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# What Really Goes on in Silicon Valley? Spatial Clustering and Dispersal in Modular Production Networks

Timothy J. Sturgeon

MIT-IPC-03-001

April 2003

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## Spatial Clustering and Dispersal in Modular Production Networks

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Spatial Clustering and Dispersal in Modular Production Networks

By Timothy J. Sturgeon

Abstract:

Is the geographic trajectory of capitalism toward spatial clustering or dispersal? Much of the recent theoretical work in the stream of “relational” economic geography includes several dynamic elements that increase the importance of spatial clustering over time. This paper develops the concept of “modular production networks” to show that spatial clustering and dispersal can be compatible, mutually reinforcing trends. I illustrate value chain modularity through its best empirical case, the American electronics industry, with a particular focus on highly competent, globally-operating contract manufacturers. Modular production networks encompass nodes of tacit activity linked through the exchange of codified information to create global-scale production systems. The historical process that is underway is one of increasing supplier competence, improving standards, and better codification schemes that enable increasingly complex information to be handed off between value chain actors. In places like Silicon Valley, industry participants rely on the benefits of proximity to help create the mechanisms that support the functioning of global-scale modular production networks.

Keywords: industrial organization, globalization, outsourcing, electronics industry, modular production network.

JEI Keywords: L63, F23, O18, L22

# 1. Introduction

Innovations in industrial organization have always been important to economic development. Although the greatest academic and popular focus has been on how technological innovations—the steam engine, the railroad, the telephone, the computer—have destroyed old industries, created new industries of their own, and enabled new developments in other industries, new systems of industrial organization have been behind many of the most important advances in economic history, from the English factory system, to Henry Ford's system of mass production, to Toyota's lean production system. A notable feature of both technological and organizational innovations is that they arise in particular locations before being adopted, and often transformed, in other places. Elsewhere I have argued that a new system of industrial organization, the modular production network, has recently come into view, driven largely by the strategies of firms based in North America. This change in industry structure has been entwined with the spatial processes of geographic dispersion, re-location, and regionalization—in short, globalization (Sturgeon, 2002).

In modular production networks firms with a high degree of autonomy rely on standardized protocols to exchange codified knowledge, sometimes on a on a global scale. These features contrast sharply with recent literature in economic geography, which has stressed the spatial embeddedness of tacit knowledge and the importance of tight interdependencies between geographically clustered firms (Storper, 1995; Gertler, 1995; Maskell and Malmberg, 1999). This divide reflects an ongoing debate between geographers who trumpet the advantages of the sub-national region as a unit of economic organization, the "localists," and scholars from a variety of disciplines who argue that the geography of economic activity is rapidly outstripping the local and even national organizational structures and institutions, the "globalists." This paper presents the concept of value chain modularity less to bolster the case of the globalists and more as a lever to gain a clearer view of recent trends in economic geography. Neither the localists or the globalisits have it entirely right—or wrong. Building on work by Amin and Thrift (1992) on "neo-Marshallian nodes in global networks," I argue that the mix of tacit and codified knowledge in global-scale production networks is the most salient characteristic of emergent systems of industrial organization. Moreover, what gets worked out within spatial clusters is exactly the codification schemes that are required to create and manage spatially dispersed but tightly integrated production systems. Transnational firms are embedded in a variety of specialized industrial clusters, and some of these, places like Silicon Valley, have emerged as the key command and control hubs for global networks. We need to better understand the various roles that local agglomerations can play within spatially extensive value chains and begin to map the activities that tend to concentrate in particular places even as the geographic "footprint" of linked economic activity expands. It is the linkages mechanisms, between firms and between places, that especially deserve more of our research attention.

The paper is organized as follows. In Section Two, I present the concept of the modular production network In Section Three I illustrate the model using its best empirical case, the American electronics industry, with a particular focus on the rise of highly competent, globally-operating contract manufacturers. The empirical evidence presented comes from the author's cumulative field research experience, mainly in the electronics and motor vehicle industries, but more specifically from more than 350 field interviews conducted during the period 1999-2002 by a team of Massachusetts Institute of Technology researchers for the Industrial Performance Center's "Globalization Study,"[1] as well as an extensive review of the trade literature. One hundred eight of

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[1] For the past three years (1999-2002), a team of 24 researchers from MIT's Industrial Performance Center (IPC) has been investigating the confluence of globalization and industry reorganization in several sectors, including electronics, motor vehicles, software, and textile/apparel. Field research for the IPC Globalization Study has consisted of semi-structured qualitative interviews with company personnel and relevant individuals from government agencies, labor unions, and academia. In-person interviews and plant tours have been conducted in Canada, Mainland China, France, Germany, Indonesia, Ireland, Israel, Italy, Japan, Korea, Malaysia, Mexico, the Philippines, Singapore, Taiwan, Thailand, and the United States. As of this writing we have conducted more than 350

the field interviews were conducted in the electronics industry. In Section Four I contrast the modular production network model to the more relational network models that have been developed in the literature. In Section Five I compare the performance characteristics of relational and modular production networks. In Section Six I look more deeply into what goes on in industrial agglomerations, pointing out that a key goal of tacit interactions in places like Silicon Valley is to develop the codification schemes that will create more fluid global-scale production arrangements. Section Seven concludes with some summary comments.

## 2. The Concept of Value Chain Modularity and the Rise of the Global Supplier

Value chain modularity emerged during the late 1980s and 1990s from the break-up of vertically integrated corporate structures and the horizontal aggregation of activities around specific sets of closely related value chain functions. Out of this change two broad sets of firms can be identified, lead firms, focused on product development, marketing, and distribution, and sometimes some late-stage manufacturing steps such as final assembly, and turn-key suppliers focused on selling, as services, many of the value chain activities that lead firms have decided to outsource. In electronics, for example, firms as different as Hewlett Packard and Ericsson have sold off their most of their worldwide manufacturing infrastructure to contract manufacturers such as Solectron and Flextronics. In semiconductors we see the emergence of "fabless" design that relies on semiconductor foundries such as TSMC, UMC, and IBM for production. In the auto industry, Ford and GM have retained vehicle design and final assembly, spun off their internal components divisions as the independent suppliers Visteon and Delphi, and outsourced an increasing volume of

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interviews, which have been written-up and stored in a searchable database. One hundred eight of these interviews were conducted in the electronics industry, 72 were conducted in the textile/apparel industry, and 61 were conducted in the motor vehicle industry. For more information about the IPC Globalization Study, including our methodology and detailed research findings, see http://globalization.mit.edu.

component and module design and production to “first tier” suppliers such as Lear, Johnson Controls, Magna, and TRW.

I call these new arrangements value chain modularity because distinct breaks in the value chain tend to form at points where information regarding product and process specifications can be highly formalized. I posit, following the literature on modular product design (Ulrich, 1995; Sanchez and Mahoney, 1996; Meyer and Lehnerd, 1997; Thomke and Reinertsen, 1998; Shilling, 2000), that within functionally specialized value chain nodes activities tend to remain tightly integrated and based on tacit linkages. Between these nodes, however, linkages are achieved according to widely agreed-upon protocols. Linkages based on codified knowledge provide many of the benefits of arms-length market linkages—speed, flexibility, and access to low-cost inputs—while allowing for a rich flow of information between firms. Such transactions, however, are not the same as classic market exchanges based on price. When a computer-aided design file is transferred from a lead firm to a supplier, for example, there is much more flowing across the inter-firm link than information about prices. The locus of these value chain break points appear to be largely determined by technical factors, especially the open and *de facto* standards that determine the protocol for the hand-off of codified specifications.[2] The network architecture that arises from such linkages has many of the advantages of modularity in the realm of product design, especially

[2] Standardized protocols do not arise spontaneously, but are part of the historical processes of industrial development. Standards can be agreed upon by committees (open standards), or they can arise from the codification of the routines of dominant firms or from equipment or software vendors (*de facto* standards). Their establishment is often contentious and part of the competitive positioning of firms. Standards are also dynamic. They change as new component, product, and process technologies emerge.

the conservation of human effort through the re-use of system elements— or modules—as new products are brought on-stream (Langlios and Robertson, 1995).[3]

Because of the important role that American firms have played in the twin processes of deverticalization and globalization, both as lead firms and as suppliers, I have characterized value chain modularity as a "new American model" of industrial organization. The turn-key suppliers in this model contain "generic" productive capacity that can easily be re-deployed to serve a range of lead firms as conditions change. The term "turn-key" stems from the large size, broad capabilities, and independent stance of the largest suppliers. The services of turn-key suppliers are generally available to lead firms on short notice with relatively little prior interaction. The fluidity of the network is supported by the ability to hand-off relatively codified product and process specifications at the inter-firm link, which has the effect of reducing asset specificity and making suppliers and lead firms substitutable. Asset specificity is also lowered and substitutability enhanced by the "generic" production capacity that resides in turn-key suppliers, capacity that is essentially shared by the supplier's customers (Sturgeon, 1997, 1999, 2000a, 2002).

I contrast the modular production network to more "relational" network models where lead firms and suppliers are more locked into their trading relationships, either through social and spatial propinquity, as in industrial districts (Piore and Sabel, 1984), or though a high level of supplier dependence on dominant lead firms, as in and Japanese-style "captive" production networks (Dore, 1986). In relational networks, product and process specifications remain relatively tacit, and

[3] The set of ideas underpinning the notion of modular production networks has much in common with Langlios and Robertson's (1995: 68-100) discussion of external capabilities, modular systems, and the rise of "decentralized networks," except that value chain modularity in their framework arises from lead firms' reliance on outside component suppliers and does anticipate the possibility that lead firms might outsource processes steps and even the entire manufacturing process itself. Their focus is on component modularity, not the process modularity that underlies the modular production network.

therefore more intense interaction between firms is required, which in turn leads to greater asset specificity in the inter-firm relationship (Williamson, 1975, 1981, 1985). Spatial clustering in industrial districts is one mechanism to suppress transaction costs in the face of asset specificity (Scott, 1988) and the power relationships and equity ties in captive networks are another.

The process of industry re-organization that has given rise to modular production networks has been occurring at the same time that firms from nearly all advanced economies, and many developing economies, have been increasing their direct and indirect involvement in the global economy.[4] International production has long been a hallmark of American firms, but today, because of "deverticalization," global reach is increasingly achieved with the help of a wide range of intermediaries, partners, and suppliers who support and even proxy for lead firms in far-flung locations (Gereffi, 1994). To try to solve some of the coordination problems that have arisen from outsourcing to multiple partners in a growing number of locations, many American lead firms have an active program in place to outsource to fewer, larger suppliers. In complex assembly industries, such as electronics and autos, this confluence of deverticalization, outsourcing, and supply-base consolidation has created a new set of important actors in the global economy, the "global suppliers" (Sturgeon and Florida, 1999, forthcoming; Sturgeon and Lester, 2002).[5] Global suppliers introduce a high degree of value chain modularity into industry structure because the large scale and scope of their operations create comprehensive bundles, or modules, of value chain activities that can be accessed by a wide variety of lead firms. To put it differently, global suppliers are nearly always turn-key suppliers. Value chain modularity can be conceptualized and observed entirely at the local level (e.g., Saxenian, 1994), but in practice industry re-organization has become

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[4] There are two main routes to global integration, indirectly through buying or selling across borders, or directly though cross-border production. This paper principally concerns itself with the latter.

[5] In others industries, such as apparel, horticulture, and household goods, the supply-base remains fragmented and the role of intermediaries such as brokers, buyers, and trading companies remains important.

deeply entwined with the processes of globalization, and it is global suppliers that perhaps best exemplify this connection.

The combination of productive scale, geographic scale, and value chain scope that has been achieved by global suppliers in only a few short years is striking. Solectron, a provider of manufacturing and engineering services for the electronics industry, grew from a single Silicon Valley location with 3,500 employees and $256M in revenues in 1988 to a global powerhouse with more than 80,000 employees in 50 locations and nearly $20B in revenues in 2000.[6] During the same period Solectron increased its offering of services related to its traditional manufacturing function to include, among others, product (re)design-for-manufacturability, component purchasing and inventory management, test routine development, final assembly, global logistics, distribution, and after-sales service and repair. Lear, a Detroit-based automotive seating supplier that generated $1.1B in revenues in 1991 grew to $14.5 in annual sales by 2000, and now operates 400 plants in 33 countries and employs 125,000. At the same time, Lear expanded its product offering to include entire automotive interior systems, including headliners, carpets, cockpit modules, and interior panels.

What is important about the geography of global suppliers is that they are firmly embedded in locations with both low and high operating costs. Locations in advanced economies support the set of important interactions between lead firms and suppliers that resist codification, such as co-design, prototype development, and manufacturing processes validation. Such locations are also used for the manufacture of high value and/or low volume products. Engineering changes tend to occur more frequently in such products and their high unit value makes the marginal savings garnered by low-cost locations less compelling. Global turn-key suppliers provide a mechanism to bridge the tacit and proprietary with the codified and generic, as well as a mechanism to integrate high-cost locations with low. The following section illustrates the concept of value chain

[6] Notably, Silicon Valley employment had increased to 6,000 by 2000.

modularity through the case of the electronics industry. Although value chain modularity appears to be increasing in other industries as well (Sturgeon, 1999; Sturgeon and Lester, 2002; Sturgeon and Florida, forthcoming), the electronics industry, thanks in part to relatively well developed standards surrounding design processes, component characteristics, and manufacturing process technologies, provides an excellent illustration of this emergent system of industrial organization.

## 3. Value Chain Modularity and the Rise of Global Contract Manufacturers in the Electronics Industry

Markets for electronics-based products, and the value chains that serve them, are extremely diverse, complex, and dynamic. Hardware and software applications are very broad and new applications and products continue to be invented. The result is an industry characterized by overlapping sets of value chains and a variegated and dynamic set of actors. Still, the structure of the electronics industry in the United States has changed enormously since the industry's birth in the late 19th century and broad historical patterns of organizational change can be identified.[7] After brief periods of infant industry fragmentation, the electronics industry in the US came to be dominated by large, vertically integrated firms, first in the telephone industry (e.g., ATT) and then the radio industry (e.g., RCA), out of which grew other consumer electronics sectors such as television and eventually, computers (e.g., IBM). In the 1960s and 1970s, with the push for better semiconductors for military and aerospace applications, an independent, or "merchant," components industry (e.g., Texas Instruments) gathered steam with the Air Force and NASA playing the role of "lead firm." In the 1980s, as the industry began to grow rapidly with the personal computer, a range of other value chain functions were outsourced, beginning with

[7] The geography and organization of the electronics industries emanating from Japan, Europe, and Korea are not covered by this section's description.

production equipment for both semiconductor fabrication and circuit board assembly, and then spreading to the manufacturing process itself in a practice called "contract manufacturing."

Today, the structure of the electronics industry is extremely modular. Process technology is being driven in large part by the vendors of production equipment such as Applied Materials (for semiconductor fabrication) and Fuji, Matsushita, and Siemens (for circuit board assembly). The use of semiconductor foundries for chip fabrication and full-service contract manufacturers for circuit-board and final product assembly is widespread and increasing (Electronic Trends Publications, 2000). Most recently, even the design process is being "unbundled," with repetitive and specialized design tasks being turned over to external suppliers (Linden and Somaya, 2002). This industry structure allows "virtual" lead firms and "fabless" component design houses to be regularly founded with no intention of ever establishing in-house production, a practice that has long been part of the organizational landscape of Silicon Valley (Davidow 1992; Saxenian, 1994; Sturgeon, 2000b) and in Taiwan (Lee and Chen, 2000), but which has now been fully embraced by large electronics firms that have historically been more vertically integrated, such as Nortel and Ericsson (Serant 2000a).

The general organizational pattern that has resulted from these changes can be described as a shift away from vertical integration toward horizontal specialization. This is not to say that value chains have fragmented into smaller elements. While value chains have "disintegrated" vertically, there has been a great deal of horizontal consolidation to achieve external economies of scale and scope.[8] Horizontal specialties sometimes constitute a single value chain function, but recent trends suggest that under certain conditions, this may be giving way to more "vertical bundling" within the horizontal pattern (Calderon, 2001; Serant and Shah, 2001). In our interviews; many lead firms

[8] Economies of scale are said to be "external" in this case because they are generated at the industry-, not the firm-level (Langlois and Robertson, 1995). External economies of scale arise because the capacity of modular suppliers is essentially shared at the industry-level.

managers stated their desire to integrate downstream from their "core" activities of product development, sales, and marketing; increasing their offerings of "value-added" services such as system integration and custom application development even as they shed upstream activities such as manufacturing. For turn-key suppliers, rapid expansion has led some toward upstream integration to ensure the supply of components that are unique to specific product models, especially in remote locations with poorly developed supply-bases.

This paper is mainly concerned with product-level electronics, and in this part of the electronics value chain it is the rise of contract manufacturers that has been one of the most notable features of organizational change over the past fifteen years. As the outsourcing of manufacturing gathered steam in the late 1980s, clusters of regional contractors emerged in a variety of locations, with Silicon Valley, California, Hunstville, Alabama, Singapore, Hong Kong, Taiwan, and Scotland being notable early centers (Sturgeon, 1999). Within the past five years there has been a striking process of consolidation and the largest five contractors, all based in North America, have expanded globally, in part through the acquisition of competitors from Europe and Asia.[9] Today the world's

[9] The description in this section cover the North American-based contract manufacturers only. A set of smaller, highly sophisticated electronics contract manufacturers also emerged in Taiwan in the 1990s (Dedrick and Kraemer, 1998; Lee and Chen, 2000). Taiwanese contract manufacturers, widely known in the industry as original design manufacturers (ODMs) have a much narrower product focus (i.e., on low- to mid-range personal computers), generate more revenue from design services, and have shown a greater penchant to compete with their customers in end markets than North American contract manufacturers. Although the Taiwanese ODMs make up an important part of the shared, modular supply-base for electronics production, and have developed in large measure in response to the outsourcing strategies of American personal computer firms such as Compaq and Dell. Sturgeon and Lee (2001) argue that the above characteristics have caused the Taiwanese contract manufacturers to grow more slowly than their American counterparts. Between 1993 and 1999 total revenues of the largest five ODMs—Acer, Quanta, HonHai, First International Computer, and Mitac—increased 35.5% annually from $1.7B to $10.3B. In the same period,

largest five contract manufacturers are Solectron, based in Milpitas, California; Flextronics International, incorporated in Singapore but managed from its San Jose, California, headquarters; Sanmina/SCI, also based in San Jose; Celestica, based in Toronto, Canada; and Jabil Circuit, based in St. Petersburg, Florida. A few of these firms have had global-scale operations for some time, but others have established global footprints quite suddenly through the acquisition of competitor and customer facilities as well as the establishment of new, “greenfield” facilities.

According to revenue estimates for 2002, the largest five contract manufacturers collectively will have grown at an average annual rate of 43% per year since 1995 (see Table 1). Estimates by Technology Forecasters, IDC, and Prudential Financial all peg contract manufacturers’ penetration of the total available market for circuit-board and product-level electronics manufacturing in 2000 at roughly 13%, leaving a great deal of room for continued growth. A recent Bear Stearns survey of lead firms in the electronics industry concluded that the rate and size of outsourcing agreements will continue to increase, with 85% of the firms interviewed planning on further increases in production outsourcing. The lead firms surveyed expected to outsource 73% of total production needs on average, and 40% stated their intention ultimately to outsource 90% to 100% of final product manufacturing. While the recent industry slowdown has certainly been painful for contract manufacturers—Solectron has slashed its worldwide workforce by 20,000—large outsourcing deals have continued to be announced, with most of the new business going to the very largest firms. On average, sales of the largest 50 CMs declined only 6.5% in 2001 from the previous year (from $77.9B to 72.8B). According to John Tuck, publisher of the industry newsletter Manufacturing Market Insider (Tuck, 2002), "If some [additional] outsourcing had not occurred in

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total revenues of the top five American contractors increased 47.7% per year, from $3.3B to $33B. Along with slower growth, institutional factors in Taiwan, such as an undercapitalized financial market, legal constraints on mergers and acquisitions, and a shortage of international management experience outside of East Asia appear to have put limits on the ODMs’ ability to expand globally (Sturgeon and Lester, 2002).

2001, the decline would have been worse."  The largest CMs are pushing hard, and are being pushed, to take on additional functions, especially build-to-order final assembly and design services for low-end products.  The downturn is causing lead firms to ask their contractors to shift production from advanced to emerging economies as rapidly as possible.  This is especially true of China where a critical mass of low cost components is becoming available.

***Place Table 1 about here.***

Electronic Trend Publications (2000) estimates that the top five contract manufacturers had captured 38% of the electronics contract manufacturing market by 1999, and expect this share to grow to 65% in 2003.  This rapid consolidation, fueled by the acquisition of competitors and customer facilities as well as internal expansion in existing and newly established facilities, was aided by the US stock market run up in the late 1990s, which concentrated 90% of the market capitalization in the top five CMs.  The importance of acquisitions to growth is shown in Table 1, which indicates that 67% of revenues projected for the year 2002 by the five largest electronics contract manufacturers are expected to be generated by acquisitions announced in the previous three years.

The geographic pattern that has resulted from this consolidation and reorganization is as follows.  The handful of dominant contract manufacturers have their headquarters in North America.  New product introduction (NPI) centers, where prototypes and volume manufacturing processes for new products are worked out in concert with lead firms, are located in advanced economies.   Contractor NPI centers tend to be located in places where there are concentrations of lead firms, such as Silicon Valley and the Boston region, or adjacent to the design centers of important customers.  Advanced economies also house “high-mix” production lines tuned to manufacturing a wide variety of high-value products in small batches.

High-volume manufacturing of price-sensitive products is generally located in lower-cost locations.  Such products fall into two broad categories.  Products that have short lead times and have requirements for last-minute configuration tend to be produced in lower-cost locations within regional trade blocs, such as Mexico and East Europe. As a result, many older plants in Scotland, Ireland and Continental Europe and Scandinavia are being closed, scaled back, and/or re-focused on new product introduction and low-volume, high-mix production. A similar trend has shifted production from US and Canadian plants to Mexico, especially Guadalajara. The most standardized, highest-volume, price-sensitive products such as personal computers, cell phones, and consumer electronics are manufactured in Asia. Southeast Asia has long been an important manufacturing location for the most standardized and price sensitive electronics products, such as parts for hard disk drives and personal computers, but nearly all new capacity in Asia is now being established in Mainland China, especially in the southern province of Guandong Province near Hong Kong.

With the industry downturn there have been a new attempts to shift the production of the lower ranges of higher-value products, such as the most basic Internet routers and telecommunications switches, to lower-cost locations. Still, it is important to note that the share of electronics manufacturing in high-wage economies remains significant. During field interviews, managers at the largest contract manufacturers stated that 50-70 percent of their production was in advanced economies and although they were rapidly building up additional capacity in low-cost locations, the share in high-cost locations was unlikely to fall below 30 percent. Some managers also suggested that the shift to low-cost locations could be slowed or reversed if demand were to increase with an upturn in the industry.

One notable effect of the recent consolidation of electronics contract manufacturing has been the re-concentration of key activities such as command and control in Silicon Valley. The region has long been a hotbed of contract manufacturing. The early PC companies, including Apple, as well as IBM's hard disk drive operations in San Jose were important early customers of two of the current leaders, Solectron and Flextronics (Sturgeon, 1999). Hewlett Packard, the well known Silicon Valley lead firm, has been a pioneer in the outsourcing trend, moving earlier and faster to sell off in-house manufacturing facilities and nurture the largest contractors than most large lead firms based in Canada, The US East Coast, Europe, and certainly in Japan, home of the fiercest resistance to this trend. Many of the most important "virtual" lead firms which have grown from their founding without large scale in-house production, such as Silicon Graphics, Sun Mircosystems. Cisco Systems, and Palm Computing, are based in the Valley. The fourth and fifth largest contractors, Celestica and Jabil Circuit, headquartered in Toronto, Canada, and St. Petersburg, FL, remain as exceptions, but the recent acquisition of SCI Systems, the long-time industry leader that began in Huntsville, AL, as a NASA sub-contractor, by the upstart San Jose-based Sanmina, and the remarkable resurgence of Flextronics as a top-tier player has shifted the center of gravity to Silicon Valley as never before. Instead of being one of several important centers of contract manufacturing in North America, Silicon Valley has, in the past few years, become the dominant center, by far. Adding to the importance of the Valley relative to the rest of the world has been the acquisition of the most important regional contractors in Europe and Asia by the largest North American firms as they moved to establish a global footprint during the 1990s.

This and the previous section have been devoted to illustrating the concept of value chain modularity. The following section compares this model to other network models that have been developed in the literature.

# 4. Building a New Paradigm for Industrial Organization: Production Network Models[10]

Through the mid-1980s the dominant paradigm for the study of industrial organization and economic development was the "modern corporation" as best defined by Chandler (1977, 1980). There was good reason for this focus. By the 1950s, the large multidivisional—and increasingly multinational—enterprise, with its extensive managerial hierarchy, had become an undeniably dominant force in economic development. This was true not only in its heartland, the United States, but also in other countries where its features were adopted by local firms. Accordingly, explaining

[10] This and the following sections are drawn in part from Sturgeon, 2002.

the rise of the modern corporation became a central project for scholars interested in industrial organization and economic development, regardless of field or analytic stripe. As an ideal type, the modern corporation was well understood, and it was assumed that successful firms would tend to come closer to its image over time. The following quote from Hymer (1976, p. 441) captures this assumption well.

> Since the beginning of the industrial revolution there has been a steady increase in the size of manufacturing firms, so persistent that it might be formulated as a general law of capital accumulation.

During the 1970s and 1980s, changes in the world economic scene, particularly the failure of large American corporations to adequately respond to new competition from Asia, cast doubt on ideas that used the modern corporation as an organizing principle, plunging a range of academic fields into a period of questioning and triggering research into aspects of industrial organization that had previously been obscured. After more than a decade of research and debate, the task of building a new paradigm for industrial organization and economic development is well underway, although consensus is still far from established. The project has shifted away from explaining the seemingly inexorable expansion of the internal structures of the modern corporation to understanding the external economies created by the ongoing interactions between firms.

The work of Marc Granovetter has contributed much to this effort. Granovetter (1985) draws on Marx and Weber to argue that economic life is a *social* process, the structure of which is certainly not governed solely by efficiency considerations. Culture, the social fabric that binds groups of people together in daily life, can create sets of shared goals and expectations that limit economic behavior to generally accepted norms and check the self-interested behavior of individuals in the group. Economic relations, then, are “embedded” in social relations, not *vice-versa* as neoclassical economists would have it. From this “institutionalist” point of view, perfectly efficient firm and market structures are not required for economic systems to function and, therefore, what we observe empirically cannot be assumed to reflect optimum efficiency. The implications of this approach for industry organization is that social relationships can—and usually do—create relationships of power and norms of behavior such as trust, reciprocity, reputation, and peer pressure that reduce the threat of opportunism, Oliver Williamson's (1975, 1981, 1985) driving force for the accretion of production functions within the vertically integrated modern corporation:

> I suggest here that small firms in a market setting may persist ... because a dense network of social relations is overlaid on the business relations connecting such firms and reduces pressures for integration (Granovetter, 1985:507).

Where such social relationships are in place, the pressure for firms to vertically integrate is dampened. Most of the literature on production networks has followed Granovetter's (1985) lead in arguing that shared goals and expectations, built through social and spatial proximity and especially through long term contracting relationships between firms, can substitute for the authority structure of the integrated firm, explaining why ongoing thick linkages are more commonly observed in economic life than neoclassical economic theory suggests, even in the much altered form that it is served up by Williamson.[11]

Other authors have taken a more economistic approach to cooperation and trust than Granovetter. Using Williamson's transaction cost framework, they argue that trust-based inter-firm relationships lower transaction costs without internalization. Jarillo (1988) argues that the main reason transaction costs arise is because of lack of trust. This version of trust retains transaction cost as the determining factor of organizational form, and therefore possible assumptions about maximally efficient outcomes. Beyond a nod to repeated interaction, the question of how trust is

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[11] In his work with Ouchi, Williamson recognizes that in certain "clan" cultures (e.g., Japan), social controls (e.g., trust) can support elaborate informal governance structures that soften the structure of bureaucratic authority relations within the firm [Williamson and Ouchi, 1981:360-363]. Oddly, the authors do not extend this insight to relationships between firms, assigning the distinction between clan and bureaucratic authority to a difference in internal management style.

generated in the first place is not asked. The argument is simply that trust can lower transaction costs to the point where externalization is a more efficient outcome than internalization (Thorelli, 1986; Johanson and Mattson, 1987; Powell, 1987; Jarillo, 1988; Lorenz, 1988, 1992). If opportunism creates "friction" in markets, then trust can act as a transactional "lubricant."

To create trust in market relationships takes time. This truism has been stressed by many network theorists. Thorelli (1988) defines the network relationship as *any* long-term relationship. Time is needed to operationalize economic actors' "hope for future business" which can act as a disciplinary mechanism in ongoing contracting relationships (Richardson, 1975; Powell, 1990). Repeated interaction is the key to creating the network in the first instance, and because setting up such relationships is costly and time consuming, the ability to change partners becomes constrained over time (Johanson and Mattsson, 1987). What differentiates trust-based relationships from market relationships based strictly on price or on authority, as when a smaller firm acts as a "captive" supplier to a much larger one, is the mutual dependence that builds up between firms and the relinquishing of a certain degree of autonomy by each party (Richardson, 1975; Thorelli, 1988).[12] Once firms in a network have adapted to one another, "strong bonds" are created that allow the network to better adapt to ongoing change (Powell, 1987, 1990; Jarillo, 1988). Again, the process of building up such interdependent relationships is a cumulative one that takes time (Johanson and Mattsson, 1987; Jarillo, 1988; Lorenz, 1988, 1992).

The inspiration for much of the production network literature has been drawn from nationally-specific examples of industrial organization, especially those that exhibit highly disaggregated industry structures such as Japan, Germany, and Italy. Because of the geographic and social specificities that undergird power, trust, and reputation, as well as the time involved in their governance, I refer to such arrangements as *relational production networks*. I divide relational

[12] This distinction has led some network theorists to argue that production networks can be relatively egalitarian systems (Piore and Sabel, 1984; Powell, 1990).

networks into two categories, *captive production networks* (e.g., Japan and Korea) and *embedded production networks* (e.g., Italy, Germany, and those of "overseas Chinese" in East Asia).

I describe the relational networks led by Japanese firms as hierarchical, captive networks because they rely on the power of dominant lead firms to coordinate tiers of largely captive suppliers (Schonberger, 1982; Dore, 1986; Sayer, 1986; Aoki, 1987; Womack et al, 1990). Suppliers that are likely to be highly dependent on one or a small number of key customer firms and buyer-supplier relationships are often formed between affiliates of the same industrial group. The qualification process for new suppliers can be extremely lengthy. Lead firms may make equity investments in their suppliers and over time come to dominate them financially. Lead firms often urge affiliated suppliers to adopt specific production technologies and quality control systems and provide the required technical assistance and financial support.

The advantages of such close buyer-supplier linkages are high efficiency, allowed by steady technological upgrading in the supply-base and close coordination of "just-in-time" deliveries, and flexibility in the face of market volatility allowed by the redeployment of workers and suppliers on short notice. The strong position of lead firms in captive networks means that suppliers can be directed to cut costs and output in bad times or invest in new customer-specific production capacity in good times. The supportive role taken by lead firms means that suppliers can count on rewards for sacrifices and business for new investments. Captive production networks are a key basis for the "lean production system" that has proved enormously influential in the automotive sector and beyond (Womack et al, 1990), and, at the firm level, are comprised of "alliance enterprises" as outlined by Teece (1996).

Embedded production networks are governed less by the authority of lead firms, and more by social relationships between network actors, especially those based on trust and reputation. Accordingly, embedded production networks tend to be emeshed in larger socioeconomic systems, allowing the temporary redeployment of workers to and from other settings—especially agriculture and the "informal" sector—when the demand requirements of buyers change suddenly. As a result, relational production networks can adapt to volatile markets quite well, as the trust, personal, and familial relationships of the community enable its members—individuals and small firms—to quickly respond to changing conditions. Network actors can quickly take on new roles as conditions change. Flexibility stems from the local concentration of specialized small firms within the same sector that can be recombined into multiple configurations according to changing market demand and the requirements of the lead firms that are embedded in the network. The highly fragmented organizational structure allows flexibility to meet the requirements of small batch runs, short lead times, fast delivery, and quick market entry and exit (Piore and Sabel, 1984).

Geographers (e.g., Scott 1988, 1999; Storper and Christopherson, 1988; Storper and Scott, 1988; Storper and Walker, 1989) have stressed that that relational production networks tend to operate within the bounds of specific localities. The industrial districts of Northern Italy (Brusco, 1982; Brusco and Sabel, 1983; Piore and Sabel, 1984; Brusco and Righi, 1989); the regional supply networks of Germany (Katzenstien, 1989; Sabel, 1989; Herrigel, 1993); clusters of apparel assembly sub-contractors and home-workers clustered around the fashion design centers of New York, Los Angeles, and Paris (Bonacich 1990, 1994; Sassen, 1987, 1988; Gereffi 1994; Taplin 1994, 1996); the family-based business networks of overseas Chinese in East Asia (Borrus, 1995, 2000; Ravenhill, 2000); Toyota City, and Silicon Valley (Saxenian, 1991, 1992, 1994; Luethje, 1997); are all examples of places where robust relational production networks operate. This work has led some economic geographers to put forward general arguments for the connection between local clustering of economic activity and the rate and quality of innovation (Amin and Thrift, 1992; Cooke and Morgan, 1992; Malmberg, 1996; Maskell and Malmberg, 1999). Interest in industrial clusters supported by specialized institutions and relational contracting between firms has been especially high in Europe, where the success or failure of local and regional industrial clusters has been identified as critical to the performance of the entire European economy (Hudson, 1999; OECD, 2001).

The most important difference between modular networks, which are rooted in the American institutional context, and the other nationally-specific network models that appear in the literature (Japan, European, and overseas Chinese), is their relatively open character and the relatively low levels of mutual dependence between economic actors. Openness in the modular network flows from efforts by all network actors to limit high levels of mutual dependence. Limited interdependence is based on several preconditions: heavy use of IT, suppliers that provide widely applicable "base processes and services,"[13] and widely accepted standards that enable the codifiable transfer of specification across the inter-firm link. These codified links between lead firms and suppliers that allow the system to operate without excessive build-up of asset specificity and mutual dependence.[14] These preconditions lead to generic (not product-specific) capacity at suppliers that has the potential to be shared by the industry as a whole.

In modular production networks, suppliers take a "full service" stance toward their customers, providing turn-key services that require relatively little support or input—beyond design specifications—from customer firms. The result is less frequent and intense interaction than in relational networks, reduced interdependence, and a reduced need for social and spatial propinquity, all of which allow for and are in turn enabled by the use of highly formalized inter-firm linkages. However, transactions may be very frequent and important to both parties in the modular network, with a great deal of value and information flowing across the inter-firm link. This feature points to

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[13] The diffusion of a standardized base process was an important part of Rosenberg's (1976) explanation for the rise of a merchant machine tool industry in the United States during the period 1840-1910.

[14] It is important to note that limited interdependence falls directly from the historical characteristics of the American production system, providing a historical link with what has come before. It is not that dependencies do not build up in modular networks. In fact, increased outsourcing by lead firms and consolidation among the largest suppliers has increased levels of interdependence in comparison with ten years ago, when suppliers were given little responsibility and judged entirely on the basis of cost. The difference is in the theoretical model. In the modular network mutual dependence is viewed as having a negative effect on network performance while in more "relational" network models it is assumed to have a positive effect.

a key qualitative difference between the rich streams of data that flow across the inter-firm links in the modular network and the simple price information and specifications that form the basis of the traditional characterization of arms-length market transactions. As in the perfectly competitive Marshallian market, the disciplining mechanism in the modular network is simply for either party to change partners in the face of conflict or malfeasance.

The proposition that product innovation can be effectively separated from manufacturing investment may be surprising. The growing split between innovation and production in the electronics industry seems to contradict literature that drew on the example of the Japanese production system to argue that American firms needed to develop tighter coordination between product design and manufacturing to improve industrial performance (e.g., Dertouzos et al, 1990; Florida and Kenney, 1991, 1993). But as the electronics industry has evolved, certain kinds of knowledge have become increasingly codified. Production equipment for circuit board assembly has come to be dominated by three firms, Fuji, Panasonic, and Siemens, making it easier to bring additional machines on-line once the process for the assembly of a particular product has been validated. Similar *de-facto* standards have come to exist for a variety of other key technologies, including electronic design software, soldering ovens, and automatic test equipment.

International standard setting bodies such as the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) emerged early on in the electronics industry to help develop industry-wide classification and specification of components and processes. Today firms in the electronics industry are using information technology, increasingly deployed via the Internet, to communicate across firm boundaries using these standard classification systems as a basis. For example, firms are increasing their use of data communications technology to pass computer aided engineering (CAE) and design files (CAD) to computer controlled production equipment on the factory floor. Components with exact specifications can be located and purchased with electronic purchasing systems, early versions of which were known as electronic data interchange (EDI), but which are coming to be integrated with manufacturing and enterprise resource planning (MRP and ERP) systems that track inventories and monitor component availability and pricing. Although there is still much room for improvement, these systems are evolving toward full-blown supply-chain-management (SCM) systems that will tie demand forecasts to component purchasing, inventory management, and capacity planning in real time. The fact that these systems are being extended across broad swaths of the value chain means that firms in the network are sharing forecast and pricing data in ways that were unheard of only a few years ago.

The recent advent of RosettaNet, a set of Internet-delivered forms and standards developed by a broad industry consortium, is pushing level of codification in the electronics industry to a new level, offering firms a set of standardized forms and procedures to govern a wide variety of business processes, especially those that structure inter-firm linkages such as contracts and relationship roadmaps. The combination of excellent standards and heavy use of information technology in the electronics industry has enabled highly formalized links at the inter-firm boundary, relative to other industries, even as the flow of information across the link has increased.

## 5. Production Networks and Economic Performance

Harrison (1994) has argued that the competitiveness of American industry has been weakened by the failure to adopt a "network" model of production organization. American industry is still dominated by huge firms that do not try to develop long-term, trust-based, participatory relationships with their employees or their suppliers. American companies remain too atomistic, too focused on lowering operating costs, and too interested in short-range profits to prevent further erosion of their competitive standing in the global economy. Instead of upgrading the entire production system in response to intensified competition from abroad, American companies are said to be taking the "low road" of enhancing short term profitability by downsizing, “hollowing out,” sending production to locations with low labor rates, squeezing their suppliers, reducing wages, and hiring more “contingent” workers. The result has been a lowered standard of living for American workers and a worsening competitive crisis for American industry.

That business practices such as downsizing, wage suppression, and the hiring of contingent workers have had negative impacts on many American workers is undeniable (Levy et al, 1996; Mishel and Bernstein, 1996), but evidence of a worsening competitive crisis, from the perspective of the late 1990s and even early 2002, is entirely unconvincing.[15] Even in situations where predatory supplier-relations are still in force, such as they are between the largest American automakers and their suppliers (Helper 1991), American firms have improved product quality, lowered costs, reduced cycle times, and improved their relative standing on world markets. The literature contributing to the production network paradigm has generated a sorely needed set of alternatives to the modern corporation, but surprisingly, scant attention has been paid to the industrial organization of American manufacturing companies as they have begun to adapt to the new forms of competition that triggered the crisis. Most often portrayed as desperately clinging to the outmoded attributes of the modern corporation, American manufacturing firms have been held up as the antithesis of new, more dynamic organizational forms that have emerged in other places. Could it be that recent evidence on American-centered production networks has been overlooked or misinterpreted because the system has not evolved in the image of networks emanating from Japan, Germany, and Italy, on which so much of the literature is based?

In network theory, production networks are held up as an alternate governance structure to the integrated firm and deemed more adaptable to change, therefore providing better economic performance in highly competitive or volatile markets (Powell, 1990; Cooke and Morgan, 1992).[16]

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[15] This is important because calls for a "high road" approach to organizational transformation as a way to solve the competitive problems of corporate America will fall on deaf ears in the boardrooms of companies that are maintaining and improving their competitive standing in world markets.

[16] Another argument for better economic performance in production networks is superior innovativeness (Langlois and Robertson, 1995; Teece, 1996). Interpersonal experience garnered through long-term relationships renders information more reliable (a point that directly contradicts Williamson (1981), who argues that firm hierarchies

There are, however, aspects of relational production networks that resist adaptation, especially when the models are projected outside the network's heartland in the context of globalization. The interdependence that exists in relational production networks leads to disadvantages because mutual dependence makes it more difficult, costly, and time consuming to begin and end relationships between economic actors. While this feature limits opportunism, it also make the overall system less adaptable since the ability to forge relationships with actors outside the network is constrained. Dore (1986), in his study of the textile industry in Japan, referred to this ironic character of the Japanese production system as "flexible rigidity" and pointed to a certain "sluggishness" in shifting the external perimeter of the system. The negative outcomes associated with captive production networks are mounting structural rigidities in the system, technological *cul-de-sacs*, geographic inertia, the development of redundant offshore production systems with globalization, excessive accumulations of debt to keep the system running during extended economic downturns, and limitations in the scale and scope of external economies. While I concur that the internal structure of relational production networks may well be more adaptable than the governance structures of integrated firms, and be well adapted to innovative activity, substantial rigidities may exist if the overall architecture of the network is itself resistant to change. The comparatively loose governance mechanisms in modular production networks make network entry and exit relatively easy, resulting in a high degree of temporal and spatial flexibility.

The specific advantages of value chain modularity can be divided into two broad categories, cost advantages and dynamic advantages. A long-standing question in the electronics industry is if using contract manufacturers costs lead firms less than in-house production (see Sturgeon, 1991, for an early discussion). Our recent research suggests that the answer to this question is yes. For

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provide better information than the market) resulting in a more innovative environment than that within the modern corporation, which suffers from a chilling effect on innovation due to empire building and "information impactedness" (Powell, 1987).

example, a respondent at a large, diversified lead firm in the electronics industry who had seen a large share of his company's manufacturing facilities sold to contract manufacturers maintained that "contract manufacturers reduce the cost of goods sold 10-15%."[17]

Using turn-key suppliers for production lowers costs in two ways, human resource "un-bundling" and capacity pooling. Production workers at lead firms typically enjoy benefit packages and, to some degree, wages that are set by higher paid employees at the firm, such as managers and engineers. When production jobs are outsourced, workers typically earn lower wages and receive inferior benefits.[18] In addition to paying lower wages and providing inferior benefits to permanent employees, contract manufacturers make heavy use of temporary workers in places were it is easy to do so (it is easier to use temporary workers in North American and Japan than in Europe, for example). Our interviews found that temporary workers typically comprise 10-50% of the workforce at the largest contract manufacturers. Temporary workers are found through employment agencies, student internship programs, and "retiree-on-call" programs. Temporary workers provide contractors with a buffer to compensate for demand fluctuations. As the human resources director a one large contract manufacturer put it during an interview, "We want to give

[17] These savings are shared between lead firms and the contractors though a process (often contentious) that is negotiated as each new product is brought into the system.

[18] In the US motor vehicle industry, where industry structure has shifted dramatically toward value chain modularity since 1985, employees at suppliers, on average, earn far less than those at lead firms, the automakers. Average hourly wages at suppliers were almost on par with those at automakers between 1958 and 1978, when they ranged from 93 percent-97 percent of wages paid by automakers. This rough parity began to erode after 1978, and by 2000 average wages at suppliers stood at an all-time low of 74 percent of those paid by automakers. (Sturgeon and Florida, forthcoming).

employment to permanent employees permanently, but temporary workers are at the mercy of our customers."[19]

The second source of lower costs at suppliers in modular production networks are what one lead firm manager referred to during an interview as the "natural efficiencies" that arise from shared production capacity, namely better utilization of plant and equipment and component purchasing scale economies. Because the base processes and services offered by turn-key suppliers have large economies of scope they can be sold to a wide range of lead firms within their industry. In product-level electronics, manufacturing plants for circuit board and final product assembly can produce products for a very wide range of customers and end markets. Such scope economies lead to better asset utilization as human effort and fixed capital are pooled, conserved, and (re)deployed across a broad customer base. High asset utilization comes from running plant and equipment for long hours. Since contract manufacturers have many customers, there is greater scope to balance manufacturing loads than with in-house facilities, which are usually dedicated to the manufacture of products for the firm that owns the plant.

Purchasing scale economies come from the pooling of component orders. Simple electronics components, such as resistors, capacitors, and connectors are required for the manufacture of nearly all electronics products, and contract manufacturers can get better terms from component manufacturers and distributors than their customers because they can pool orders. As

[19] Not surprisingly, labor unions take a dim view of outsourcing unionized manufacturing jobs to non-union contract manufacturers. Although unionization rates in the electronics industry have been low historically, there are places, such as the Northeast United States and in Europe, where labor unions have been important. A union Secretary interviewed in the Northeast US who had seen his local's membership shrink from 4,000 to 1,000 between the mid 1985 and 2001 as the local telecommunications plant outsourced more and more jobs to contract manufacturers stated, "The companies are going to use the contract manufacturers to bust the unions." Shortly after the interview, the plant was sold to a leading contract manufacturer.

the buying power of contract manufacturers has increased, many component manufacturers and distributors have created dedicated sales teams to cater to them (Serant, 2000b).

The second broad category of advantages are dynamic in nature. In what is often referred to in the industry as "upside and downside flexibility;" contract manufacturers provide lead firms with the ability to ramp production output levels up and down without installing or idling in-house capacity. This is especially important in volatile industries such as electronics. During an interview we were told by a lead firm manager that, "[Our firm] was selling 24,000,000 [units] each year in the mid-1990s and this increased to 40,000,000 in just a few years. This ramp-up could never have been done in-house. The administrative time alone for getting new in-house capacity on-line is six months, forget about construction. So, upside flexibility is important. And when business is down, you are sitting on underutilized factories that may be in the wrong location."[20]

The geographic scale of global turn-key suppliers plays into both cost and dynamic advantages. Since their largest and most important customers require goods and services delivered in a range of geographic locations, turn-key suppliers have rapidly developed a global footprint. A global footprint allows a supplier's customers to locate production in a variety of places with less, or even no, direct investment, lowering the risk of globalization. Many of these places have lower operating costs than locations where lead firms have facilities. Lower operating costs come from lower prevailing wage rates, taxes, component prices, and less stringent environmental and labor standards. The volatility of the global economy in general, and in particular in the specific industries where global suppliers are important, has only made the dynamic advantages afforded by global suppliers even more attractive.

There are questions about the magnitude of the advantages of using global suppliers in the realm of global integration. Conceivably, global suppliers might be able to pool activities such as

[20] To protect the confidentiality of the organizations and individual respondents, we mask company names and exact products.

logistics and materials management to provide scale efficiencies that would be out of reach for any single customer. During an interview, one lead firm manager stated, "The global nature [of the largest contract manufacturers] is truly unique, and this is an extraordinary value added. Activities such as distribution and tooling are still very regional. Even OEs [lead firms] are more regional because they have to sell to different end markets. These global competencies give contract manufacturers a huge opportunity to 'roll up' [consolidate through acquisition] other regional industries [to create global-scale, centrally managed systems]. Others argue that it is possible to deploy in-house assets globally, as some consumer products companies have done, and that we must therefore conclude that lead firms in the electronics industry have either failed to do so or have chosen not to (personal communication, Donald Lessard, May 3, 2002). Another explanation might be the complexity of the products where modular value chains are important; the risks of global deploying of in-house assets go up with the number of inputs required, as do the challenges for logistics and materials management.

At the very least, it is clear that the establishment of spatially dispersed operations has pushed global suppliers to develop new sets of competencies in areas related to global integration. Operating in a wide variety of national contexts is a difficult challenge, especially since a high degree of inter-plant compatibility and an ability to collect data and control inventory across diverse and distant facilities has become a crucial part of global integration. It was repeatedly stated during our interviews with lead firm managers that the largest contract manufacturers were struggling with their new role as global suppliers. As one manager put it during an interview, "Contrary to the picture they've painted of themselves, contract manufacturers are not very good at forecasting, materials management, or logistics. They are only good at manufacturing." Another stated, "Engineering and materials management teams at contract manufacturers are less capable than those at lead firms. Personnel are paid less, and there is less time and money to work out difficult problems."

While there are clearly problems that remain to be solved, I do argue that modular production networks offer theoretical performance advantages over relational networks. Figure 1 depicts the characteristics of modular production networks that lead to superior economic performance. The performance advantages that flow from the openness of modular networks stem from the agility (flexibility) of the system along two fronts: geographic and customer. Relatively low mutual dependence lowers barriers to network entry and exit. The result is organizational flexibility, which makes the system less locked in to either specific places or to specific products or customer relationships. As a result, 1) the network can more easily be extend and withdrawn from specific locations (what I am calling geographic flexibility) and 2) the suppliers can be shared by a variety of lead firms. The performance advantages of modular networks are thus twofold. First, geographic flexibility creates greater access to a variety of place-specific factors and markets. An important result of geographic flexibility is the system's easy reach into (and retreat from) areas with lower factor costs. Second, shared suppliers can better match and adjust capacity to demand, resulting in more intensive capacity utilization. The overall result is lower costs and less risk than network systems which are more firmly rooted in particular places and generate high levels of asset specificity and mutual dependence.

**Place Figure 1 about here.**

In an economy increasingly integrated on a global scale, captive networks and stand-alone industrial districts can become geographically and technologically isolated. The industrial clusters tapped by modular production networks have many of the characteristics of the "Marshallian industrial districts" of the Italian model and the captive model from Japan in that they depend on dense territorially-based external economies, but with an important difference: local agglomerations are relatively open systems that can fulfill a specialized role within a larger, global-scale production network. In the electronics industry contract manufacturers providing a full range of leading edge production services have emerged in various geographic locations. Taken as a group, the worldwide supply-base of contract manufacturers offer their customers a global-scale network of leading-edge manufacturing capacity for hire. By utilizing this network, lead firms can reconfigure the geography of their manufacturing operations on an ongoing basis without the costs, risks, and time commitments associated with setting up new offshore production facilities of their own.

## 6. What Really Happens in Silicon Valley?

The discussion so far has pointed to the differences between relational and modular production networks, and why modular networks might provide superior performance in the context of global-scale production, but in fact, one of the most powerful approaches to globalization is when firms leverage both the relational and modular aspects of industrial organization to reap the benefits of local agglomerations *and* global-scale production networks (Sturgeon and Lee, 2001; Sturgeon and Florida, 2002). A problem with much of the literature in the relational economic geography stream is an underdeveloped view of global-scale production arrangements. According to Maskell and Malmberg (1999. P. 172), tacit knowledge is becoming more important as codification increases. Once knowledge is codified, it becomes "ubiquitous," and therefore irrelevant for competition. Leamer and Storper (2001) similarly equate the process of codification with "commodification." The further argument, and this is the main point of this literature, is that the exchange of tacit information between autonomous economic actors is best handled at the local level, where social and spatial propinquity substitute for the failure of market mechanisms in the exchange processes. The trust, reputational effects, and personal ties that build up at the local level help to overcome the "exchange inability" of tacit knowledge.

In my view, this is a convincing argument, but it need not be joined with the argument about information being irrelevant once it is codified and globalized. Instead of disappearing into the ether of the global, codified information is used to integrate various territorially-based activities on a global-scale, such as the transfer of fully validated manufacturing instructions from a plant in an advanced economy to a series of plants in developing countries that use identical production equipment and methods, or to create global views into in-bound and out-bound inventory flows. Such data is usable on a global scale because identical, or at least compatible, manufacturing and IT systems are (increasingly) being put into place. This is the generic capacity of the turn-key supplier; it relies on codified information to help create and manage global-scale production systems. Instead of being commodified and becoming irrelevant to competition, codification is the mechanism that weaves specialized agglomerations into global-scale production systems. How effectively global turn-key suppliers create and manage such systems has become a key competitive differentiator. For their part, lead firms must learn how to leverage the cost and dynamic advantages of modular production networks in the context of volatile demand. This is not a simple task, especially for lead firms with a long legacy of in-house production.

Since codified information is better suited to spatially dispersed networks, global-scale production systems tend to disappear from the analysis of relational economic geography just as codified information disappears, leaving spatially clustered activity in a vaunted, but theoretically isolated position. We are left with the view that spatial clusters are important, and globalization is not, which flies in the face of even the most cursory observation of contemporary economic development, which is rife with examples of increasing foreign investment, global production, and global retailing (e.g., Gereffi, 1994; Reardon and Berdegue, 2002).[21] In fact, globalization and

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[21] Despite obvious signs of change, there are some that argue that globalization is an illusion because the vast majority of international trade remains between adjacent countries and has fallen as a share of world economic activity since the late 19th century (e.g., Hirst and Thompson, 1996). On this point I follow Dicken (1998) in arguing that globalization represents a qualitative change in world-scale economic organization brought on by the sheer volume of international trade and investment, and especially the improvements in transportation and communications technologies that have led some firms to attempt—albeit with mixed results so far—to integrate key day-to-day functions on a global scale. A similar critique might be made of the trend toward outsourcing. Firms have long used outside suppliers for important inputs and cases of true vertical integration, such as Ford's River Rouge plant complex in the 1920s, are best considered historical anomalies. My own view is that trend toward deverticalization in the 1990s represents a qualitative change akin to globalization. Outsourcing has moved beyond standardized material and component inputs, and even beyond specialized services such as accounting, toward

spatial agglomeration can go hand-in-hand, as when the details of a product's design and production are worked out within an industrial district, codified, and then deployed according to standardized protocols though an integrated global system of production facilities, sales offices, and service organizations (Sturgeon and Florida, 2002).

Michael Storper, in his 1995 article on un-traded interdependencies in regional clusters (Storper, 1995), complains of how critics of earlier work on new "post-Fordist" organizational forms, from flexible specialization to technology districts, have tended to "over-read" arguments about the underlying causes for the putative "resurgence of regional agglomeration economies." I do not want to fall into this trap in my critique of relational economic geography. Michael Storper believes that the key force behind the success of some spatial clusters are the "un-traded interdependencies" that can only arise with close proximity. He differentiates such interactions from the interdependencies that are created through trading (input-output) relationships, and he acknowledges that the process of codification is always underway and that this can weaken a locality's role as standardized functions are re-located and exchange, even complex exchange, is handled more remotely.

This process has been evident in my own research, where I observed that proximity remains important for a range of exchange relationships, especially those processes that resist codification. Engineers from lead firms and contract manufacturers worked closely together to bring new products on-stream, for example. But often, firms engage in such collaborations more out of necessity than design. Engineers from lead firms and contract manufacturers were often brought together to "fight fires," and so there was a strong perceived need to improve the methods of interacting by driving out the tacit wherever possible. The traded dependencies were seen as more

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complex, dynamic, and critical functions such as manufacturing and product design. My central argument is that the combination of globalization and outsourcing has created something unprecedented in the world economy: an integrated global supply-base.

of a problem than a solution. Proximity was needed to solve problems as they arose, but why not eliminate the problem instead? So, there are serious efforts underway to streamline the activities that occur at the inter-firm link by creating better standards for new product introduction and a host of other "sticky" business processes. Success in this area, however gradual, can be seen as a force that is constantly codifying what has been tacit. This is precisely the process that has given rise to modular production networks. The integration of some industrial districts into more "global" organizational systems and the loosening of captive network relationships can also be seen as part of this process. But Michael Storper argues that something more is going on in industrial districts, something akin to the "industrial atmosphere" mentioned by Marshall (1919). These are "un-traded interdependencies…[governed by] the rules of action that permit participants in the production system to develop, communicate and interpret information, as well as develop knowledge, and to develop the people who develop and interpret knowledge…"

Indeed, our research revealed a set of rule-setting activities that took place outside of exchange, such participation in consortia, informal meetings, and workshops that brought together key players to work out common problems. The irony is the common problem that was occupying these managers and engineers was precisely the need to better codify complex information, especially through the development of common standards for IT. The goal is to generate and deploy these standards—globally—as quickly as possible, even to firms that do not participate in the standard-setting process. During our interviews, contract manufacturers even claimed to be willing to share what they had learned internally with their competitors. An IT manager at a contract manufacturer with a particularly advanced approach to using IT for global integration stated, "Many US and Japanese companies still don't outsource at all, so we don't bother fighting with [Competitor A] and [Competitor B]. We want the whole pie to grow. We encourage CIOs [Chief Information Officers from our competitors] to look at what we are doing [with IT]. We have taken the lead on this. We would be happy to share systems with our competitors since we share customers. Customers want multiple sources."

Silicon Valley is *the* key location for such standard-setting activity (Gordon, 2001). During an interview an IT manager at a leading contract manufacturer stated, “Being in Silicon Valley is a huge advantage. This is where it is happening. All the big players are here, OEs [lead firms], dot-coms, venture capitalists. You must be breathing RosettaNet or you will be incompatible in a few years.” What is important here is that the purpose of RosettaNet, at base, is to codify what has so far resisted codification in order to make the global system of value chain modularity more effective even as inter-firm linkages become more dense. The fact that Silicon Valley has remained the hub of innovation and control in the electronics industry even as activities that it spawned have diffused to other locations has led Michael Storper (Storper, 1995, p.209) to ask the question, “Might this be the case because the geographically-constrained un-traded interdependencies outlive geographically-constrained input-output linkages?” My answer would be yes, but I would underline that the tacit underpinnings of global command and control are precisely the “problem” that these spatially clustered interactions seek to resolve.

## 7. Concluding Remarks

What is the geographic trajectory of capitalism? Is it toward spatial clustering or global integration? Much of the recent theoretical work in relational economic geography includes several dynamic elements that increase the importance of spatial clustering over time. Industrial districts are where innovation happens, where learning occurs, and because the fixity and longevity of built and institutional infrastructure, labor markets, and the like, path dependency causes local clusters to grow more idiosyncratic over time, not less. The historical part of this argument, that place-based routines tend to become more idiosyncratic over time, is identical to the argument in transaction costs economics that asset specificity tends to build up over time (Williamson, 1981). Relational economic geography assumes that increasingly idiosyncratic interactions will cause spatial clusters to become more inward-looking over time just as institutional economics assumes that increasing asset specificity will drive firms to grow larger over time through vertical integration. The problem is that neither of these outcomes are fully captured by empirical observation. Certain industrial districts are thriving, and some, such as Detroit, show signs of renewed vigor even as they retain their distinctive character. Managers do worry about becoming locked into their trading relationships through asset specificity, and acquisitions, especially to capture critical technology, were made abundantly in the 1990s. Cisco alone made 73 acquisitions during the 1990s. Although the mechanisms promoted by both schools appear to be operating, both overlook the strong push toward codification in certain industries that enables lead firms to extend their geographic reach by interacting with the local affiliates of global turn-key suppliers. Industrial clusters can serve as nodes on global-scale production networks, and global suppliers are increasingly providing the thread that binds such systems together.

In arguing for the importance of spatial clustering over spatial dispersal, geographers poke themselves in the eye by implying that global-scale production systems do not matter. Failing to theorize the process of globalization will only drive the field of economic geography into irrelevance. The concept of value chain modularity get us part of the way there. Modular production networks are comprised of nodes of tacit activity, often clustered in a particular geographic locations and/or within the confines of integrated firms, linked through the exchange of codified information between firms and/or across space. The historical process that is underway is one of improving standards and better codification schemes that enable increasingly complex bundles of information to be handed off between value chain actors and put to immediate use in a wide variety of locations.

I do not want to overdraw my case. There is a big difference between the theoretical performance characteristics of conceptual models and real-world performance. Firms and their specific value chains can be observed with an almost infinite variety of characteristics, and the definition of any value chain "type" is at best an approximation of what might be observed in the field. The standards that enable the codification of product and process specifications are different in different industries and are constantly evolving. Some sectors use technologies that are more easily codified than others. The tight tolerances required for the assembly of hard disk drive heads, for example, appear to be an important part of the reason that this process has been retained in-house by the firms that develop and market disk drives (personal communication with David McKendrick, February 24, 2001). Standards for codifying product and process specifications can become obsolete as technologies change or when there is a drive to bundle value chain activities in new ways. As Michael Storper has pointed out, new technologies can restart the clock on the process of codification (Storper, 1995, p 207). Even when the underlying conditions for value chain modularity are well established, as in the Japanese personal computer industry, large scale outsourcing might be antithetical to long-standing corporate strategies. Finally, capturing the theoretical advantages of value chain modularity requires that lead firms and suppliers alike perform well in their respective areas of responsibility. Our field interviews have shown that this does not always occur, even when both parties fully embrace the model.

So, conceptual models provide only limited utility in the field and we should expect empirical outcomes to be highly variable. The evolution of value chain structure can be extremely rapid, and generalizations, however true they may ring in the moment, may become outmoded as time goes on. Still, I do maintain that some value chains have characteristics that are more "modular" than others, and that the broad historical trend appears to be toward value chain modularity. Global integration, the emergence of better product and process standards, and the increasing competence and geographic reach of suppliers are all long-term trends that might support the growth of modular production networks over time. This is not to say that the shifts that have led to value chain modularity have gone uncontested or that modular production networks have not created new problems as they have solved others. To the extent that the modular system exists in the real world, it is by definition new, untested, and unrefined.

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**Table 1. Revenue, Revenue Growth, and Revenue from Acquisitions at the Top Five Electronics Contract Manufacturers, 1995 and 2002 Estimates (Thousand of Current US Dollars)**

| | 1995 Revenue | Analyst Revenue Outlook for 2002 | Compound Annual Growth Rate, 1995-2002 | Estimated Revenue from Acquisitions, 2002 ** | Estimated Sl of Revenu from Acquisitior 2002 |
|---|---|---|---|---|---|
| Solectron | $1,679,158 | $16,470,000 | 46% | $8,850,000 | |
| Flextronics | $389,100 | $13,160,000 | 80% | $9,500,000 | |
| Sanmina/SCI | $3,514,029 | $12,140,000 | 23% | $13,575,000 | 1 |
| Celestica | $600,000* | $11,250,000 | 63% | $5,975,000 | |
| Jabil Circuit | $686,183 | $4,870,000 | 39% | $625,000 | |
| Top Five Total | $6,868,470 | $57,890,000 | 43% | $38,525,000 | |

*** All Celestica revenues in 1995 were from IBM.**
**** Announced in 1999, 2000, and 2001.**
Source: Company annual and quarterly reports.

**Figure 1. Performance Benefits of Modular Production Networks**