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Cohesion and Power-Law as an "Elite Club" in a Large-Scale Industrial District: Flexible Specialization or Dual Economy?

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Abstract

(80 words for the limit of 80)

The Marxian "dual economy" became obsolete after the mid-20th century, and collaborative network arrangements between large and small firms became widely practiced after the 1980s. For many SMEs in industrial districts, with the explosion of globalization, partnership experiences were disappointing. Our network analysis of a giant Tokyo industrial cluster shows a cohesive core of large OEMs and powerful suppliers that excluded most SMEs. As of the mid-1990s, the egalitarian "flexible specialization" appears to generate a structural divide.

1. Introduction: "Dual Economy," Industrial Districts, and Production-Chain Network

Strategic alliances and supplier systems have been widely studied for over a decade especially in corporate strategy and organization studies. This rising interest in studying collaborative arrangements among firms has its theoretical origin in the debate known as the market-and-hierarchy thesis—Granovetter's first critique (1985) of Williamson's (1981) transaction cost economics (TCE) from a social network approach. TCE theorized merits of the multidivisional structure for the first time, explaining how large firms can minimize their monitoring cost under the bounded rationality problem of CEOs as posed by March and Simon (1958), as fiat and order under an organizational hierarchy should discourage collusion and opportunism in economic transactions. This vertical integration by multidivisional firms actually made the mass production system larger and more efficient, and the organization structure became a dominant paradigm of the twentieth-century American capitalism until the 1970s (Fligstein 1985).

Granovetter in contrast argued that embedded networks among trading partners that can generate trust and peer pressure to deter opportunism and collusive behavior can be a better governance mechanism at a lower cost (1985) than the hierarchy or command line within multidivisional firms. These embedded relationships also achieve more efficient information search through the network (1982). Many studies followed or rediscovered the importance of these embedded ties as social capital (Coleman 1988), which can also facilitate diffusion and churning of information and knowledge through communication and coordination within and across organizations (Dore 1983; Eccles and Crane 1988; Powell 1990; Stinchcombe 1959).

What do these embedded ties do for the firms? Later studies of interfirm strategic alliances empirically found a variety of merits of having these ties, including access to complementary resources and proprietary knowledge in a speedy timely manner as well as risk sharing of investment in ventures (Ahuja 2000; Collis and Montgomery 1997). Moreover, Podolny (2001) pointed out that these ties work not only as "pipes", or access channels to proprietary information and other critical resources, but also as "prisms", as partnerships indicate comparable quality and reputation of each node and even their rank in the community of players. Empirically, for example, Stuart, Hoang & Hybels (1999) presented that many successful new startups in the American IT industry in the 1990s formed strategic alliances with the leading firms as to leverage their reputation, and later gradually broke the ties as they grew and became legitimate. Jensen (2003) argued that the American leading commercial banks selected their alliance partners of comparable quality and reputation in the investment banking business when they entered the market in the 1990s. These empirical findings, like those of Gulati (1995) and Burt (2001) on the effect of the social context of prior alliances on new alliance formation, might suggest that the cohesive networks should tend to generate strong institutional forces to foster network closure through the legitimization process, as with an emergent core of powerful members

The role of firm scale in production economies has mattered in different ways in the evolution of perspectives on management and organization theory over the last century. Starting with the earliest period, critiques of industrial Taylorism of the late 19th to the mid-20th century held firm size accountable in the Marxian framework—through constraints on availability and access to organizational resources that manufacturing firms can mobilize—in creating structural inequality and perpetuating a structural divide that may well describe a new dual economy. This perspective identified two unequal sectors as part of the monopoly capitalism: A primary core comprised of large firms that enjoy efficiency, productivity, security, social status, and high wages in good work conditions; and a secondary periphery 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). As a result, there are dual labor markets (Doeringer and Piore 1971).

Flexible specialization theory (Piore and Sabel 1984) then proposed a fundamental break from the conventional wisdom, or advantages of large-sized firms. They theorized the merits of organized networks among SMEs embedded in regional clusters. With the increased speed of technological innovations in the information society that emerged in the 1980s (Drucker 1988), markets became much more uncertain, unpredictable and volatile due to the constantly changing tastes and demands of customers for variations of quality products (Eisenhardt 1989). In these relentlessly moving markets, Piore and Sabel contend, the network of SMEs has competitive advantage over the earlier system of mass production, standardized and sequential manufacturing, that is mainly carried out by the slow-moving large firms of multidivisional structure. These egalitarian SME networks can produce small quantities in variety to meet the constantly changing customer needs and tastes on the foundations of a coordinated division of labor among technologically specialized, dedicated SMEs—a very flexible and nimble, regional production system of competitive cooperation along with the notion of simultaneous engineering.

Transnational management strategy (Bartlett and Ghoshal 1998) became popular in the management literature after the 1990s, presenting hopes and high aspirations for SMEs in regional clusters to engage in truly collaborative partnerships with multinational conglomerates globally. Employing advanced manufacturing technologies of mass customization or diversified quality production (Streeck 1992), the large original equipment manufacturers (OEM) can achieve both volume and variety simultaneously These formerly incompatible targets in terms of production costs could combine seasoned and specialized workers' skills and craft contained in the SMEs with the digital information and machining technologies emerged after the 1990s.[1]

Current experience, for many SMEs, nonetheless seems quite disappointing because the key strategic decisions have been mostly confined to the headquarters of large multinational enterprises (MNE), and the SMEs as local suppliers have been put under the higher cost-cutting pressures from multinational OEMs as their powerful buyers (Kristensen and Zeitlin 2005). Actually the large OEMs have become leaner, more flexible, and more powerful than ever, taking advantage of the collaborative arrangements with their SME suppliers (Helper, MacDuffie, and Sabel 2001).

While firm size per se appears to have become less important for contemporary firms, as they engage in the various collaborative arrangements discussed above, Dodds, Watts and Sabel (2003) examine the organizational networks of clusters of components within firms having somewhat the same structure as interfirm production hierarchies. Their research focused on the robustness of different hierarchical network configurations,[2] and illustrates the

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[1] We do not differentiate such terms as "OEMs", "leading manufactures," and "top firms in the hierarchy of supplier-prime buyer relations." 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 the complex supplier-buyer networks, most of the leading prime buyers are probably OEMs for other prime buyers.

[2] They argue that a certain kinds of organizational networks are more robust than others with respect to environmental stresses (2003:1-2 – Tom, I put the full quote here on robustness because your critique was off the mark): "protecting individual nodes from being overtaxed by the direct and indirect effects of changing and unpredictable patterns of collaboration; and on the other hand, protecting the organization as a whole from disintegration in cases where individual failures occur regardless. More specifically, when task definitions are ambiguous, individual collaborators will often exchange information with other problem solvers (10), if only to ask after and obtain information about potential partners or to keep abreast of design changes relevant to their immediate task. In cases where the information is exchanged indirectly (e.g., via a superior), the relevant intermediaries incur an information processing burden. The burden imposed by any single coordinating message may be small, but high rates of message passing in combination with concentration of traffic will tend to overload key nodes. An analogous problem arises in other kinds of organizational networks, such as the Internet, airline networks, or the postal system, which must redistribute information, personnel, or

common principle that the key analytical units in complex organizational fields should not be individual firms or units but cluster of coordinated, if not fully organized, networks that might be beyond the hierarchy or command line within each firm, or might benefit from redundant ties that are outside the hierarchy proper. This perspective, as with the notion of flexible specialization, leads to a critical question in conducting organizational studies of industrial districts—what is the prime organizational unit? Is it the hierarchy within each firm as a single node, a particular local network as a coordinated or organized cluster of firms, whether , large or small? Or is it a group of these local networks? Based on our previous studies of Ohta and other theoretical undertakings, the overlapping local networks appear to shape and reshape relational boundaries for the firms as these networks form a complex web of production-chains in regional clusters, involving thousands of cooperating but competing linked nodes. While the local relational properties are important, to articulate the global linking mechanisms, we focus on the last unit of the three levels, a group or groups of these overlapping local networks.

These studies in and around regional clusters raise a series of questions that we address in this paper. We introduce contemporary issues about a large-scale regional cluster, a major industrial district in Tokyo in the mid 1990s, which can be studied as a model of Harrison White's production network and its market mechanism (2002). As background for examining contemporary issues about the production-chain market with its relevance to the issue of firm size, Table 1 summarizes our four ideal types of interfirm relations from the point of view of stylized manufacturing paradigms and organizational design.

Table 1 about here

The objective of the present research therefore is to see whether the dual economy thesis, once denied and largely forgotten after the widespread acceptance of network perspectives, is valid again in the age of advanced information and machining technologies. Can it be valid when firms are linked as complex production-chains to form large-scale regional clusters? Moreover, in this age of collaborative partnerships, with the dual economy thesis as a point of reference, does the size of each firm, which no longer appears to play as decisive a role as it used to, still matter in the large-scale industrial districts? Do the new technologies create a new kind of exploitation of a retarded secondary economy by an efficient primary sector through the linking mechanisms of firms in the production-chain market? Is there an overwhelming advantage of the large and powerful firms at the expense and de-skilling of craft workers contained in SMEs, as seen from a network and relational approach?

The remainder of the paper begins with a brief overview of previous literature and theoretical issues relevant to regional clusters, followed by the research design and

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materials while simultaneously minimizing the likelihood of overload. Organizational networks that minimize the probabilities of such failures exhibit what we call ''congestion robustness.''

In addition to resisting failure at the level of individual nodes, contemporary organizational networks must continue to function even when individual elements do fail. The Internet, for example, suffers little performance loss in the event that individual routers fail. Business firms can display remarkable resilience with respect to (seemingly) catastrophic breakdowns in their supply chains (20), involving loss of key component producers, equipment, personnel, and office space (24, 25). In contrast, under conditions of environmental uncertainty and catastrophe recovery, hierarchies are extremely prone to cascading breakdowns because the failure of nodes near the top of the hierarchy effectively severs large subnetworks from the main organization, thereby impairing global coordination. Organizations that reduce the adverse consequences of externally driven failures exhibit what we call ''connectivity robustness.'' Finally, we call organizational networks that exhibit both congestion and connectivity robustness ''ultrarobust.''

methodological issues: including data, concepts, and analytical tools. While the structuralist dual economy perspective viewed SMEs as technologically retarded "sweat shops" being exploited by large firms, flexible specialization theory reinterprets the role of SMEs as a key component of the advanced and efficient economy, or creative and innovative equal partners of large firms, owing to the rich stock of their workers' craft and seasoned skills (Goodman and Bamford 1989; Lazerson 1995; Locke 1995; Putnam 1993; Pyke, Becattini, and Sengenberger 1990; Sabel and Zeitlin 1997; Uzzi 1997).

While many researchers have endeavored to articulate mechanisms of flexible specialization in various industrial districts and time periods, these studies have limitations. First, as they relied mainly on qualitative research techniques in order to empirically test the theory and its network mechanisms, these findings have evoked considerable debate. Paniccia (1998) for instance argues that there exist many different patterns and forms of industrial districts across space and time even in Italy. While those studies qualitatively provided rich details about positive implications of the SMEs' social capital, they were not able to communicate the relational mechanisms systematically. Second, they mainly studied smaller regional clusters where either a single or relatively few industries were involved, leaving large-scale regional clusters mostly outside the research area. Both the rarity of such network datasets and the overwhelming complexities also placed technical limitations on researchers wanting to carry out such quantitative analysis. In effect, while past and current examples abound that are relevant to the study of complex interactive networks, for large-scale industrial districts, only a very few network studies have yet been made.[3] Finally, introducing the notion of a coordinated division of labor among SMEs through regional ties, flexible specialization theory implicitly focuses on the local structure, or smaller parts of the whole network. It is beyond the scope to discuss the global or overall integration mechanisms of complex clusters as the complexities go well beyond the egalitarian notion of flexible specialization. In effect, large regional clusters are understudied, and there is today a paucity of alternative theories available with which to explain their network mechanisms.

We aim to articulate some of the network mechanisms of large-scale regional clusters, employing some of the recent innovations both in theory and analytical techniques in network analysis. We will quantitatively analyze structural network properties while also using information from existing qualitative studies of other supplier networks.[4] We test hypotheses about how the large-scale interfirm trade network, or a web of supplier-prime buyer relationships, is organized to form a complex production-chain. We explicate its relational boundaries and embedded core groups using a central network analytical notion of "structural embedding" (Granovetter 1985, 1992; Moody and White 2003).

Initially, we discuss how the global, or overall, production-chain is integrated on the foundations of the locally organized division of labor, employing analytical techniques of egocentric networks and tie distributions of scale-free networks. To further decompose the relational properties, we then present how these overlapping, sub-networks can be analytically identified and re-ordered in the global network of the regional cluster, introducing the concept of a directed acyclic network and its network scaling. Next, we depict structural cleavages in

[3] For a summary discussion regarding historical changes in manufacturing technologies, see for example Trigilia (2002:198-218) and Teece, Dosi, and Chytry eds (1998).

[4] Some studies of the Japanese supplier system and *keiretsu* business networks (Asanuma 1989; Fujimoto, Iansiti, and Clark 1996; Fujimoto, Nishiguchi, and Ito 1998; Lincoln and Gerlach 2004; Nishiguchi 1994; Nishiguchi and Brookfield 1997; Smitka 1991) are valuable sources of information although not directly relevant to our supplier-buyer relationships in regional clusters. There are other qualitative studies of Japanese regional clusters including Ohta (Ishikura, Fujita, Maeda, Kanai, and Yamazaki 2003; Itami, Matsushima, and Kikkawa 1998; Kiyonari 1972; Seki and Kato 1990; Watanabe 1997; Watanabe 1998; Whittaker 1997; Yamazaki 2002).

the complex production-chain with the use of various scaling procedures as to visually present "structural cohesion"; and "assortative correlation" of ties among layers of inter-processing and production stages. As these tests and analyses lead to the identification of what we call an "elite club," a powerful core, we discuss our findings with respect to the contemporary production-chain and its relational boundaries, comparing ours with the classical firm size-based theory of structural dualism. Finally, given the possibilities that the institutional forces can lock-in networks as with closures of their memberships, we discuss social implications of these relational properties, including in particular who can get benefits, with some possible generalizations and limitations of our research study. Throughout this paper, we employ notions of network properties at two interactive but different levels: "Global" as to refer to a whole network system and "local" as smaller part of the whole. *Pajek* (Batagelj and Mrvar 2005) was used both to calculate network analytical measures and to draw graphs.

2. Data and Network Properties

2.1 Ohta Industrial District

The present research studied a web of supplier-prime buyer relationships in 1994-95among manufacturing firms linked to Ohta, one of 23 wards in Tokyo, and one of the two largest regional clusters in Japan. What are regional clusters? Becattini (1990: 38) defines regional clusters as "a socio-territorial entity which is characterized by the active presence of both a community of people and a population of firms in one naturally and historically bounded area." Moreover, Rabellotti (1997: 23) points out that they share four key elements, as follows:

1. A cluster of mainly small and medium enterprises that are spatially concentrated and sectorally specialized (locational and spatial factors)
2. A strong and relatively homogeneous cultural and social background linking the economic agents and creating a common and widely accepted behavioral code, sometimes explicit but often implicit (social and cultural factors)
3. An intense set of backward, forward, horizontal and labor linkages, based both on market and non-market exchanges of goods, services, information and people (organizational and economic factors)
4. A network of public and private local institutions supporting the economic factors

Our research site, Ohta industrial district, is among one of the largest and most complex regional clusters ever to exist on a global scale. It is located in Japan and therefore embedded in the Japanese institutional settings. While it has some relevance to the stylized Japanese firm group system, often referred to as 'keiretsu' business group networks, and the Japanese supplier system, the affiliation can explain only a small part of the mechanisms.

To begin with, there are qualitative differences between the complex production-chain market spatially bound to Ohta and the stylized Japanese supplier system. For instance, the Ohta supplier-prime buyer relationships are different from much smaller subcontracting networks in 'kigyo jokamachi,' or company-cities, in other local provinces in Japan like Hitachi-city, where a very small number of large buyers control their suppliers located around their large plants as predominant if not the exclusive parent (Chuo Daigaku Keizai Kenkyujo 1976). In the latter case, the entire regional economy is often dependent upon a very small number, if not one, of such parents. Tight control by the parents through 'kyoryoku-kai' memberships, or the official production network groups endorsed by these parents, is often observed in these regions, with its relevance to the keiretsu system as for quality control, technological improvement, and operations management.

In contrast, the interfirm relationships in Ohta are much more complex. This type of regional network can be studied as a model of production-chain market recently theorized by Harrison White (2002). It forms a value-chain where many thousands of firms are engaged in the tiers of enmeshed subcontracting relationships. These successively value-adding linked stages of manufacturing activities generally include processing services of raw materials in the upstream, followed by parts, components, and modules production, and assembling and finishing work towards the downstream to eventually reach the end-consumers. Thus, as a caveat, we can directly compare the supplier-buyer relationships in Ohta with those in other regional clusters including California, Birmingham and the Third Italy, but not with the other kinds of Japanese interfirm networks aforementioned.[5]

To elaborate, the industrial district has been well known as a machine-tools industry where the SMEs function as suppliers for leading Japanese OEMs in other applied industries. At the time of the survey in 1994-95, over 7,000 SMEs were engaged in a variety of manufacturing activities. A majority of those SMEs, in terms of the number of employees, had the size of a typical family household, or even smaller. Historically, the industrial district has been an engine of the Japanese economy, or a major national industrial base since the pre-war period, which promoted transfer and fusion of knowledge and fermentation of technologies for innovations.[6]

Among over 7,000 manufacturing firms in the industrial district, a majority of firms, mainly SMEs, were specialized in their own areas of discrete processing activities including assembling, buffing, contraction, engraving, forging, grinding, milling, lathing, painting, polishing, pressing, printing, processing, trimming, welding, and wiring. In particular, many were engaged in various metal-cutting processes. A minority were suppliers of parts, components, and modules in the 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 others. Roughly only 10-20% of suppliers had their own brand products for general consumers (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. As a result, 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; 530 firms (10.4%) only two; and 1,679 firms (32.9%) listed the upper limit of 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 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.

2.2 Large-Scale Networks and Regional Clusters

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[5] For more details about the difference between the stylized Japanese supplier network and supplier-prime buyer relationships in large-scale regional clusters, see Appendix A.

[6] From the macro economic viewpoint, SMEs in the manufacturing processes have been the backbone of the Japanese economy. According to survey data in 1994, SMEs comprised 99.4% of all establishments in Japan. The over 80,000 businesses employed 71.5% of the work force in manufacturing sectors, which absorbed approximately a quarter of Japanese workers. Regarding industrial shipments, SMEs' activities accounted for 51.4% of the total value and 55.9% of the value added (Altbach 1997; Patrick and Rohlen 1987).

Complex systems have gained attention in many academic disciplines since the late 1990s. In the area of knowledge and technology management, for instance, Powell et al. (2004) studied the recent co-evolution of cohesion and recruitment of novelty in large-scale collaboration networks among firms in the life sciences. Padgett, Doowan and Collier (2003) simulated the co-evolution of firms in production and distribution markets, with firms as bundles of skills transformed by goods passing through them. In anthropology, White, Schnegg and Brudner (1999) conducted a large-scale and diachronic analysis of marriage, sponsorship and elite networks in Mexico and 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. Many applied the small-world model 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 structural properties of large-scale clusters.

2.3 A Power law Logic and 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. According to Barabási and Bonabeau (2003), in large-scale networks, distribution of node links often follows a power law where most nodes have just a few ties and a very small number of nodes have an extremely large number of ties, and frequency by size tends to vary inversely by (some exponential power, close to one, of) size. Networks containing such powerful nodes, or hubs, tend to be scale-free in the sense that a self-similar scale-up in size of hubs continues at larger firm sizes. Other qualitative research studies and ethnography (Itami, Matsushima, and Kikkawa 1998; Koseki 1997; Seki and Kato 1990; Watanabe 1997; Watanabe 1998; Whittaker 1997) provided with some information on the possible node link distributions in Ohta.

Two lines of inquiry are evidence: (1) firms try to connect to larger firms at all levels of size, and (2) older firms that are disadvantaged with smaller sizes tend to compensate by connecting in larger groups. These two tendencies interact.

On the one hand, these qualitative field studies and our own field interviews suggest that the suppliers' access to leading OEMs is extremely important for most SMEs as the networks give them not only large-volume orders but also technical and business-related information directly from these leading firms.[7] In effect, small factories were heavily dependent upon larger factories to receive regular orders.[8] A quarter of those micro factories actually had direct links to factories with more than 100 employees or possibly larger (Whittaker 1997:78).

[7] One of the authors lived in Ohta for two years from 1998 to 2000 as to conduct field interviews, and the results largely confirmed information from the qualitative studies by other researchers used here.

[8] By establishing ties to the OEMs as their prime buyers, these SME suppliers can also leverage their social recognition to gain endorsement in the local business community. Merton (1968) perceived this Matthew effect as a kind of human nature—some get more favorable response to their performance than others do even if they take exactly the same action. He gave the explanation that the difference originates from each actor's reputation in the community.

As a result, these powerful OEMs put a lot of pressure on their SME suppliers in terms of cost, quality, speed, and flexibility.

To avoid a holdup in orders, it is critical for the SME suppliers to develop their own brand product lines for end-consumers as to reduce influence of these powerful OEMs' business decisions while keeping the ties.[9] This independence can give SMEs not only bargaining power in negotiations with their prime buyers but also a kind of social recognition in the embedded local community as winners with a symbolic achievement (Koseki 1997). In short, the regional network is a product of social competition among the SMEs to become suppliers of popular OEMs for enhanced reputation and large trade volume while they try to gain independence and social recognition by developing brand lines of their own end-products.

On the other hand, many SMEs at marginal positions were also heavily relying on the 'nakama-torihiki' or "conferee" trading, business transactions among members of a mutually supporting, small family group of SMEs, among which it was very important for the SME suppliers to become suppliers of reputable OEMs. In the prevalence of this kind of trading, the close ties are based on the former master-apprentice relationships of craftsmen that continue to develop even after the disciple becomes independent as the proprietor of a micro spin-off. Whittaker describes how many micro SMEs had these strongly embedded ties within their "bicycle distance" as small cohesive cliques. They place frequent orders with each other to supplement their limited technological capabilities and skills beyond their specialized areas, and they often share overflow work with the trusted member firms. This institutionalized mechanism works as a cushion for the SMEs during the cyclical ups and downs of the macro economy. Those small factories and workshops carried out a substantial amount of these activities (1997:78). As the SMEs often relied on these locally embedded ties, especially for small-lot production, there exist many such small cliques of interfirm linkages in the periphery of the complex web.

These two processes reinforce one another to produce more smaller firms linking horizontally and to larger firms and larger firms linking to yet larger firms in hierarchical fashion, with the structure of the hierarchy generally following upward supply lines to end producers. Therefore, the first hypothesis to test is as follows:

Hypothesis 1: In large-scale regional clusters, supplier-prime buyer relationships tend to be scale-free in their number of links to suppliers according to a power law where ever smaller numbers of powerful OEMs at the top of the hierarchy get larger numbers of ties from SME suppliers as reputable prime buyers while most of the SME suppliers extensively use local trading partners that form many small cliques.

The distribution of positive in-degree for all 8347 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 node attachment for the network size of 4-8,000 (White and Johansen 2005:17).[10] First, the dataset contains a relatively large number of firms with extremely high scores of in-degree as powerful hubs as with a fat tail spreading its width towards the end of its distribution. Toshiba was the most popular prime buyer, as 112 suppliers in Ohta listed the firm while 53 listed NEC, 45 listed Hitachi, and so forth. Overall, no single firm constitute a

[9] In the 1990s, many SME suppliers went bankrupt by unwillingly accepting very demanding and harsh terms and conditions asked by prominent buyers especially when the Japanese economy was falling into deepening recessions (Koseki 1997).

[10] 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.

hub that dominated the network but some are marginally so, as there are many hubs along a gradient, not just one. Moreover, 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. Second, the distribution also suggests that there are numerous prime buyers listed only a few times by the SME suppliers in the aggregate. Thus, the "pecking order" for in-degree 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. This result supports Hypothesis 1.

Figure 1 about here

2.4 OEMs' Group Networks and Local Structure

How can we identify the local relational properties suggested by flexible specialization theory? Egocentric networks give an approximation. The notion of competitive cooperation, an organized division of labor among the competing but cooperating SMEs, is illustrated to a certain degree by Figure 2 for the supplier chains of a leading OEM in Ohta. Ranked second in terms of in-degree from its 53 Tier-1 suppliers, NEC's hierarchically organized, double hub-and-spoke network structure extends to include 124 suppliers at Tiers-1, -2 and -3. The graph shows how NEC uses local Tier-1 firms to assemble or organize parts and components manufacturing. Each firm at Tier-2 or lower also organizes and coordinates a variety of technological competence, engineering knowledge, and workers' skills contained in their dedicated suppliers. Similarly, supplier-group networks of other large OEMs operate on the foundations of this kind of coordination and organization.

Figure 2 about here

3. Network Integration Mechanisms in Ohta

3.1 Oriented Network and Components as a Production-Chain Market

The links nominated by suppliers as to their prime buyers constitute a digraph, or directed graph. While the directions of the links did not prevent it, not a single pair of firms named one another reciprocally as prime buyers. Hence, this property of supplier-prime buyer relationships makes them a fully oriented network that constitutes an oriented digraph (Harary 1969: 10): a digraph with no symmetric pairs of directed links. A weakly-connected *component* of a digraph is a maximally 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 parties (Freeman 1979; Hanneman 2001), weak components, which disregard the directions of ties, bear social meanings. In Ohta, complex interactions among suppliers, suppliers/prime buyers, and prime buyers may generate a large such component.

To relate these concepts to our analysis, an emergent role structure in the production-chain network is a complex value-chain in which two kinds of organized division of labor should be embedded: A horizontal configuration among suppliers jointly organized by prime buyers or hubs, as suggested by flexible specialization theory (see Figure 2 for example); and vertically linked stages from the upstream to the downstream as linked flows of procurement, processing activities, parts and components manufacturing, modules production and assembling, marketing and sales, and distribution stages. In other words, a series of horizontal division of labor among suppliers organized by hubs should be vertically linked or oriented as entangled production chains that flow down towards the assembly work by OEMs, as an institutionalized 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 large firms involve a redefinition of the categories and statuses of agents in relation to their brand equity. Because these value-chains can draw from many different clusters in the overall network, they should form a large component as a complex web of suppliers and their prime buyers. Therefore, the second hypothesis to test is as follows:

Hypothesis 2: In each of large-scale regional clusters, horizontally coordinated and vertically organized, enmeshed supplier-prime buyer relationships among thousands of the firms generate large components as an overall value-chain. And because it takes only one random link to connect two large components, there will typically be only a single dominant ("giant") component in such networks.

The largest component of 4,500 firms (indeed "giant") was in fact identified. The component-finding network operation thus created a simpler and somewhat reduced network by excluding 3,847 firms that are disconnected from the giant component. Hypothesis 2 is thus supported.

3.2 Acyclic Depth Partition and DAG Structure

While there are many local clusters as exemplified with the graph of NEC's supplier group network and other smaller cliques as for the conferee trading, how is the giant component organized as a complex value-chain? Watanabe (1997:158-68), based on his fieldwork research in the Ohta industrial district, suggests that the overall network structure form a "mountain range" where many prominent OEMs at the peaks share their SME suppliers at low levels in the subcontracting hierarchies, as overlapping mountains across a variety of industries. Furthermore, Nishiguchi's qualitative study of the Japanese supplier system in the automotive and the consumer electronics industries, although not of ties in any particular regional cluster, provides an imagery of the possible configuration in Ohta:

> The conventional characterization of the Japanese industrial supply system as a pyramid is correct insofar as it describes the relationships between a single prime contractor and its subcontractors, but it is misleading if it is meant to imply a closed system. Taking into account the complex relationships among multiple prime contractors and cross-serving subcontractors, it is more accurate to describe the whole system as a series of pyramids overlapping one another, as do a range of mountains. Hence my own preferred term, the Alps. (Nishiguchi 1994:122)

These qualitative findings, following the concept of the production-chain network aforementioned, lead to the next hypothesis:

Hypothesis 3: Supplier-prime buyer networks in large-scale regional clusters form a "mountain range" type of structure, as many group networks organized by leading OEMs share their suppliers in the lower tiers of their hierarchies as overlapping pyramids across different but related industries.

The one-way directedness of supplier-prime buyer links is one of the fundamental characteristics of the complex subcontracting relationships, as discussed earlier. The Ohta network actually had no reciprocated or symmetric links. In a separate paper (author publication 2006 to be inserted after review), we showed, with statistical evidence, that these *large sparse networks* (LSN) will, when sufficiently sparse, generally take the form of *directed acyclic graph* (DAG).[11] We also argued, based on our Ohta study and comparative observations of contemporary regional clusters, that the DAG should have a limited number of hierarchical levels as an approximation of subcontracting layers.

The analysis of levels in an acyclic network is an effective method by which hierarchical properties can be detected even in an extremely complex network. This acyclic depth partitioning is robust in that it will capture a great deal of the structure of large and sparse, oriented graphs, simply by ordering rather than reduction of data. The algorism assigns rank to partially ordered elements in an upper triangular adjacency matrix based on the following 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.

Figure 3 shows the outcome of an acyclic depth partition of the largest component. With the network size of 4,500 firms, it includes 54% of the firms in the whole network. Node size reflects in-degree of nodes. Labels, largely obscured, are those of the top 105 prime buyers in terms of degree centrality with an in-degree of 6 or more.[12] All of the top 105 buyers in the full network of 8,347 firms are included in the component.

To elaborate, there are seven linked but hierarchically ranked levels as an approximation of the value-chain levels. The vertical paths that connect firms across the levels represent linked manufacturing processes that produce an enormous variety of parts, components, modules, and end-products. There are peaks of overlapping group networks that span boundaries across a variety of industries. The streams of goods and chains of services are enmeshed threads weaving through various manufacturing processes as a kind of food-chains structure running within and beyond the Ohta ward.

The hierarchically partitioned layers map out the relative position of each firm in the upstream/downstream production-chain. In general, the larger the number from Level 1 to 7, the closer the manufacturing processes and services are to the end-products that reach the consumers. The relatively low layers include large numbers of firms, and the relatively high layers have small numbers of firms. The number of suppliers decreases gradually as the process moves from the upstream left to the downstream right owing to the coordinating roles of local buyers as network integrators or organizing hubs.[13] Hypothesis 3 is thus supported.

Figure 3 about here

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[11] 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; Scott 2000). When there is no cycle in the network, the relationships among the nodes constitute, by proof following from definition, a hierarchy (Harary 1969:200). In contrast, if egalitarian relationships among firms in this kind of network take a non-hierarchical structural pattern, as could possibly be found in the Italian industrial districts, there should be cycles found where a manufacturing process starts off from one of the firms and eventually comes back to the firm of origin, after going through the linked processing and manufacturing stages. No directed cycles were found in the Ohta case.

[12] An exception to the rule is the government agency in charge of the security and defense of the homeland (the Self Defense Agency) which is also labeled but has an in-degree of 5.

[13] As a caveat, these depth levels do not correspond to suppliers at Tier-1, -2, and so forth, but starting from a firm that is sufficiently high in the depth level, its suppliers at Tier-1, -2, and so forth, will always be at successively lower levels in the hierarchy.

4. Analysis of Cohesion Measures

As discussed above, our network analysis of the largest component has unveiled the underlying structure as mountaintops and ridges (White, Owen-Smith, Moody, and Powell 2005) toward which goods and services flow toward launchings from the production-chains to global consumers of industrial products. It appears that the depth hierarchy has multiple peaks of prominent OEMs at the top of the overlapping pyramids, which share numerous SME suppliers at low levels in the hierarchy. In these scalings of Figure 3, however, 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.

Further, different measures of cohesion can distinguish types of hierarchical structure in the network. As Powell, White, Koput and Owen-Smith (2004) show, forms of network analysis that incorporate cohesion analysis as measurement of multiconnectivity of nodes can 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 measures of the structural cohesion for which Moody and White (2003) provided an algorithm that also computes a related measure of theirs called "structural embedding."

The simplest lower-order measure of network cohesion is the bicomponent, where all the nodes are connected by two or more independent paths defines a structural unit relevant to the structural cohesion. The existence of alternative paths makes the bicomponent minimally robust.[14] Examining multiconnectivity, the largest component of 4,500 firms contains a large bicomponent of 1,609 firms—structurally cohesive and robust at a multiconnected level of two, one level higher than the giant component. From the point of view of embedding, all of the top 105 prime buyers in the full network are contained in the bicomponent. Of the 97 firms with in-degree of 5 or more in the bicomponent, 88 are firms listed as the top 105 prime buyers and only 9 firms are not among the top 105 list. A hierarchical nesting is apparent in the composition.

The above analyses of acyclic orientation and the embedding of components suggest that the whole network should converge towards a single core. Therefore, the fourth hypothesis is as follows:

Hypothesis 4: In each of complex supplier-prime buyer relationships embedded in large-scale regional clusters, there exists a cohesive core with some levels of multiconnectivity in the structural embedding.

Although there is no more than bicomponent structural cohesion in the industrial prime-buyer network – which is itself remarkable – we will study higher levels of cohesion within the bicomponent in terms of the density of cycles.

4.1 Structural Cohesion

Structural cohesion is not about density but about multiconnectivity, as White and Harary

[14] That is, moreso than simple linear connection. 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.

(2001), Moody and White (2003) and Powell, White, Koput and Owen-Smith (2004) have noted in their tests of the predicted effects of cohesion on other network and attribute variables.

To test Hypothesis 4, a 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. γ 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 case, $\gamma = 855$ 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 1996:49-51), or the ratio of the observed number of independent cycles, or 855, to the maximum possible number of independent cycles in a nonplanar graph, which is $n^2/2 - 3n/2 + 1$, the ratio is 0.0008%. The index is extremely low. Are there one or more subunits of the industrial hierarchy with an unusually high density of cycles as indicated by the alpha index?

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. Cohesion tends to be lacking up to Level 4 (from the bottom), but the very top three levels (with 37, 8, and 3 nodes respectively) can be seen to be highly cohesive as shown by the way that 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. The graph depicts a cohesive core in the hierarchy.[15]

Figure 4 about here

On a larger scale, in testing and further specifying Hypothesis 4, of the 4,500 firms in the largest component, 2,921 are above Level 1. When we delete Level 1, the largest component within these 2,921 has 947 firms, as shown in Figure 5. Here, an overall tendency is seen for a single hierarchy to form through the layers but also to differentiate at the next level up.[16]

Figure 5 about here

4.3 Cohesion in Hierarchies and Assortative Correlation

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[15] 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. Note that the central column of nodes at rungs 5-7 are not pulled together by spring embedding due to the existence of complete triads. Although there are no links by definition within rungs, they have the same or similar connections above and below them.

[16] 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, within the large bicomponent, smaller *k*-components of higher cohesion will also be likely to occur. But no tricomponents or more highly cohesive groups occurred in the Ohta network.

An acyclic depth hierarchy such as visualized in Figure 4 does not necessarily entail that the top of this hierarchy is structurally cohesively integrated. Taking into account the restrictions in data collection as up to three prime buyers, we need to evaluate whether there are greater tendencies toward cohesion in the distribution of node attachments in some parts of the network compared to others (i.e., to measure assortativity).[17] 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 produced for the full network of 8,347 firms, 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 2 for the largest component of 4,500 firms 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 these levels (column C in Table 2). 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 ($R^2 = 0.998$),[18] 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—Levels of 1 to 4 respectively; 5-9; 10-15; and 16 or more—suggest that increases in this ratio might possibly vary instead in proportion to the seven levels of the depth partition.

Table 2 about here

Figure 6 about here

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 for 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.[19] 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 power-law decay curve. The greatest assortative correlation among hubs occurs at Levels 5 to 7. The evidence here for cohesive integration at the upper levels is positive very slight: overall, cohesive integration by this measure declines moving up the hierarchy, but does not continue the decline at the uppermost level.[20]

Figure 7 about here

[17] We cannot do this by the standard methods for measuring assortativity (Maslov and Sneppen 2002), as for example where firms in a certain range of levels or number of suppliers are more likely to have ties, because the not all those nominated at prime buyers were interviewed, so the missing data will affect the results.

[18] 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 $R^2 = 0.998$.

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

[20] Although we could compute the assortative correlation or "mixing" ((Maslov and Sneppen 2002, Newman 2002) of whether links are more likely between hubs than would be expected from random, we have noted how our data sampling problem would affect that measure adversely, and we prefer a simpler measure such as ours that will also display results that are not monotonic.

Table 2, columns A-C, provides an index of our problem of evaluating cohesion relative to differential indegree of firms as they rise in the hierarchy with greater numbers of suppliers. For the giant component of 4500 firms the alpha index of cohesive cycles is extremely low (.0008) but does provide a standardized measure of subgroup cohesion for connected subgroups. When we take subsets of firms based on rising levels of degree, as in columns A-C, we are removing nodes at the bottom of each new hierarchy that contribute to the connectedness of the network, and this creates disconnected components. It is no surprise, as in Table 2, that the ratio of links to nodes declines as successively smaller subsets are examined. Further, we cannot compute the alpha index which assumes a connected component. Thus, columns A′-C′ Table 2 locate successive connected components of firms higher up the hierarchy, at levels 2, 3, and 4, by first eliminating firms with no suppliers (a bottommost tier) and then extracting the largest component within the remainder. This procedure yields three components: 1100 connected firms with original level 1 removed, 140 with original levels 1 and 2 removed ("level 3"), and 13 with original levels 1-3 removed ("level 4"). Figure 8 shows the results for the top two levels. Table 2 shows that the level 3 component that contains both top OEMs and leading SMEs has 22.9 times the alpha connective measure as the larger component of 4500 firms but the level 4 containing only OEMs has no internal cohesion whatever. This gives support to Hypothesis 4—presence of a single "most cohesive" core not at the very top level of OEMs but at the level of these OEMs and their leading SMEs.

There are 11 top-level firms at level 4 that are connected in Figure 8, but not cohesively so. The cohesion at level 3 shows up in two bicomponents connected by a single firm ("nsk", the largest node, colored green, which belongs to both), one large (38 firms, colored yellow and to the left and including "rsk") and one small (four firms, colored yellow and to the right and including "rsk"). The 84 firms (cyan, smallest nodes) at the periphery of this figure are connected to the core bicomponents by single link.

The core bicomponent of 41 firms, then, containing the elite OEMs and their elite SMEs, as shown, in the top of figure 8, are, then, our candidate for an "elite core" of this industrial hierarchy. The method used relies on graph-theoretic methods for detecting cohesion and does not rely on a complete sampling where all prime buyers named by Ohta firms were themselves interviewed.

5. Conclusions and Discussion

The present research study attempted to articulate structural mechanisms of supplier-buyer relations in large-scale industrial districts, applying some advanced techniques of network analysis. Based on findings from our previous studies of industrial districts, we employed some relevant theoretical undertakings in the areas of organization theory, regional clusters, and social networks in combination in order to conceptualize our analytical framework as follows. The prime organizational unit that we focus on is neither an embedded individual firm, a single node, nor any particular local network, a cluster of these nodes. There are numerous such overlapping local clusters in a large-scale industrial district. Each of these group networks is organized by a prime buyer that coordinates its suppliers, loosely at least, as an organizational network beyond the command line control within each firm. Complex local interactions among thousands of firms in competition, cooperation and coordination, which link these supplier groups, should create emergent linking mechanisms of the overall production-chain at a larger global level.

As a recap of our research findings, to begin with, the full network actually had hierarchical structure in the degree distributions of the hubs at the local level. Further, at the global level, the interfirm dynamics operative among thousands of specialized SME suppliers and their prime buyers generated a giant component and bicomponent. Graphically speaking, many hierarchical supplier networks of leading OEMs produced a multiple mountaintops-style structure where these group networks share thousands of SME suppliers at lower levels in the subcontracting hierarchies.

Yet, deeper in the complexities, we also found a very cohesive single core at high levels of the hierarchies, which is composed of super hubs, or extremely powerful OEMs, and their powerful suppliers, as unveiled by probing the largest component and bicomponent especially with the analyses of different cohesion measures and a series of graph scalings. In the overall convergence, we detected differential patterns by the discrete categories of node links. While most of the firms were linked by a power-law order, the core was an exception as the assortative correlation of these hubs indicates. Embedded in the giant component and a largest bicomponent, this structurally inter-cohesive group was an invisible "elite club," clearly the most powerful linked unit, integrating supplier networks of these elite members from the highest peak levels across a variety of manufacturing industries. While this emergent core was the engine of the complex production-chain network located at the power-law tail, most SMEs were excluded from the "club" through the linking mechanisms.

To conclude, our research findings show that, in this age of collaborative partnerships and advanced manufacturing, the egalitarian flexible specialization of local competitive cooperation among SMEs gives rise to a global network structure of dual economy in a large-scale industrial district. It is dualism not on the basis of size of each firm as traditionally claimed but from the local node connectivity and the global network integration of the contemporary production-chains. Under the divide, while the powerful core played a critical role in integrating if not fully controlling the overall production-chain, SMEs fill important but only secondary roles by providing a huge pool of workers' craft, engineering knowledge, technologies and social capital as a source of flexibility and innovations for the prominent OEMs, as part of Japan's industrial foundations. Against the conventional wisdom of flexible specialization where SMEs are regarded as creative and innovative partners of large firms to share their profits on a rather equal footing, this research study explicated relational boundaries that put structural constraints even on the flexible activities of SMEs.

As for further discussion, why does this powerful core ever exit especially from the standpoint of SMEs? What are substantive implications? The cohesive core provided the engines that propelled the flows of goods and services as a production-chain through linked stages of manufacturing processes. A vast variety of goods, a series of processing services, and a broad range of technologies funneled into these regional flow processes so as to eventually gain access to the consumers. Thus, it is obvious, first, that the elite core was practically the only access point for the geographically-bound and financially-constrained SME suppliers to sell their products or processing services indirectly to the consumers. These prominent OEMs, as assemblers of components, parts and modules from their suppliers, have maximum outreach to major markets with a variety of end-products for a wide range of consumers. In other words, given their limited span and scope of skills and resources as well as their relatively poor marketing experience, capacity and capability, most of SME suppliers needed a window of opportunity that was available only through ties to these gate keepers, or extremely powerful OEMs via the powerful suppliers. Actually, according to fieldwork studies and survey data (Seki 1994; Whittaker 1997), only 10-20% of firms in Ohta had their own brand product lines while the rest were dedicated suppliers in various processing activities or components and parts manufacturers without their own brand products. The top OEMs were probably able to take advantage of this institutionalized role structure in the downstream of the value-chain.

Second, most of the specialized SME suppliers probably needed to rely on the extremely powerful OEMs via the well-placed, powerful suppliers in order to enhance reputation and to get social endorsement, not only in the local business community but also among consumers at large who were socially and spatially located outside the industrial district. A lack of reputation about and confidence in the management of these SMEs appears to have put them in a very dependent position upon these established OEM brands.

Then, where does the power of these elite suppliers come from? Resource dependence theory argues that, as organizational resources only scarcely exist in the environments, firms that control these resources can gain influence and power in their external relations (Pfeffer and Salancik 1978). In the role structure of the production-chain market, these powerful suppliers appear to make use of their coordination and controlling skills of their own suppliers as organizing agents on behalf of the top OEMs as well as their technological edge and other competencies. Nishiguchi's qualitative study (1994; 1997), although not about any of specific regional clusters but of the Japanese supplier system in the automotive and the consumer electronics industries in general, points to suggest that a key underlying mechanism can be a variant of the "clustered control structure" that has emerged after the 1960s. Nishiguchi writes as follows:

> …changes resulted in turning the traditional semi-arm's length or loosely tiered structure of subcontracting into a "tightly tiered" one, or what may be called a *clustered control* structure; that is, the firms at the top of this clustered control structure buy complete assemblies and systems components from a concentrated base (and therefore relatively limited number) of first-tier subcontractors, who buy specialized parts from a cluster of second-tier subcontractors, who buy discrete parts or labor from third-tier subcontractors, and so on. In this clustered structure, many subcontractors who used to supply directly to the top firm became second-tier subcontractors (to supply contract assemblers and subsystems manufacturers) within a designated "cluster." As many first-tier subcontractors over time took over more comprehensive tasks from their customers, including testing, design, and parts procurement, they began to control their own subcontractors under their own regime….this system absolved those on top of the hierarchy from the increasingly complex controlling functions typical of external manufacturing organizations...Even though these developments took place in both the electronics and automotive industries,... (Nishiguchi 1994:122)

Hence a general extension of our argument is that, first, the presence of a powerful core is suggestive of the rise of Tier-1 suppliers in the production-chain of large regional clusters, as a coordinating and organizing agent of the complex system, especially in the age of advanced information and machining technologies after the 1990s. At the same time, these findings also suggest that the global linking mechanisms are not driven primarily by the preferential node attachments from the bottom or periphery as theorized by the logic of scale-free network that Barabási (2002) proposed.

Second, the relational boundaries are probably perpetuating an unequal distribution of resources and wealth, as this emergent structural inter-cohesion will further consolidate the divide. Firms are more likely, given choice among potential trading partners, to form partnerships with firms that have previous alliance partnerships (Gulati 1995). In analogy, the elite firms in the large component are likely to choose partners from ones that are already members of the component, or with whom the formation of the partnership will place both partners in the bicomponent. Practically speaking, especially after the 1990s, as the SMEs were short of financial capital to invest in very expensive high-tech equipments and advanced information technologies, they probably needed to depend upon the top OEMs via the powerful suppliers more than before, in order to get a share of revenue generated from sale to the consumers. In other words, the assortative correlation of hubs at the highest levels should be generative of and is probably reinforcing the cohesive elite club with its membership limited to the extremely powerful OEMs and their powerful suppliers.

Our empirical study has limitations, as follows. First, while we discuss the global linking properties as emergent and institutionalized mechanisms, our network data is basically a snap shot at a point in the mid-1990s. We initially conceptualized our framework as foundational mechanisms of the contemporary production-chain from the point of view of competitive cooperation among thousands of nodes and of supplier coordination and control by local OEMs, applying findings from our previous empirical studies of the industrial district and other relevant theoretical undertakings. Then, our network analysis found a very cohesive core with clear relational boundaries. As Ohta industrial district has its own development history of a well-over half century, we infer that these properties are some intrinsic and fundamental linking mechanisms of large industrial districts at a late stage in the evolution of such complex networks. We however also acknowledge that the contemporary production-chains should constantly reshape the local and global relational properties to a certain extent as they grow or decline.

Finally, it is 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 such complex web embedded in the cultural context and institutional settings of the Japan's 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, it 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 collaborative partnerships and advanced manufacturing technologies.

Appendix

Appendix A: Notes on Some Substantive Differences between the Stylized Japanese

Supplier System and the Supplier-Prime Buyer Relations in Ohta

The supplier-prime buyer relationships in the regional cluster are different from the so-called 'keiretsu' system, which includes ties between Japanese large manufacturing firms and their main banks; between prominent parents and their suppliers in company-cities; 'kyoryoku-kai' memberships or parent-endorsed, family groups of suppliers as seen in the Japanese manufacturing industries; and cross-shareholdings among the Japanese large firms.

It is difficult to access to what extent SME suppliers in Ohta were affiliated with kyoryoku-kai memberships, but the stylized notion of the so-called Japanese supplier system alone including the keiretsu system and kyoryoku-kai memberships cannot explain the complex supplier-prime buyer relationships. As an example, Ricoh, a leading manufacturer in the electronic and precision machinery including copy machines and optical equipments had 94 kyoryoku-kai members in 1993 with its large plant in Ohta. Among the 94 suppliers, 28 suppliers were located in Ohta. The rest of the suppliers were located in the following areas: 14 in Shinagawa and Meguro, or adjacent wards in Tokyo; 19 in other wards of Tokyo; 15 in Kanagawa and 5 in Saitama, or adjacent prefectures to Tokyo; and, 13 in other regions. Moreover, Isuzu, a leading automaker, had a large plant in Shinagawa, an adjacent ward, having relocated from Ohta. Among the 337 members of its 'kyoryoku-kai', 27 were still located in Ohta in 1994, having diminished from 43 in 1957 (Folk Museum of Ohta-City 1994:56).

It is also important to note however that presence of leading firms as prominent OEMs linked to suppliers in Ohta was industry-dependent, as the 1994-95 network data substantiates. While most of the well-known, leading Japanese manufacturers of electronics products, light electrical appliances, and heavy electrical equipments were listed as top prime buyers by the SMEs, visibility of some leading names both in the automotive production and in the general and industrial machinery was not as high in Ohta. Those leading firms had their smaller subcontracting networks that were spatially clustered around their large production facilities in company-cities of other local provinces.

Second, an extremely wide variety of manufacturing processes and technologies provided by firms in Ohta is its distinctive characteristic. Actually the so-called machine tools industry is a mother industry of such applied industries as the auto parts, the electrical appliances and equipment, the electronics parts and products, and the general and industrial machines, analyses based on the final outputs from the regional cluster would miss most of the value-adding linked processes and parts and components production on various intermediate stages (Seki and Kato 1990).

Finally, the nature of products and services that SME suppliers in Ohta provide is somewhat different from the one in other company-cities. Especially in the 1990s, many Japanese OEMs changed their outsourcing destinations to other local provinces and overseas especially for standardized bulk production and technologically simple processing. In effect, OEMs used SMEs in Ohta primarily for special purpose manufacturing and processing services including research-oriented trial or prototype production, small-lot production that could not be executed cost-efficiently internally by large firms, and parts and processes that require highly-specialized advanced machining technologies or seasoned workers' skills contained in the SMEs (Koseki 1990; Seki 1994).

In the regional economy, both suppliers and their prime buyers have to be careful about their partner selection, as they should share proprietary knowledge and technologies. At the same time, as for trial or prototype production, the regional supplier-prime buyer relationships can be quite fluid too. The trade relationships in the regional cluster thus tend to encompass elements of competitive bidding, arms-length transactions, and relation-specific long-term contracting in combination, with a broad range in the level of embeddedness.

Appendix B: Notes on the Name Generating Data

It is not easy to access importance of the listed prime buyers for SME suppliers. According to data from a survey conducted by *Chushokigyo Sogokenkyu Kiko* in 1997 (Chushokigyo Kenkyu Center 1999), among 1,341 SMEs in Ohta, with the response rate of 19.6% from 6,853 firms, SME suppliers with three employees or less typically had two to three buyers while those with 30 or more usually had over 100 buyers as for repeated business transactions. As for regular transactions, SMEs with three employees or less retained two to three suppliers of their own while those with 30 or more kept 10 to 19. Overall roughly 70% of SMEs in Ohta had two to three firms to receive and to place orders one another as the "conferee" members. Therefore, it is obvious that these listed prime buyers are crucial for the SME suppliers in Ohta although the impact of each prime buyer should also be dependent upon the total number of prime buyers that each supplier had as well as relative volume of the transactions and types of knowledge and skills involved.

The term "prime buyers," or 'Tokuisaki' in Japanese, used for our dataset should generally be much more exclusive and narrower than "all buyers" listing. The actual number of "prime buyers" was dependent upon the firm size of suppliers to a certain extent. The listed names of up to three prime buyers imposed on all 5,111 respondents should be less than one of "all prime buyers" that otherwise could have been listed especially by large suppliers. As the proportion of firms with 30 or more employees in 1990, however, was only 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 as 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" should only be 1.62-1.89 per firm, had free listing been allowed (author publication 2006 to be inserted after review).

Figures

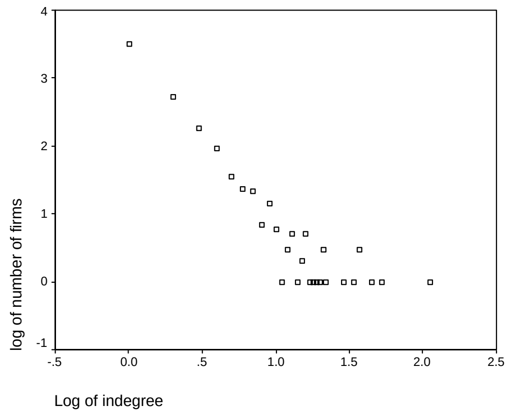

Figure 1 A Power Law in Ohta.
Data was created from *Ohta-ku Akusesu Deta 1 & 2* (Ohta-ku Sangyo Shinko Kyokai 1997a; 1997b).

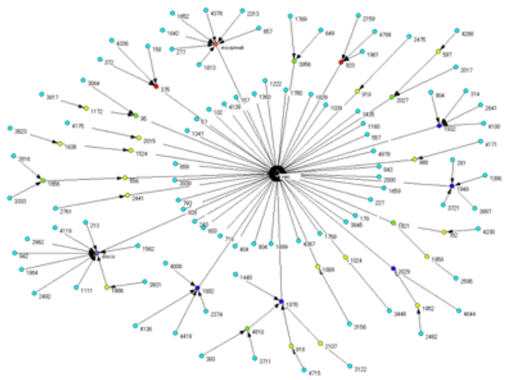

Figure 2 NEC's Supplier Network in Ohta: A Local Structure.
Graph produced from data in *Ohta-ku Akusesu Deta 1 & 2* (Ohta-ku Sangyo Shinko Kyokai 1997a; 1997b).
Colors by in-degree.

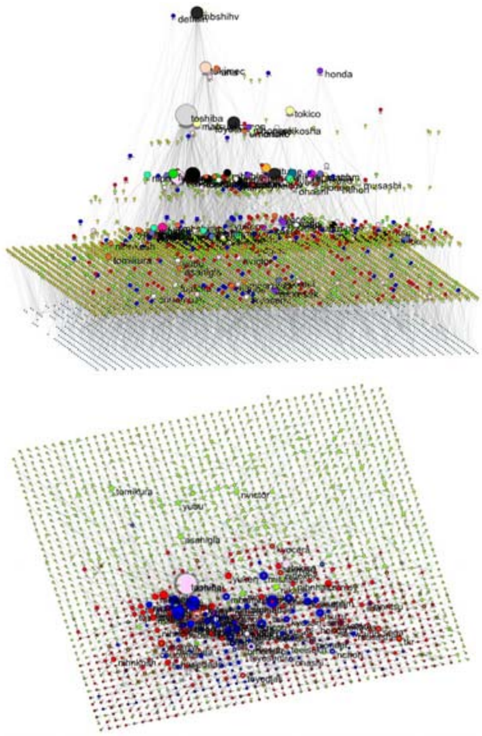

Figure 3 A Global Structure.
The graph shows subcontracting layers, according to the acyclic depth partition of the 4,500 firms in the main supplier/buyer component from the *Ohta-ku Akusesu Deta 1 & 2* (Ohta-ku Sangyo Shinko Kyokai 1997a; 1997b) data. The sizes of nodes reflect firm in-degree, or times 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 lower drawing is a projection onto the x-y plane showing more of the network topology.

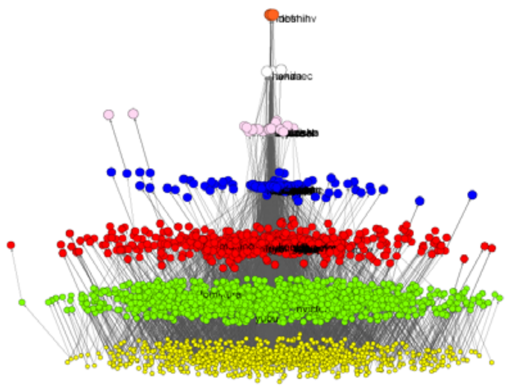

Figure 4 A Global Structure.
The graph shows subcontracting layers, according to acyclic depth partition of the largest component and a spring-embedding scaling for cohesion across layers among connected nodes.

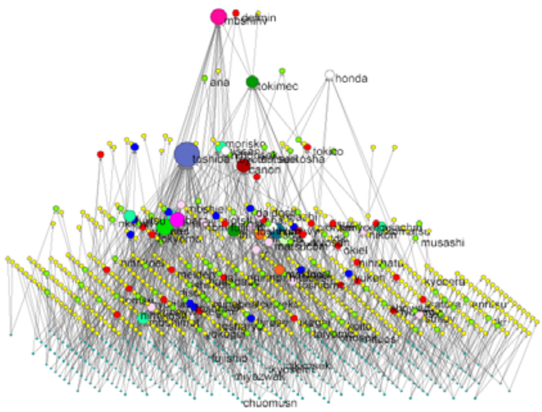

Figure 5 Level 2 and Up: Largest Component.

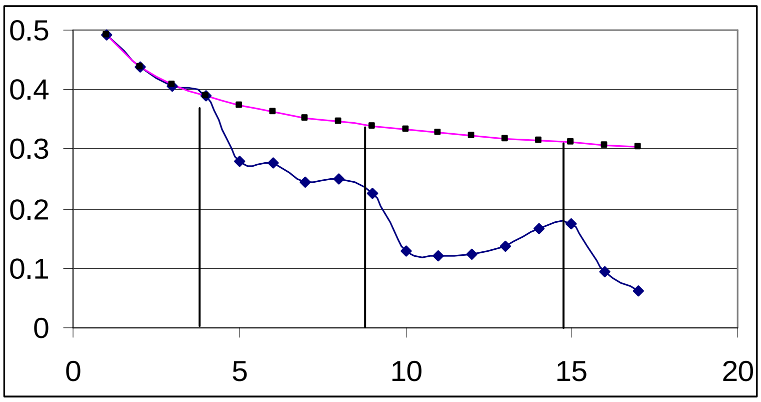

Figure 6 Categorical Decay of Links in the Hierarchical Layers of the Largest Component, by In-degree.

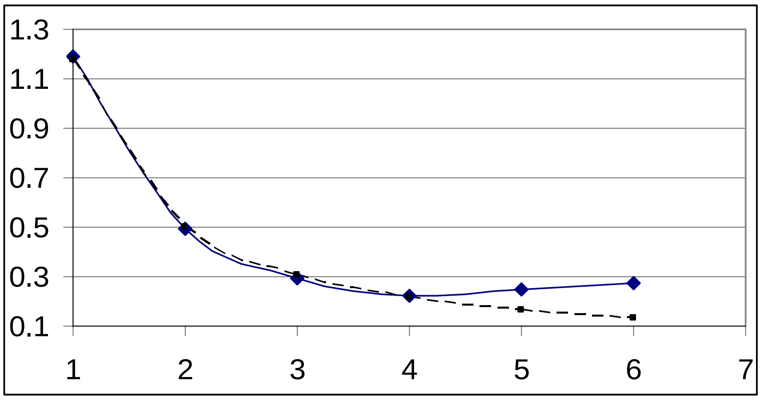

Figure 7 Assortative Correlation for Links in the Upper Hierarchical Layers of the Largest Component, by Depth Partition.
A solid line shows actual number of links per node at each level; a dotted line shows this ratio as extrapolated from power-law decay.

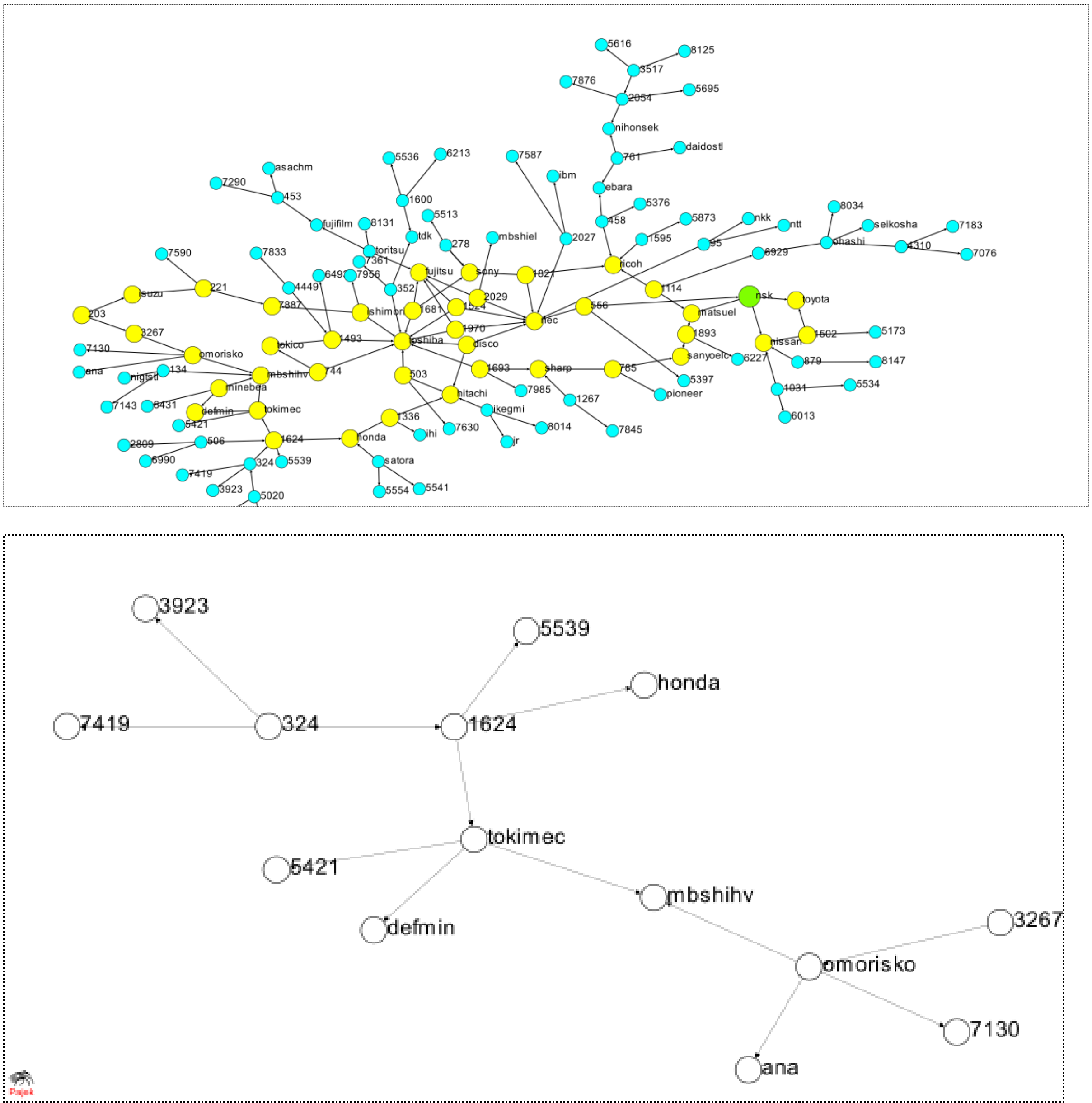

Figure 8 Connected components of firms, eliminating levels one-two and one-three in the industrial hierarchy, and corresponding to the "most cohesive core" of elite OEMs and elite SMEs (top), and a connected but not biconnected core of elite OEMs.

Tables

Table 1 Manufacturing Paradigms and Ideal Types of Organizational Design

	manufacturing paradigms and ideal organizational design types			
	dual economy	transaction cost economics	flexible specialization	transnational management
time periods	late 19th- mid-20th centuries	early 20th century-1960s	1970s- present	after 1990s-present
key concepts	" dual markets" by firm size	monitoring opportunism by command line under CEOs bounded rationality	flexibility and craft	short lead- time with advanced information and machining technologies
governance mechanisms	structural divide in society (primary of large firms versus secondary of SMEs)	organizational hierarchy and order (division of labor between Headquaters and divisional managers)	egalitarian " competitive cooperation" (division of labor among SMEs on the basis of trust and peer pressure)	collaborative and complementary arrangements between large multinational conglomerates and local SMEs
applicable market conditions	slow market dominated by oligopolistic capitalists	slow and stable markets	constantly moving, consumer-oriented markets in " information age"	fast- moving global markets in competition for global consumers
mode of production	automation and de- skilling of workers (exploitation of SMEs by large firms)	mass production (sequential, standardized manufacturing for volume and cost)	flexible manufacturing (great variety in small quantity in concurrent engineering)	mass customization (both volume and variety in concurrent engineering)
organizational structure	n.a.	multidivisional large firm	local network of SMEs in regional clusters	a global network of large multinationals and local SMEs
who get benefits: large firms or SMEs?	unequal distribution of profits in favor of large firms at the expense of SMEs	atomistic large firms	craft workers in specialized SMEs (SMEs as equal partners of large firms to get a share of profits)	both large multinational conglomerates and local SMEs to share profits

Table 2 Links-to-nodes ratio in largest-component hierarchical laye Connected Component rs, by in-degree

Levels	A # of links, by in-degree	B # of nodes	C Linking ratio (# of links/# of nodes)	A′ # of links, by in-degree	B′ # of nodes	C′ Linking ratio (# of links/# of nodes)	Alpha	Alpha Ratio
whole largest component	5354	4500	1.190	5354	1.190	1.190	.00008	1.0
	Disconnected Components			Connected Component				
In-degree of 1 and above	1435	2921	0.491	1100	947	1.162	.00034	4.1
In-degree of 2 and above	385	877	0.439	140	126	1.111	.00194	22.9
In-degree of 3 and above	166	409	0.406	13	14	0.920	.00000	0.0
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	0.250					
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					

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