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Supply-Chain Network Analysis of Kyoto's Traditional Craft Industry*

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Abstract

In recent years, due to changes in consumer demand, accompanied by generational transformations, the traditional craft industry in Kyoto has lost substantial sales revenue. In this paper, our goal is to characterize Kyoto's traditional craft industry from the analysis of the supply chain network between individual companies within the Kyoto region. We clarify the community structure, the bow-tie structure, the robustness, and the vulnerability of the supply chain network as keys for sustainable growth. From the community detection and bow-tie structure analysis, it is evident that the traditional craft industry still occupies an important position in the industrial network of Kyoto. Furthermore, we have clarified the relationship between the network characteristics of modern and traditional craft industries and their profitability and productivity. It became clear that the traditional craft industry has a different network structure from both the modern consumer game industry and electromechanical industry. Modern industries have a core loop structure in the industrial community. The companies there create high added value and play a role in driving the entire industry. On the other hand, because Nishijin fabric and the Kyoto doll industry don't have a loop structure, the profitability of the industry is declining. This is presumed to be a factor in the decline of the traditional craft industry.

Keywords: traditional craft, inter-firm transaction network, community detection, bow-tie structure, profitability and productivity
JEL classification: D85, L14

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1 Introduction

In a highly developed industrialized society, mass production is at the center of economic activity. This mass production arguably stands in stark contrast to production methods such as the "flexible division of labor" system[1] that characterizes the collaboration among companies and the manufacturing system of traditional craft industries. As early as 1980, such a traditional flexible division of labor attracted a certain amount of attention as a substitute model for the American-style mass production system in regional economies, such as those in and around Kyoto. However, with the improvement in the functions of software and the development of Internet-based communication, the global supply chain has developed, and an international horizontal division of labor has been established over the last few decades[2]. Despite this, the flexible and regional-based production methods have recently begun to attract renewed interest as a developmental concept of redistributed manufacturing(RDM)[3][4]. Modern global market manufacturing tends to be characterized by centralized production and a complex global supply chain, has resulted in homogenized materials, cost volatility, and some uncertainty regarding energy and transportation costs[5][6][7]. Meanwhile, localized, flexible and community-centered traditional craft manufacturing methods are expected to democratize production and the markets and as well as simplify the supply chains[8].

Kyoto, the region of interest for this research, has a long history of crafts and, as the long-time capital of Japan, is highly representative of Japanese culture. The traditional crafts industry in Kyoto produces so-called "Kyoto products", which are characterized by sophisticated sensibilities grounded in over a thousand years of history and a high-quality build produced through an extreme subdivision of labor system[9][10][11], where each manufacturing process is based on advanced craftsmanship that has been handed down from generation to generation. However, while the industry remains deeply rooted in the lives of the Japanese, the changes in consumer demand and the generational transformations have resulted in a substantial decrease in revenue for the industry[12][13][14][15]. It would appear that the formerly effective flexible division of labor as well as the production equipment, know-how, and conventional procedures of a skilled labor force have become increasingly unable to cope with the market fluctuations and technological changes brought about by economic globalization. It is thus crucial to clarify the operational forms of traditional industries and to identify the attendant issues.

Here, we address this by working toward establishing a method for clarifying the structure of the supply chain network among the individual companies within the current traditional craft industry in the Kyoto region. To this end, we regard the production activity in terms of complex networks consisting of firms (as nodes) and transaction relationships (as links). Recently, numerous studies have suggested that analyzing farm-level transaction relationships as a supply-chain network could prove useful to understanding specific economic issues[16][17][18]. By taking Kyoto's traditional crafts industry as a supply-chain network formed by interfirm transaction relations, we can elucidate its characteristics in relation to other industries. Our main aim is to understand the underlying structures and dynamics to ultimately nurture sustainability and ensure the survival of the traditional cultural industry within the existing broader and ever-changing market environment. To present a concrete discussion, we examine the problems of the traditional craft industry from the viewpoint of productivity and profitability using actual data. As a result of our research, we expect to make a valuable contribution toward raising production efficiency while preserving the desired quality in terms of the traditional procedures and products.

The paper is organized as follows. In the next sections, we explain the dataset and the method of network analysis used in this paper. Following this, the results section, the main part of the paper, outlines the main characteristics and issues of the supply-chain network of Kyoto's traditional craft industry before the last section reviews the results and provides a conclusion.

2 Materials and methods

2.1 Data

The data analyzed in this paper is a subset of 5,943,072 supply chain transaction relationships among 1,668,567 individual Japanese companies (including the company name, location, industry, number of employees, etc.), as investigated by Tokyo Shoko Research, Ltd(TSR) in 2016. From this data, we constructed a supply chain network, where each individual company is a node, and specific links connect pairs of companies with at least one supplier-customer relationship, such that we could construct a directed graph. Due to the dataset limitation, the links have no weights. Focusing on companies in Kyoto and those that have business relationships with companies in the region, our analysis involves 79,678 nodes and 153,684 links.

2.2 Network communities

Community detection analysis divides the network into closely connected groups, and we used this method to distinguish the traditional craft industry network from the supply-chain network in Kyoto. The most popular method for community detection is the modularity maximization approach[19]. However, as is well known, this method is not suitable for dividing large networks due to the significant resolution limitation issue. Therefore, we used the map equation method[20][21] for our analysis, which is one of the more accurate methods among those available[22]. A set of nodes with a high probability of staying when a random walker randomly walks on a network was regarded as a community when we applied the method to a given network. The map equation method involves encoding based on information theory, which ensures a reduction of the overall breadth of the information without losing the original information. When encoding, attention must be paid to the information frequency, with short codes assigned to the information with a high frequency of appearance and long codes assigned to that with a low frequency of appearance. A random walker is also highly likely to stay in a node set with a high link density and is also highly likely to move to another node set from one with a low density. In a well-divided community, the occurrence probability of a code indicating movement between communities is considered low. However, if some movement between communities is unlikely to occur, regarding the network as one community presents the best division. Therefore, in the map equation method, the average code length L in the community division M that divides the network into C is defined by

$$L(M) = q_{\curvearrowright} H(Q) + \sum_{i=1}^{c} p^{i}_{\circlearrowright} H(P^{i}), \tag{1}$$

where, $q_{\curvearrowright}$ is the probability that a random walker moves to another community, $H(Q)$ is the average description length of the community index codewords given by the Shannon entropy, $p^{i}_{\circlearrowright}$ is the probability that a random walker in community i will stay in the same community in the next step, $H(P^{i})$ is the entropy of the codewords in the module codebook i, and c is the number of communities.

2.3 Network centrality indices

Network centrality indices indicate the importance and influence of the nodes within a network[23]. Here, we measured two centralities, degree centrality and betweenness centrality, to clarify the company type that plays a central role in each supply-chain network community.

- Degree centrality
  Degree centrality is an index used to measure the centrality according to the number of links on each node[24]. Companies with a high degree centrality are likely to play a role in aggregating information in the supply-chain network because they hold numerous business relationships. To compare the degree centrality of different sized networks, normalization must be carried out by dividing the total degree of nodes by the maximum possible number of adjacent connections, $2(N-1)$. The degree centrality of a node i is defined by

$$x_i = \frac{k_i}{2(N-1)}, \tag{2}$$

  where, N is the number of nodes in the network and k_i is the number of degrees of node i.s

- Betweenness centrality
  Betweenness centrality is an index used to measure centrality according to the number of shortest paths passing through a node[25]. Companies with a high betweenness centrality act as connectors to connect network groups and, in a supply-chain network, they play the role of connecting companies with different roles. The betweenness centrality of a node i is defined by

$$x_i = \frac{\sum_{j=1(j\neq i)}^{N} \sum_{k=1(k\neq i)}^{N} \frac{n_{jk}(i)}{n_{jk}}}{N(N-1)}, \tag{3}$$

  where, n_{jk} is the number of shortest paths between nodes j and k, and $n_{jk}(i)$ is the number of paths that pass through node i among the shortest paths between nodes j and k. This was normalized by dividing the maximum number of pairs of nodes excluding the node itself.

2.4 Network topological characteristics

We used network topological characteristics to analyze the topological structure and the dynamics of each industry's supply-chain network. Here, we focused on average shortest path length, clustering coefficient, assortativity, and density for the directed graph.

- Average shortest path length
  The average shortest path length is given by the average number of the shortest paths for all possible pairs of nodes in the network. This presents an index that indicates how many companies are involved in producing goods in the supply-chain network. Given that the larger the average shortest path length is, the more companies are involved in manufacturing, this would indicate a costly supply chain[26]. The costs here include time and transportation costs. The average shortest path length R is defined by

$$R = \frac{\sum_{i=1}^{N} \sum_{j=1(i \neq j)}^{N} d_{ij}}{N(N-1)}, \tag{4}$$

  where, d_{ij} is the average shortest path length between nodes i and j.

- Clustering coefficient
  The clustering coefficient is used to measure how connected a node's neighbors are to one another[27]. Within the social network context, this can be explained as "the friend of your friend is also likely to be your friend". The cluster coefficient of a certain node i defined by

$$c_i = \frac{L_i}{k_i(k_i - 1)}, \tag{5}$$

  where, $k_i(k_i - 1)$ is total number of possible connections between the neighbors of node i, and L_i is the actual number of links among the neighbors of node i. The clustering coefficient C of an entire network is the average of the clustering coefficient of all nodes i. C is defined by

$$C = \frac{\sum_{i=1}^{N} c_i}{N}. \tag{6}$$

- Assortativity
  Assortativity indicates the similarity among the connections in the graph with respect to the node degree. If a node is connected to nodes with degree values similar to its own, the network is assortative, and its assortativity is close to 1, while if the opposite is the case, the network is disassortative, and its assortativity is close to -1. It is well known that biological networks tend to be disassortative, while social networks tend to be assortative. In the case of an assortative network, the damage to the network due to the removal of the hub node will be small, but in the case of a disassortative network, the removal of the hub node may cause significant damage to the network[28]. The hub node is a node that has many links.

- Density
  The density is calculated according to the proportion of the actual number of links in a graph within the maximum possible number of links and indicates how closely the entire network is connected. The density D of a network is defined by

$$D = \frac{m}{N(N-1)}, \tag{7}$$

  where, m is the actual number of links in a graph.

2.5 Network robustness

To measure network robustness, we applied percolation theory to the supply-chain network concept. Percolation theory informs us how many nodes must be removed for breaking down the network into isolated elements and is used to describe the stability of a system in terms of disturbances[28]. In the case of a supply-chain network, the robustness corresponds with measuring the stability of the system in terms of economic crisis. In this study, we simulated two types of attacks: random failure and target attack. In the random failure simulation, we randomly selected and removed certain sets of nodes from the network, while for the target attack simulation, we removed specific sets of nodes in order of decreasing centrality. Here, two types of centrality, degree centrality, and betweenness centrality, were sumulated. We could then measure the change in size of the largest connected component to determine the robustness.

2.6 Bow-tie decomposition

Bow-tie decomposition is widely used to understand the flow structure of various complex networks, such as hyperlink networks on the web[29] and metabolic networks[30]. Here, macroscopic flow structures of the graph were obtained to decompose the graph into components according to the connectivity of its nodes, i.e., each node was assigned to a given component according to its reachable nodes set. To clarify the bow-tie structure from the directed network G, we first referred to the undirected graph obtained by G without direction of its links. Assuming this graph is G^*, all nodes in G are classified as one of the following components:

- SCC: nodes in the largest strongly connected component of G.
- IN: nodes reachable to SCC, but not from SCC.
- OUT: nodes reachable from SCC, but not to SCC.
- TENDRIL: nodes not in the previous categories, reachable to OUT (OUT TENDRIL), or reachable to IN (IN TENDRIL), but not both.
- TUBE: nodes reachable from IN and to OUT, but not SCC.
- OTHER: nodes not connected to G^*

Each component makes different contributions to the network in terms of economic activity, while the SCC plays a central role here. All industries in the specific economy are closely connected, and the growth of the core industries may have greater significance for the growth of the economy compared with that of the peripheral industries[31].

3 Results

3.1 Communities of Kyoto's traditional craft industry

First, we calculated the degree distribution to better understand the trends of the Kyoto supply-chain network. As shown in Fig. 1, it was confirmed that both in and out degree distribution is a scale-free network where the tail of the distributions is characterized by a power law of the form $P(k_{in/out}) \sim$k$^{-\gamma_{in/out}}$ with $\gamma_{in} = 2.34$ and $\gamma_{out} = 2.38$ respectively. The power law tail of the degree distribution is also presented in the past research of the empirical supply chain network[32][33]. Following this, we identified the communities of the supply-chain network in Kyoto's traditional craft industry using a map equation and subsequently the 79,678 companies related to Kyoto into 1,212 communities. Each community has a hierarchical structure, which consists of subcommunities in a lower hierarchical layer. Table 1 shows the detail results of the 20th largest communities in 1st level communities. There are two communities that are by far the largest. The community of index 2 is the largest community and the main sector of the community is manufacturing sector. In the second largest community, mainly construction sector was observed. From the hierarchical structure, we chose three communities as representatives of Kyoto's traditional craft industry as a whole: the Nishijin silk fabrics industry, the Kyoyuzen dyeing industry, and the Kyoto doll industry. The traditional craft industry communities were established by identifying the communities to which the companies of each traditional craft association list belong[34][35][36][37][38][39][40][41]. Figure 2 shows the embedding of all three industries within Kyoto's supply chain network as a whole. Subcommunity 4-1 is identified as the Nishijin silk fabrics indutry, while subcommunity 4-6 corresponds to the Kyoyuzen dyeing industy and subcommunity 4-25 to the Kyoto doll industry. Here, a-b means that community a includes subcommunity b. It can be seen that the traditional craft industry exists within the same first level community. To compare the traditional craft communities, we also analyzed the supply-chain network of Kyoto's leading industries, including the consumer games industry(subcommunity 14-1), the electric machinery industry(subcommunity 2-18), and the civil engineering industry(subcommunity 1-115). Figure 3 shows the network structures for Nishijin silk fabrics industry (left), Kyoyuzen dyeing industry (center), and Kyoto doll industry(right). The disassortative nature is clearly observed for Kyoyuzen dyeing and Kyoto doll industries.

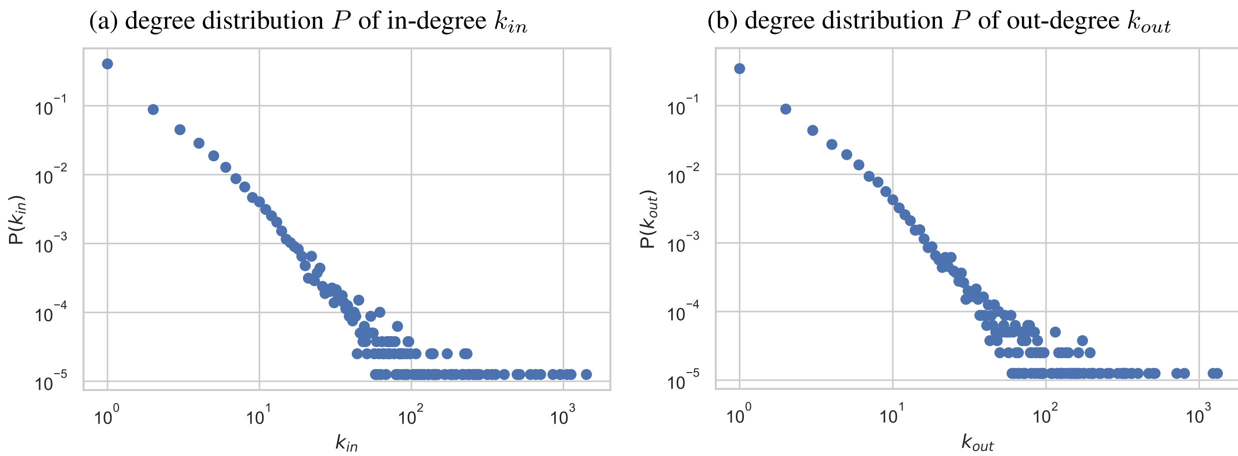

Figure 1: **In- and out- degree distribution of Kyoto's supply-chain network.** Logarithmic binning of the horizontal and vertical axes is used in (a) and (b). The power law tail of the degree distribution can be observed here.

Table 1: **Overview of the 1st level communities.**

Index	Size	Sector
1	16911	Construction(0.57), Wholesale and retail trade(0.16)
2	17892	Manufacturing(0.44), Wholesale and retail trade(0.3)
3	9664	Wholesale and retail trade(0.44), Manufacturing(0.27)
4	5911	Wholesale and retail trade(0.6), Manufacturing(0.25)
5	2866	Medical, health care and welfare(0.32), Wholesale and retail trade(0.3), Manufacturing(0.18)
6	3630	Wholesale and retail trade(0.37), Transport and postal activities(0.21), Manufacturing(0.12), Services, N.E.C.(0.1)
7	4262	Manufacturing(0.39), Wholesale and retail trade(0.27)
8	5089	Wholesale and retail trade(0.36), Transport and postal activities(0.23), Manufacturing(0.13)
9	837	Wholesale and retail trade(0.42), Manufacturing(0.27), Construction(0.11)
10	1220	Wholesale and retail trade(0.41), Manufacturing(0.4)
11	2003	Construction(0.44), Wholesale and retail trade(0.32), Manufacturing(0.15)
12	677	Manufacturing (0.44), Wholesale and retail trade (0.35)
13	1189	Wholesale and retail trade(0.72), Manufacturing(0.11)
14	547	Wholesale and retail trade(0.35), Information and communications(0.3)
15	437	Living-related and personal services and amusement services (0.27), Wholesale and retail trade(0.24), Manufacturing (0.15), Construction(0.1)
16	285	Construction (0.28), Real estate and goods rental and leasing (0.2), Services, N.E.C.(0.14), Wholesale and retail trade(0.11)
17	340	Construction (0.38), Wholesale and retail trade (0.2), Manufacturing (0.13)
18	522	Wholesale and retail trade(0.46), Living-related and personal services and amusement services(0.26), Manufacturing (0.1)
19	413	Wholesale and retail trade(0.52), Living-related and personal services and amusement services(0.28), Manufacturing (0.12)
20	124	Wholesale and retail trade (0.26), Manufacturing (0.14), Information and communications(0.1), Scientific research, professional and technical services(0.1), Services, N.E.C.(0.1)

The overview of the 20th largest communities in the 1st level. "Size" is the number of firms that the community has. The percentage of nodes classified with a particular industry sector is shown in parentheses. This classification is based on Japan Standard Industrial Classification, November 2007, Revision 12. Those with less than 0.1 are not listed.

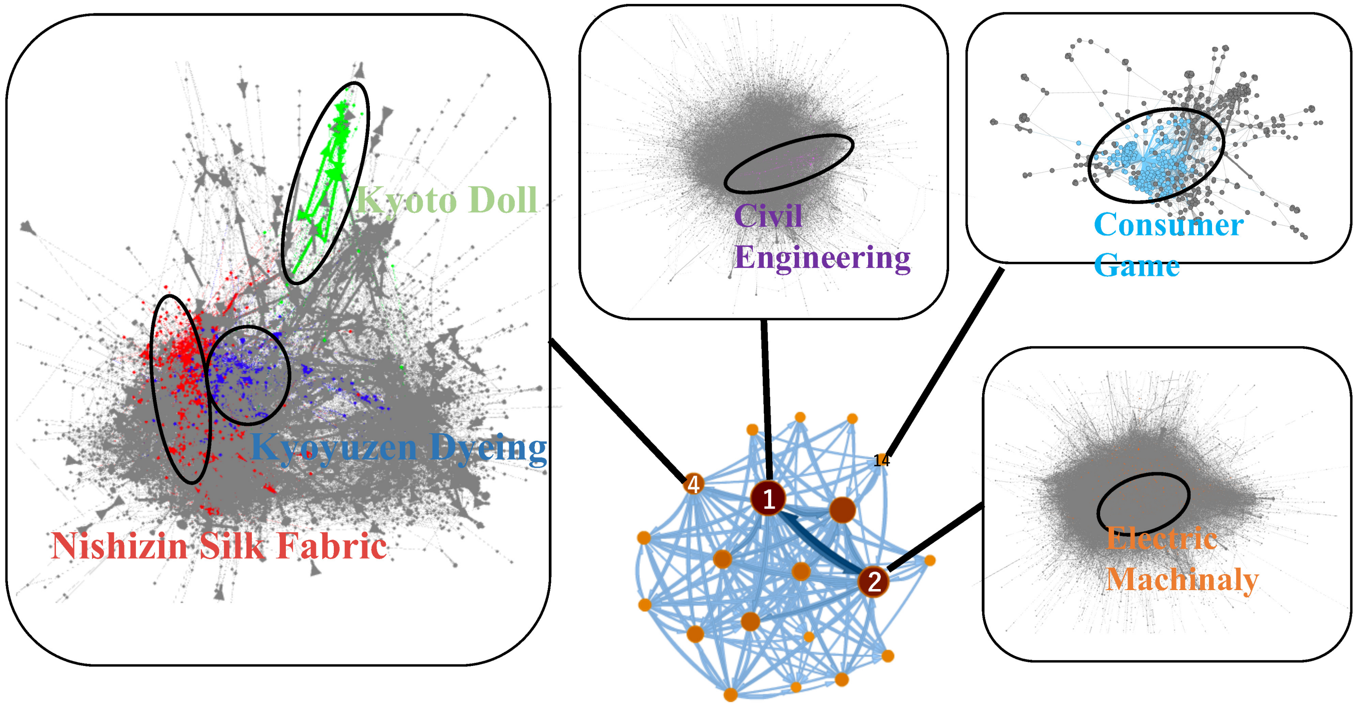

Figure 2: **Community structure of Kyoto's supply-chain network.** The network below the center represents Kyoto's supply-chain network. Here, the nodes represent a first-layer community. Of the 1,212 communities, only the largest 20 are described. The highlighted community is the community we analyzed. The nodes of the highlighted community network are firms.

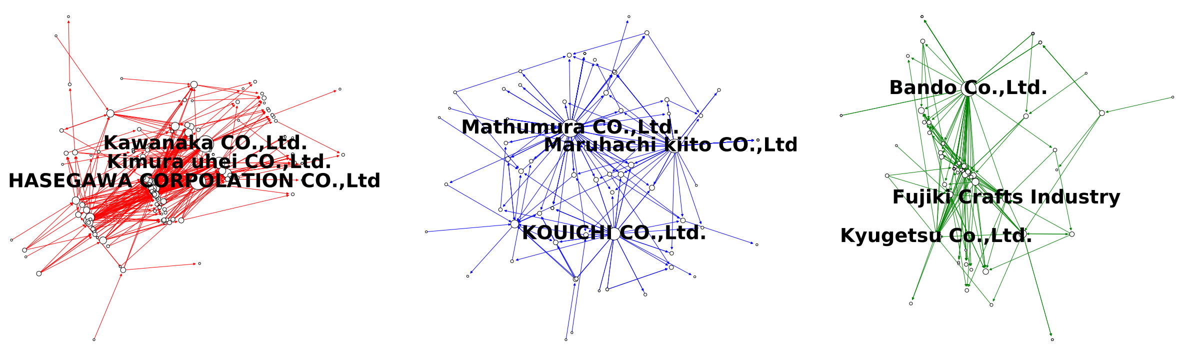

Figure 3: **Network structure of Kyoto's traditional craft industries.** The communities of Kyoto's traditional craft industries are extracted from the supply-chain network. The network structures are shown for Nishijin silk fabrics industry (left), Kyoyuzen dyeing industry (center), and Kyoto doll industry(right). The name of the three companies with the highest degree centrality are written for each industry. The disassortative nature is clearly observed for Kyoyuzen dyeing and Kyoto doll industries.

3.2 Key firms in the selected subcommunities

By identifying the nodes that play a central role in the network, we could clarify the key firms in the supply-chain networks of each of the selected subcommunities. Figures 4 and 5 show the centrality and business type of the top 10 firms with high degree centrality and betweenness centrality. The results indicated that the consumer games, electric machinery and civil engineering communities are the networks where the most central players play a significant role. The most central firm of these communities has around 0.5 degree centrality, indicating more than half of firms in the community have supplier or customer relationship with the firm. However, the business type of the central players is different. In the consumer games and electric machinery communities, the most central player is manufacturer, while in civil engineering community, the wholesaler that sells the equipment and materials is the central player. It is also clear that the consumer games and electric machinery communities have a centralized production system. Compared to such communities, traditional craft communities have no outstanding central companies and thus represent a decentralized supply chain. Characteristically, the most central firm in all the traditional craft communities is the wholesaler in contrast to consumer games and electric machinery communities. The fact that the wholesalers have many business relationships indicates that the roles of wholesale and manufacturing are clearly divided in Kyoto's traditional craft industry. As for betweenness centrality, there are only firms with less than 0.1 betweenness centrality in Nishijin silk fabrics and Kyoto doll communities, suggesting these communities have no firms responsible for aggregating information and managing the entire supply chain.

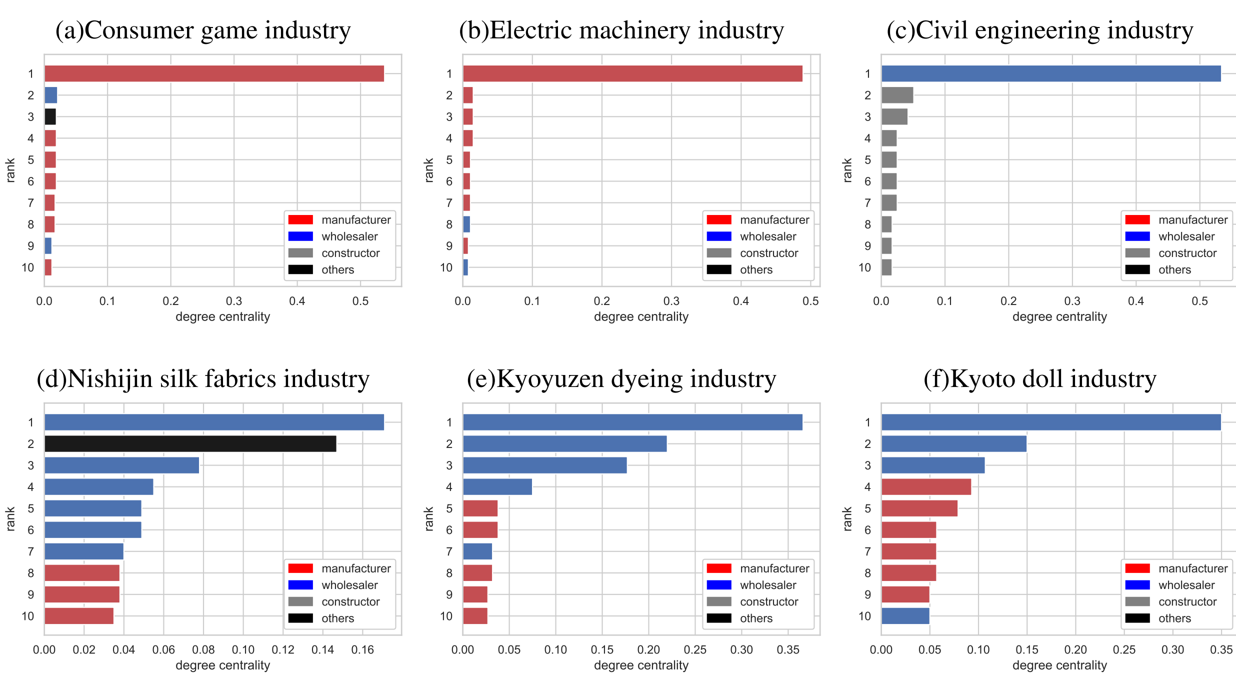

Figure 4: **Degree centrality of Kyoto's supply-chain network.** The color of the bar distinguishes the business type, with red, blue, gray, and black designating manufacturer, wholesaler, constructor, and others, respectively.

Figure 5: **Betweenness centrality of Kyoto's supply-chain network.** The color of the bar distinguishes the business type as with Fig. 4.

3.3 Topological characteristics of the selected subcommunities

Table 2 presents the topological characteristics of the selected subcommunities. The assortativity is negative in all the communities, i.e., the nodes that have many links tend to be connected to nodes that have fewer links. The supply-chain network is considered a network with relatively poor robustness in terms of the removal of any hub nodes from the network. With regard to the average shortest path length, all communities we analyzed has a value between 2.0 and 3.0 and there seems to be little difference between communities. However, the feature of the network of each community varies, we had to be cautious when comparing the topological characteristics. For this reason, the network quantities were calculated for networks with a degree-preserving randomization of each community; these are shown in parentheses. Compared with the networks with degree-preserving randomization, the communities of contemporary industries have a almost same average shortest path length, while those of the Nishijin silk fabrics and Kyoto doll communities are short, indicating the Nishijin silk fabrics and Kyoto doll communities have low cost supply chain structure. In addition, the traditional craft communities have a fairly low clustering efficient compared to the networks with degree-preserving randomization, suggesting these communities don't have a structure in which information is efficiently shared, but are divided.

Table 2: **Comparison of traditional industries with contemporary industries.**

	Kyoto traditional craft industries			Contemporary industries		
	Nishijin silk fabrics	Kyoyuzen dyeing	Kyoto doll	Consumer games	Electric machinery	Civil engineering
Number of nodes	174	94	71	212	132	60
Number of links	416	186	161	325	150	76
Assoratativity	-0.350 (-0.209)	-0.595 (-0.463)	-0.454 (-0.409)	-0.564 (-0.564)	-0.681 (-0.677)	-0.741(-0.738)
Average path length	2.38 (4.19)	2.99(2.66)	2.24(3.05)	2.05(2.07)	2.15(2.04)	2.04(2.054)
Clustering coefficient	0.00344 (0.086)	0.0301 (0.254)	0.0518 (0.216)	0.101 (0.191)	0.0344 (0.0565)	0.0394 (0.12)
Density	0.0137 (0.0137)	0.0208 (0.0208)	0.0315 (0.0315)	0.0072 (0.0072)	0.00854 (0.00854)	0.0207 (0.0207)

The network quantities calculated for networks with degree-preserving randomization are in parentheses.

3.4 Robustness of the selected subcommunities

The robustness of the network is an extremely important factor for the traditional craft industry, where the number of companies is declining rapidly. Figure 6 presents the results of the random failure simulation. Here, the random failure is assumed to emulate bankruptcy in an economic crisis. The simulation shows the change in size of the largest connected component when sets of nodes are randomly deleted from the network. The size of the largest connected component is average number of 1,000 trial of random failure simulation. The supply-chain networks of the Nishijin silk fabrics and Kyoto doll industries are the most robust, followed by that of the Kyoyuzen dyeing industry. The traditional crafts industry's supply-chain network is making it possible to build a supply chain that is resilient to economic crises and bankruptcy. Figure 7 shows the results of the target attack simulation. Here, the target attack is assumed to emulate the bankruptcy that occurred due to successor issues and corporate takeover involving subsequent corporate restructuring. Compared to the random failure simulation, the size of the largest component decreased much faster in the target attack simulation. The analysis also demonstrates that the supply-chain networks of the traditional craft communities are more robust than those of communities of more contemporary industries. The decentralized supply-chain network of the traditional craft communities may have contributed to the robustness of these industries.

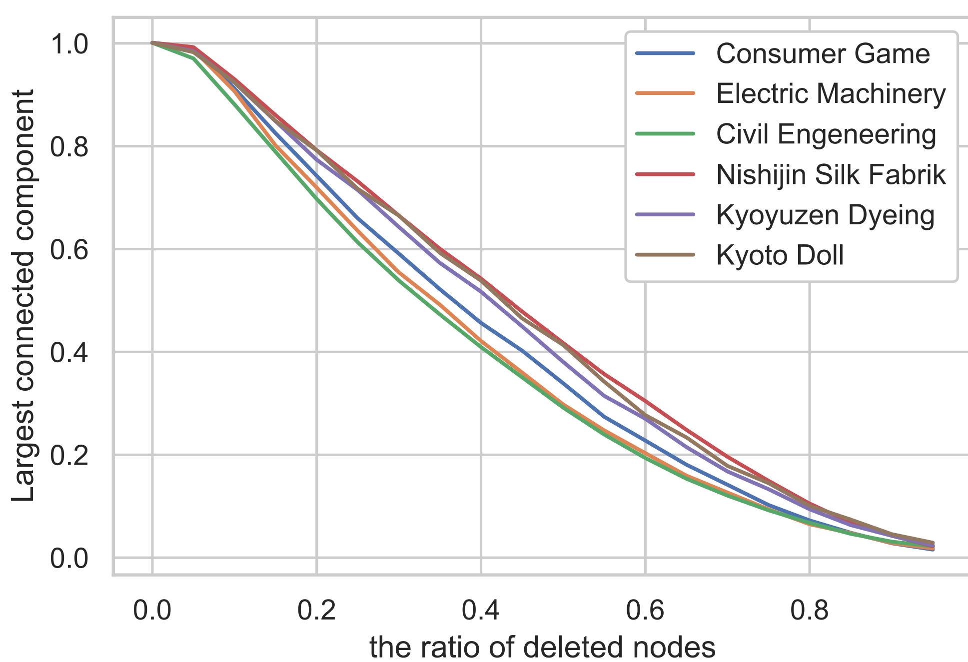

Figure 6: **Random failure simulation.** Response of the selected subcommunities to random failure; the size of the largest connected component is plotted against the percentage of nodes removed from each network.

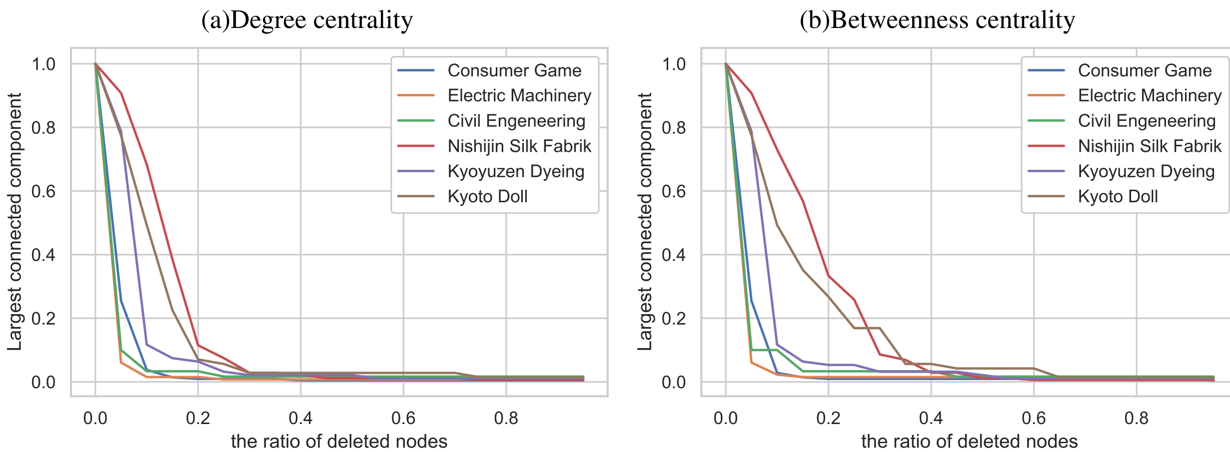

Figure 7: **Target attack simulation.** Response of the selected subcommunities to target attack; the size of the largest connected component is plotted against the percentage of nodes removed from each network. Here, we removed specific sets of nodes in order of (a) decreasing degree centrality and (b) decreasing betweenness centrality.

3.5 Profitability and productivity in bow-tie structure

3.5.1 Bow-tie structure of Kyoto's supply-chain network

Figure 8 presents the distribution of the firms in each bow-tie component when Kyoto supply-chain network is decomposed into a bow-tie structure. The distribution is significantly different from the well-known distribution of firms in the bow-tie components of the hyperlink network on the web. The hyperlink network has 27.74% of nodes in the SCC category and 8.24% of nodes in the OTHER category, while IN, OUT, and TENDRIL have similar figures (21.29%, 21.29%, and 21.52%, respectively)[29]. Meanwhile, the largest component of Kyoto's supply-chain network is the OUT component (38.84%), followed by IN (29,67%), SCC (16,57%), OUT TENDRIL (6.41%), OTHER (4.74%), IN TENDRIL (3.39%), and TUBE (0.36%). These figures also differ from those related to the Japanese supply-chain network analyzed in a previous paper[18], which indicated that half of the firms were in the SCC category. This difference is due to the extraction of Kyoto's firms, where we not only used the firms in Kyoto but also those that have a supplier-customer relationship with these firms. As shown in Fig. 8, the SCC category accounts for the largest number of firms in Kyoto, while IN and OUT account for many firms in the other regions. It is clear that Kyoto firms hold a great number of transaction relationships with the OUT side and that they play a role in supplying many products to other prefectures.

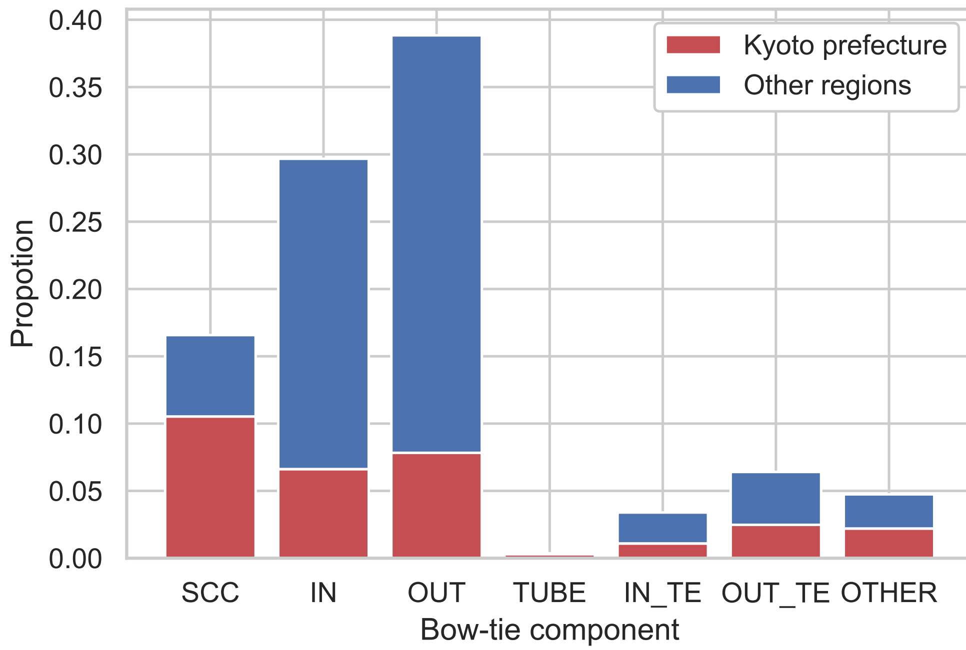

Figure 8: **Distribution of firms in each bow-tie component of Kyoto's supply-chain network.** "Proportion" refers to the ratio of the number of firms to the total number of firms in the largest weekly connected component in Kyoto's supply-chain network. The color of the bars denotes where the firms are located, with red designating Kyoto prefecture and blue the other regions.

Figure 9 presents the profitability and productivity of the bow-tie components in Kyoto's supply-chain network. Profitability is the ratio of profit to revenue, while productivity is the profit per employee. We calculated the values using the data related to profit, sales, and number of employees in the TSR dataset. In terms of profitability, there was little difference between the components, but the values for IN was slightly lower and that for SCC was the highest among SCC, IN, and OUT. There was a similar tendency in terms of productivity. In Kyoto's supply-chain network, the firms that distribute in a loop structure that forms the core of the network operate more efficiently and more effectively than firms in the IN category that supply products to Kyoto.

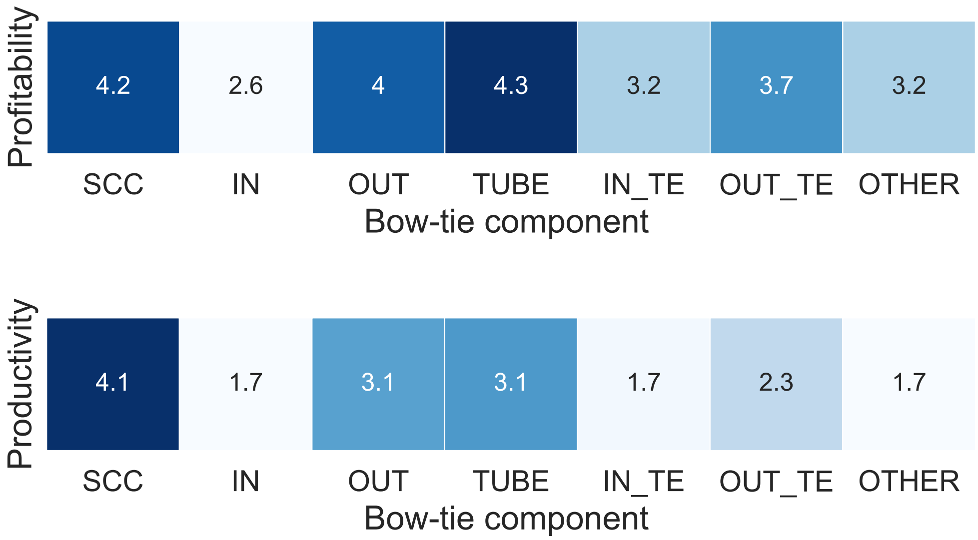

Figure 9: **Profitability and productivity of the bow-tie components in Kyoto's supply-chain network.** The unit of productivity is million JPY. SCC has the highest and IN the lowest value among SCC, IN, and OUT.

3.5.2 Bow-tie structure of the selected subcommunities

Figure 10 presents the distribution of the firms in each bow-tie component of the selected subcommunities. The aim of this analysis was to infer the role of each selected subcommunity within Kyoto's supply-chain network and to reveal the flow structure of each community's supply-chain network. The results indicate that more nodes are distributed in the IN category for the consumer games, electric machinery, and civil engineering communities, the SCC for the Nishijin silk fabrics and Kyoyuzen dyeing communities, and the OUT for the Kyoto doll community. The Nishijin silk fabrics and Kyoyuzen dyeing communities are located in the loop structure of Kyoto's supply-chain network, indicating that these industries play an important role in Kyoto's economy and are relatively independent of other regions. This suggests that the decline of these industries could have a negative effect on Kyoto's economy as a whole. Meanwhile, the bow-tie structure of each industrial community reveals that while almost all the nodes in consumer games, electric machinery, civil engineering, and Kyoyuzen dyeing communities are located in the SCC, IN and OUT categories, the nodes in the Nishijin silk fabrics and Kyoto doll communities tend to be located in the peripheral components. These communities have an extremely small loop structure, that is, there is no feedback loop among the companies in these communities.

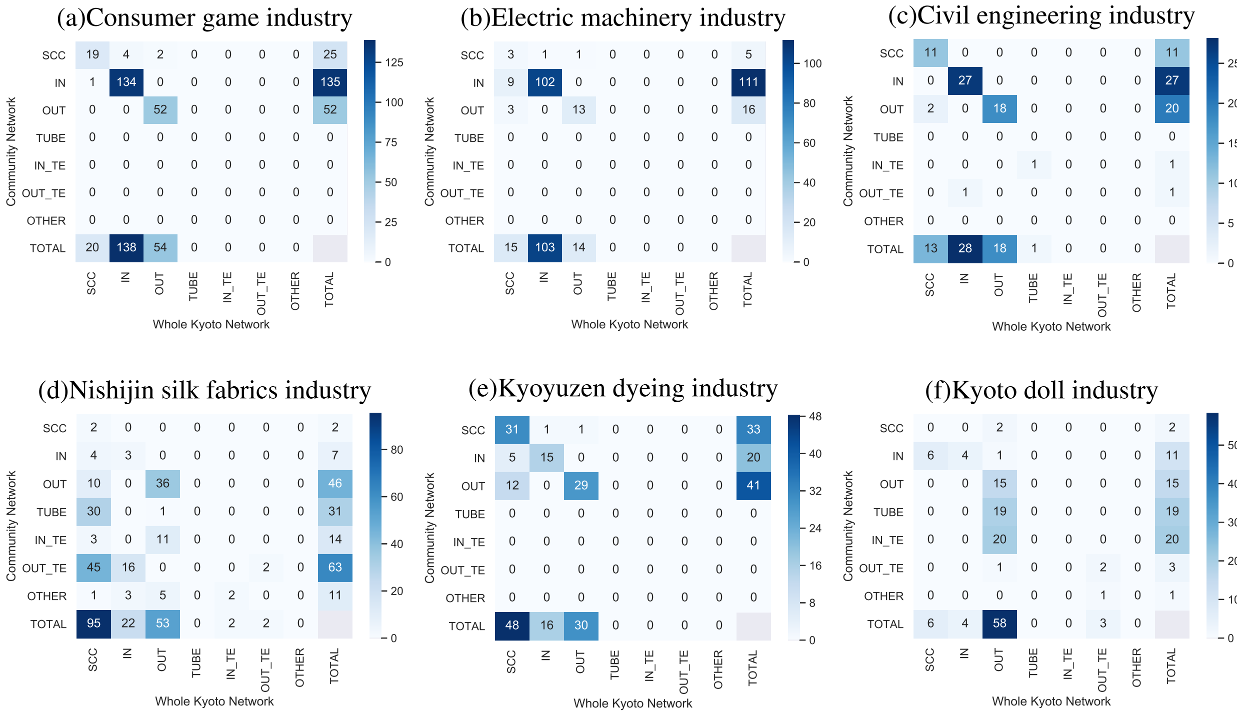

Figure 10: **Distribution of firms in each bow-tie component of the selected subcommunities.** The numbers represent the number of firms. The Nishijin silk fabrics and Kyoto doll communities have a relatively small number of firms in SCC.

The profitability and productivity of each bow-tie component of the selected subcommunities are shown in Fig. 11 and 12, respectively. On examining the profitability and productivity of each industry as a whole, it is clear that the consumer games community has the highest profitability and productivity, followed by the electric machinery community. These industries present relatively efficient economic activities and are producing high value added compared to other industries. What these two communities have in common is that the nodes in the SCC category have high profitability and productivity within the industrial community. The core firms of the community create a great deal of value added, which has a positive effect on the entire industry. However, it cannot be argued that the traditional craft industry has nodes that have high profitability and productivity in the SCC category, and it is clear that they may not be able to add value in the core loop structure of the economy. In addition, despite the fact that many firms of the Nishijin silk fabrics community are located in the SCC category in Kyoto's supply-chain network, its total profitability and productivity is negative, which indicates that improving the business situation of the Nishijin silk fabrics industry is important for Kyoto's economy as a whole.

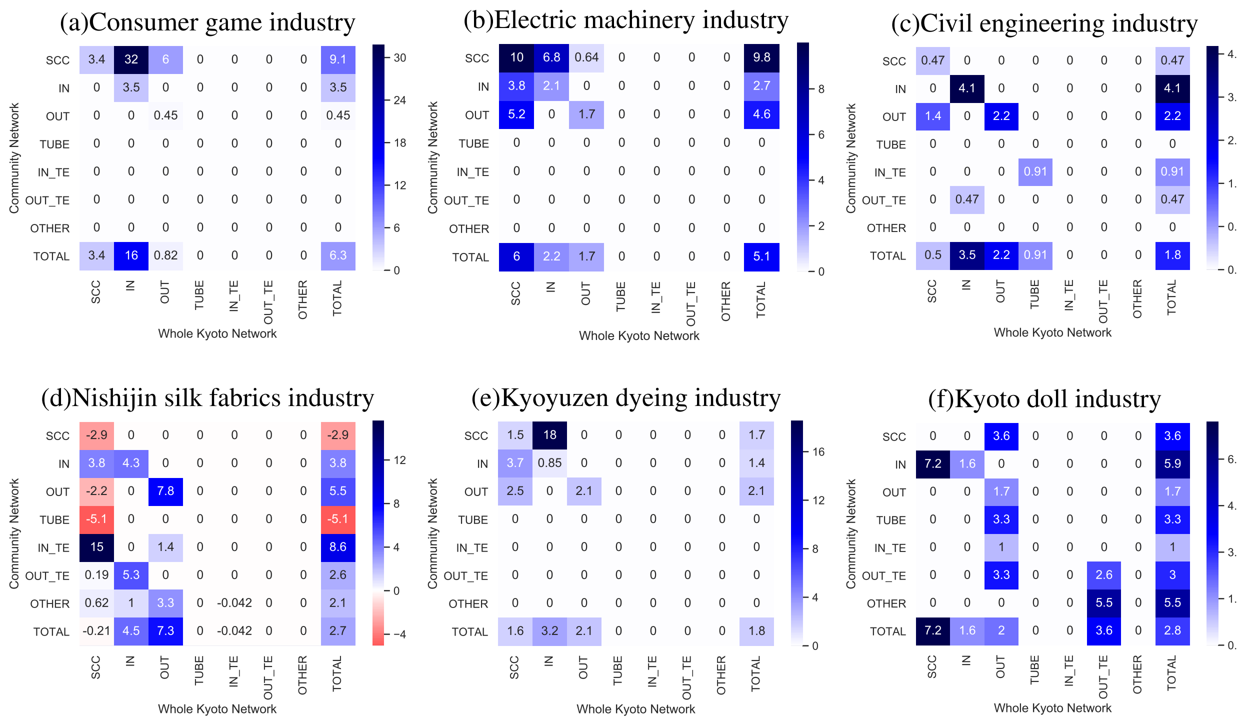

Figure 11: **Profitability of each bow-tie component of the selected subcommunities.** The firms in SCC have high profitability within the consumer games and electric machinery communities.

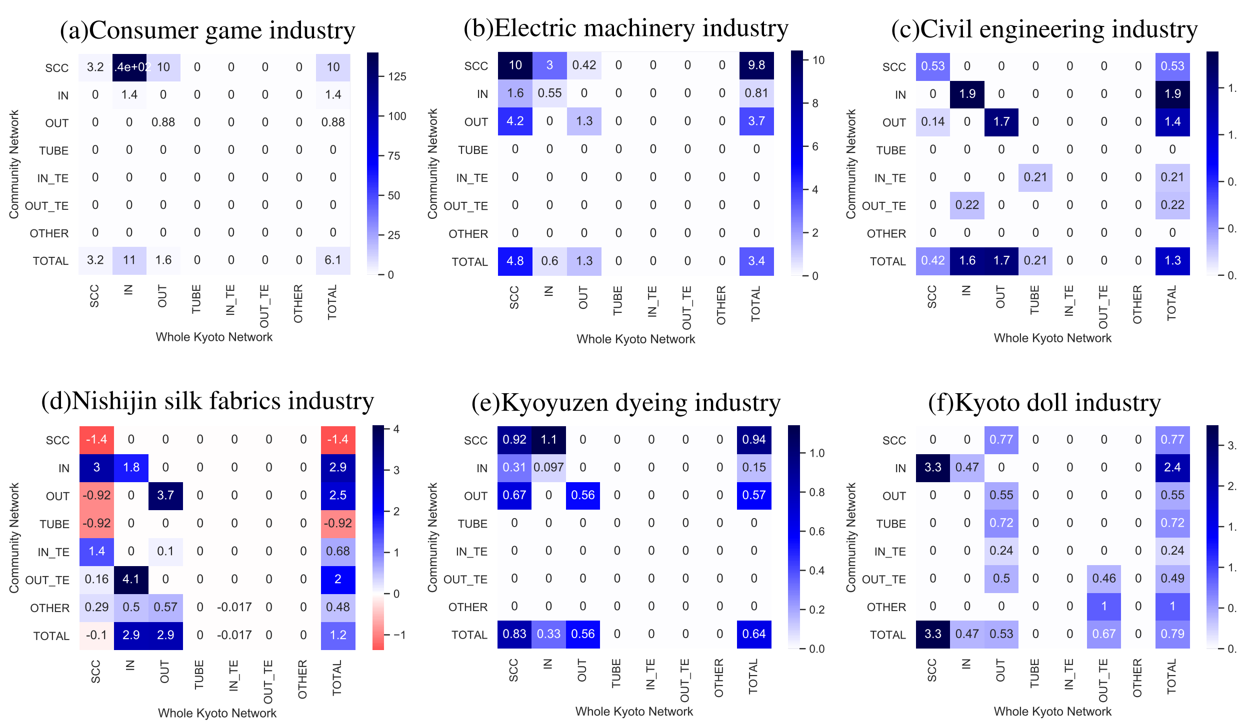

Figure 12: **Productivity of each bow-tie component of the selected subcommunities.** The unit of productivity is million JPY. The firms in SCC have high productivity within the consumer games and electric machinery communities.

4 Discussion

The findings from this study are summarized as follows.

- The Nishijin silk fabrics, Kyoyuzen dyeing, and Kyoto doll communities all belong to the fourth largest community in the Kyoto's supply-chain network.
- The consumer games and electric machinery communities have high-centered manufacturing firms.
- The Nishijin silk fabrics, Kyoyuzen dyeing, and Kyoto doll communities are relatively decentralized in firm's centrality, with a high degree centrality in wholesale rather than manufacturing firms.
- The Nishijin silk fabrics, Kyoyuzen dyeing, Kyoto doll, consumer games, electric machinery, civil engineering communities are disassortative.
- The average shortest path of Nishijin silk fabrics and Kyoto doll communities are short length compared to the networks with degree-preserving randomization.
- Compared to the networks with degree-preserving randomization, the clustering coefficients are much lower for Nishijin silk fabrics, Kyoyuzen dyeing, and Kyoto doll communities.
- Kyoto's traditional industries have a robust network that is more resistant to firm bankruptcy than modern industries.
- The SCC component has high profit margins and productivity in the Kyoto's supply-chain network.
- Consumer games and electric machinery communities are more profitable and productive than other communities of the Nishijin silk fabrics, Kyoyuzen dyeing, Kyoto doll, and civil engineering industries.
- Companies belonging to the SCC component in the consumer games and electric machinery community are highly profitable and productive.
- Nishijin silk fabrics and Kyoto doll community do not have the SCC component.

From the community analysis and the bow-tie structure analysis, it became clear that the traditional craft industry continues to play an important role in Kyoto's supply-chain network. In addition, it was found that the traditional craft industry has a markedly different network structure to more contemporary industries such as the consumer games and electric machinery industries.

According to the centrality analysis, the consumer games and electric machinery industries, which are the leading industries in Kyoto, have established a central production structure in which a single manufacturer has an unparalleled centrality. Such a structure is considered to be an advantageous structure for responding to a rapidly changing market because one company has a consensus on manufacturing and manages every aspect from production to sales, which enables the manufacturers to directly capture the consumers' needs and immediately respond to them. In contrast, the traditional craft industry has a clear division of labor throughout the entire process, where the wholesale companies continue to play a central role. Such a structure is regarded as having been formed in an age in which good-quality products always sold out.

On examining the results related to the network topology characteristics, it became clear that the traditional craft communities have low cluster coefficients compared with networks with degree-preserving randomization. The traditional craft industry also has issues in terms of exchanging information, while the innovative industry has a dense structure with a high cluster coefficient[42].

Furthermore, more contemporary industries have a core loop structure within the industrial community, with the attendant companies creating high value added and playing a major role in driving the entire industry. In contract, the Nishijin silk fabrics and Kyoto doll industries do not have a core loop structure and have thus not been able to create a feedback loop for the entire industry.

5 Conclusion

The division of labor, manufacturing equipment, know-how, and skilled workers of the traditional craft industry in Kyoto have not allowed the industry to respond to the changes in market structure or to technological innovation. We designated Kyoto's traditional crafts industry as a supply-chain network formed by interfirm transaction relations to elucidate its characteristics and the reasons behind the decline of the industry from a network theory perspective. The extensive dataset of interfirm supplier-customer relations related to Kyoto allowed us to analyze the structure of the traditional craft industry in relation to those of other industries. Specifically, we focused on the community structure, the bow-tie structure, the robustness, and the vulnerability of the supply chain network as key factors for sustainable growth.

The results of these analysis summarized in the previous section imply that the one of the issues lies in the fact that the traditional craft industry in Kyoto does not have a structure to integrate information that will allow it to respond to the markets. To take advantage of the strength of a region-based industry, it is important that Kyoto's traditional craft industry creates a production system that accurately reflects the voice of the consumer and carries out its manufacturing in close collaboration with the industry as a whole. For instance, if there is a place where each artisan can disclose his or her skills, there is a possibility that artisans who have not had any business relationship with each other will be connected, leading to the planning and production of new crafts in collaboration with the wholesale companies. This measure will help build a dense supply chain by increasing the cluster coefficient within the industry, which will contribute to the revitalization of traditional craft industries in Kyoto.

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Data Availability Statement

The TSR Company Profile Data File and the TSR Business Linkage File that the authors have used in this study are maintained by Tokyo Shoko Research (TSR), and are not owned by the authors. Researchers can contact Tokyo Shoko Research to receive access to the data at Tokyo Shoko Research, Ltd., JA Bldg., 1-3-1 Otemachi, Chiyoda-ku, Tokyo 100-6810, JAPAN; Tel: +81 (0)3-6910-3142; Fax: +81 (0)3-5221-0712; Web: http://www.tsr-net.co.jp/ Data can be retrieved by contacting Tokyo Shoko Research. The authors did not have any special privileges to the data.

Authors' Contributions

DS provided key contributions in performing the network analysis and visualization and made a survey of the related work. YI supervised the project and conceptualized the network analysis and productivity/profitability analysis. SK brought invaluable knowledge on Kyoto's traditional industry. MS conceptualized the bow-tie structure analysis. All authors read and approved the final manuscript.

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