overtaken by Thailand. In 1995, China had a network density of 18.2 percent and this figure has increased steadily to more than 27 percent in 2005. The increase in China's integrated level is probably associated with the "open door" policy earlier adopted by that country.

In the case of final automobiles, Japan once again became the main actor as she posits more than 45 percent of network density in most of the year under study (see Table 11). Additionally, starting from 1995 the Republic of Korea follows Japan's footstep to become the second important actor in East Asia's automobile network with a network density of more than 20 percent between 2000 and 2005. Based on the values of NDC and ND in Table 11, Thailand has emerged as the third biggest actor in East Asia's automobile network with a density of more than 18 percent between 2000 and 2005. However, since 2010 Thailand became the second main actor. Based on the above findings, we can say that in East Asia's automobile network, Japan and the Republic of Korea are the two powers that are competing with each other, while Thailand has emerged as one of Japan's wings in Southeast Asia.

Table 11. The Patterns of East Asian Countries' NDC and ND for Final Automobiles Based on Binary Analysis between 1990 and 2015

Country	1990		1995		2000		2005		2010		2015	
	NDC_i	ND_i	NDC_i	ND_i	NDC_i	ND_i	NDC_i	ND_i	NDC_i	ND_i	NDC_i	ND_i
CHI	4	0.182	2	0.091	2	0.091	2	0.091	3	0.136	3	0.136
IND	1	0.045	2	0.091	3	0.136	2	0.091	2	0.091	2	0.091
JPN	10	0.455	10	0.455	10	0.455	9	0.409	7	0.318	7	0.318
KOR	2	0.091	4	0.182	6	0.273	5	0.227	3	0.136	3	0.136
MAL	2	0.091	2	0.091	2	0.091	3	0.136	3	0.136	3	0.136
PHI	1	0.045	1	0.045	3	0.136	2	0.091	2	0.091	2	0.091
SIN	2	0.091	2	0.091	2	0.091	2	0.091	3	0.091	3	0.136
VN	1	0.045	3	0.136	2	0.091	2	0.091	3	0.136	3	0.136
THA	2	0.091	1	0.045	4	0.182	4	0.182	4	0.182	4	0.182

Note: The values of NDC and ND have been calculated using formulae $NDC_i = \sum_{j=1}^{N} a_{ij} + a_{ji}$ *and* $ND_i = \frac{NDC_i}{2(N-1)}$ *respectively*

5.3.2 *Weighted analysis*

Tables 12 and 13 present the values of node strength centrality (NSC) and ranks for East Asia's auto P&C and final automobiles respectively between 1990 and 2015. Based on Table 12, Japan has the highest NSC for each year under study when compared to other East Asian countries in auto P&C. In terms of ranking, Japan occupied the first place in each year under study, which is consistent with the findings in the binary analysis. Meanwhile, Table 12 also shows that China became the second main actor in the auto P&C trade for she has the second largest value of NSC and occupied the second place in the years 1990, 2000, 2005, 2010 and 2015. In addition, this table also indicates that Thailand is the third main actor in East Asia's auto P&C trade as it has the third largest value of NSC and ranked third in the years 1990, 2000, 2005 and 2015. Interestingly, this result can only be traced clearly using the weighted analysis. In fact, what has been achieved by Thailand's auto industry is closely associated with the active involvement of Japanese companies such as Toyota and Mitsubishi in that country.

In the case of final automobiles, Japan as expected became the main actor as she had the highest score of NSC and consistently occupied the top rank for each year under study (see Table 13). The Republic of Korea seems to follow Japan's footstep to become the second main actor in East Asia's automobile networks for she had the second highest score of NSC and consistently occupied the second place for each year under study. In addition, based on the values of NSC and the rank given to each country in Table 11, Thailand has emerged as the third important player in East Asia's automobile networks for each year under study with the exception of the year 2010. The findings discussed above are consistent with those in the binary approach which also concluded that Japan and the Republic of Korea are the two most important powers in East Asia's automobile networks, while Thailand has emerged as a new but significant power in that network.

Table 12. East Asia's NSC for Auto P&C Based on Weighted Analysis between 1990 and 2015

Country	1990		1995		2000		2005		2010		2015	
	NSC_i	Rank	NSC_i	Rank	NSC_i	Rank	NSC_i	Rank	NSC_i	Rank	NSC_i	Rank
CHI	0.067	2	0.021	4	0.051	2	0.107	2	0.145	2	0.150	2
IND	0.020	4	0.024	3	0.012	4	0.013	6	0.013	5	0.014	5
JPN	0.278	1	0.314	1	0.285	1	0.218	1	0.164	1	0.158	1
KOR	0.017	5	0	8	0	9	0.019	4	0.066	3	0.045	4
MAL	0.008	7	0.016	5	0.009	5	0.015	5	0.011	6	0.012	6
PHI	0.003	8	0.006	7	0.007	6	0.008	7	0.006	7	0.007	7
SIN	0.011	6	0.009	6	0.006	7	0.004	8	0.003	9	0.002	9
VN	0	9	0	9	0.001	8	0.002	9	0.004	8	0.005	8
THA	0.022	3	0.042	2	0.018	3	0.040	3	0.047	4	0.049	3

Note: The value of NSC_i has been calculated using formula $NSC_i = \sum_{j=1}^{N} w_{ij} + w_{ji}$

Table 13. East Asia's NSC for Final Automobiles Based on Weighted Analysis between 1990 and 2015

Country	1990		1995		2000		2005		2010		2015	
	NSC_i	Rank	NSC_i	Rank	NSC_i	Rank	NSC_i	Rank	NSC_i	Rank	NSC_i	Rank
CHI	0.003	6	0.008	5	0.004	5	0.009	4	0.047	3	0.017	4
IND	0.002	8	0.005	7	0.003	7	0.002	7	0.005	6	0.004	6
JPN	0.338	1	0.330	1	0.309	1	0.208	1	0.170	1	0.167	1
KOR	0.009	2	0.044	2	0.059	2	0.067	2	0.052	2	0.051	2
MAL	0.006	4	0.010	4	0.004	6	0.004	5	0.006	5	0.005	5
PHI	0.003	7	0.004	8	0.002	8	0.001	8	0.003	8	0.001	8
SIN	0.004	5	0.007	6	0.006	4	0.003	6	0.002	9	0.002	9
VN	0	9	0.002	9	0.001	9	0.001	9	0.003	7	0.003	7
THA	0.008	3	0.011	3	0.010	3	0.011	3	0.021	4	0.018	3

Note: The value of NSC_i has been calculated using formula $NSC_i = \sum_{j=1}^{N} w_{ij} + w_{ji}$

5.4 Network Domination by Country

5.4.1 Binary analysis

Tables 14 and 15 present the values of $DDI_i^X DDI_i^X$ and $DDI_i^M DDI_i^M$ of auto P&C based on export and import analyses respectively, using a binary approach in nine East Asian countries between 1990 and 2015. From the export analysis (see Table 14), we can see that Japan has the highest dominating power as an exporter of auto P&C between 1990 and 2015 with a $DDI_i^X DDI_i^X$ of well over 0.6 in most of the years under study. Nevertheless, in terms of trend, Japanese domination seemed to have reached a peak in 2000 and then gradually declined in subsequent years. This implies that Japan is still one of the world's biggest suppliers of auto P&C as many countries in the world, particularly those in the Asian region, still rely on her as an auto P&C source, either for their local needs or for exports. The slight reduction in the $DDI_i^X DDI_i^X$ after 2000 does not mean that Japanese dominating power in the auto P&C had begun to fade. Japanese companies continue to dominate but not necessarily from Japan, such that probably something more complex is happening here. This is likely due to many Japanese auto parts manufacturers moving their operations abroad in order to supply components to Japanese automakers from their overseas affiliates.

Table 14. Domination Degree Index (DDI) for Auto P&C by Country and Year Based on Export Side Analysis Using Binary Approach

Country	1990	1995	2000	2005	2010	2015
CHI	0	0	0	0.09	0	0
IND	0	0	0	0	0	0
JPN	0.647	0.647	0.671	0.647	0.477	0.431
KOR	0	0	0.091	0.182	0.091	0.175
MAL	0	0	0	0	0	0
PHI	0	0	0	0	0	0
SIN	0	0	0	0	0	0
VN	0	0	0	0	0	0
THA	0	0	0	0.068	0.364	0.395

Table 15. Domination Degree Index (DDI) for Auto P&C by Country and Year Based on Import Side Analysis Using Binary Approach

Country	1990	1995	2000	2005	2010	2015
CHI	0	0	0	0	0.137	0.137
IND	0	0	0	0	0	0
JPN	0	0	0	0	0	0
KOR	0	0	0	0	0	0
MAL	0	0	0	0.119	0	0
PHI	0	0	0	0	0	0
SIN	0	0	0	0	0	0
VN	0	0	0	0	0	0
THA	0	0	0.091	0.091	0.091	0.091

Meanwhile, the period 2000-2015 witnessed the Republic of Korea and Thailand beginning to exert more dominating power as exporters of auto P&C (see Table 14). In this respect, these two countries have begun to dominate the source of auto P&C. For the Republic of Korea, its dominating power is made apparent by the fact that countries such as Vietnam and China rely on her for their source of input of auto P&C. We also found that Thailand has begun to dominate exports of P&C in 2005 with a DDI_i^X DDI_i^X value of 0.068, and in 2010 and 2015 Thailand became the second auto P&C's dominator after Japan, followed by Korea with a $DDI_i^X DDI_i^X$ value of 0.175. From the import side of auto P&C, however, Thailand seems to have shown some consistent power of $DDI_i^M DDI_i^M$ at a value of 0.091 in 2000, 2005, 2010 and 2015. In this manner, Japan consistently relied on her as a major market of auto P&C in East Asia. Interestingly, in 2010, China began to exert dominating power in the import of P&C when Japan starts to rely on her as an important export destination of auto P&C (cf. Table 15). This situation is likely a consequence of changes in the Chinese industrial policy where the tariff for imported auto parts was lowered to 10 percent after China joined the WTO in 2001 [19].

Tables 16 and 17 illustrate the values of $DDI_i^X DDI_i^X$ and $DDI_i^M DDI_i^M$ for final automobiles based on export and import analyses respectively, using binary approach in nine East Asian countries between 1990 and 2015. As can be seen in Table 16, the export analysis indicates that Japan and the Republic of Korea have the most dominating power as exporters of final automobiles between 1990 and 2015, even though Japan is still far ahead of the Republic of Korea in terms of dominating power for each year under study. From these results, it is obvious that the dominating power of Japan as the world's leading car exporter is very significant even though this country has experienced severe economic problems such as the economic stagnation of the 1990s (i.e., after its stock market and property bubbles burst) and the global financial crisis that beset its economy in 2008/9.

Table 16. Domination Degree Index (DDI) for Final Automobiles by Country and Year Based on Export Side Analysis Using Binary Approach

Country	1990	1995	2000	2005	2010	2015
CHI	0	0	0	0	0.091	0.091
IND	0	0	0	0	0	0
JPN	0.682	0.682	0.682	0.573	0.496	0.496
KOR	0.091	0.091	0.273	0.182	0.091	0.182
MAL	0	0	0	0	0	0
PHI	0	0	0	0	0	0
SIN	0	0	0	0	0	0
VN	0	0	0	0	0	0
THA	0	0	0	0.182	0.273	0.273

In other words, economic turmoil does not seem to have any significant impact on the rank of Japan's dominating power as a car exporter even though there appears to be a diminishing trend in the Japanese $DDI_i^X DDI_i^X$ after 2000. In the case of the Republic of Korea, the significant improvement in $DDI_i^X DDI_i^X$ during the period 2000-2015 indicates that Korean cars became popular particularly for Western customers due to the competitiveness in price of its small-size cars.

Table 17. Domination Degree Index (DDI) for Final Automobiles by Country and Year Based on Import Side Analysis Using Binary Approach

Country	1990	1995	2000	2005	2010	2015
CHI	0	0	0	0	0	0
IND	0	0	0	0	0	0
JPN	0	0	0	0	0	0
KOR	0	0	0	0	0	0
MAL	0	0	0	0	0	0
PHI	0	0	0.090	0	0	0
SIN	0	0	0	0	0	0
VN	0	0	0	0	0	0
THA	0	0	0	0	0	0

In addition, after the year 2000, the dominating power of both Thailand and China as exporters of final automobiles seems to have grown. Also, these two countries seem to follow in the footsteps of Japan and the Republic of Korea, with Thailand slightly ahead of China. This phenomenon might be due to the active involvement of some Japanese automobile firms in both Thailand and China. The likely effect of such action is to have increased the dominating power of Thailand and China and in turn shifted the traditional dependency of other countries on Japan slightly towards these two countries. In other words, the increase in Thai and Chinese dominating powers after 2000 is probably due to a slight reduction in Japan's dominating power during the economic turmoil, wherein the dependency of other countries on Japan seems to have shifted towards these two countries.

To sum up, the results from the binary analysis seem to divide East Asian countries into two groups: (1) countries that have dominating power in the automobile industry whether as an exporter, importer, or both (i.e., those that possess $DDI_i^X > 0$ $DDI_i^X > 0$ and/or $DDI_i^M > 0 DDI_i^M > 0$); (2) countries that do not have any dominating power in the automobile industry whether as an exporter, importer, or both (i.e., those that possess $DDI_i^X = 0$ $DDI_i^X = 0$ and/or $DDI_i^M = 0 DDI_i^M = 0$). Based on the above findings, the first group consists of Japan, Republic of Korea, Thailand, and China, while the second consists of Indonesia, Malaysia, the Philippines, Singapore, and Vietnam. As expected from this analysis, Japan is consistently the biggest dominator in the East Asian region in terms of both auto P&C and final automobiles since many countries still rely on her for both auto P&C and final automobiles. Meanwhile, the rapid developments of the automobile industry in the Republic of Korea, Thailand and China have also given them some dominating power in the East Asian automobile network.

5.4.2 Weighted approach

Tables 18 and 19 below show the value of the domination intensity index (DII) for auto P&C based on export and import analyses respectively, using the weighted approach. Based on these tables, the results from using the weighted approach seem to generally support the previous findings from the binary approach. In the weighted approach, DII represents the strength of the interactions as mediated by each country. Despite the fact that two countries can have the same DDI when using the binary approach, they can also be associated to slightly different DII. We hope that the two approaches can provide complimentary insights.

Table 18. Domination Intensity Index (DII) for Auto P&C by Country and Year Based on Export Side Analysis Using Weighted Approach

Country	1990	1995	2000	2005	2010	2015
CHI	0.000	0.001	0.001	0.007	0.030	0.034
IND	0.000	0.000	0.000	0.001	0.001	0.000
JPN	0.126	0.142	0.100	0.094	0.097	0.099
KOR	0.000	0.001	0.004	0.010	0.019	0.021
MAL	0.000	0.000	0.000	0.000	0.000	0.000
PHI	0.000	0.000	0.000	0.000	0.001	0.000
SIN	0.000	0.000	0.000	0.000	0.000	0.000
VN	0.000	0.000	0.000	0.000	0.000	0.000
THA	0.000	0.000	0.001	0.004	0.008	0.011

Note: 0.000 indicates that the value is extremely small.

Table 19. Domination Intensity Index (DII) for Auto P&C by Country and Year Based on Import Side Analysis Using Weighted Approach

Country	1990	1995	2000	2005	2010	2015
CHI	0.023	0.002	0.002	0.010	0.025	0.031
IND	0.001	0.002	0.001	0.001	0.003	0.002
JPN	0.000	0.000	0.000	0.000	0.000	0.000
KOR	0.000	0.000	0.000	0.000	0.000	0.000
MAL	0.002	0.002	0.001	0.002	0.002	0.002
PHI	0.000	0.000	0.001	0.000	0.001	0.001
SIN	0.003	0.004	0.000	0.001	0.001	0.001
VN	0.000	0.000	0.000	0.000	0.000	0.000
THA	0.004	0.008	0.003	0.006	0.011	0.018

Note: 0.000 indicates that the value is extremely small.

The highest score of $DII_i^X DII_i^X$ for both auto P&C and final automobiles between 1990 and 2015 belongs to Japan, while the second highest went to the Republic of Korea between 1990 and 2005 (cf. Tables 18 and 20). Meanwhile, Chinese auto P&C's $DII_i^X DII_i^X$ increased over time, namely from 0.001 in 1995 to 0.034 in 2015. In 2010, the position of the Republic of Korea as the second highest exporter of auto P&C has been overtaken by China. Between 2005 and 2015, Thailand emerged as the third and fourth highest $DII_i^X DII_i^X$ for final automobiles and auto P&C, respectively. This result is consistent with $DDI_i^X DDI_i^X$ using the binary approach. However, in 2015 the result between these two approaches is slightly different in the case of auto P&C. For example, the auto P&C's $DII_i^X DII_i^X$ for China of 0.034 is the second highest after Japan, but this cannot be identified using the binary approach where its $DDI_i^X DDI_i^X$ is 0.00, as shown in Table 14.

As far as the import of auto P&C is concerned, we can see that Thailand posited the highest score of $DII_i^M DII_i^M$ between 1995 and 2000. Its position, however, has been overtaken by China in 2005, 2010 and 2015, wherein Chinese auto P&C's $DII_i^M DII_i^M$ increased dramatically in those years (cf. Table 19). In general, for Indonesia, Malaysia, Singapore and the Philippines, the scores of their auto P&C's DII_i^M DII_i^M are somewhat low and consistent throughout the year under study. In the case of import of final automobiles, scores of $DII_i^M DII_i^M$ indicate that both Japan and the Republic of Korea did not have any dominating power as importers of final automobiles, while other East Asian countries had a lower score. Moreover, we also found that China has the highest dominating power as a final automobile market compared to other East Asian countries, but its DII_i^M DII_i^M is diminishing over time, i.e., from 0.018 in 1990 to 0.010 in 2010 (cf. Table 21) (The values of DDI cannot be captured using binary approach (cf. Table 17).

Table 20. Domination Intensity Index (DII) for Final Automobiles by Country and Year Based on Export Side Analysis Using Weighted Approach

Country	1990	1995	2000	2005	2010	2015
CHI	0.000	0.000	0.000	0.000	0.002	0.005
IND	0.000	0.000	0.000	0.000	0.000	0.000
JPN	0.227	0.163	0.141	0.115	0.112	0.110
KOR	0.002	0.012	0.019	0.026	0.023	0.021
MAL	0.000	0.000	0.000	0.000	0.000	0.000
PHI	0.000	0.000	0.000	0.000	0.001	0.000
SIN	0.000	0.000	0.000	0.000	0.000	0.000
VN	0.000	0.000	0.000	0.000	0.000	0.000
THA	0.000	0.000	0.000	0.004	0.009	0.011

Note: 0.000 indicates that the value is extremely small.

Table 21. Domination Intensity Index (DII) for Final Automobiles by Country and Year Based on Import Side Analysis Using Weighted Approach

Country	1990	1995	2000	2005	2010	2015
CHI	0.018	0.003	0.001	0.000	0.007	0.010
IND	0.000	0.000	0.000	0.001	0.003	0.001
JPN	0.000	0.000	0.000	0.000	0.000	0.000
KOR	0.000	0.000	0.000	0.000	0.000	0.000
MAL	0.001	0.003	0.000	0.001	0.001	0.001
PHI	0.000	0.000	0.000	0.000	0.001	0.001
SIN	0.001	0.001	0.000	0.001	0.000	0.000
VN	0.000	0.001	0.000	0.000	0.000	0.000
THA	0.000	0.002	0.000	0.001	0.002	0.002

Note: 0.000 indicates that the value is extremely small.

6. Conclusion

The broad aim of this paper is to analyse the nature of East Asia's automobile network using social-network methods. Specifically, this paper analysed the following: (1) the development of East Asia's automobile networks between 1990 and 2015; (2) the degree of integration among East Asian countries into the automobile networks; (3) identifying the main actor(s) in East Asia's automobile networks. In addition, in this paper we have also developed a domination degree index (DDI) and domination intensity index (DII) to measure the dominating power of each East Asian country in the automobile networks.

The results suggested that the networks of East Asia's automobile industry are expanding over time both in terms of the number of links in the network as well as the strength of those links. This finding indicates that both export and import of automobile products in this region increase significantly over time. This development occurs probably because production (particularly parts and components) is increasingly being traded across national borders. In this respect, East Asian countries are becoming more tightly interconnected through trade flows regardless of whether they are poor or rich, big or small economy, small (e.g. Singapore) or big (e.g. China) country.

In addition, as expected, Japan has emerged as the main player, both in the case of auto P&C and final automobiles. The Republic of Korea has also emerged as the second most important player in East Asia's final automobile networks, while China has become the second most important player in East Asia's auto P&C networks. Even though Thailand is the third most important player in East Asia's automobile networks in both auto P&C and final automobiles, the binary analysis of this paper has suggested that there is a possibility for this country to overtake China and the Republic of Korea to become the second most important player in terms of both auto P&C and final automobiles. The dramatic changes in the development of Thailand's automobile industry as well as significant development in China's auto P&C have been made possible by the pivotal role played by Japan (on Thailand) and the Republic of Korea (on China) – all of which have stimulated the development of their subordinates' auto industry in a so-called "win-win situation".

In terms of the dominant power in East Asia's automobile networks, Japan has consistently been the most dominant power in the cases of both auto P&C and final automobiles, as many countries still rely on her for these products. Compared with other East Asian countries, Japan has strong economic fundamental since post-war and has experienced a spectacular economic growth particularly throughout the 1970s and most of the 1980s. After recovering from the so-called "bubble economy", the Japanese economy continues to grow, transforming the global economy and assisting with the economic development of many countries, particularly those in the Asian region, through FDI. Japan also emerged as the leading automobile producer in the 1980s. This achievement was due to rises in Japanese export of automobiles to the rest of the world, the growth of automobile production in Japan itself, as well as the growth of Japanese automobile production abroad.

Meanwhile, the rapid developments in the automobile industry of the Republic of Korea since the 1980s, as well as those of Thailand and China in the 2000s, have also given them dominating power in East Asia's automobile network, albeit to varying degrees. For the Republic of Korea, its automobile industry became one of the priority industries in that country's Heavy and Chemical Industry Plan of 1973. The remarkable growth of this industry has placed South Korea as the world's eighth largest auto producer in 2008. In addition, Korean auto producer Hyundai already has production plants abroad in countries such as China, India, Czech Republic, United States, and Turkey, such that more than 40 percent of its production are now located abroad. In the case of China, its automobile sector is growing very fast, and now China has become a components' producer with exports worldwide. Thailand has specialised in the production of pick-up trucks and passenger cars, exporting them to developed countries as well as ASEAN nations.

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