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# Power-Law and "Elite Club" in a Complex Supplier-Buyer Network: Flexible Specialization or Dual Economy?

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## Abstract

After the 1990s, original equipment manufacturers (OEM) as multinational conglomerates have become more powerful than ever, exerting control over their suppliers, owing in part to the advanced machining and information technologies. Is this a revival of the traditional Marxian framework, or a "dual economy"? Conducting network analysis of supplier-prime buyer relations among over 8,300 firms in an industrial district, we found not only structural properties of "flexible specialization" as a division of labor among dedicated small- and medium-sized suppliers but also an invisible "elite club" or cohesive core composed of extremely powerful OEMs plus their elite suppliers, employing analyses of cohesion and assortative correlation in the structural embedding. An overwhelming majority of the suppliers were not free from dependency upon the core in order to gain access to and social endorsement from the consumers, as substantiated by the overall power-law node links, against the claims of "flexible specialization." The present study suggests a "dual economy" not on the basis of firm size as traditionally claimed, but of competition to be suppliers of prominent OEMs in the acyclically hierarchical network, from the relational approach of network integration mechanisms, as a latent but decisive explanatory variable.



**Key Words**: Complex systems; dual economy; flexible specialization; industrial districts; network analysis; power-law; structural embedding

## 1. Introduction: "Dual Economy," Industrial Districts, and Complex Networks

In the traditional Marxian framework of the so-called "dual economy" perspective, firm size plays a decisive role in perpetuating the structural divide in the macro economy. This is due to availability of and access to crucial resources, such as financial capital and human resource that each of the manufacturing firms can mobilize. In effect, according to the theory, there are two different sectors in the economy: The primary core comprised of large firms that enjoy efficiency, productivity, security, social status, and high wages in good work conditions; and the peripheral secondary, composed of small- and medium-sized enterprises (SME) that are denied access to the affluence by the powerful large firms, being dependent upon and exploited by the latter (Averitt 1968; Edwards 1979). Accordingly, there are dual labor markets (Doeringer and Piore 1971).[1]

The vertical integration by large firms of the multidivisional form (M-form) was in fact a dominant paradigm of the twentieth-century American capitalism until the 1970s (Fligstein 1985). *Transaction cost economics* (TCE) (Williamson 1981) explained the advantage of the vertical integration, focusing on the transaction cost of the firms such as for monitoring of opportunism and information search under the *bounded rationality* (March and Simon 1958). Relying largely upon the coordination skills of the divisional managers within the firms, through the direct supervision of their own divisions as profit centers within the firm, the middle managers were seen to fill a critical role. This was to maximize the organizational profit, as the "visible hand" for the cognitively constrained CEOs who cannot monitor the entire organization directly from the corporate headquarters (Chandler 1962). In addition, *agency theorists* (Fama 1980) also accounted for an advantage of the M-form from financial perspectives, arguing that self-interest of the divisional managers should lead to a maximization of shareholder values. Given the appropriate incentive packages offered to those managers, firms are regarded simply as a "nexus of contracts" and residual claims, disregarding the fact that they are indeed social entities where people as stakeholders interact through a complex web.

A turning point from these rather under-socialized perspectives came with some empirical studies of organizations from social network approaches in the 1970s, when Granovetter, in an early first critique of TCE, argued that embedded relationships among trading partners is a better governance mechanism for the firms than the M-form structure, creating peer pressure that should discourage opportunism at the lower monitoring cost (1985), and generating more efficient information search mechanisms through the networks (1982). Many studies followed or rediscovered the importance of social capital (Coleman 1988; Dore 1983) as an articulation of embedded relationships that can facilitate churning and fusion of information and tacit knowledge within and across organizations (Eccles 1981; Nonaka 1994; Powell and Stuart 1996; Stinchcombe 1959).

A theoretical framework that articulated the advantage of SMEs over the large firms, as another critique of TCE, is "flexible specialization" theory (Piore & Sabel). From a network perspective, the theory contends that, as the so-called "information age" has rapidly grown since the 1980s, the speed of technological innovation has increased dramatically and markets have become much more uncertain, unpredictable, and volatile, due to constantly changing customers' tastes and demand for variations of quality products. In such relentlessly moving markets, nimble and flexible manufacturing systems in industrial districts, which function on the foundations of the division of labor among technologically specialized SMEs,[2] have a competitive advantage over the mass production system traditionally carried out by atomized, large firms with their M-form structure (Goodman and Bamford 1989; Lazerson 1995; Locke 1995; Putnam 1993; Pyke, Becattini and Sengenberger 1990; Sabel and Zeitlin 1997; Uzzi 1997).[3] These network perspectives offered drastically different images of SMEs embedded in their social capital as creative and innovative, being part of the advanced and efficient economy.

The new digital technologies after the 1990s, however, appear to have made the OEMs leaner, more efficient and more powerful than ever (Helper, MacDuffie and Sabel 2001), as they can leverage the collaborative arrangements with their SME suppliers as for "mass customization" or "diversified quality production" (Streeck 1992). The new manufacturing paradigm is distinct from both the mass production by large, atomized firms as an extension of Tayler's "scientific management" (1947 (1911)) on the one hand, and the variety-based flexible manufacturing for small volume production as conceptualized by "flexible specialization" on the other. In effect, large OEMs can organize an efficient flexible production system simultaneously for both volume and variety, formerly incompatible in terms of the production costs.

The notion of "transnational management," introduced by (Bartlett and Ghoshal 2000), became a popular term in the early 1990s in the management literature, presenting hopes and high aspirations to the SMEs in regional economies for the possibilities of truly collaborative arrangements with large conglomerates, on a global scale. The experience afterwards, nonetheless, seems quite disappointing for many SMEs that have worked for multinational conglomerates, because strategic decisions were confined in the hands of these headquarters as concerned a variety of quality control know-hows, advanced machining technologies, and information management systems rooted in the modern management science (Kristensen and Zeitlin 2005).

Thus, these recent developments in the regional manufacturing clusters have brought the old issue back into question—Is the "dual economy" thesis, once denied and largely forgotten as memories of the past with the widespread acceptance of network perspectives, including "flexible specialization," valid again in the age of the advanced manufacturing and information technologies? Moreover, is this a kind of exploitation of the retarded secondary economy by the efficient primary, or overwhelming advantage of the rich and powerful large firms at the expense and de-skilling of craft workers contained in the SMEs?

While many researchers have endeavored to articulate mechanisms of "flexible specialization" in various industrial districts and time periods, those studies had limitations. First, given the conceptual framework as the division of labor among technologically specialized SMEs through regional ties in rather cohesive networks, "flexible specialization" implicitly put focus on local structure, or the smaller parts of whole networks. It was conceptually beyond the scope to discuss global, or overall, integration mechanisms of complex networks.

Second, studies of regional interfirm networks relied mainly on qualitative research techniques in order to depict the structural integration mechanisms, and these findings have evoked considerable debate. Some insist that there are no universally applicable structural models of industrial districts. Paniccia (1998), for instance, argued that even in Italy where the research pioneers conceptualized and then empirically tested "flexible specialization" theory, there existed many different patterns and forms of industrial clusters across space and time. While those studies qualitatively provided rich details about the competitive advantage of the SMEs' social capital, they were not able to communicate systematically the structural mechanisms of interfirm networks in industrial districts.

Lastly, existing empirical investigations mainly studied smaller-scale industrial districts where either a single or relatively few industries were involved, leaving large-scale industrial districts largely outside the research area. These are systems whose complexity goes well beyond the egalitarian notion of "flexible specialization" to produce numerous parts, components, and modules for a variety of end products. The local SME suppliers should differentiate in the division of labor under the leading roles of organizing prime buyers, in the tiers of subcontracting networks that eventually lead to the top original equipment manufacturers (OEM) for the assembling work as hubs.[4]

In effect, the complex webs in large industrial districts are understudied, as both the rarity of such network datasets and the overwhelming complexities placed technical limitations on researchers wanting to carry out quantitative analysis of the interfirm networks. There is today a paucity of alternative theories available with which to explore and explain the network properties.

The objective of the present research, therefore, was to articulate, with the "dual economy" thesis as a point of reference, the network integration mechanisms whereby OEMs organize their suppliers as hubs by probing the complex web of supplier-prime buyer networks from the approach of large-scale network analysis. The project was an attempt to analyze these structural properties, full-fledgedly employing some of the recent innovations both in theory and analytical techniques in the area of quantitative network analysis. While past and current examples abound that are relevant to the study of complex interactive networks, still, for large-scale industrial districts, only a very few network studies have yet been made.[5]

Accordingly, the initial study question was set to find how the complex systems of regional interfirm networks function as structural mechanisms of large-scale "flexible specialization." How is the global structure of interfirm linkages in large-scale industrial districts—the overall structure of supplier networks as trade relationships—organized on the foundations of local structure? Can we find any clear structural cleavages in the regional economies when we test the dualism from a relational approach of network analysis?

The remainder of the paper begins with a brief overview of previous network literature and theoretical issues relevant to the study of industrial districts, followed by the research design and methodological issues, including data, concepts, and analytical tools applied from the study of social network analysis as a complex system. We end with a discussion of findings and their implications.

As a note, the present discussion uses "suppliers" and "subcontractors" in industrial districts rather interchangeably. It also employs such terms as "regional supplier networks," "suppler-prime buyer networks" and "subcontracting hierarchies" interchangeably to refer to hierarchical interfirm networks in large-scale industrial districts where the SME suppliers work for or with their prime buyers in various manufacturing activities executed in the regional economies. *Pajek* (Batagelj and Mrvar 2005) was used both to calculate network analytical measures and to draw graphs.

## 2. Data and Network Properties

### *2.1 Large-Scale Network and Regional Supplier-Prime Buyer Relationships*

The study of complex systems has gained attention in many academic disciplines since the late 1990s. In the area of knowledge management, for instance, Powell and his colleagues (2005) studied the recent co-evolution of cohesion and in recruitment of novelty in large-scale collaboration networks among firms in the life sciences. Padgett, Doowan and Collier (2003) simulate the co-evolution of firms in production and distribution markets, with firms as bundles of skills transformed by goods passing through them. In anthropology, a large-scale and diachronic analysis of marriage, sponsorship and elite networks in Mexico (White, Schnegg and Brudner 1999) found co-evolution of a distinctive cultural heritage with a two-level "invisible state" that bound together districts in a large geographic region.

Among the alternative models for complex interactive networks, studies of small-world (Watts 1999) and scale-free networks (Barabási 2002) represent breakthrough achievements that have drawn much recent attention. Many applications of the small-world model have been made recently, including Newman's study of scientific collaboration networks (2001), and organizational studies in the areas of corporate interlocks and governance structure (Davis, Yoo and Baker 2003; Kogut and Walker 2001; Robins and Alexander 2004), interfirm alliance formation and joint ventures (Baum, Shipilov and Rowley 2003), and emergence of industries (Uzzi and Spiro 2005).

While the study of complex networks has expanded rapidly and been fraught with debates over models and applications, it offers a variety of both analytical and conceptual tools that can be employed in order to unveil the structural properties in large-scale industrial districts.

### *2.2 Ohta Industrial District*

The present research studied a web of supplier-prime buyer relationships among manufacturing firms linked to Ohta, which is one of 23 wards in Tokyo, as one of the two largest industrial districts in Japan. Over 7,000 SMEs were engaged in a variety of manufacturing processing activities, parts, components, and modules production, and assembling work to compose a complex web of regional interfirm linkages. A majority of the SMEs had the size of a typical family household, or even smaller, in terms of the number of employees. The industrial district has been well known as a so-called machine-tools industry where the SMEs functioned as suppliers for leading Japanese OEMs in other applied industries.

At the time of the survey, in 1994-95, among over 7,000 manufacturing firms in the industrial district, a majority of firms were specialized in their own areas of processing activities. In particular, many firms were engaged in various metal-cutting processes. At the same time, a minority were suppliers of parts and components in areas such as automobile production, aerospace technologies, computer-related products, electrical and electronic equipment and devices, general industrial and precision machinery, jigs and tools, and shipbuilding, among other areas. Roughly only 10%-20% of suppliers that specialized in certain areas of processing and parts and components production had product lines of their own brands (Seki and Kato 1990).

To conduct the present network analysis, name-generating data from *Akusesu Data* (Ohta-ku Sangyo Shinko Kyokai 1997a; Ohta-ku Sangyo Shinko Kyokai 1997b) were used. The dataset encompasses approximately 70% of all manufacturing establishments in operation in Ohta-ward during the years of 1994-95. The questionnaire employed asked each of the roughly 7,000 SMEs located in Ohta-ward to list up to three names of their prime buyers. To be specific, among the 5,111 firms in Ohta from the dataset, 2,710 firms (53%) listed a total pool of 4,077 other firms as their prime buyers. Another 2,401 firms (47%) listed no prime buyers. Of the 5,111 SMEs that responded, 501 firms (9.8%) listed only one prime buyer; 530 firms (10.4%) only two; and 1,679 firms (32.9%) listed three names as their prime buyers. Of the 4,077 listed prime buyers, 841 were supplier-prime buyers located in Ohta, which were named by peer SME suppliers in Ohta, and 3,236 were prime buyers outside Ohta. The total number of firms in the dataset and included in the network was 8,347.[6]

### *2.3 Distribution of Node Links*

Node centrality has been a key analytical concept in social network analysis (Freeman 2004). The in-degree centrality score of a firm was determined by the aggregate number of times the 5,111 SME suppliers listed a given firm as one of their three prime buyers. Overall, no single firm constituted a hub that dominated the large-scale regional web, but some were marginally so. Toshiba was the most popular prime buyer, and 112 suppliers in Ohta listed Toshiba as one of their three prime buyers, while 53 listed NEC, 45 listed Hitachi, and so forth. There are many hubs along a gradient, not just one.

The "pecking order" for in-degree, including the frequency of ties to powerful OEMs, is consistent with the kind of power law that Barabási (2002) uses to characterize preferential attachments of ties to hubs proportional to degree in a scale-free network. The distribution of in-degree for all firms is plotted in Figure 1 on a double-logarithmic scale, and the slope ($\alpha \sim 2.3$) of the straight line that approximates the distribution ($y = 1539.4x^{-2.2862}$ and $R^2 = 0.8537$) is within the range of values ($\alpha \sim 1.8$ to 2.5) for scale-free preferential attachment networks of size 4-8,000 (White and Johansen 2005, p. 17).[7] Furthermore, the various indices of graph centralization for the largest component proposed by Freeman (1979)—degree, betweenness, and closeness centralization—are all extremely low, showing again no single dominant node to which most other nodes are directly connected.

A scale-free model of hub centralities rather than a single hub with spokes might be applicable as a model of a centralized network in Ohta, except for the fact that it is linkages *from* central nodes and not attachments to them that organize the network (author publication 2006 to be inserted after review). For example, in the subcontracting hierarchies in industrial districts, typically firms at high levels as hubs recruit and control their suppliers, and most suppliers largely follow their lead. Barabási overgeneralizes when he infers preferential attachment from fitting the slope of a degree distribution of this sort to a power law.

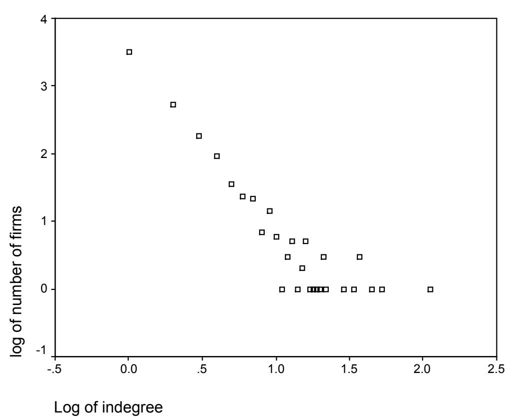



**Figure 1** A Power Law in Ohta.
Data was created from *Ohta-ku Akusesu Deta 1 & 2* (Ohta-ku Sangyo Shinko Kyokai 1997a; 1997b).

### *2.4 OEMs' Hierarchical Group Networks*

How can we identify subgroups of core firms, as local structures, embedded in a large-scale complex network? Egocentric networks give us a first approximation. The "competitive cooperation" conceptualized by "flexible specialization" as the division of labor among SMEs in regional networks in Ohta is illustrated, to a certain degree, by Figure 2. NEC's hierarchically organized "double hub-and-spoke" network structure extends to include 124 supplier firms at Tiers-1, -2 and -3. Ranked second in terms of in-degree from its 53 Tier-1 suppliers, as a leading OEM in Ohta, NEC uses local-core Tier-1 firms as assemblers or organizers of parts and components production. While the Tier-1 suppliers did not supply one another, each lower tier also uses independent subordinates as Tier-2 or lower in order to organize the division of labor among dedicated SME suppliers to work in various specialized areas. Similarly, to a certain degree, the supplier group networks of other large OEMs operate on the foundations of this kind of division of labor among specialized SME suppliers in their areas of technological competence, engineering knowledge, and workers' skills.

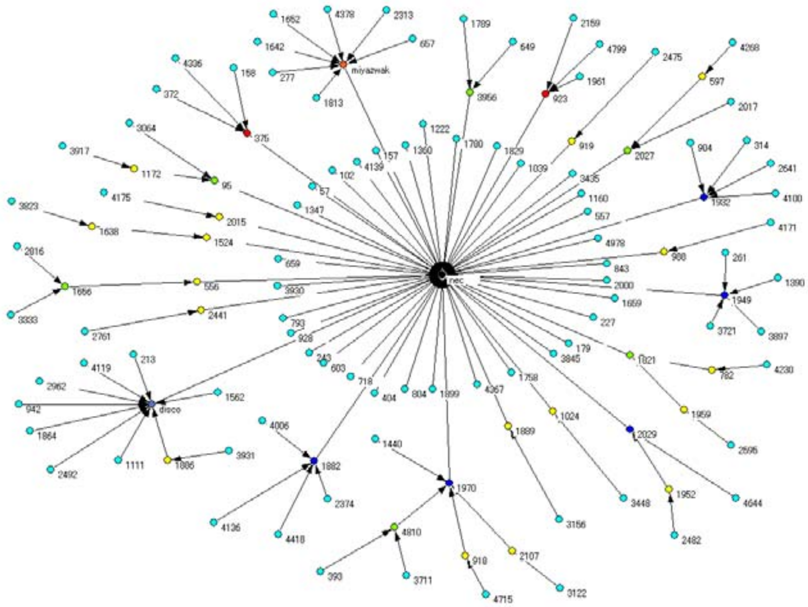


**Figure 2** NEC's Supplier Network in Ohta: A Local Structure.
Graph produced from data in *Ohta-ku Akusesu Deta 1 & 2* (Ohta-ku Sangyo Shinko Kyokai 1997a; 1997b). Colors by in-degree.

## 3. Network Integration Mechanisms in Ohta

### *3.1 Oriented Network and Components*

To introduce network analytical concepts, the links nominated by suppliers as to their prime buyers constitute a *digraph*, or *directed graph*, in which the directionalities of the links do not prevent links from being reciprocated. In fact, however, not a single pair of firms named one another as prime buyers. Hence, the network of firms constitutes an *oriented digraph* (Harary 1969: 10), or digraph in which no symmetric pair of directed links exists. Thus, the term *oriented network* can be used to describe this property of the subcontracting supplier-prime buyer network.

A *component* is a maximal connected sub-graph in which all the nodes are connected to one another through one or more non-directed paths. As any exchange of goods through directional ties is most likely to involve at least some communication, or two-way information exchange between the two partners (Freeman 1979; Hanneman 2001), weakly-connected components still bear social meanings even if they disregard the directions of ties. In the case of the Ohta's supplier networks, components should be composed of ties among connected suppliers, suppliers-prime buyers, and prime buyers.

To relate the above concepts to the analysis of the interfirm networks in industrial clusters, there are deep and extensive implications of the advancement in machining technologies after the 1990s on the network integration mechanisms in industrial districts. First, as the SMEs lack financial capital to invest in the very expensive high-tech equipments and advanced machining technologies, these SMEs as dedicated suppliers need to depend upon the controlling, powerful OEMs more than ever, belonging to the efficient but hierarchical production systems in order to get access to the advanced management science techniques and information technologies, such as concurrent engineering, just-in-time (JIT) inventory control, supply-chain management, and total quality control, among others.

Second, an emergent role structure in the production network appears to be institutionalized on the basis of the complex value-chain. Two kinds of division of labor should be embedded in the complex network as the enmeshed role structures: A horizontal configuration among suppliers organized by prime buyers or hubs, as suggested by “flexible specialization” theory; and vertical as linked flows of manufacturing processes, marketing and sales, and distribution stages. A series of horizontal division of labor among suppliers organized by hubs should be vertically linked or oriented as entangled chains of production flows towards the assembly work by OEMs,[8] as the emergence of a production hierarchy where the subsequent marketing and sales and delivery stages follow. While the consumer stands outside the set of linked manufacturing processes, the marketing and distribution stages by reputable large firms involve a redefinition of the categories and statuses of agents in exchange with their brand equity.

Thus, as each of the large-scale industrial districts is an extremely complex regional cluster of firms, a complex web of suppliers and prime buyers should form a large component that contains hierarchical properties. Therefore, the first hypothesis to test is as follows:

Hypothesis 1: In each of large-scale industrial districts, there should be a large component in existence where SMEs interact in order to form a division of labor under the lead of many OEMs or hubs

Consistent with this hypothesis, the largest component of 4,500 firms was identified. The operation created a simpler and somewhat reduced network, by excluding 3,847 firms disconnected from the component.

Hypothesis 2: The supplier-buyer relations within this component are hierarchical, due to the nature of the network as regional subcontracting system.

This second hypothesis is explored in the next section.

*3.2 Acyclic Depth Partition and DAG Structure in Ohta*

Why did the complex web of regional supplier networks generate such a giant component of 4,500 firms? How was it hierarchically organized through commodity chains and other network structures or processes? The Ohta supplier-prime buyer network has no reciprocated or symmetric links. In a separate paper (author publication 2006 to be inserted after review), we argued that the one-way directedness of supplier-prime buyer links is one of the fundamental characteristics of complex hierarchical subcontracting relationships as *large sparse networks* (LSN), with statistical evidence that these networks should generally take the form of *directed acyclic graph* (DAG), based on our empirical study of the Ohta industrial district and comparative observations on modern industrial districts.[9]

To elaborate on some of the global properties, an *acyclic network* is a special kind of *oriented network* that contains no directed cycles. If we start a path from any node in the network and follow the direction of arcs (directional lines), there is no way to return to the node of origin (Batagelj and Mrvar 2005; Degenne and Forsé 1999; Scott 2000; Wasserman and Faust 1994). When there is no cycle in the network, the acyclic relationships among the nodes in the network constitute, by proof following from definition, a hierarchy (Harary 1969:200).

Assigning rank to partially ordered elements in an upper triangular adjacency matrix can be done by construction of an *acyclic depth partition* based on two repeated steps. First, all vertices that do not have any in-degree are assigned as level $d$=1. Second, these vertices and their outgoing lines are removed, and steps one and two are repeated to identify level $d$=$d$+1 until no vertices remain (Batagelj and Mrvar 2005). The algorithm reorganizes the complex network into hierarchical levels such that if a node at any level has any incoming lines, at least one must be directed from the next lower level. Otherwise the node it connects to would drop down one or more levels. The analysis of levels in an acyclic network is thus an effective method by which hierarchical structures can be detected even in an extremely complex network. It is a highly effective method in this case because no directed cycles were found in the complex web in Ohta.

Acyclic depth partitioning is robust in that it will capture a great deal of the network structure of a large sparse oriented graph. Figure 3 shows the outcome of a depth partition of the largest, weakly connected component of 4,500 firms. As shown in the figure, the partition reveals the basic hierarchical characteristics of this extremely complex web. This is done simply by ordering of the data rather than data reduction. There are seven linked but hierarchically ranked levels of firms, according to the partition criteria. The vertical paths that connect the firms across levels represent linked manufacturing processes that produce an enormous variety of parts, components, modules, and end products in the industrial district of Ohta, with the result that the industry value-chain is similar to "food-chains" running within and beyond the Ohta ward. The streams of goods and chains of services provided by these firms act as enmeshed threads weaving through various manufacturing processes.

Figure 3 includes 54% of the firms in the whole network. Node size reflects the in-degree of nodes. Labels, largely obscured, are those of the top 105 prime buyers with in-degree of 6 or more. All of the top 105 buyers in the full network are included in the largest component. Note that these levels do not correspond to Tier-1, -2, etcetera, suppliers, but starting from a firm that is sufficiently high in level, its suppliers at Tier-1, -2, and so forth, will always be at successively lower levels.

The hierarchically partitioned layers in Figure 3 map out the relative position of each firm in the upstream/downstream industry value-chain. In general, the larger the number from class 1 to 7, the closer the manufacturing processes and services are to the end products that reach final customers. The relatively low layers include large numbers of firms, and the relatively high layers have small numbers of firms. In these scalings, nodes are assigned on the x-y plane according to the average x-y coordinates of their neighbors (initially assigned randomly). The z coordinate in the 3D topology is assigned by the depth partition. It appears that the depth hierarchy has multiple peaks of prominent OEMs at the top of the overlapping "mountains," or a series of "pyramids," which were sharing numerous SME suppliers at low levels of the layers. Hence, Hypothesis 1 and 2 are accepted, and the hierarchical levels and proximities reflect a division of labor operating over a complex web of commodity chain transfers.

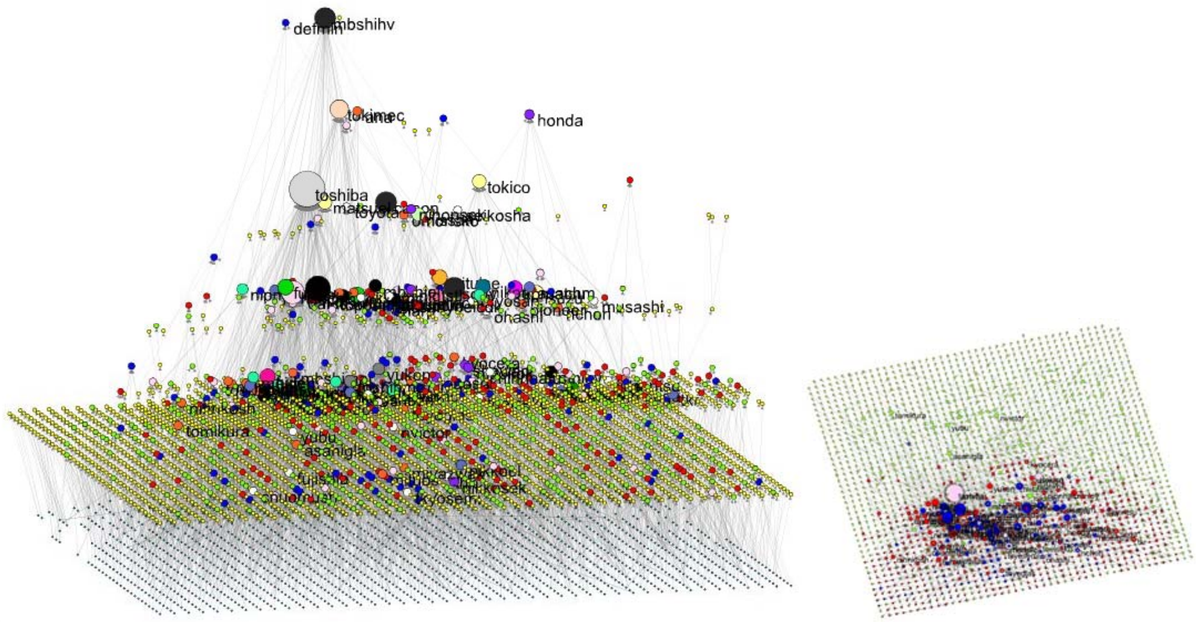



**Figure 3** A Global Structure.
The graph shows subcontracting layers, according to the acyclic depth partition of the 4,500 firms in the main supplier/buyer component from the *Ohta-ku Akusesu Deta 1 & 2* (Ohta-ku Sangyo Shinko Kyokai 1997a; 1997b) data. The sizes of nodes reflect firm in-degree, or times listed by others as a prime buyer. Alphabetical labels are given to 105 firms with highest in-degree scores, those of 6 or more. The Defense Agency is also given an alphabetical label, although it is not among the 105 firms with its in-degree of 5. The drawing on the right is a projection onto the x-y plane showing more of the network topology.

## 4. Analysis of Cohesion Measures

Our analysis of the acyclic depth partition of the largest component has unveiled the underlying structure as multiple peaks of prominent OEMs, or "mountaintops" and "ridges" (White *et al.* 2005) that represent the downstream sinks (inverted mountaintops) toward which goods and services flow in weavings through the complex, hierarchical network as entangled chains of processing activities.[10]

Further, different measures of cohesion can help to distinguish different types of hierarchical structure from the viewpoint of underlying organizing principles of the network. As Powell, White, Koput and Owen-Smith (2005) show, forms of network analysis that incorporate cohesion analysis, as measurement of multiconnectivity of nodes, can help to identify powerful drivers or dynamical engines of a network, including those with hierarchical properties. White, Owen-Smith, Moody, and Powell (2005) identified a similar kind of dynamical engine involving multiconnectivity in a different large-scale network. While Granovetter (1985; 1992) calls this type of entangled weavings "economic embedding," White and Harary (2001) developed a similar but precise network concept and measure of structural cohesion for which Moody and White (2003) provided a computational algorithm that also computes a related measure of theirs, called *structural embedding*.

Examining multiconnectivity, the large component of 4,500 Ohta firms contains a large bicomponent of 1,609 firms—structurally cohesive and robust at a multiconnected level of 2. A *bicomponent* where all the nodes are connected by two or more independent paths defines a structural unit relevant to cohesion and the existence of alternative paths makes the bicomponent network robust.[11] All of the top 105 prime buyers in terms of in-degree in the full network are contained in the bicomponent, and of the 97 firms in the bicomponent with in-degree of 5 or more, 88 are firms listed as the top 105 prime buyers for the whole network. A hierarchical nesting is apparent in the composition of the Ohta network.

The acyclic orientation and the embedding of two layers of nested components suggest that the whole network should converge towards a single core. Therefore, the third hypothesis to test is as follows:

Hypothesis 3: Within the complex webs of the supplier-buyer network in industrial districts, there should be a cohesive core of the hierarchy with some level of multiconnectivity.

*4.1 Structural Cohesion*

To test Hypothesis 3, the supplier-prime buyer network was analyzed further. One simple measure of cohesion in a component is the *cycle rank* (Harary 1969, p. 39) or *cyclomatic number* $\gamma = N - n + 1$, where $N$ is the number of links (with all lines taken to be symmetric) and $n$ is the number of nodes. $\gamma$ is also the number of *independent undirected cycles*, defined as the maximal number of cycles (undirected) such that each contains at least one link not found in the others. In the Ohta industrial district network, $\gamma = 856$ which, as a percentage of 4,500 nodes in the largest component, is 19%. Further, when we standardize the number of independent cycles as an *alpha index* (Hage and Harary 1996, pp. 49-51), or the ratio of the observed number of independent cycles in a nonplanar graph, or 856, to the maximum number of independent cycles in a nonplanar graph, which is $n^2/2 - 3n/2 + 1$, the ratio is .004%, which is extremely low. But structural cohesion is about multiconnectivity rather than density, as White and Harary (2001), Moody and White (2003) and Powell, White, Koput and Owen-Smith (2005) have noted in their tests of the predicted effects of cohesion on other network and attribute variables.

*4.2 Spring-Embedding Images of Cohesion*

One way to help visualize cohesive structure graphically, for a network component with a hierarchical dimension like the one in Figure 3, is to use *Pajek* scaling procedures to place the hierarchy variable in the z dimension buffer of a 3-D graph and scale the nodes in the X-Y plane with Fruchterman spring embedding while holding Z fixed. After completion of the scaling for this network, as in Figure 4, results were rotated to orient the Z dimension toward the vertical while rotating the X dimension to visualize both the levels and the placement of nodes, according to the cohesion-oriented spring embedding. These results show, graphically, that cohesion tends to be lacking up to level 4 (from the bottom) but that the very top three levels (with 37, 8, and 3 nodes respectively) can be seen to be highly cohesive because of how they are pulled together by their cohesive cycles. Further, the majority of the top 105 prime buyers are located along the central cohesive axis of this figure, in rungs 3-5. Note that the central column of nodes at rungs 5-7 are not pulled together by spring embedding because of complete triads (there are no links by definition within rungs) but because they have the same or similar connections above and below them. The graph depicts a cohesive core in the hierarchy.[12]

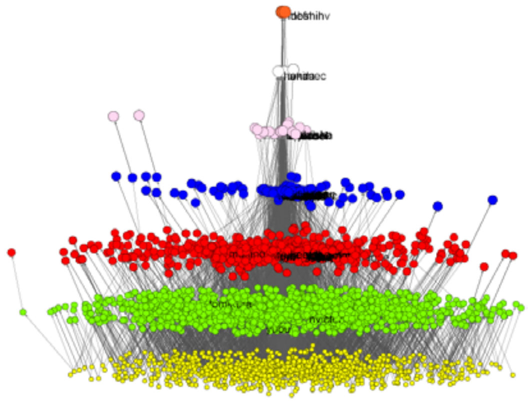


**Figure 4** A Global Structure.
The graph shows subcontracting layers, according to acyclic depth partition of the largest component and a spring-embedding scaling for cohesion across layers among connected nodes.

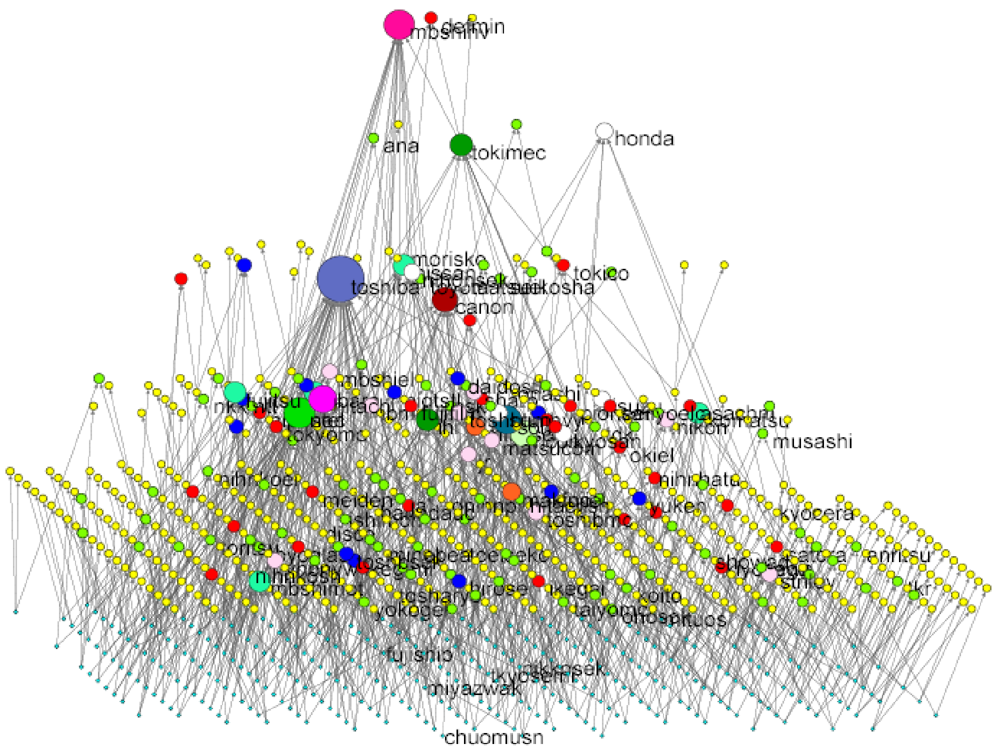



**Figure 5** Level 2 and Up: Largest Component.

On a larger scale, in testing and further specifying Hypothesis 3, of the 4,500 firms in the largest component, 2,921 are above level 1. When we deleted level 1, the largest component within these 2,921 had 947 firms, as Figure 5 presents. It shows more clearly the overall tendency for a single hierarchy to form through the layers of shared suppliers with the enmeshed links among the firms but also to differentiate at the next level up, as in Figure 4. Note that a large bicomponent will also occur in a network where ties are formed randomly. A random network, however, will not be free of directed cycles. Even if we impose on a random network some restriction that forces the avoidance of directed cycles, however, within the large bicomponent, smaller *k*-components of higher cohesion will also likely to occur. But in fact, no tricomponents or more highly cohesive groups occurred in the Ohta network.

### *4.3 Cohesion in Hierarchies and Assortative Correlation*

An acyclic depth hierarchy such as visualized in Figure 4 does not necessarily entail that the top of this hierarchy is cohesively integrated. Taking into account the restrictions in data collection as up to three prime buyers, we need to evaluate in probabilistic terms whether there is a greater tendency toward cohesion in the distribution of node attachments as we move up the hierarchy. By employing the in-degree distribution for nodes in the largest component of 4,500 firms, which is more discriminating than the seven depth partition levels, the ratio of links in subsets of nodes with higher in-degrees to nodes with those in-degrees can be used to indicate whether in-degree is a proxy variable for the extent to which nodes as hubs are likely to form links with other hubs.

The result of this procedure is shown in Table 1 where we give the ratio of the number of links among nodes at each in-degree level and above, relative to the number of nodes at those levels, for the largest component of 4,500 firms. The graph of the results in Figure 6 shows that the first four bins for firms of in-degree 1 to 4, which constitute 95% of all nodes with in-degrees 1 or more, fit a power-law decay ($R^2 = 0.998$),[13] but beyond that the diminution in link-to-node ratios tends to vary in discrete intervals from 5-9; 10-15; and 16 or more. These seven categories in the decay function, or levels of 1 to 4 respectively; 5-9; 10-15; and 16 or more, suggest that increases in this ratio might vary instead in proportion to the seven levels of the depth partition.

**Table 1** Links-to-nodes ratio in largest-component hierarchical layers, by in-degree

| Levels | # of links, by in-degree | # of nodes | Linking ratio (# of links/# of nodes) |
|---|---|---|---|
| whole largest component | 5354 | 4500 | 1.190 |
| In-degree of 1 and above | 1435 | 2921 | 0.491 |
| In-degree of 2 and above | 385 | 877 | 0.439 |
| In-degree of 3 and above | 166 | 409 | 0.406 |
| In-degree of 4 and above | 90 | 231 | 0.390 |
| In-degree of 5 and above | 39 | 140 | 0.279 |
| In-degree of 6 and above | 29 | 105 | 0.276 |
| In-degree of 7 and above | 20 | 82 | 0.244 |
| In-degree of 8 and above | 15 | 60 | 0.25 |
| In-degree of 9 and above | 12 | 53 | 0.226 |
| In-degree of 10 and above | 5 | 39 | 0.128 |
| In-degree of 11 and above | 4 | 33 | 0.121 |
| In-degree of 12 and above | 4 | 32 | 0.125 |
| In-degree of 13 and above | 4 | 29 | 0.138 |
| In-degree of 14 and above | 4 | 24 | 0.167 |
| In-degree of 15 and above | 4 | 23 | 0.174 |
| In-degree of 16 and above | 2 | 21 | 0.095 |
| In-degree of 17 and above | 1 | 16 | 0.063 |

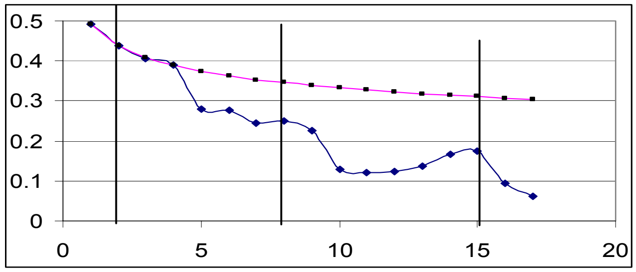



**Figure 6** Categorical Decay of Links in the Hierarchical Layers of the Largest Component, by In-degree.

We then computed the ratios of node links to the number of nodes in each subset of nodes at the seven depth levels and above in the largest component of 4,500 firms, with the subsets as follows: Levels 1-7; 2-7; 3-7; 4-7; 5-7; and 6-7.[14] These ratios can be used to indicate the extent to which nodes as hubs are likely to form links with other hubs, as *assortative correlation* (Newman 2002). As Figure 7 shows, the first four bins for firms of levels 1 to 4, which constitute 94% of all nodes, fit a power-law decay ($R^2 = 0.999$), but those in levels 5-6 have more links to nodes at higher levels than expected by the decay curve. Thus, the firms at levels 5 and 6 have more connections with those at 6 and 7 than would be expected by power-law decay. This is evidence of cohesive integration at the upper levels of the depth hierarchy. The graph shows assortative correlation among hubs of the network.[15]

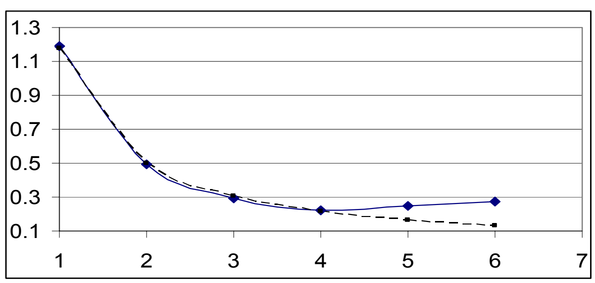



**Figure 7** Assortative Correlation for Links in the Upper Hierarchical Layers of the Largest Component, by Depth Partition.
A solid line shows actual number of links per node at each level; a dotted line shows this ratio as extrapolated from power-law decay.

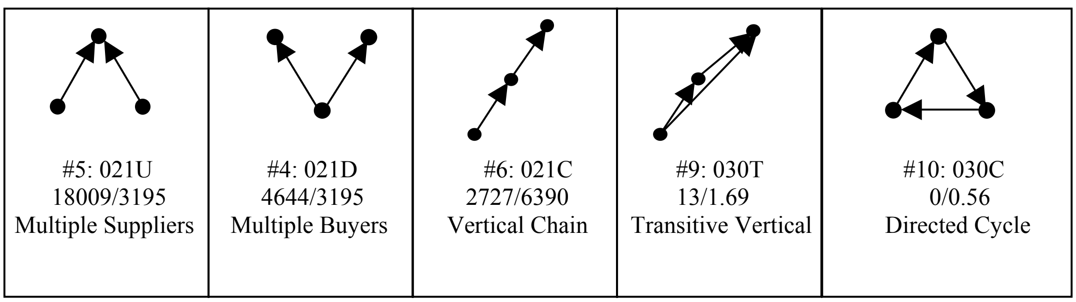
Because Figure 7 shows that the greatest assortative correlation among hubs occurs at levels 5 to 7, we also know that the cohesive integration—on the basis of multiple partners involving either two prime buyers for a supplier or two suppliers for a prime buyer—grows stronger as we move up the hierarchy from levels 1 to 4 and intensifies at the highest levels 5 to 7 where the number of firms thins out. For more detail on forms of cohesion and the multiplicity of buyers or suppliers, we need the more precise analyses afforded by a triads census, and a locational census of where certain types of triads occur within the levels of the depth hierarchy.

*4.4 Triads Census*

A *triads* census, which we conducted for both the largest component and the largest bicomponent, offers another way to measure the cohesive and hierarchical properties of the subcontracting network. Table 2 shows the nontrivial statistical results concerning occurrences of five critically relevant triad types, as follows: A prime buyer with two suppliers (021U); a supplier with two prime buyers (021D); vertical chains in the subcontracting tiers (021C); transitive vertical closures (030T); and directed cycles (030C).

**Table 2** Triad census of largest component and bicomponent in comparison

| | Largest Component (4500 nodes) | | | Largest Bicomponent (1609 nodes) | | |
|---|---|---|---|---|---|---|
| Triad Types | Actual | Expected | Ratio (Actual / Expected) | Actual | Expected | Ratio (Actual / Expected) |
| 5 021 U | 18009 | 3195 | 5.637 | 11737 | 1882 | 6.236 |
| 4 021 D | 4644 | 3195 | 1.454 | 1658 | 1882 | 0.881 |
| 6 021 C | 2727 | 6390 | 0.428 | 1181 | 3766 | 0.314 |
| 9 030 T | 13 | 1.68 | 7.692 | 13 | 3.59 | 3.621 |
| 10 030 C | 0 | 0.56 | 0 | 0 | 1.19 | 0 |




First, in this table, the most frequent triad corresponds to that of multiple suppliers for a prime buyer, or 021U triad. As conceptualized by "flexible specialization" theory, the multiple suppliers triad happens in situations, one where two suppliers are competing to be suppliers of a common prime buyer when they are engaged in the same area of specialized manufacturing processes. Alternatively, two dedicated suppliers are organized by a prime buyer to work as its suppliers in different specialized areas in the division of labor. As in these cases, it is often observed empirically that leading Japanese OEMs let a few suppliers engage in similar if not the same processing activities or parts and components manufacturing simultaneously in order to keep them competitive in product quality and pricing as well as for hedging and security purposes preparing for contingencies. There were 18,009 and 11,737 such triads in the Ohta component and bicomponent, respectively, more than 5.6 times many as expected by chance in the largest component ($p < 0.00000000000001$), and 6.2 times as many in the largest bicomponent ($p < 0.000000001$).[16]

Second, in contrast, the multiple buyers triad, labeled 021D in Table 2, happens when a supplier provides its processing services and goods to two prime buyers simultaneously that might be in direct competition in the same industry. There were 4,644 and 1,658 cases in the large component and bicomponent, respectively.[17] These numbers are only 1.45 and 0.88 times the expected frequency of such triads in the component and bicomponent respectively ($p < 0.01$ for the large component). This tendency is much weaker than the case for the multiple suppliers triad overall.

Compared to the general triads census, however, with an overall actual ratio of 4:1 in the multiple suppliers triads over the multiple buyers triads, we found a reversed trend 1:12 at the upper level of the hierarchy 5-7 by the depth partition. As seen in Figure 8, which depicts the node links at levels of 5–7, while the number of the firms at these high layers is very small, the reversal of ratios from 18,009:4,644 compared to 1:12 is statistically significant at $p < 0.000000000001$. This disparity, of course, occurs with the hubs of the network.[18]

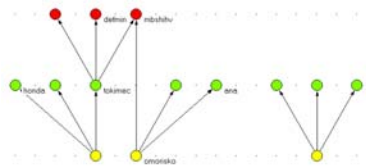



**Figure 8** Multiple Prime Buyers as Dominant Configuration at Depth Levels 5–7.

Next, as shown in Table 2, a path of two vertical links and no transitivity is very common. The vertical chain 021C occurs when a supplier indirectly supplies its products or processing services to a hierarchical distance-2 prime buyer through some value-adding role of the adjacent, intermediating prime buyer-supplier. The vertical chain is expected to occur by chance more often than the transitive vertical closure or 030T. Actually, the former occurred relatively less often than expected by chance in both the component and the bicomponent although the actual numbers of occurrence were relatively large. There were 2,727 such occurrences for the component and 1,181 for the bicomponent.

By comparison, while the transitive vertical closure triad 030T is expected to occur very rarely, it occurred by eight and four times more often than expected by chance in the component and the bicomponent, respectively. This difference is significant ($p < 0.01$) only for the large component that involves only 13 transitive triples. Thus there is only a miniscule tendency for firms to form a *transitive* hierarchy where a buyer's buyer is a buyer, even though such a tendency is not avoided. A very mild transitivity of this sort asserts itself to an insignificant degree that does not carry over to the bicomponent. As discussed in a separate paper (author publication 2006 to be inserted after review), the paucity of transitive triples contributes to a minimum level of clustering, as would have been expected in a small-world model. Suppliers do not need the intermediating roles of their adjacent prime buyer-suppliers when they can work for the prime buyers directly, except in the case that the intermediary has very unique value-adding technologies.

Finally, in Table 2, a path of two vertical links and no transitivity is very common. The vertical chain 021C occurs when a supplier indirectly supplies its products or processing services to a hierarchically once-removed, prime buyer through some value-adding role of the adjacent, intermediating prime buyer-supplier. The vertical chain is expected to occur a lot more often than the transitive vertical closure or 030T. Although the former occurred much less often than expected by chance in both the component and the bicomponent, the actual numbers of occurrence were relatively large, as there were 2,727 such occurrences for the component and 1,181 for the bicomponent.

The structural evidence for convergences toward a single hierarchy, the prevalence of "multiple suppliers triad," is a much stronger tendency than the "multiple prime buyers" triad. But the reverse is true for the hubs of the networks because the latter configuration tends to be concentrated in the upper levels of the hierarchy. With the triads census, the possible bias in the dataset introduced by listing only up to the three prime buyers is controlled.

Thus, Hypothesis 3, of a cohesive core within the supplier-buyer hierarchy, is supported with the above test results from a variety of cohesion measures including the different graphic scalings, the assortative correlation of the hubs, and the triads census.

## 5. Conclusions and Discussion

The present research attempted to explain structural mechanisms of "flexible specialization" in a large-scale industrial district, applying the analytical techniques of complex systems. To begin with, the network does have a hierarchical structure in the degree distributions of the hubs, at the local level. Further, the acyclic depth partition of the largest component unveiled structural mechanisms present in the larger network of the industrial district. At the more global level, the interfirm dynamics operative in the entangled chains of linked manufacturing processes—composed of thousands of specialized SME suppliers and their prime buyers—generated a giant component, linking the OEM's supplier group networks.

From the viewpoint of flows of goods and services, these structural mechanisms formed a multiple "mountaintops" style structure where the overlapping, group networks under prominent OEMs shared thousands of SME suppliers at relatively low levels in the subcontracting hierarchies. The findings indicate that these SME suppliers functioned as technological base for prominent OEMs located at the "peaks" of the hierarchies. The notion of social competition among suppliers is supported by the 3D topology of the complex, hierarchical relationships.

Yet, deeper in the complexities, there was a very cohesive core in existence, as a powerful organizing principle, or strong driver of the links in the entangled relationships, as unveiled by probing the largest component and bicomponent, especially with the analysis of the different measures of cohesion and a series of graphic scalings. To be specific, in the overall convergence of the hierarchical network, differential patterns were detected by the discrete categories of node links and also by the triadic census of the high depth levels, owing to the existence of a limited number of powerful suppliers that were directly providing their goods and services to multiple, extremely powerful OEMs.

The triad configuration of "a supplier with two prime buyers," which was prevalent at the highest levels of the hierarchy, can be explained by applying *resource dependence* theory. The theory argues that, as organizational resources are limited, firms that control these scarce resources can gain enormous power in their external relations of interfirm networks (Pfeffer and Salancik 1978). This view offers an interpretation that those "bridging" suppliers, which were dealing with those powerful OEMs, or top prime buyers, should be very powerful ones as organizing hubs, controlling scarce resources effectively, including core competencies in technology, workers' engineering knowledge, craft and skills, and competitive advantage in their cost structure, among others.

Moreover, from the viewpoint of graph theory, those powerful suppliers were in a position to take advantage of *structural holes* (Burt 1992; Burt 2001) by trading with two possibly competing, prominent OEMs in the triads. This somewhat "decentralizing" tendency at the highest levels—embedded within an overall convergent tendency towards the single core—indicates that those links at the highest levels were generative of and probably reinforcing the cohesive core, with its membership limited to extremely powerful OEMs and their powerful suppliers, as such.

There must be many reasons why most of the numerous SME suppliers, which were supporting the prominent OEMs as a pool of a variety of engineering knowledge, technologies, and workers' craft in the Japan's high-tech economy, were linked to their prime buyers by an overall power-law order hierarchy. First, generally speaking, "flexible specialization" theory argues that financially constrained SMEs, with their limited span and scope of skills and human resources, need to become dedicated suppliers in order to survive with a competitive edge in their specialized areas, and the theory further implies that some node attributes such as manufacturing style, production mode, or processing areas that they are engaged should require certain network configurations in the division of labor among manufacturing firms in the local community network. Actually, previous fieldwork research studies of Ohta (Itami 1998; Seki 1994; Watanabe 1997; Whittaker 1997) found that micro SME manufacturers in general also needed to form very small-scale but extremely tightly embedded, cohesive cliques known as "conferee" trading as to share excess orders and machinery among the member firms for a smoothing-out of the unavoidable cyclical and seasonal business fluctuations. In addition, a social competition for reputation to be powerful suppliers for prominent OEMs and the positive impact of the drive upon sales volume and stability in their businesses appear to have been a critical factor responsible for the formation of the power-law hierarchy.

These findings indicate that the firms in the cohesive core played a crucial role as organizing agents of the complex network, from the top, and that the integration mechanisms are not primarily driven by the preferential attachments from the bottom, or spontaneous initiatives of the suppliers to choose their prime buyers. Most of the SME suppliers had very limited chance to do so within the hierarchical levels of their relationships.

Further, the cohesive core, or "elite club," was practically the only access point for most of the SME suppliers to sell their products or services indirectly to the end consumers. It was not the regionally-bound micro suppliers but only those OEMs as assemblers of components, parts and modules from their powerful suppliers had maximum outreach to major markets, across different manufacturing areas with a variety of end-products in demand. Therefore, only those prominent OEMs could provide access to a wide range of consumers across markets for the geographically-bound and financially-constrained SME suppliers. This was made possible only by the numerous streams of independent paths passing through the powerful suppliers. Given their limited span and scope of skills and resources as well as their relatively poor marketing experience, capacity and capability, most of the SME suppliers needed the "window of opportunity" that was available only through connections to the extremely powerful OEMs via the powerful suppliers. According to previous fieldwork studies and survey data (Seki 1994; Whittaker 1997), it is known that only 10-20% of firms in Ohta had their own brand product lines, while the rest were dedicated suppliers in components and parts manufacturing or in various processing activities without their own brands. In contrast, the large OEMs also needed to use their powerful suppliers in order to coordinate their complex chains of logistics among the skills and specialized technologies provided by the numerous SME suppliers, and to take advantage of the complex division of labor among the suppliers.

Second, the micro SME suppliers dedicated to their specialized manufacturing processes must have needed to rely on those OEMs, via the powerful SMEs as organizing hubs, in order to get social endorsement and reputation not only in the local business community but also among the consumers at large. A lack of reputation about and confidence in the product quality manufactured by these micro SMEs is likely to have put them in the very dependent position upon those established and reputable OEM brands. Recent studies of strategic alliance in the area of corporate strategy (Jensen 2003; Podolny 2001; Stuart, Hoang and Hybels 1999) showed evidence that firms' external reputation management through their partner selection in alliance formation is a critical strategic decision for their survival and further success although these studies put a focus on the so-called horizontal strategic alliances rather than this kind of vertically-oriented supplier-prime buyer relations.

In effect, as a clear exception to the power-law order, only a limited number of suppliers successfully took their positions as members of the "elite club" where they could directly deal with extremely powerful OEMs, owing to their core competencies, including technological edge and coordination skills of their own suppliers, as "bargaining chips." Only thus could they escape from the general power-law order of the node links dominated by the "elite" core in the regional supplier-prime buyer network, as *resource dependence theory* suggests.

In short, the cohesive core appears to provide the engines that propel the flows of goods and services in the hierarchical regional industry value-chain through stages of manufacturing processes contained mainly in the hands of SME suppliers. It constitutes a key access point for the micro SME suppliers to reach out to market consumers socially and spatially located outside the industrial district. A vast variety of goods, a series of manufacturing processing services, and a broad range of technologies were funneled into these hierarchal layers of regional flow process so as to gain access to the final consumers. Manufactured, assembled and socially-endorsed, end products from the large-scale industrial district pass through an "elite" core of "gate-keepers" consisting of prominent and reputable OEMs and their well-placed, powerful suppliers.

To conclude, these findings give support to a kind of dualism, from the relational point of view of network analysis, with a clear structural divide between the strong OEMs and their powerful suppliers as an "elite club," and a pack of numerous SME suppliers for the rest. Against the conventional wisdom of "flexible specialization" where SMEs are regarded as a creative and innovative partner of large firms to share their profits on a rather equal footing, the present research points to a "dual economy" defined by a structural boundary that puts constraints even on the flexible interfirm activities of more micro SMEs that still play important, although secondary, roles in the regional subcontracting relationships because of their rich social capital.

Theoretically, the present research study unveiled the underlying structural mechanisms of a "dual economy" not on the basis of firms size as traditionally claimed, but of social competition among nodes to be suppliers of prominent OEMs for reputation in the complex network, from the relational approach of node links and network integration mechanisms, as a latent but decisive explanatory variable.

A general extension of our argument is that, first, firms are more likely, given choice among potential trading partners, to form partnerships with firms that are already members of a large component, or with whom the formation of the partnership will place both partners in the bicomponent. Further, in this nested structure, the most exclusive "elite club" of cohesive core is composed of a small number of the top OEMs and their powerful suppliers. An unequal distribution of resources and wealth is perpetuated by this divide, and further consolidates the exclusive membership in the power-law nature of the hierarchical supplier-prime buyer network.

Second, the finding of the "elite" core is suggestive of the rise of the Tier-1 firms in the hierarchical production networks embedded in large industrial clusters, as the network integrator of the complex systems, among the players with different roles. In other words, the Tier-1 suppliers may well be the powerful suppliers, possibly as agents for the powerful OEMs, organizing their own subordinates in the lower tiers. While this seems related to the advancement of the information and machining technologies after the 1990s, which has reorganized the production systems not only within each of the firms but also across the firms in the complex production networks, we will probably need more evidence to make the concrete case.

As for further discussion, it will prove important in the future to see whether the present findings are consistent across time, space, and content of different supplier networks in industrial districts. The present research study is only one case of a complex web of regional supplier networks in a large-scale cluster in the cultural context and institutional settings of the Japanese network economy in the mid-1990s. The regional economy as well as the macro economy was under the prolonged deflationary pressure, one dragged, after the peak of its "bubble," into the spiral of severe recessions in the early 1990s, unprecedented scale in the history of the economy, which lasted for the time span of fifteen years. Yet, some of the principles we articulated here may well carry over to other industrial districts in the new age of advanced information and machining technologies.

**Appendix: Notes on Supplier-Buyer Relations in Industrial Districts**

While the Ohta's supplier network contains some part of the Keiretsu group networks, the affiliation can explain only a small part of it. Rather, our research site is one of industrial clusters bound to a regional economy, which happens to be located in Japan and therefore embedded in the Japanese institutional settings. Therefore, first, the supplier networks in the industrial district have distinctive embedded relationships, as business transactions are executed in the local business communities geographically embedded. As a matter of fact, the supplier relations in the Japanese industrial district can be quite different than the ties between large Japanese firms and their main banks, between a prominent parent and their suppliers in the Japanese automotive industry primarily operated in "company cities," and the cross shareholdings among large Japanese firms, especially as these networks do not possess spatial or geographic attributes. Moreover, degree of embeddedness, good will and reciprocity, trust and reputation, and consideration about long-term versus short-term gains can be very different, for instance, among the competitive bidding typically known as the "Anglo-American" practices, the so-called arms-length transactions, and the highly embedded relation-specific contracting exemplified by the Japanese automotive industry, to name a few. These are qualitatively different kinds of supplier-buyer relations in many respects. Therefore, as a caveat, we could directly compare the supplier-buyer relationships in Ohta with those in other industrial districts including Birmingham, California or the Third Italy, to name a few, but not with the other kinds of interfirm networks aforementioned.

In the regional economy, both suppliers and their prime buyers have to be careful about their selection of partners in the subcontracting relationships, as they need to mutually share technological knowledge and technical skills as partners, to a certain extent at least, which may include proprietary knowledge, or the "lifeline" of SMEs in the often relation-specific contracting. At the same time, the regional supplier-buyer relationships can be quite fluid too, being not so strictly controlled by powerful OEMs as much as in the case of more relation-specific contracting exemplified by the Japanese automotive supplier networks in "company cities." The trade relationships in the industrial district, therefore, generally have elements of the competitive bidding, the arms-length transactions, and the very relational contracting in combination, with a broad range of degree of embeddedness, depending upon required skills and knowledge of manufacturing processes, quality, quantity and variety of products, and institutional settings of industries, among others.

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## Footnotes

[1] For a brief summary of the dualism arguments, see, for example, Nishiguchi (1994, pp. 9-11).
[2] We use the term SME rather loosely throughout our discussion, as the concept has various definitions. For instance, the definition of the Official Journal of the European Union and the counterpart of the official public statistical data by the Japanese government differ in term of the number of employees. The term generally encompasses micro-, small- and medium-sized enterprises.
[3] "Flexible specialization" theory generally includes social aspects of division of labor among stakeholders as an institutionalized role structure embedded in each of the regional economies. The conception encompasses not only the division of labor among the SMEs engaged in the manufacturing per se but also other actors filling important roles, including administrative and political supporting institutions, banks and other financial institutions, family networks of proprietors, public training institutions and private educational initiatives, and industrial associations. However, as our network analytical study focuses on the integration mechanisms of the regional production system, employing interfirm trade network data, we use the division of labor in a narrower sense as to refer to the supplier-prime buyer relationships.
[4] We do not differentiate such terms as "OEMs", "leading manufactures," and "top firms in the hierarchy of supplier-prime buyer relations" throughout our discussion. Literally speaking, an OEM is original equipment manufacturer, or a firm that produces end products, which are purchased by the consumers possibly under different brand names. In other words, these are the actual assemblers. To give an example, in year 2004, Sanyo is known as a major OEM for many digital cameras sold under different brand names worldwide. Practically, however, it is almost impossible to tell the real OEMs behind the top brand names, as each brand consists of so many different products manufactured by different OEMs. In the case of the complex supplier-buyer networks, any supplier that assembles products for a buyer sitting at the top of the subcontracting hierarchies can be an OEM when the top buyer puts its own brand name on the supplied end-products. Therefore, we rather call these buyer/suppliers OEMs in the aggregate. Any large prime buyer as an organizing hub can be an OEM for another prime buyer. Most large prime buyers are probably OEMs for other large prime buyers that have reputable brand equity.
[5] For a summery theoretical discussion regarding the historical changes in the manufacturing technologies related to industrial clusters, see for example Trigilia (2002, pp. 198-218).
[6] The term "prime buyers," or "Tokuisaki" in Japanese, used for our dataset should generally be much more exclusive and narrower than "all buyers" listing. At the same time, the limit of up to three prime buyers, imposed on all 5,111 respondents, will be less than the numbers of all prime buyers that otherwise could have been listed in Ohta, especially by large suppliers. As the percentage of firms with 30 or more employees in 1990, however, was less than 4.6% in the industrial district, and approximately 80% of the firms in Ohta had nine or fewer employees (Whittaker 1997), the impact of the restriction to up to three on the average number of total prime buyers should not be that great. According to our statistical estimate, the actual number of all buyers might be as high as 6-8, including prime buyers, per firm, while the counterpart of prime buyers only should be 1.62-1.89 per firm, had free listing been allowed (author publication 2006 to be inserted after review).
[7] We follow here the fitting procedure of Goldstein, Morris and Yen (2004) to fit to the lowest bins that contain the bulk of the sample observations in a power-law distribution, instead of the simple linear fit.
[8] This configuration is also a deepening process of manufacturing specialization by SME suppliers dedicated to narrow areas of their own processing activities in the tiers of subcontracting. The number of suppliers involved at each of the stages should decrease gradually as the process moves from the bottom to the top, owing to the coordination and network integration by the organizing prime buyers as hubs.
[9] Studies of directed cycles in social organization often build on ideas from anthropological exchange theory and structuralism, Hage and Harary (1996) identified acyclic exchange cycles that bound together cultural networks among South Pacific islanders, and Bearman (1997) leveraged the concept of directed cycles for network investigations in proposing a structural theory of generalized exchange. For a literature review, see Douglas White

(2004) and White and Johansen (2005). Few network researchers, however, have followed their lead. Among the exceptions, Robins, Pattison, and Woolcock (2005) attempted to simulate an emergence of small-world, applying the analytical concept of cycles. Studies in the relatively new field of network economics (Plott and Callander 2002) show general conditions under which directed cycles of exchange provide stable configurations for optimal price formation as a market pricing mechanism.

[10] "Downstream" here is used in the economic sense consonant with Harrison White (2002; 2003) of flow from upstream suppliers to downstream buyers, e.g., buyers who assemble parts, components, and modules into finished products that eventually flow to end consumers. If we think of our mountaintops of the hierarchy as inverted, downstream flows are toward these inverted tops.

[11] A bicomponent (tricomponent, *k*-component, multiconnected component) is also defined as a maximal subgraph that cannot be disconnected by fewer than two (three, *k*) nodes. By Menger's theorem, this is equivalent to every pair of nodes having two (three, *k*) or more node-independent paths connecting them. This is also equivalent to a maximal subgraph having at least one cycle that includes every pair of nodes in the bicomponent when the directions of the arcs are disregarded.

[12] The degree to which we can visualize and measure how a cohesive core of the hierarchy tends to manifest itself is constrained by the fact that, in an acyclic depth partition, none of the nodes at the same level can connect to one another directly because the algorithm would force them into different levels.

[13] We follow here the fitting procedure of Goldstein, Morris and Yen (2004) to fit to the lowest bins that contain the bulk of the sample observations in a power-law distribution; that fit has the reported $R^2 = 0.998$.

[14] The figure only shows six of the seven levels generated by the depth partition, as nodes at level 7 cannot have internal links because they are at the same level. Level 7 nodes are involved, however, in the assortative links originating at lower levels.

[15] Although we could compute the assortative correlation or "mixing" (Newman 2002) of whether links are more likely between hubs than would be expected from random oriented links holding constant the in- and out-degree distributions, we prefer this simpler measure because it will also display results that are not monotonic.

[16] These probabilities may be estimated by a chi-squared test for $(\text{actual-expected})^2/\text{expected}$ in a triad sample size for a network with $N$ nodes and $\binom{N}{3}$ triads.

[17] In most cases, our other analysis of the dataset indicated that this kind of "bridging" activity by the suppliers to work for two prime buyers, especially at the level of Tier-1 suppliers for prominent OEMs, was performed in limited cases. However, this bridging connections, possibly the Tier-1 taking advantage of "structural holes" in between the two competing OEMs, were more often seen in the light and heavy electric and consumer electronics manufacturing than in the automotive components production in Ohta although the actual numbers of such cases were relatively very small.

[18] Although the actual number of firms at the levels of 5–7 as 48 is relatively small compared to the size of the component or 4,500, the finding from the triadic census are substantively very important, as these firms are the ones that are controlling the complex network, being positioned at the highest levels of the overall hierarchy.