



RIETI Discussion Paper Series 26-E-025

Role of Japanese Firms in the East Asian Electronics Industry: A supply chain network perspective

IYETOMI, Hiroshi

Rissho University

ARAI, Yuta

Reitaku University

IKEDA, Yuichi

Kyoto University



Research Institute of Economy, Trade & Industry, IAA

The Research Institute of Economy, Trade and Industry

<https://www.rieti.go.jp/en/>

Role of Japanese Firms in the East Asian Electronics Industry:
A supply chain network perspective¹

Hiroshi Iyetomi¹, Yuta Arai², and Yuichi Ikeda³

¹Department of Data Science, Rissho University

²Department of Business Administration, Reitaku University

³Graduate School of Advanced Integrated Studies in Human Survivability, Kyoto University

Abstract

The ongoing geopolitical tensions between the United States and China are reshaping global production networks, particularly in the electronics industry, where East Asia serves as a central manufacturing hub. This study empirically examines Japan's position within the evolving East Asian electronics value chain using firm-level supply chain data. We construct a global supply chain network consisting of 15,292 nodes (firms) and 27,751 links (transactional relationships), centered on the electronics industry along with its two closely related sectors: the automotive and aerospace-defense industries. Our findings indicate that Japan continues to occupy an important upstream position, particularly in electronic components, manufacturing equipment, and precision instruments. However, a decline in the relative market share and network centrality of Japanese firms in the mainstream semiconductor industry suggests a departure from Japan's former dominance. In contrast, we identify a distinct automotive cluster in which Japanese firms remain highly competitive. The analysis also reveals an aerospace and defense community dominated by U.S. and European firms, characterized by limited participation from Japanese firms and the potential strategic exclusion of China. Furthermore, we uncover a separate cluster linking electronics, automation, and utilities, where Japanese firms play a prominent role with a 58% share. This cluster highlights a unique structural feature of industrial organization in Japan.

Keywords: electronics industry, East Asia, supply chain, network analysis

JEL classification: C81; F63; L14; O12

The RIETI Discussion Paper Series aims at widely disseminating research results in the form of professional papers, with the goal of stimulating lively discussion. The views expressed in the papers are solely those of the author(s), and neither represent those of the organization(s) to which the author(s) belong(s) nor the Research Institute of Economy, Trade and Industry.

¹This study is conducted as a part of the Project “Dynamics of Price in Crypto Assets and Real Economy and Their Underlying Complex Networks” undertaken at the Research Institute of Economy, Trade and Industry (RIETI). The draft of this paper was presented at the RIETI DP seminar for the paper. We would like to thank participants of the RIETI DP Seminar for their helpful comments. We are also grateful to Hideaki Aoyama, Yoshi Fujiwara, Wataru Souma, and Hiroshi Yoshikawa for their continued discussions on the topics in this paper and related issues.

I. Introduction

The structure of production in the electronics industry cannot be adequately understood from aggregate trade or sectoral statistics. What matters instead is the architecture of firm-level supply relationships, where a limited number of upstream suppliers often exert system-wide influence that is not visible in conventional data. This perspective is consistent with a growing body of work on production networks, which emphasizes the role of input-output linkages and network topology in shaping aggregate outcomes (Acemoglu et al., 2012; Carvalho, 2014). This feature is particularly pronounced in East Asia, where cross-border production has evolved into a densely interconnected network linking Japan, China, South Korea, and Taiwan (Thorbecke, 2023).

In the 1980s, Japan was the dominant force in semiconductors, especially in memory chips, and its rise was closely tied to the restructuring of global competition and trade conflict with the United States (Irwin, 1996). Yet this position did not remain unchallenged. From the late 1980s into the early 1990s, firms in other East Asian economies—most notably South Korea and Taiwan—expanded their technological and manufacturing capabilities and began to displace Japanese firms in key segments of the industry (Cho et al., 1998; Hobday, 1995). This transition marked one of the most important episodes in the reorganization of the semiconductor industry in East Asia and provides an important historical background for understanding Japan’s present role: no longer the overwhelmingly dominant producer of the late twentieth century, but still a critical actor in strategically important upstream segments.

Over the past decade, the global production network has been subject to two distinct but interacting pressures. On the one hand, technological constraints—most notably in semiconductors and advanced manufacturing equipment—have reshaped the organization of production. On the other hand, geopolitical tensions, especially those between the United States and China, have altered the configuration of supply relationships. These changes are not simply reflected in trade volumes; they involve the reorganization of firm-level connections, including the substitution, duplication, or strategic isolation of suppliers. Recent studies of the semiconductor global value chain show that such restructuring is closely tied to geopolitical strategies and technological chokepoints, particularly in the context of US–China rivalry and East Asian production networks (Malkin, 2024; Wong et al., 2024; Grimes and Du, 2024). More broadly, research on global value chains suggests that these adjustments operate through network reconfiguration rather than simple shifts in trade flows (Antràs and Chor, 2020; Coe and Yeung, 2019).

This paper examines Japan’s position in this evolving network from the perspective of econophysics (Aoyama et al., 2017). Rather than relying on country-level aggregates, we reconstruct the supply chain as a directed network of firms and analyze its structural properties using tools from network science (Barabasi and Pósfai, 2016; Newman, 2018). This approach makes it possible to identify how individual

firms are embedded in the system and how their positions relate to the propagation of shocks. In particular, it allows us to detect the role of upstream suppliers whose importance arises not from size alone but from their placement within the network, a mechanism closely related to recent findings on shock amplification in production networks (Baqae and Farhi, 2019).

While our primary focus is the electronics industry, the analysis also incorporates the automobile and aerospace-defense sectors. These industries share critical technological dependencies—especially on semiconductors and electronic components—yet differ markedly in their market structures and exposure to geopolitical risk. Considering them jointly provides a clearer picture of how the industrial capabilities of Japan are distributed across interconnected production systems.

The remainder of this paper is organized as follows: The subsequent section describes the methodology employed in the collection and subsequent reshaping of the supply chain data utilized in this study. Section III gives the methodology employed in the construction of the global supply chain network, drawing upon the database as a primary source of information. Section IV presents the empirical outcomes of the aforementioned network analyses, encompassing fundamental network properties, bowtie decomposition augmented by the Helmholtz–Hodge decomposition, community detection, and the identification of connector hubs. Finally, Section V offers a summary of the findings obtained in this study, accompanied by concluding remarks on Japan’s evolving role in the new global economic order.

II. Data Collection

The firm-level supply-chain data used in this study were obtained from the S&P Capital IQ Pro database¹, which provides extensive information on inter-firm business relationships across a wide range of industries and countries. The dataset includes identified supplier–customer linkages at the firm level, allowing for the construction of directed production networks that capture both upstream and downstream connections in global value chains.

We should note that the database compiles supply-chain relationships from two primary sources: publicly disclosed information (e.g., company reports, filings, and official statements) and trade-based data derived from Panjiva. In this study, we restrict our analysis to relationships identified from publicly available sources in order to ensure transparency and consistency in the definition of inter-firm linkages. In contrast, Panjiva-based relationships, which are inferred from shipment-level trade records, may reflect transactional co-occurrence rather than stable production linkages and are often subject to geographic and reporting biases; excluding such data helps to reduce noise and improves the interpretability of the resulting network structure.

¹Thanks to RIETI, we were able to access to this proprietary database:
<https://www.spglobal.com/market-intelligence/en/solutions/products/sp-capital-iq-pro>

We began by identifying firms classified within the electronics industry, which is the focal sector of our analysis. For each of these firms, we extracted information on their upstream (suppliers) and downstream (customers) transactional relationships, thereby constructing a directed network of inter-firm linkages. While the initial sample was restricted to firms in the electronics industry, the network was subsequently expanded by adding firms connected to these focal firms through supply-chain relationships. In particular, when suppliers or customers belonged to closely related industries, that is, the Automobile industry and the Aerospace and Defense industry, those firms were incorporated into the network dataset. This procedure allows the network to capture cross-industry production linkages that are essential for understanding the broader structure of the electronics-centered value chain. The present data collection scheme is depicted in Fig. 1.

The resulting dataset comprises 19,135 firms, of which 7,002 are publicly listed companies. Although not exhaustive, the dataset represents a carefully curated subset based on the best available information within the original database. It is sufficiently rich to reveal the structural features of the electronics-centered production network, while maintaining a high level of reliability in the identified inter-firm relationships.

Before leaving this section, we note that the following cleaning filters were applied to the collected data. We standardized the names of firms (Unicode normalization; case/whitespace harmonization), harmonized the names of countries across tables, and removed self-loops and duplicate links. Multiple disclosures of the same relationship were collapsed into a single link retaining the richest attributes. Links tagged as “former/terminated” prior to the as-of date were excluded; only “recent” relationships were kept. The location of some firms in the U.S. is specified by state, not by country. In such instances, the state name was replaced by the country name.

III. Construction of Supply Chain Network

The foundation of our network study is the supplier-customer relationship data as described in the previous section, which explicitly identifies transactional linkages between firms. In our network model, each firm represents a node. A directed link is then established from a supplier to a customer, representing the directional flow of goods or services. The global supply chain network centered on the electronics industry that we have thus constructed has 19,135 nodes and 30,585 links. In fact, the network is fragmented into completely separated pieces. The largest weakly-connected component (WCC1) of the network has 15,292 nodes and 27,751 links. The remaining pieces are very small as compared with the WCC1; the second largest weakly-connected component has only 22 nodes. The composition of firms in the WCC1 regarding countries and industrial sectors serves as a reference in the comparative analyses that follow.

The WCC1 of the network is illustrated in Fig 2, where its layout of nodes was

determined by invoking an electric spring model in which a pair of adjacent nodes are connected by a spring to be located nearby and all nodes have the same sign of charge to be repelled to each other. Table 1 presents a tabular overview of the distribution of firms across countries and industries for the WCC1, with the top 20 entities listed for each classification. The top five countries, the United States, China, India, Taiwan, and Japan, collectively account for over 60% of all firms in the WCC1. However, the presence of European countries including the United Kingdom, Germany, and France is not negligible. The primary industries for firms in the WCC1 should be readily understandable, given the nature of the data collection scheme.

Table 2 classifies firms within the WCC1 by industry and country, specifying the top 10 industries and five key countries (Japan, the U.S., China, Taiwan, and South Korea). It shows that Japan maintains a significant position in the upstream segments of the electronics sector, as reflected in the number of firms in industries such as Electronic Components, Electronic Equipment and Instruments, and Electrical Components and Equipment.

Figure 3(a), (b), and (c) illuminate how firms belonging to Japan, the United States, and China, respectively, are distributed on the WCC1 as shown in Fig. 2. The distribution of US firms exhibits a most dispersed pattern, while that of Japanese firms demonstrates a pronounced concentration.

IV. Network Analyses

A. Basic properties

This section details the fundamental structural and statistical properties of the network (Barabasi and Pósfai, 2016; Newman, 2018). Initial analysis focuses on the scale and general connectivity of the network through the network density ρ defined as

$$\nu = \frac{L}{N(N-1)}, \quad (1)$$

where N and L denote the numbers of nodes and links of a network, respectively. The actual values of the WCC1 for N and L gives $\nu = 0.00012$. Such a small value of ν indicates that our network is extremely sparse.

The degree of a node reflects its immediate connectivity, providing insight into the roles of individual firms. Due to the directed nature of the network, we analyze in-degree and out-degree separately:

- Out-Degree (k_{out}): The number of edges originating from a node, representing the firm's direct customers or downstream partners. Firms with high k_{out} act as significant suppliers or distributors.
- In-Degree (k_{in}): The number of edges terminating at a node, representing the firm's direct suppliers or upstream partners. Firms with high k_{in} are major

buyers or integrators.

The degree distribution $P(k)$ is examined to identify structural patterns. The results for $P(k_{\text{out}})$ and $P(k_{\text{in}})$ are shown in Fig. 4. We observe that the distributions possess a heavy tail, which indicates the presence of network hubs—firms with exceptionally high degrees that exert disproportionate influence on global flows.

Figure 5 examines correlation between k_{in} and k_{out} for each of nodes in the WCC1. Computing the Kendall’s τ and the Spearman’s ρ , we find that the two degrees have weak negative correlation; the actual values² are $\tau = -0.240$ and $\rho = -0.259$. This outcome may defy our initial assumptions, as larger firms have a propensity to augment the number of transactions on both upstream and downstream sides.

Path analysis provides a metric for the efficiency of material or information flow:

- Geodesic Distance ($d(i, j)$): The shortest path length between firm i and firm j .
- Average Path Length (\bar{d}): The mean of the shortest path lengths over all reachable pairs of nodes

$$\bar{d} = \frac{1}{N(N-1)} \sum_{i \neq j} d(i, j) \quad (2)$$

The average distance \bar{d} is calculated as $\bar{d} = 5.89$ for the WCC1, which reminds us of the “six degrees of separation” in a small-world network. This results indicates that the supply chain is highly efficient in connecting distant firms. However, this structure can also facilitate the rapid propagation of shocks across the global network.

B. *Bowtie and Helmholtz-Hodge decompositions*

The bowtie decomposition (Baldi et al., 2003) is a fundamental architectural analysis method for directed networks that partitions a supply chain into functionally distinct node sets based on their accessibility to and from the central control structure. This decomposition centers on the largest strongly connected component (SCC), which is often referred to as a giant SCC (GSCC), which represents a core of mutually reachable firms or processes—the resilient, central operational engine. The remaining nodes are segregated into the IN-component (supplier nodes that feed the core) and the OUT-component (customer nodes served by the core), analogous to upstream and downstream segments. Peripheral components, such as Tubes and Tendrils, account for flows bypassing the core or isolated dependencies. Analyzing this bowtie

²We carried out the statistical hypothesis testing. We prepared the null model by randomizing the combination of k_{in} and k_{out} . The results based on the null model are $\tau = 0.000 \pm 0.007$ and $\rho = 0.000 \pm 0.008$ with standard deviation for 1000 samples.

structure provides critical insight into supply chain robustness, identifying single-point-of-failure risks in the IN-component, potential bottlenecks in the Core, and the extent of disruption propagation into the OUT-component.

The Helmholtz-Hodge decomposition (HHD) (Jiang et al., 2011; Kichikawa et al., 2019) is a fundamental theorem that provides a systematic way to analyze and segment flow fields, making it valuable for studying the flow of materials, information, or capital across a supply chain network. The HHD states that any arbitrary flow can be uniquely broken down into three independent and orthogonal components. The first is the curl-free component, which represents flow driven by potential gradients; this flow is determined locally on each link by the difference between the scalar Hodge potential values of the two end nodes. The magnitude of the Hodge potential assigned to each node quantifies its position in the flow hierarchy, reflecting its overall upstream or downstream role in the network. The second is the divergence-free component, which captures persistent, closed-loop circulation and cyclical movements, highlighting internal dependencies and material or risk recycling within the system. The final component is the harmonic flow, which represents steady, global throughput that passes through the entire system without being stored or cycled internally. Applying this method allows researchers to clearly separate the net, linear throughput from the self-contained circular activity, which is important for identifying structural vulnerabilities and measuring true systemic efficiency.

The bowtie structure of a directed network is schematically illustrated in the upper part of Fig. 6. Correspondingly, the distributions of the Hodge potential values of firms in the IN component, the GSCC, and the OUT component are displayed in the lower part of the figure, where the overall average of the potential values is set to zero. The figure was further decomposed into the contributions of firms in Japan, the United States, and China, as illustrated in the three panels of Fig. 7. Comparison of the results for Japan and China with those of the United States reveals a higher concentration of upstream firms in the former two countries. As anticipated, the mean values of the Hodge potential are 0.239, -0.119 , and 0.209 for the three countries, respectively. In addition, the distribution of firms across countries or industries for the three bowtie components is tabulated in Tables 3, 4, and 5.

C. Community detection

The third stage of network analysis involves detecting the community structure, defined as a partitioning of the network’s nodes into groups (modules or communities) such that connections are dense within groups and sparse between groups. Identifying these modules in the global supply chain network is crucial for understanding its inherent organizational principles, which often correspond to geographic, industrial, or functional clusters.

To simplify the community detection procedure, we converted the WCC1 to an *undirected* network by neglecting the direction of links. The communities in

the undirected network was identified through the optimization of the **modularity** quality function, Q . The modularity Q is a scalar value that measures the strength of the division of a network into communities. It compares the actual number of intra-community links to the expected number of such links in a randomized null model:

$$Q = \frac{1}{2L} \sum_{i,j} \left[A_{ij} - \frac{k_i k_j}{2m} \right] \delta(c_i, c_j), \quad (3)$$

where A_{ij} is the adjacency matrix, k_i and k_j are the degrees of nodes i and j , and $\delta(c_i, c_j)$ is 1 if i and j belong to the same community, 0 otherwise. The simple greedy algorithm (Clauset et al., 2004) was employed to find the partition that maximizes modularity. Despite being a computationally simple approach, its effectiveness in real-world systems often confirms the existence of clear, non-ambiguous community organization.

The community detection analysis yielded an exceptionally strong result, highlighting significant structural segregation in the supply chain network. The maximum modularity achieved was $Q = 0.747$. This value is substantially higher than the typical range (0.3 to 0.7) observed in complex systems, confirming the existence of a highly segregated and robust modular organization. The success of the simple greedy algorithm in achieving such a near-optimal Q value validates that the underlying community structure is profound and clearly defined, suggesting minimal ambiguity in the assignment of firms to clusters. This can be visually confirmed in Fig. 8, where the largest five communities are illuminated.

The analysis partitioned the network into 300 distinct communities. However, the size distribution of communities is highly heterogeneous so that just several communities should be focused. The high modularity implies strong “local” reliance; firms overwhelmingly transact with partners within their own community. Conversely, connections between communities are extremely sparse, confirming weak inter-cluster coupling.

The seven largest communities comprise 2896 (18.8%), 2604 (17.0%), 2110 (13.8%), 929 (6.1%), 597 (3.9%), 450 (2.9%), and 427 (2.8%) firms, in descending order of size (relative shares in parentheses). Their country and industry distributions are detailed in Tables 6 through 13. A key finding is that each community possesses unique national and industrial characteristics.

The largest community is the global backbone of semiconductor, ICT manufacturing, and digital infrastructure, linking upstream chip supply with downstream telecom, cloud, and enterprise demand. An examination of the relative shares of the United States, Taiwan, China, and South Korea reveals an increase in reference to the composition of the WCC1. Notably, the rise of Taiwan and South Korea is of particular significance, from 8.48% to 20.0% and from 2.84% to 4.73%, respectively. In contrast, the proportion of Japan exhibited a modest decline, from 7.96% to 7.53%. This fact signifies Japan’s decline in its dominant status within the mainstream semiconductor industry.

To ascertain this observation, we pay attention to degree centrality C_D and betweenness centrality C_B as complementary measures of firms’s structural importance in the supply chain network. Degree centrality $C_D(i)$ for node i is defined as

$$C_D(i) = k_{in}(i) + k_{out}(i). \quad (4)$$

On the other hand, betweenness centrality is defined as

$$C_B(i) = \sum_{s \neq i \neq t} \frac{\sigma_{st}(i)}{\sigma_{st}}, \quad (5)$$

where σ_{st} is the total number of shortest paths between nodes s and t , and $\sigma_{st}(i)$ is the number of those paths that pass through node i .

The degree centrality is a measure of the extent of a firm’s direct transactional ties—both upstream and downstream—and thus serves as a proxy for its immediate embeddedness and activity level in the network. A high degree of centrality for firms is indicative of their sustained engagement across a diverse array of supply relationships. Conversely, betweenness centrality is indicative of the extent to which a firm serves as an intermediary between otherwise unconnected components of the network. This metric captures the firm’s function as a bottleneck or coordinator in the transmission of goods, information, or value. Firms with high betweenness centrality occupy structurally strategic positions that can influence the resilience and controllability of the entire network.

Table 7 shows the degree and betweenness centralities averaged over firms in the WCC1 and its largest community (Com1) across five countries, Japan, the U.S., China, Taiwan, and South Korea. For Japan, the average degree centrality in the Com1 is nearly identical to that in the WCC1. This outcome is in sharp contrast to the results for the U.S., Taiwan, and South Korea, where the centrality increases by 34%, 28%, and 7%, respectively, when switching from the WCC1 to the Com1. A 25% increase in the betweenness centrality of Japanese firms was observed in the Com1 compared to that in the WCC1. However, a more pronounced increase in betweenness centrality is exhibited by the U.S., Taiwan, and South Korea, with increases of 168%, 69%, and 138%, respectively. This finding thus corroborates the decline of Japan’s predominant status within the mainstream semiconductor industry, as has been inferred by the reduced share of Japanese firms in the Com1. In the case of China, both centralities decrease, suggesting that China has not yet attained a leading position in the mainstream semiconductor industry.

The second largest community is a global automotive–mobility–energy supercluster. This cluster encompasses the entire automotive value chain, ranging from raw materials and Tier-1 suppliers to OEMs, EV batteries, and downstream finance and logistics. It is currently converging on EVs, connectivity, and the energy transition. Japan’s relative share has undergone a substantial increase, rising from 7.96% to 11.21%. This development indicates that the nation continues to maintain its leading position within this industrial community.

The third largest community, which places primary emphasis on aerospace and defense, is led by the United States and European countries. Japan’s involvement in this matter is negligible. The hypothesis that China is deliberately excluded from this community is not implausible.

The fourth largest community is an Indian mega-cluster of Public Sector Undertakings in India, private conglomerates, and global suppliers, integrating hydrocarbons, grids, renewables, defense, and infrastructure. We find only four Japanese firms here. This community clearly reflects the Make in India initiative.

The fifth largest community is a Japan-based electronics–automation–utilities cluster, blending passives, robotics, utilities, telecom, and finance into one industrial ecosystem. This community is dominated by Japan, reflecting its unique industrial world.

The sixth largest community is a metals-to-electronics-to-infrastructure system, where Asian suppliers in steel, copper, cables, semis, and renewables feed into U.S. and global infrastructure projects and iconic tech brands such as Apple and Adidas.

The seventh largest community is a globally integrated solar–storage–utility ecosystem, led by the U.S. and China. This industrial community is paving the way for a promising future of economic development. We find only nine Japanese firms here. Japan may have been late in taking this train.

D. Connector hubs

We now proceed to examine the relationship between the communities identified in the preceding section. To this end, we use a method in which the participation coefficient and the within-community degree are combined to characterize the function of a node. This is a classification framework for nodes proposed by Guimera and Amaral (2005), often referred to as a $P - Z$ plot.

The within-module degree k_i measures the local importance of a node i by calculating its number of links within its own community.³ The participation coefficient P_i , conversely, quantifies the global connectivity of a node by measuring how its links are distributed among different communities. Its formula is

$$P_i = 1 - \frac{\sum_{s=1}^M k_{is}^2}{\left(\sum_{s=1}^M k_{is}\right)^2}, \quad (6)$$

where k_{is} denotes the number of links node i has to nodes in community s . A node with a low participation coefficient has links confined primarily to its own community, whereas a high coefficient indicates that its links are spread across multiple

³The within-module degree k_i is standardized in the original paper. However, we adopt the raw value for each node here.

communities. By plotting each node on these two axes, we can classify them into distinct functional roles, such as provincial hubs (high k , low P), which are central only to their own community, and connector hubs (high k , high P), which serve as critical bridges between communities and are essential for global network cohesion. The k - P diagrams for the top three communities are shown in Fig. 9.

The identification of the connector hubs was achieved through the implementation of the following conditions: $k_i > 10$ and $P_i > 0.3$. We then identified 17 firms were in the largest community, 11 in the second, and 5 in the third. Figure 10 highlights those firms on the WCC1 layout as shown in Fig. 2. The connector hubs in the largest community include Amazon, Honeywell, and Samsung. In the second community, Bosch, Tesla, and Volvo play a role of the connector hub. For the connector hubs in the third community, we find General Dynamics and General Electric.

V. Summary

This paper investigates Japan’s strategic position within the East Asian electronics value chain from a network science perspective. We constructed a directed supply-chain network using firm-level transaction data, focusing on the electronics industry alongside two closely related sectors: automobiles and aerospace/defense. Standard network metrics were employed to characterize the centrality of firms and the community structure of the network.

The analysis confirms the continued strength of Japan in upstream segments, such as electronic components, manufacturing equipment, and precision instruments. However, its presence in mainstream semiconductor manufacturing has weakened relative to competitors in the U.S., Taiwan, and South Korea. In contrast, Japan maintains a stable and influential position in the automotive sector. We further identify a distinct aerospace and defense community led by U.S. and European firms, where Japanese participation remains limited and Chinese firms are virtually absent. Additionally, a specific cluster dominated by Japanese firms emerges at the intersection of electronics, factory automation, and utilities, reflecting the unique industrial architecture of the Japanese economy.

These findings demonstrate that a network-based approach is highly effective for monitoring structural shifts in global supply chains. Specifically, this framework identifies systemic nodes whose disruption could fragment the network, providing a quantitative basis for stress testing and policy analysis amid increasing geopolitical risks, such as export controls and friend-shoring.

References

- Acemoglu, Daron, Vasco M. Carvalho, Asuman Ozdaglar, and Alireza Tahbaz-Salehi**, “The Network Origins of Aggregate Fluctuations,” *Econometrica*, 2012, *80* (5), 1977–2016.
- Antràs, Pol and Davin Chor**, “Conceptual aspects of global value chains,” *World Bank Economic Review*, 2020, *34* (3), 551–574.
- Aoyama, Hideaki, Yoshi Fujiwara, Yuichi Ikeda, Hiroshi Iyetomi, Wataru Souma, and Hiroshi Yoshikawa**, *Macro-Econophysics: New Studies on Economic Networks and Synchronization*, Cambridge University Press, 2017.
- Baldi, Pierre, Paolo Frasconi, and Padhraic Smyth**, *Modeling the Internet and the Web*, Wiley Chichester, 2003.
- Baqae, David Rezza and Emmanuel Farhi**, “The macroeconomic impact of microeconomic shocks: Beyond Hulten’s theorem,” *Econometrica*, 2019, *87* (4), 1155–1203.
- Barabasi, AL and M Pósfai**, *Network Science*, Cambridge University Press, 2016.
- Carvalho, Vasco M.**, “From Micro to Macro via Production Networks,” *Journal of Economic Perspectives*, 2014, *28* (4), 23–48.
- Cho, Dong-Sung, Dong-Jae Kim, and Dong Kee Rhee**, “Latecomer Strategies: Evidence from the Semiconductor Industry in Japan and Korea,” *Organization Science*, 1998, *9* (4), 489–505.
- Clauset, Aaron, M. E. J. Newman, and Cristopher Moore**, “Finding community structure in very large networks,” *Phys. Rev. E*, Dec 2004, *70*, 066111.
- Coe, Neil M. and Henry Wai chung Yeung**, “Global production networks: Mapping recent conceptual developments,” *Journal of Economic Geography*, 2019, *19* (4), 775–801.
- Grimes, Seamus and Debin Du**, “China’s interdependent positioning in the semiconductor global value chain,” *Area Development and Policy*, 2024.
- Guimera, Roger and Luís A Nunes Amaral**, “Cartography of complex networks: modules and universal roles,” *Journal of Statistical Mechanics: Theory and Experiment*, 2005, *2005* (02), P02001.
- Hobday, Mike**, “East Asian Latecomer Firms: Learning the Technology of Electronics,” *World Development*, 1995, *23* (7), 1171–1193.

- Irwin, Douglas A.**, “The U.S.-Japan Semiconductor Trade Conflict,” in Anne O. Krueger, ed., *The Political Economy of Trade Protection*, Chicago: University of Chicago Press, 1996, pp. 5–14.
- Jiang, Xiaoye, Lek-Heng Lim, Yuan Yao, and Yinyu Ye**, “Statistical ranking and combinatorial Hodge theory,” *Mathematical Programming*, 2011, *127* (1), 203–244.
- Kichikawa, Yuichi, Hiroshi Iyetomi, Takashi Iino, and Hiroyasu Inoue**, “Community structure based on circular flow in a large-scale transaction network,” *Applied Network Science*, 2019, *4* (1), 92.
- Malkin, Anton**, “The geoeconomics of global semiconductor value chains: extraterritoriality and the US–China technology rivalry,” *Review of International Political Economy*, 2024.
- Newman, Mark E. J.**, *Networks*, 2nd ed., Oxford University Press, 2018.
- Thorbecke, Willem**, *The East Asian Electronics Sector: The Roles of Exchange Rates, Technology Transfer, and Global Value Chains*, Cambridge University Press, 2023.
- Wong, Chung-Yee et al.**, “Geopolitics and the changing landscape of global value chains and competition in the global semiconductor industry: Rivalry and catch-up in chip manufacturing in East Asia,” *Technological Forecasting and Social Change*, 2024.

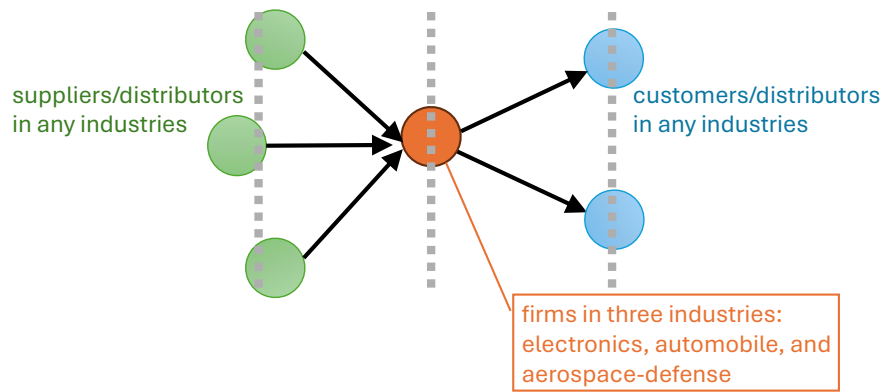


Figure 1. Scheme of the data collection for transaction relations between firms.

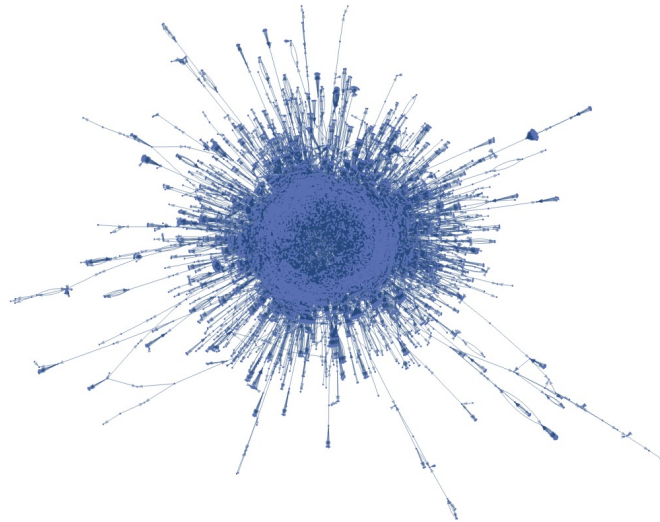


Figure 2. Visualization of the largest weakly-connected component (WCC1) of the global supply chain network centered on the electronics industry.

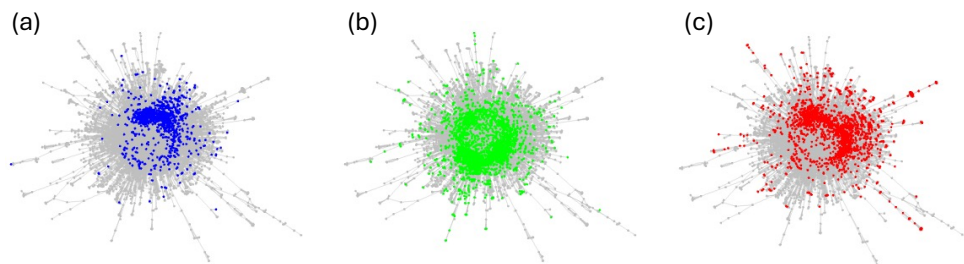


Figure 3. Distributions of firms belonging to Japan (a), the U.S. (b), and China (c) on the WCC1 as shown in Fig. 2.

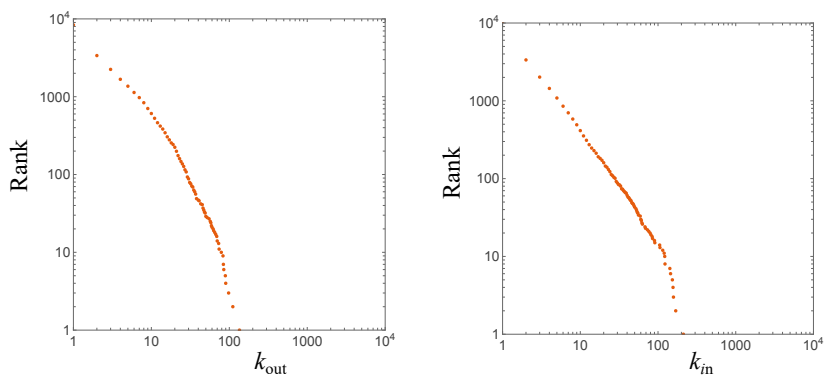


Figure 4. Cumulative distributions of in-degree k_{in} and out-degree k_{out} of nodes in the WCC1.

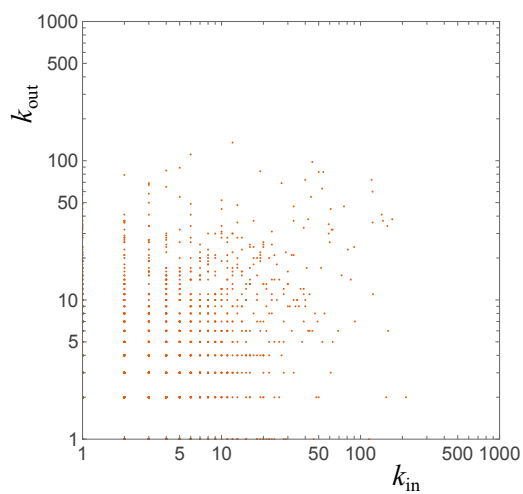


Figure 5. Scatter plot of in-degree k_{in} and out-degree k_{out} of nodes in the WCC1, indicating weak negative correlation between the two degrees.

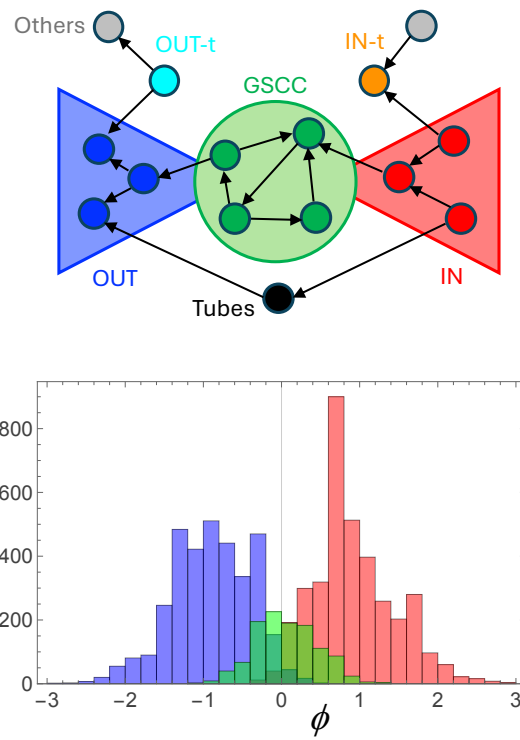


Figure 6. Bowtie decomposition of the WCC1. The upper figure is a schematic view of the bowtie structure. The lower figure shows the distributions of the Helmholtz–Hodge potential ϕ of firms in the IN component (red), GSCC (green), and OUT component (blue) of the bowtie structure.

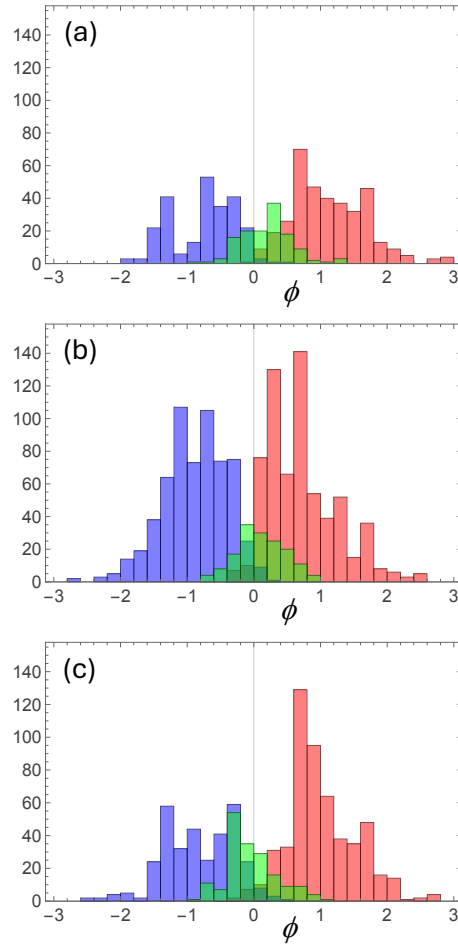


Figure 7. Distributions of the Hodge potential ϕ of firms in Japan (panel (a)), the U.S. (panel (b)), and China (panel (c)), which are decomposed into the three components in the same way as the lower figure of Fig. 6.

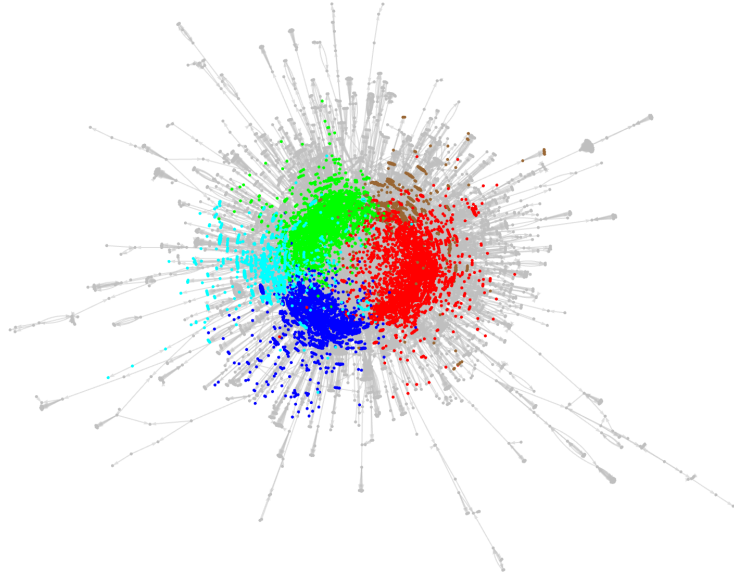


Figure 8. Community structure of the WCC1 as displayed in Fig. 2, where the top five communities are highlighted in red, green, blue, cyan, and brown, in order from largest to smallest.

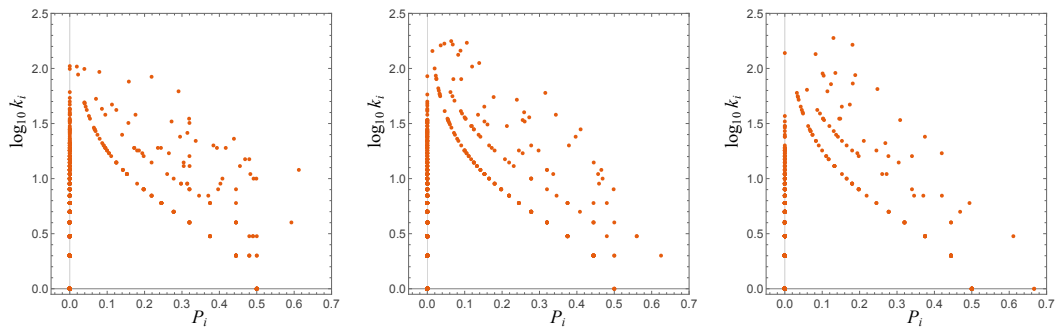


Figure 9. The k - P diagram for the top three communities, in order from panel (a) to panel (c), where k_i and P_i are the total degree and the participation ratio defined by Eq. (6) for the i th node.

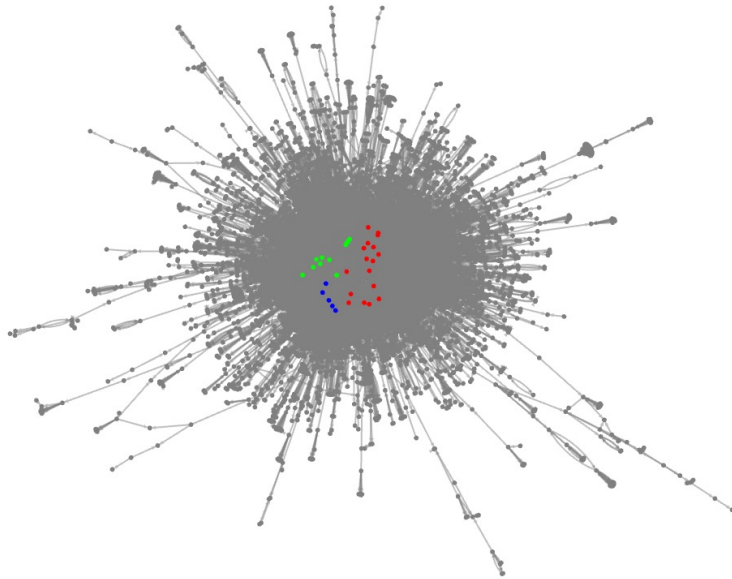


Figure 10. Connector firms for the top three communities in the WCC1, where the color coding for nodes is the same as that in Fig. 8.

Table 1. Distribution of firms over countries (left) and industries (right) for the WCCI, where the top 20 entities are listed for each classification.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
USA	2975	19.45	Automotive Parts and Equipment	1499	9.80
China	1948	12.74	Aerospace and Defense	898	5.87
India	1535	10.04	Technology Distributors	881	5.76
Taiwan	1296	8.48	Semiconductors	821	5.37
Japan	1217	7.96	Electronic Components	695	4.54
United Kingdom	616	4.03	Electronic Equipment and Instruments	553	3.62
Germany	539	3.52	Electrical Components and Equipment	527	3.45
South Korea	435	2.84	Automobile Manufacturers	517	3.38
France	356	2.33	Trading Companies and Distributors	393	2.57
Thailand	284	1.86	Diversified Support Services	386	2.52
Singapore	270	1.77	Electronic Manufacturing Services	351	2.30
Canada	261	1.71	Technology Hardware, Storage and Peripherals	336	2.20
Malaysia	255	1.67	Construction and Engineering	334	2.18
Italy	244	1.60	Communications Equipment	313	2.05
Hong Kong	221	1.45	Application Software	301	1.97
Australia	216	1.41	Passenger Airlines	262	1.71
Indonesia	213	1.39	IT Consulting and Other Services	247	1.62
Sweden	189	1.24	Industrial Machinery and Supplies and Components	242	1.58
Netherlands	184	1.20	Electric Utilities	235	1.54
Israel	149	0.97	Electrical Components and Equipment: Light Electrical Components and Equipment	233	1.52

Table 2. Number of firms in the WCC1 across the top 10 industries and five selected countries.

Industry	Japan	U.S.	China	Taiwan	S. Korea
Automotive Parts and Equipment	202	155	274	52	69
Aerospace and Defense	14	341	61	7	10
Technology Distributors	48	109	61	119	12
Semiconductors	39	177	167	224	41
Electronic Components	83	92	161	182	47
Electronic Equipment and Instruments	60	147	61	44	11
Electrical Components and Equipment	49	89	95	30	14
Automobile Manufacturers	23	78	136	12	10
Trading Companies and Distributors	54	57	18	38	16
Diversified Support Services	9	90	15	5	4

Table 3. The same table as that in Table 1, but for the IN component of the WCCL.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
USA	648	17.86	Automotive Parts and Equipment	539	14.86
China	532	14.66	Semiconductors	267	7.36
Taiwan	396	10.92	Electronic Components	245	6.75
India	368	10.14	Aerospace and Defense	179	4.93
Japan	362	9.98	Electrical Components and Equipment	153	4.22
United Kingdom	130	3.58	Electronic Equipment and Instruments	151	4.16
South Korea	126	3.47	Electronic Manufacturing Services	110	3.03
Germany	108	2.98	Application Software	107	2.95
France	83	2.29	Industrial Machinery and Supplies and Components	99	2.73
Singapore	68	1.87	Semiconductor Materials and Equipment	97	2.67
Canada	66	1.82	Technology Distributors	95	2.62
Malaysia	59	1.63	Commodity Chemicals	91	2.51
Indonesia	58	1.60	Diversified Metals and Mining	90	2.48
Australia	56	1.54	Steel	87	2.40
Sweden	53	1.46	Electrical Components and Equipment: Light Electrical Components and Equipment	80	2.21
Thailand	48	1.32	Construction and Engineering	77	2.12
Spain	43	1.19	IT Consulting and Other Services	74	2.04
Hong Kong	43	1.19	Communications Equipment	61	1.68
Italy	38	1.05	Trading Companies and Distributors	60	1.65
Israel	37	1.02	Technology Hardware, Storage and Peripherals	46	1.27

Table 4. The same table as Table 1, but for the GSCC of the WCCI.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
Taiwan	202	17.64	Automotive Parts and Equipment	143	12.49
China	176	15.37	Semiconductors	128	11.18
USA	154	13.45	Automobile Manufacturers	102	8.91
Japan	131	11.44	Technology Distributors	100	8.73
India	94	8.21	Electronic Components	94	8.21
Singapore	35	3.06	Aerospace and Defense	87	7.60
Germany	34	2.97	Technology Hardware, Storage and Peripherals	49	4.28
South Korea	32	2.79	Electronic Manufacturing Services	44	3.84
France	30	2.62	Electrical Equipment and Instruments	37	3.23
Hong Kong	28	2.45	Electrical Components and Equipment: Light Electrical Components and Equipment	37	3.23
Italy	25	2.18	Communications Equipment	29	2.53
Indonesia	20	1.75	Electrical Components and Equipment	21	1.83
United Kingdom	17	1.48	Trading Companies and Distributors	18	1.57
Thailand	14	1.22	Semiconductor Materials and Equipment	14	1.22
Netherlands	13	1.14	Application Software	13	1.14
Israel	12	1.05	IT Consulting and Other Services	13	1.14
Malaysia	12	1.05	Industrial Conglomerates	10	0.87
Vietnam	11	0.96	Steel	10	0.87
Canada	8	0.70	Automotive Retail	9	0.79
Australia	7	0.61	Industrial Machinery and Supplies and Components	8	0.70

Table 5. The same table as Table 1, but for the OUT component of the WCC1.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
USA	614	18.11	Technology Distributors	319	9.41
China	335	9.88	Passenger Airlines	233	6.87
Taiwan	304	8.97	Aerospace and Defense	191	5.63
Japan	244	7.20	Diversified Support Services	177	5.22
India	221	6.52	Automotive Parts and Equipment	171	5.04
United Kingdom	155	4.57	Automobile Manufacturers	132	3.89
Germany	111	3.27	Automotive Retail	113	3.33
Thailand	103	3.04	Trading Companies and Distributors	110	3.24
France	86	2.54	Technology Hardware, Storage and Peripherals	106	3.13
South Korea	80	2.36	Semiconductors	98	2.89
Italy	69	2.04	Communications Equipment	86	2.54
Hong Kong	67	1.98	Electronic Equipment and Instruments	84	2.48
Malaysia	65	1.92	Electronic Components	72	2.12
Canada	63	1.86	Distributors	58	1.71
Indonesia	62	1.83	Construction and Engineering	57	1.68
Singapore	58	1.71	IT Consulting and Other Services	53	1.56
Netherlands	55	1.62	Electronic Manufacturing Services	48	1.42
Australia	48	1.42	Application Software	43	1.27
Sweden	48	1.42	Electrical Components and Equipment	42	1.24
Vietnam	34	1.00	Air Freight and Logistics		

Table 6. Distribution of firms over countries (left) and industries (right) for the largest community in the WCC1, where the top 20 entities are listed for each classification.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
USA	685	23.65	Semiconductors	463	15.99
Taiwan	578	19.96	Technology Distributors	398	13.74
China	385	13.29	Electronic Components	225	7.77
Japan	218	7.53	Technology Hardware, Storage and Peripherals	200	6.91
South Korea	137	4.73	Communications Equipment	131	4.52
Singapore	99	3.42	Electronic Equipment and Instruments	126	4.35
Germany	83	2.87	Application Software	111	3.83
Hong Kong	77	2.66	Electronic Manufacturing Services	100	3.45
United Kingdom	68	2.35	Semiconductor Materials and Equipment	88	3.04
Netherlands	53	1.83	Systems Software	67	2.31
India	41	1.42	Electrical Components and Equipment	60	2.07
Canada	37	1.28	IT Consulting and Other Services	57	1.97
France	36	1.24	Trading Companies and Distributors	50	1.73
Thailand	33	1.14	Automotive Parts and Equipment	40	1.38
Italy	30	1.04	Construction and Engineering	40	1.38
Indonesia	29	1.00	Distributors	35	1.21
Malaysia	26	0.90	Industrial Machinery and Supplies and Components	33	1.14
Sweden	25	0.86	Consumer Electronics	32	1.10
Switzerland	25	0.86	Electrical Components and Equipment: Light Electrical Components and Equipment	26	0.90
Israel	24	0.83	Integrated Telecommunication Services	22	0.76

Table 7. Comparison of degree centrality and betweenness centrality across five selected countries, based on firms in the largest weakly connected component (WCC1) and the largest community (Com1) within WCC1. The upper row in each cell shows the average degree centrality, while the lower row shows the average betweenness centrality.

Country	WCC1	Com1
Japan	4.63 2.33×10^4	4.58 2.91×10^4
U.S.	3.45 8.93×10^3	4.64 2.40×10^4
China	2.83 3.29×10^3	2.67 2.88×10^3
Taiwan	5.40 3.70×10^4	6.89 6.26×10^4
S. Korea	4.55 9.70×10^3	4.88 2.30×10^4

Table 8. The same table as Table 6, but for the second largest community in the WCC1.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
India	514	19.74	Automotive Parts and Equipment	787	30.22
China	357	13.71	Automobile Manufacturers	334	12.83
USA	345	13.25	Automotive Retail	151	5.80
Japan	292	11.21	Distributors	60	2.30
Germany	138	5.30	Application Software	58	2.23
South Korea	118	4.53	Electrical Components and Equipment	53	2.04
United Kingdom	107	4.11	Construction Machinery and Heavy Transportation Equipment	51	1.96
Italy	65	2.50	Steel	47	1.80
France	62	2.38	Industrial Machinery and Supplies and Components	46	1.77
Thailand	54	2.07	Machinery and Equipment: Construction and Heavy Transportation	43	1.65
Malaysia	45	1.73	Motorcycle Manufacturers	43	1.65
Canada	38	1.46	Diversified Metals and Mining	43	1.65
Sweden	36	1.38	Machinery and Supplies and Components: Industrial	39	1.50
Australia	34	1.31	Commodity Chemicals	39	1.50
Taiwan	26	1.00	IT Consulting and Other Services	34	1.31
Netherlands	25	0.96	Trading Companies and Distributors	30	1.15
Brazil	25	0.96	Electronic Equipment and Instruments	30	1.15
Indonesia	23	0.88	Construction and Engineering	30	1.15
Hong Kong	22	0.84	Advertising	29	1.11
Poland	16	0.61	Agricultural and Farm Machinery	27	1.04

Table 9. The same table as Table 6, but for the third largest community in the WCC1.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
USA	802	38.01	Aerospace and Defense	653	30.95
United Kingdom	170	8.06	Passenger Airlines	258	12.23
France	113	5.36	Diversified Support Services	188	8.91
Canada	79	3.74	Electronic Equipment and Instruments	55	2.61
Germany	79	3.74	IT Consulting and Other Services	45	2.13
Australia	51	2.42	Trading Companies and Distributors	45	2.13
Italy	47	2.23	Application Software	42	1.99
Sweden	46	2.18	Industrial Machinery and Supplies and Components	40	1.90
China	46	2.18	Research and Consulting Services	38	1.80
Israel	43	2.04	Air Freight and Logistics	37	1.75
Japan	38	1.80	Construction and Engineering	37	1.75
India	36	1.71	Communications Equipment	31	1.47
District of Columbia	32	1.52	Alternative Carriers	30	1.42
Singapore	32	1.52	Electronic Components	28	1.33
Taiwan	29	1.37	Construction Machinery and Heavy Transportation Equipment	23	1.09
South Korea	26	1.23	Electrical Components and Equipment	22	1.04
Netherlands	26	1.23	Electronic Manufacturing Services	22	1.04
Norway	24	1.14	Health Care Equipment	21	1.00
Spain	21	1.00	Airport Services	21	1.00
Switzerland	19	0.90	Diversified Metals and Mining	20	0.95

Table 10. The same table as Table 6, but for the fourth largest community in the WCC1.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
India	656	70.61	Electric Utilities	81	8.72
USA	47	5.06	Electrical Components and Equipment	61	6.57
United Kingdom	28	3.01	Construction and Engineering	59	6.35
Germany	23	2.48	Aerospace and Defense	52	5.60
France	17	1.83	Electrical Components and Equipment: Light Electrical Components and Equipment	47	5.06
China	16	1.72	Electronic Equipment and Instruments	38	4.09
Canada	9	0.97	Trading Companies and Distributors	32	3.44
Italy	8	0.86	Diversified Support Services	29	3.12
Singapore	7	0.75	Renewable Electricity	27	2.91
Australia	6	0.65	Electrical Components and Equipment: Heavy	25	2.69
Spain	6	0.65	Automotive Parts and Equipment	22	2.37
Vietnam	6	0.65	Steel	21	2.26
Romania	6	0.65	Semiconductors	21	2.26
United Arab Emirates	6	0.65	Technology Distributors	20	2.15
Sweden	5	0.54	Machinery and Supplies and Components: Industrial	19	2.05
Netherlands	5	0.54	Machinery and Equipment: Construction and Heavy Transportation	18	1.94
Switzerland	4	0.43	IT Consulting and Other Services	15	1.61
Bangladesh	4	0.43	Research and Consulting Services	13	1.40
Norway	4	0.43	Rail Transportation	12	1.29
Thailand	4	0.43	Industrial Conglomerates	11	1.18

Table 11. The same table as Table 6, but for the fifth largest community in the WCC1.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
Japan	346	57.96	Technology Distributors	66	11.06
USA	38	6.37	Electronic Components	55	9.21
China	35	5.86	Electronic Equipment and Instruments	41	6.87
Taiwan	23	3.85	Automotive Parts and Equipment	41	6.87
Singapore	16	2.68	Electrical Components and Equipment	39	6.53
Thailand	14	2.35	Electronic Manufacturing Services	31	5.19
Hong Kong	13	2.18	Trading Companies and Distributors	27	4.52
Germany	12	2.01	Construction and Engineering	18	3.02
South Korea	11	1.84	Industrial Machinery and Supplies and Components	18	3.02
United Kingdom	10	1.68	Semiconductor Materials and Equipment	15	2.51
Malaysia	8	1.34	Regional Banks	15	2.51
India	8	1.34	Semiconductors	15	2.51
Indonesia	6	1.01	Distributors	13	2.18
Australia	6	1.01	Electric Utilities	12	2.01
Philippines	5	0.84	Commodity Chemicals	12	2.01
Canada	4	0.67	Electrical Components and Equipment: Light Electrical Components and Equipment	9	1.51
Vietnam	4	0.67	Machinery and Supplies and Components: Industrial	8	1.34
Denmark	3	0.50	Technology Hardware, Storage and Peripherals	7	1.17
France	3	0.50	Other Distributors	7	1.17
Italy	3	0.50	Diversified Support Services	7	1.17

Table 12. The same table as Table 6, but for the sixth largest community in the WCC1.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
Taiwan	149	33.11	Semiconductors	40	8.89
China	74	16.44	Electronic Components	38	8.44
USA	71	15.78	Electrical Components and Equipment	27	6.00
Japan	41	9.11	Trading Companies and Distributors	22	4.89
Indonesia	25	5.56	Steel	21	4.67
Singapore	11	2.44	Technology Distributors	21	4.67
Thailand	10	2.22	Electrical Components and Equipment: Light Electrical Components and Equipment	20	4.44
Hong Kong	8	1.78	Automotive Parts and Equipment	20	4.44
United Kingdom	7	1.56	Diversified Support Services	19	4.22
South Korea	7	1.56	Electronic Manufacturing Services	16	3.56
Germany	5	1.11	Construction and Engineering	16	3.56
Malaysia	5	1.11	Electronic Equipment and Instruments	14	3.11
Vietnam	4	0.89	Electrical Components and Equipment	13	2.89
France	4	0.89	Semiconductor Materials and Equipment	13	2.89
Switzerland	3	0.67	Diversified Metals and Mining	12	2.67
Australia	3	0.67	Communications Equipment	10	2.22
Cayman Islands	3	0.67	Commodity Chemicals	10	2.22
Norway	2	0.44	Technology Hardware, Storage and Peripherals	8	1.78
Oman	2	0.44	Copper	6	1.33
Mexico	2	0.44	Electrical Components and Equipment: Light	6	1.33

Table 13. The same table as Table 6, but for the seventh largest community in the WCC1.

Country	#firms	#firms(%)	Industry	#firms	#firms(%)
USA	83	19.44	Electrical Components and Equipment	55	12.88
China	65	15.22	Semiconductors	49	11.48
India	34	7.96	Renewable Electricity	37	8.67
Germany	17	3.98	Construction and Engineering	29	6.79
Australia	16	3.75	Electrical Components and Equipment: Light Electrical Components and Equipment	25	5.85
Sri Lanka	14	3.28	Trading Companies and Distributors	19	4.45
Israel	14	3.28	Technology Distributors	15	3.51
United Kingdom	13	3.04	Automotive Parts and Equipment	14	3.28
South Korea	13	3.04	Electronic Equipment and Instruments	14	3.28
Canada	13	3.04	Electric Utilities	13	3.04
Italy	10	2.34	Electronic Components	10	2.34
France	10	2.34	Semiconductor Materials and Equipment	9	2.11
Taiwan	10	2.34	Diversified Metals and Mining	9	2.11
Spain	9	2.11	Independent Power Producers and Energy Traders	8	1.87
Japan	9	2.11	Automobile Manufacturers	7	1.64
Singapore	9	2.11	Diversified Support Services	6	1.41
Brazil	9	2.11	Application Software	5	1.17
Malaysia	8	1.87	Commodity Chemicals	5	1.17
Hong Kong	8	1.87	Asset Management and Custody Banks	4	0.94
Poland	7	1.64	Electrical Components and Equipment: Light	4	0.94