Industrial and Corporate Change, Volume 11, Number 3, pp. 451–496

Modular production networks: a new American model of industrial organization

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This paper uses the case of contract manufacturing in the electronics industry to illustrate an emergent American model of industrial organization, the *modular production network*. Lead firms in the modular production network concentrate on the creation, penetration and defense of markets for end products—and increasingly the provision of services to go with them—while manufacturing capacity is shifted out-of-house to globally operating *turn-key suppliers*. The modular production network relies on codified inter-firm links and the *generic manufacturing capacity* residing in turn-key suppliers to reduce transaction costs, build large external economies of scale and reduce risk for network actors. I test the modular production network model against some of the key theoretical tools that have been developed to predict and explain industry structure: Joseph Schumpeter's notion of innovation in the giant firm; Alfred Chandler's ideas about economies of speed and the rise of the modern corporation; Oliver Williamson's transaction cost framework; and a range of other production network models that appear in the literature. I argue that the modular production network yields better economic performance in the context of globalization than more spatially and socially embedded network models. I view the emergence of the modular production network as part of a historical process of industrial transformation in which nationally specific models of industrial organization co-evolve in intensifying rounds of competition, diffusion and adaptation.

1. Introduction

1.1 *The rise and fall of the modern corporation as the dominant paradigm in industrial organization*

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). 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. By 1930, 49% of all non-banking corporate wealth in the United States, and 22% of all national wealth had

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accumulated in the largest 200 corporations (Berle and Means, 1934: 33). By 1957, 135 companies owned 45% of the United States' industrial assets (Hazard, 1957, cited in Baran and Sweezy, 1966: 33). Accordingly, explaining 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: 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 US 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.[1] 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. Some of what had been obscured has now come into view. The focus has shifted away from the logic and ramifications of the seemingly inexorable expansion of the *internal structures* of the modern corporation to the *external economies* created by the ongoing interactions between firms (Langlois and Robertson, 1995). I call this new focus the *production network paradigm.*

Ideas about the importance of external economies and production networks have come from a variety of academic disciplines. In management, outsourcing has been touted as a highly effective strategy, especially in fiercely contested and fast-moving sectors such as electronics (Prahalad and Hamel, 1990; Quinn and Hilmer, 1994; Fine, 1998). Lead firms should focus on the 'core' competence areas that are perceived as being essential to the formation of competitive advantage, especially product innovation, marketing and other activities related to brand development. Once 'deverticalized' in this manner, such 'virtual corporations' are urged to use specialized suppliers to provide all 'non-core' functions (Davidow, 1992). By divesting non-core functions, lead firms can more quickly reap value from innovations while spreading risk in volatile markets (Venkatesan, 1992).

[1]According to Kuhn (1970), such paradigm shifts typically involve cycles of theoretical consensus and crisis. Periods of consensus allow for a flowering of theoretical work because effort shifts from constructing the 'object of knowledge' (what and how) to theorizing about the object of knowledge (why and in whose interest). While such theoretical paradigms provide basis for debate by bringing some things into sharper focus, phenomena that do not fit the dominant model tend to be obscured. Periods of crisis arise when things that have been obscured, for one reason or another, are forced to the surface. What were 'anomalies' under the old paradigm then become the building blocks of the new.

Sociologists and organizational theorists have helped to build the production network paradigm by providing ideas about how trust, reputation and long-term 'relational' contracting can create stable external economies that resist the apparent tendency for economic activity to aggregate within the ever-larger control hierarchies of the modern corporation (Richardson, 1972; Thorelli, 1986; Johanson and Matson, 1987; Powell, 1987, 1990; Jarillo, 1988; Lorenz, 1988, 1992; Bradach and Eccles, 1989; Cooke and Morgan, 1993). Political scientists and country specialists have provided nationally specific models of industrial organization, some hierarchical and some more egalitarian, that rely extensively on external economies. Many of these models have been derived from research on the industrial systems of Japan (Schonberger, 1982; Dore, 1986; Sayer, 1986; Aoki, 1987; Womack *et al.*, 1990), Germany (Katzenstein, 1989; Sabel, 1989; Herrigel, 1993) and Italy (Brusco, 1982; Brusco and Sabel, 1983; Piore and Sabel, 1984; Brusco and Righi, 1989). Geographers and planners have provided insights into how the spatial and social propinquity of geographically clustered, sector-specific industrial activity work to buoy ongoing external economies (Scott, 1988a,b, 1999; Storper and Christopherson, 1988; Storper and Scott, 1988; Storper and Walker, 1989; Saxenian, 1991, 1992, 1994).

Often the production network paradigm has been advanced in an effort to explain why firms, industries and national economies organized according to their tenets were outperforming industrial systems organized according to the Anglo-American norm of the vertically integrated modern corporation. External economies allow for the development of trust; industry-, or at least locality-wide sharing of production capacity; greater opportunities for learning and technology transfer within the system; and perhaps most importantly, a superior ability to reconfigure the functional elements of production according to rapidly changing output requirements and the rise of new markets, a feature captured by the term 'flexible specialization' (Piore and Sabel, 1984).

1.2 The resurgence of US manufacturing firms

Today, more than twenty years after the competitive crisis of the modern corporation began, we have seen unmistakable evidence of recovery by US manufacturing firms. In the electronics industry, for example, dire predictions that US manufacturing firms would continue to lose entire segments of their markets to Asian rivals have proved to be unfounded. The continued dominance of many market sectors for electronic hardware by US firms has surprised observers who warned that Japanese electronics companies were poised to leverage their dominance in core components, such as memory chips and flat panel displays, into dominance of markets for high-performance computers and data communications equipment, just as had happened in consumer electronics (Hart and Borrus, 1992).[2] US electronics firms have now

[2]The success of Asian firms in consumer electronics in the 1970s and 1980s was in part based on Japanese improvements on solid-state technology that had been licensed from American firms in the 1950s and 1960s. Eventually, American firms lost control of product definition and were reduced to affixing their brand names to Japanese designed and manufactured products (known in the industry as an 'OEM' contract).

reasserted their control over product definition and design, and continue to lead the higher-value segments of the electronics industry. Continued dominance of key product sectors has allowed US electronics firms to control much of the innovative trajectory of the industry, and to reap the lion's share of the rewards (and penalties) associated with the emergence of entirely new application 'spaces', such as the Internet and e-commerce.

So, there are strong signs of life in the heartland of the modern corporation. Still, we cannot simply resurrect models of industrial organization based on the modern corporation as if nothing has changed. Even a cursory examination of the contemporary industrial organization of the United States in the 1990s reveals organizational patterns that look not at all like the modern corporation. The largest single employer in the country is not General Motors, but a temporary employment agency called Manpower Inc. The largest owner of passenger jets is not United Airlines, or any other major carrier, but the aircraft leasing arm of General Electric. US automakers have spun-off their in-house parts subsidiaries and outsourced the design and manufacture of entire automotive subsystems to first-tier suppliers (Sturgeon and Florida, 1999). Since 1992, IBM has literally turned itself inside-out, becoming a merchant provider of the basic components and technologies it had previously guarded so jealously for exclusive use in its own products. If what we see today seems to have little relation to the ideal type of the modern corporation, there may be good reason. Perhaps the US industrial system has begun to adapt to the new, more intense global competitive environment that triggered the competitive crisis in the first place. Perhaps we have witnessed the rise of a *new American model* of industrial organization, and not simply the resurgence of the old.

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 US manufacturing companies as they have begun to adapt to the new forms of competition that triggered the crisis.[3] Most often portrayed as desperately clinging to the outmoded attributes of the modern corporation, US manufacturing firms have been held up as the antithesis of new, more dynamic organizational forms that have emerged in Italy, Germany and especially Japan (Florida and Kenney, 1991, 1993; Harrison, 1994). The low visibility of US-centered production networks in academic circles may stem from their recent vintage and the notoriously slow production cycle in academic publishing (but see Sabel, 1989; Donaghu and Bariff, 1991; Bonacich *et al.*, 1994; Gereffi, 1994; Saxenian, 1994; Borrus, 1995; Dedrick and Kraemer, 1998; Abernathy *et al.*, 1999; Borrus *et al.*, 2000; Best, 2001). On the other hand, it also seems likely that some recent evidence on US-centered

[3]There is an extensive literature on recent changes in the internal organization of American companies in response to new competition, including work reorganization (e.g. employee involvement and cross-training) and the flattening of corporate hierarchies (e.g. Florida and Kenney, 1993; Applebaum and Batt, 1994; Kochan and Osterman, 1994), though research on the effects of downsizing and outsourcing on internal organization is sorely lacking (Biewener, 1997).

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.

While it has been widely noted in the management literature that widespread outsourcing by US firms has resulted a deverticalized industrial landscape (Hitt *et al.*, 1999), little attention has been paid to the evolution of the supply-base that has arisen in response to the shedding of 'non-core' assets. This lacunae—a result of the literature's focus on organizational changes in lead firms (e.g. Miles *et al.*, 1997)—has led to the erroneous characterization of the deverticalization process as one where industries are evolving toward smaller, highly specialized firms, each of which has shed its non-core activities to focus on a few core competencies. The deverticalization trend looks very different from the supplier's perspective. To meet the growing demand for full-service outsourcing solutions, suppliers have in many cases had to add entirely new competence areas, increasing their scope of activities while improving quality, delivery and cost performance. I call such firms 'turn-key' suppliers because their deep capabilities and independent stance *vis-à-vis* their customers allows them to provide a full-range of services without a great deal of assistance from, or dependence on lead firms. Increased outsourcing has also, in many instances, vastly increased the scale of suppliers' operations. Thus, outsourcing has led to a deepening of competence and an increase in scale at supplier firms. As an industry's supply-base comes to be comprised of large, highly capable turn-key suppliers, the prospects for increased outsourcing are improved. In this way, turn-key suppliers and lead firms co-evolve in a recursive cycle of outsourcing and increasing supply-base capability and scale, which makes the prospects for additional outsourcing more attractive, not just to the lead firms that drove the upgrading of the supply base in the first instance, but for those lead firms just beginning to seriously consider large scale strategic outsourcing (Sturgeon and Lee, 2001).

In this paper I argue that a significant number of US electronics companies are adapting to the pressures of market volatility and intensified international competition by developing their own distinctive model of networked production. I call this model the *modular production network*, because distinct breaks in the value chain tend to form at points where information regarding product 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; Schilling, 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 by the transfer of codified information. Such linkages have many of the benefits of arm's length linkages—especially speed and flexibility—while allowing for a rich flow of information between firms. 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. The network architecture that arises from such linkages has many of the advantages of modularity in the realm of product design, especially the conservation of human effort through the reuse of system elements (Langlois and Robertson, 1995).[4]

The modular production network model is derived from research on product-level electronics manufacturing (computers, communications equipment, consumer electronics, etc.), where the organizational shift, from in-house to outsourced manufacturing, has been dramatic in recent years. However, other research strongly suggests that comparable changes are underway in many other sectors as well, such as apparel and footwear, toys, data processing, offshore oil drilling, home furnishings and lighting, semiconductor fabrication, food processing, automotive parts, brewing, enterprise networking, and pharmaceutical production. The aim of this paper is not to assert that the shift is occurring in every US firm, but to provide a detailed analysis of the changes in the electronics industry to build a new model of industry organization. Section 2 of the paper provides a thumbnail sketch of the new organizational model through the case of organizational changes in the US electronics industry. In Section 3 the model is related to some of the classic theoretical tools that have been developed to predict and explain industry structure: Joseph Schumpeter's notion of innovation in the giant firm; Alfred Chandler's ideas about economies of speed and the rise of the modern corporation; and Oliver Williamson's transaction cost framework. Section 4 compares the modular production network model to other production network models that have been developed in the literature. In Section 5 I argue that modular production networks yield greater economic performance than other models, especially in the context of volatile demand, rapid technological change, and increasingly extensive and elaborate production geographies. I conclude the paper by pondering the notion of a worldwide convergence of industrial paradigms, placing the modular network in the historical context of the ongoing diffusion and adaptation of nationally specific models of industrial organization.

2. An introduction to modular production networks and turn-key suppliers

2.1 The case of Apple Computer and SCI Systems

In April 1996, Apple Computer announced that it was selling its largest US personal computer manufacturing facility in Fountain, CO, to a little-known electronics company called SCI Systems. Apple had just posted the largest quarterly loss in its history ($740 m.) and had narrowly avoided being acquired by Sun Microsystems, so it may not have been surprising that it was shedding some of its assets. What seemed strange about the deal was that, according to Apple management and industry pundits

[4]The set of ideas underpinning the notion of modular production networks has much in common with Langlois 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 the manufacturing process itself.

alike, Apple's troubles did not stem from poor demand, but from its inability to meet unexpected demand.[5] Why would a company having trouble meeting demand sell one of its most important production facilities? One could easily imagine an effort to improve responsiveness and efficiency at existing facilities, but a move to decrease capacity at such a moment seemed, on the face of it, foolish. Did Apple plan to make up for the resulting loss in manufacturing capacity by expanding its remaining in-house production facilities in Ireland or Singapore, moving production to lower-cost offshore locations? A closer look at Apple's restructuring strategy and its partner in the deal, SCI, provides some answers to this puzzle and serves as an example of the organizational sea-change that has been occurring in the US electronics industry since the late 1980s.

Surprisingly, the sale of the Apple facility to SCI did not mean that Apple computers would no longer be produced in the Colorado facility. On the contrary, the deal included a three-year agreement for SCI to continue to manufacture Apple products. SCI was at the time the largest of an emerging cadre of specialized firms whose sole business is to provide electronics manufacturing services on a contract basis; accordingly, companies like SCI are known in the electronics industry as 'contract manufacturers' and 'electronics manufacturing service' providers. SCI had the right to use the plant's production lines to manufacture products for any of its other customers as well as Apple, which at the time included more than 50 firms including Hewlett Packard and IBM, companies that compete directly with Apple in the personal computer market. The majority of the five year old plant's 1100 workers were to stay on as SCI employees.

So, Apple was not selling its sole remaining US plant to generate cash and moving offshore to lower-cost production locations; it was contracting with SCI to continue to manufacture Apple products in Colorado. According to Apple's CEO, the company's strategy was to outsource production to companies such as SCI and other contract manufacturers in order to reduce Apple's manufacturing overhead and inventory

[5]Apple's gambit to protect its market share against those companies offering PCs based on Microsoft's Windows operating system and Intel's x86 microprocessor architecture (known in the industry as 'WINTEL') by offering cheaper, lower-performance machines backfired when customers flocked to Apple's higher-performance products instead. Apple's manufacturing operations were not nimble enough to make up for this poor forecasting by quickly increasing production of higher-end machines. The PC industry as a whole had grown 25% during 1995 and many key components, particularly memory chips, were in short supply. Orders for high-end machines went unfilled and low-end machines began piling up as unsold inventory. The result was that Apple lost its already tenuous hold on some of its customers, who, unable to buy Apple machines with the capability of fully utilizing the industry's new 'killer application', the World Wide Web, migrated to readily available, powerful and relatively inexpensive WINTEL machines. By April 1996, Apple's share of the worldwide PC market had fallen to an all-time low of 5.8%, down from 7.7% in the first quarter of 1995. Apple's new CEO, Gilbert Amelio, who was brought in to address the crisis, instituted a three-track plan to revive Apple by targeting new product development on Internet and multimedia applications, streamlining the company's crowded product line, and drastically restructuring its operations, notably by outsourcing its manufacturing, technical support services and internal telecommunications system management to outside suppliers (*San Francisco Chronicle*, 1996).

carrying costs while concentrating the its resources more intensively on product design and marketing (*Electronics Buyers News*, 1996). As Apple's Director of Operations put it, Apple was moving to a 'variable cost position' *vis-à-vis* its manufacturing operations. This meant that more of the company's manufacturing assets were to be held by outside companies: contract manufacturers. The sale provided Apple with the ability to alter the volume of its production upward or downward at very short notice without installing or idling any of its own plant and equipment. Of particular interest to Apple's management was the improved 'upside flexibility'—the ability to quickly ramp production volumes upward to meet unexpected surges in demand—that the deal with SCI provided.[6]

Another oddity about the press reports surrounding SCI's acquisition of the Apple's Fountain plant was the following statement by Apple's senior vice-president of worldwide operations: 'By outsourcing the manufacturing activities of our Fountain site to a company of SCI System's size, experience, and broad business base, Apple has the opportunity to benefit from SCI System's economies of scale' (Apple Computer, 1996). Although SCI was a large company, its revenues were less than a third of Apple's at the time.[7] How could a company of SCI's size achieve greater manufacturing and component purchasing scale economies than a company whose market share in the PC industry has hovered between number one and three since the birth of the industry in the late 1970s? The answer lies in the fact that SCI's sole business is manufacturing. Beyond an small design services business, the company has no internal product development capacity, and its sales and marketing activities are limited to developing its business as a contract manufacturer of other firms' products. In fact, despite its size, and the fact that it manufactures no products under its own name, at the time SCI's 22 worldwide plants may well have contained more manufacturing capacity than any other single electronics firm.[8]

2.2 *The rise of contract manufacturing in the electronics industry*

The Apple/SCI deal was far from unusual. If anything, according to some industry analysts, some of Apple's problems stemmed from the fact that it had been too slow to

[6]As events at Apple had proved, inability to meet demand during an industry upturn is just as devastating in a fast-moving marketplace such as PCs as being stuck with excess capacity during an industry downturn. In an industry with a highly volatile growth pattern such as electronics, such upside flexibility is extremely important.

[7]In 1998, SCI's sales surpassed Apple.

[8]The manufacturing-specific business profile of SCI can be demonstrated by the following comparison. In 1995, SCI generated $1.8 bn in revenues while assembling 50 million circuit-boards (devices which provide the product-scale functionality for electronics products) ($36/board). Hewlett-Packard, a well known brand name company that had half of its 20 million circuit-boards assembled by contractors in 1994, generated $20 bn in revenues ($1000/board). If SCI generated as much revenue per circuit board as Hewlett-Packard, its revenues would be $50 bn. By comparison IBM, the largest electronics firm in the world, generated $64 bn in 1994.

outsource its production, even though nearly 50% of the company's manufacturing was performed by outside manufacturers prior to the sale (Technology Forecasters, 1996). By selling the Colorado facility to SCI, Apple management was simply placing the company more squarely on a bandwagon that was well underway. Following a trend that began in the late 1980s and has accelerated since, established US electronics firms in the computer and networking sectors, such as IBM, Nortel, Apple Computer, 3Com, Hewlett Packard, Maxtor and Lucent, rapidly moved toward outsourcing their circuit-board and product-level assembly, notably by selling off much of their domestic and offshore production facilities to the largest contract manufacturers. Many newer US electronics companies, such as Sun Microsystems, Silicon Graphics, EMC, Juniper Networks, Sycamore Networks, Cisco Systems and Network Appliance, outsourced most of their production from the outset, and their rapid growth during the late 1990s further fueled growth of the largest electronics contract manufacturers. As a result of this wave of outsourcing, the firms providing contract manufacturing services to the electronics industry have experienced extraordinary levels of revenue growth, top-level consolidation and geographic expansion.

In the latter part of the 1990s, the outsourcing trend began to spread to most of the major European communications infrastructure and mobile telephone handset firms as well, including Ericsson, Nokia and Alcatel. In 1997 Ericsson made a decisive series of moves, first by outsourcing production to Solectron, Flextronics and SCI, and then by selling its principal domestic production facilities in Karlskorna, Sweden, to Flextronics and a plant in Brazil to Solectron (Dunn, 1997). Solectron established a local presence in Sweden as well, but shifted the bulk of Ericsson's circuit-board assembly to its existing network of plants in France, Germany and Scotland (Jonas, 1997). In 2000, Ericsson shifted the remainder of its cellphone production to these US contract manufacturers, and sold its US production facilities to SCI (*Electronics Weekly*, 2000).[9]

In the past two years even a few Japanese electronics firms have tested the waters. In December 2000 NEC, whose cellphone handset business was doing poorly in the midst of a fierce shakeout, announced that it was selling its cellphone production facilities in England and Mexico to Solectron, while keeping facilities in Japan and China (*Bloomberg News*, 2000). In October 2000, Sony announced that it was selling two underutilized Asian facilities to Solectron, one in Miyagi, Japan, and a second in Kaohsiung, Taiwan. In January 2002, NEC announced the sale of two of its advanced manufacturing facilities in Miyagi and Yamanashi, Japan, to Celestica.[10] About 1200 highly skilled NEC manufacturing specialists and related support staff will become Celestica employees. As part of the deal, Celestica will assume supply chain management, subassembly, final assembly, integration and testing for a broad range of NEC's

[9]In 2001 SCI was acquired by Sanmina.

[10]The design and development functions currently performed by NEC Miyagi will remain with NEC, and NEC Miyagi will continue as a developer of optical transmission systems. The development and manufacturing of optical devices and optical submarine cable systems at NEC Yamanashi's Otsuki Plant will also remain with NEC.

optical backbone and broadband access equipment. The companies expect the deal to generate revenue of approximately $2.5 bn for Celestica over a five-year period. According to Kaoru Yano, senior vice-president of NEC and company deputy president of NEC Networks:

> NEC's growing partnership with Celestica will allow us to improve our competitive positioning by further leveraging our leading-edge R&D, product development and manufacturing expertise with Celestica's global manufacturing capabilities and supply chain management expertise. Through the alliance with Celestica, NEC intends to improve price competitiveness, production lead-times and supply chain flexibility to optimize overall manufacturing efficiency. NEC also chose to work with Celestica based on its reputation for providing global, advanced manufacturing capabilities and cost-effective supply chain solutions for the world's best communications and information technology companies.

All of the top five contract manufacturers are based in North America.[11] They consist of Solectron, based in Milpitas, CA; Flextronics International, incorporated in Singapore but managed from its San Jose, CA, headquarters; Sanmina/SCI, based in San Jose; Celestica, based in Toronto, Canada; and Jabil Circuit, based in St Petersberg, FL. According to revenue estimates for 2002, these firms 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 brand-name electronics firms 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 brand-name electronics firms surveyed expected to outsource 73% of total production needs on

[11] A set of smaller, highly sophisticated electronics contract manufacturers also emerged in Taiwan in the 1990s (Dedrick and Kraemer, 1998). 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 US 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 $1.7 bn to $10.3 bn. In the same period, total revenues of the top five American contractors increased 47.7% per year, from $3.3 bn to $33 bn. 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).

Table 1 Revenue, revenue growth and revenue from acquisitions at the top five electronics contract manufacturers, 1995 and 2002 estimates

	1995 revenue ($)	Analyst revenue outlook for 2002 ($)	Compound annual growth rate (%)	Annual revenue from acquisitions[a] ($)	% of revenue from acquisitions
Solectron	1 679 158	16 470 000	46	8850	54
Flextronics	389 100	13 160 000	80	9500	72
Sanmina/SCI	3 514 029	12 140 000	23	13 575	112
Celestica	600 000[b]	11 250 000	63	5 975	53
Jabil Circuit	686 183	4 870 000	39	625	13
Top five total	6 868 470	57 890 000	43	38 525	67

Source: company annual and quarterly reports.

[a]Announced in 1999, 2000 and 2001.

[b]All Celestica revenues in 1995 were from IBM.

average, and 40% stated their intention ultimately to outsource 90–100% of final product manufacturing. The CEO of Flextronics has stated publicly that he expects annual revenues at his company to reach the $100 bn range in the next 5–10 years.

As we have already mentioned, most of the growth in electronics contract manufacturing has taken place in the very top tier of firms. 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 expansion, fueled by the acquisition of competitors and customer facilities as well as organic 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 contract manufacturers. The importance of acquisitions to growth is shown in Table 1: 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.

In the late 1980s and early 1990s, globally operating lead firms in the electronics industry began by outsourcing to smaller regional contract manufacturers in Asia, Europe and North America, but as the scale of outsourcing increased, so did the complexity of managing a multiplicity of relationships with suppliers based in multiple locations. In order to streamline the management of their outsourcing relationships, brand-name electronics firms increasingly demanded that their key contractors have a 'global footprint'. As a result, the largest contract manufacturers have been aggressively internationalizing since the mid-1990s. For example, the current largest electronics contract manufacturer, Solectron, was concentrated in a single campus in Silicon Valley until 1991, when its key customers, including Sun Microsystems, Hewlett Packard and IBM, began to demand global manufacturing and process engineering support. Within ten years, the company's footprint had expanded to nearly 50 facilities worldwide (see Table 2). Today Solectron operates a set of global and regional headquarters, high and low mix manufacturing facilities, purchasing and materials management centers, new product introduction centers, after-sales repair service centers for products manufactured by Solectron and others, and technology centers to develop advanced process and component packaging technologies. To provide another example, Celestica began with only two production locations which spun off from IBM in 1996, a large complex near Toronto, Canada and a small facility in upstate New York, since closed. By the end of 2001, after completing 29 acquisitions of competitors and customer facilities, Celestica owned nearly 50 facilities in North America, South America, Europe and Asia.

2.3 The drivers of contract manufacturing revenue growth

Many factors have contributed to increased outsourcing by US brand-name electronics firms, and thus the boom in contractor revenues. First, relative to firms from Asia and Europe, US electronics firms have generally placed manufacturing in a low position on the hierarchy of corporate esteem. Accordingly, as the capabilities of contract manufacturers have improved, US brand-name electronics firms have been more than willing to use them while curtailing, and even closing, internal manufacturing operations which are often seen by top management as draining resources away from more crucial innovation and sales activities. (See Thomas, 1994, for a detailed account of these tensions at a leading US electronics firm.) Second, ongoing market volatility in many segments of the electronics industry has made production scheduling exceedingly difficult. By using contract manufacturers, brand-name firms gain the ability to ramp the volume of their production upward or downward on short notice, *without* the need to install or idle in-house plant and equipment. Third, since the mid-1980s, contract manufacturers have shifted from assembling products from kits of parts supplied by customer firms on a 'consignment' basis, to purchasing all the needed components up-front for customer firms on a 'turn-key' basis. Turn-key component purchasing drives up contractor revenues as these payments pass through the contractor to component suppliers. Fourth, turn-key contractors have added a range of front- and back-end services related to the assembly process, such as redesign-for-manufacturability, circuit-board layout, testing, final product assembly, final packaging and after-sales service, creating new sources of revenue. Fifth, a technological shift in the base process of product-level electronics manufacturing, circuit-board assembly, has heralded widespread automation of electronics manufacturing processes that were previously performed by hand (Sturgeon, 1999). The pressure to acquire and master new, more expensive automated manufacturing equipment at in-house manufacturing plants has made the prospect of using highly capable contract manufacturers even more attractive. Similarly, the higher throughput enabled by automated production equipment has increased the risk of installing additional in-house capacity in the face of

Table 2 Solectron's global locations and functions, 2001

	HQ	Mfg	Mat	NPI	Serv	Tech
Americas						
Milpitas, CA, USA	×	×	×	×	×	
Fremont, CA, USA		×	×	×		
Austin, TX, USA		×	×	×		×
Charlotte, NC, USA		×	×	×		×
Columbia, SC, USA		×	×	×		
San Jose, CA, USA		×	×	×		
Atlanta, GA, USA		×	×	×	×	
Westborough, MA, USA		×	×	×		
Suwanee, GA, USA		×	×	×	×	
Fremont, CA, USA		×	×			×
Everett, WA, USA		×	×			
Raleigh, NC, USA		×		×		
Aguadilla, Puerto Rico, USA		×				
Aguada, Puerto Rico, USA		×				
Los Angeles. CA, USA					×	
Austin, TX, USA					×	
Memphis, TN, USA					×	
Louisville, KY, USA					×	
San Jose, CA, USA						×
Vaughn, Canada					×	
Calgary, Canada		×				
Guadalajara, Mexico		×	×			
Monterrey, Mexico		×	×	×		
São José dos Campos, Brazil		×	×	×	×	
Hortolândia, Brazil		×			×	
Europe and Middle East						
Reading, UK	×					
Bordeaux, France		×	×	×		×
Herrenberg, Germany		×	×	×		
Munich, Germany		×	×	×		×
Östersund, Sweden		×	×	×		×
Istanbul, Turkey		×	×	×	×	
Dublin, Ireland		×	×			
Carrickfergus, N. Ireland		×	×			
Dunfermline, Scotland		×	×			
East Kilbride, Scotland		×	×			
Timisoara, Romania		×	×			
Asia						
Taipei, Taiwan	×					
Singapore		×	×	×		
Johor, Malaysia		×	×	×		
Penang, Malaysia		×	×	×		×
Suzhou, China		×	×			
Penang, Malaysia		×	×			
Wangaratta, Australia		×				
Singapore			×			
Liverpool, Australia				×		
Bangalore, India						×
Tokyo, Japan	×					×
Kanagawa, Japan			×	×	×	

Source: Solectron.

HQ, global and regional headquarters; Mfg, manufacturing facilities; Mat, materials purchasing and management centers; NPI, new product introduction centers; Serv, after-sales repair service centers; Tech, technology centers.

ongoing market volatility, and increased the incentives for pooling that capacity in shared external suppliers.

The recent boom in contract manufacturing revenues highlights the basic shift underway in the organizational fabric of the electronics industry. Since such exponential growth curves are, by definition, unsustainable, we can surmise that contractor sales growth will eventually flatten out to create an S-curve when viewed in time series. This suggests that we are currently witnessing a one-time transition in the electronics industry from in-house to out-of-house manufacturing.

3. Theories of organizational change: accounting for the modern corporation is not enough

> As usual, economic facts are running ahead of models of the economy. (Brusco and Sabel, 1981: 99)

In this section three theories that contain explanations for the emergence of the giant corporation are reviewed: innovativeness, economies of speed and transaction costs. By distilling the theoretical mechanisms that existing theories have provided to explain vertical integration and increasing firm size, we can test their efficacy for explaining the rise of modular production networks.

3.1 A Schumpetarian view: the delinking of production from product innovation in the modular network[12]

The work of Joseph Schumpeter was deeply affected by the rise of the large corporation. Schumpeter's early work *The Theory of Economic Development* (1934), written in Germany and first published in 1911, focused on the role of the small-firm entrepreneur in driving innovation. Schumpeter's later work, written in the United States, recognized the empirical reality of the large firm in US industry. By the time he wrote *Capitalism, Socialism, and Democracy* (1942), Schumpeter's focus had shifted from the innovative entrepreneur to innovation in the corporate R&D laboratory, from tacit to codified knowledge, from low to high market entry barriers, and from small to large firms (Nelson and Winter, 1982; Malerba and Orsenigo, 1995). He argued that observable productivity increases in the US economy were largely due to innovations delivered by the R&D laboratories of large firms in an environment of high barriers to market entry (Schumpeter, 1942).

Schumpeter believed that the stability provided by oligopolistic market structures created a better environment for industrial research. Large firms have the longevity and financial resources to build up the 'knowledge base' required to apply scientific principles to ever more complex innovative problems. As the importance of codified knowledge increased in the early 20th century, barriers of entry were erected that reduced the role of small-firm entrepreneurs who tended to base their innovations on

[12]An earlier draft of this section appeared as chap. 4 in Jürgens (2000).

tacit knowledge.[13] In the context of monopoly theory, these ideas became known as the *Schumpetarian hypothesis:* 'the claim that a market structure involving large firms with a considerable degree of market power is the price that society must pay for rapid technological advance' (Nelson and Winter, 1982: 278). In the long run, Schumpeter believed that oligopolistic market structures would inevitably be torn asunder by ongoing rounds of innovation, competition and new market creation.

Nelson and Winter (1982) built on Schumpeter's conception of innovation as the motor of capitalist development to construct their theory of 'evolutionary economics'. Because successful firms tend to invest in additional productive capacity, the dynamic process of industrial evolution tends to create larger firms and more concentrated market structures over time—up to the point where market concentration begins to stifle competition and hence innovation. The assumptions in Nelson and Winter's model point out a key problem with using the Schumpetarian approach to predict the evolution of industry organization. In the Schumpetarian frame, firms tend to get larger over time because successful innovations lead to higher profits and greater investments in productive capacity that put them further ahead of their competitors. Aggressive capital investment becomes a barrier to entry for new firms and, as a result, firms become larger and market structure more concentrated over time. But what if we allow for the possibility that increases in market share can be organizationally delinked from increases in firm-specific capital investment, as when US electronics firms increasingly rely on outside sources (contract manufacturers) for manufacturing capacity? If a firm successfully innovates (e.g. develops a electronics product with dramatically better price/performance characteristics than any existing competitor), it can quickly ramp up production through its contract manufacturers without the lag or risk associated with building up internal capacity. In the modular network market, concentration can increase without concomitant concentration in the ownership of productive capacity. As a result, barriers to entry based on the holding of productive capacity by leading firms fail to develop.

As large-scale shared external economies emerge in an industry, the link between gaining market share through successful product innovation, on one hand, and firm size and scope, on the other, breaks down. This link was the cornerstone of Schumpeter's conception of industry structure and his explanation for the rise of the large, vertically integrated industrial firm in the early part of the 20th century. Firms that outsource a large share of their manufacturing no longer have to carry the financial, administrative and technical burdens of fixed capital for production, allowing them to focus on product innovation and become more organizationally and geographically flexible. Product innovation, in the modular system, has been freed from

[13]Schumpeter did not recognize, as Arrow (1964) and Williamson (1975) later did, that the internalization of production functions can lead to 'information impactedness' (e.g. isolation from the state of the art) that can suppress innovation in the large firm. The literature on production networks stresses the superior environment for learning and cross-fertilization of ideas, and therefore innovation, provided by network forms of industry organization (Powell, 1990).

the shackles of large-scale investment in fixed capital for the manufacturing of those products, allowing the lead firm's resources to be more tightly focused on the ongoing process of new product development.

If there are risks associated with letting go of manufacturing, they appear to have less to do with losing the ability to innovate, and more to do with losing the protection afforded from new market entrants by large-scale, firm-specific investments in plant and equipment. With modular production networks, dominant firms are no longer buffered from competitive pressure by large scale in-house fixed capital. Barriers to new entrants are lowered because competitors can tap the same set of suppliers and therefore gain access to leading-edge, global-scale production capacity used by established firms. Turn-key suppliers, because they are not tied too tightly to any single customer, simply apply more of their manufacturing capacity to the firm that has gained market share, while scaling back (or increasing more slowly) the production of products for the firm(s) that have lost market share. Barriers to entry are reduced and markets remain more fluid because gains in market share are not necessarily associated with large increases in the size of lead firms.

Thus, for the innovating firm, competitive outcomes become more tightly tied to product-level innovation, such as product strategy, definition, development, design and marketing. For example, Cisco Systems, a Silicon Valley-based company that designs and sells high-performance switches for data communications, gained a wide market share lead with very little internal manufacturing capacity, depending instead on a worldwide network of highly proficient contract manufacturers for nearly all of its core manufacturing. If, however, another firm develops a better switch, Cisco's contract manufacturers would certainly be willing and able to build them. In fact, the same contract manufacturers that manufacture Cisco's products also manufacture for Cisco's competitors, such as Juniper Networks. At the industry level, modular production networks make it possible for market share to change hands without the idling of productive capacity, mollifying the 'destructive' aspect of innovation predicted in Schumpeter's conception of 'creative destruction'.[14] With modular production networks, successful innovation does not necessarily lead to giant corporations.

From the supplier's perspective, long-term viability in a network environment that tolerates competitive switching means maintaining a large and diverse pool of customers. To facilitate this, turn-key suppliers often specialize in a cross-cutting *base process*, one which is used to manufacture products sold in a wide range of end-markets (e.g. pharmaceutical manufacture, semiconductor wafer fabrication, plastic injection molding, electronics assembly, apparel assembly, brewing, telecommunications backbone switching); *base component*, one that can be used in a wide variety of end-products

[14]The possibility for market share to change hands without idling any productive capacity is a also a characteristic of production networks in industrial districts (Brusco, 1982). The key difference is that the shared external economies in modular production networks, because they are based on highly formalized, not idiosyncratic inter-firm linkages, can be more easily extended geographically, resulting in larger economies of scale (see below).

(e.g. semiconductor memory, automotive braking systems, engine controls); or *base service*, one that is needed by a wide variety of end-users (e.g. accounting, data processing, logistics), rather than on processes or services that are idiosyncratic or highly customer-specific. Turn-key suppliers, then, tend to develop *generic* manufacturing capacity and services that allow product variation to be very large as long as their specifications fall within the parameters of the base process. In the manufacturing sectors mentioned above, most turn-key suppliers use highly automated production systems (apparel assembly is a major exception) that can be programmed and reprogrammed on short notice to produce a wide variety of products.

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 US 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, for example, 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. Electronics firms 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. 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 the level of codification in the

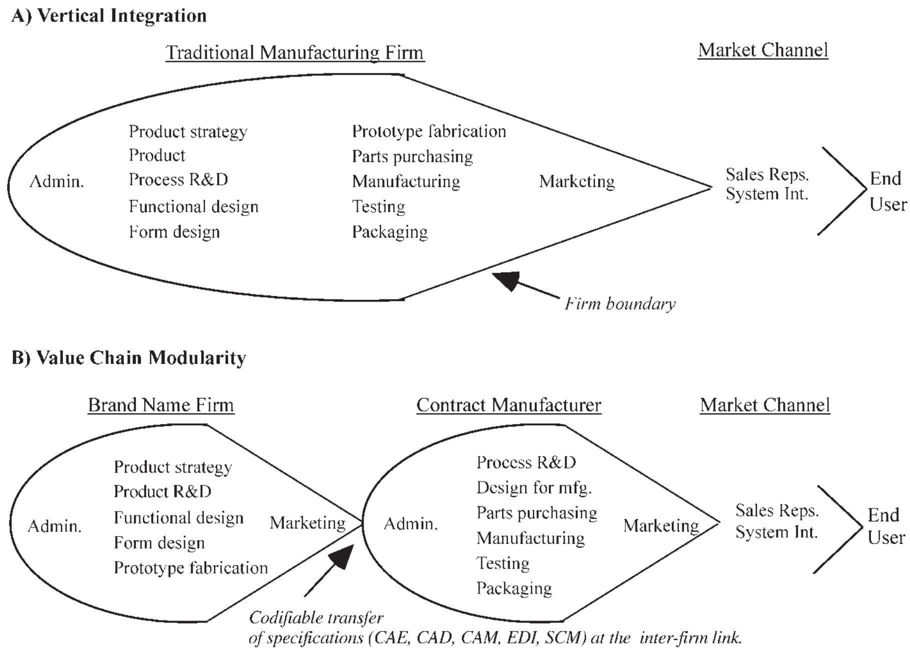

Figure 1 From vertical integration to value chain modularity: the delinking of product innovation from manufacturing in the modular network.

electronics industry to a new level, offering firms a set of standardized blueprints 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 a highly formalized link at the inter-firm boundary, even as the flow of information across the link has remained extremely high. Figure 1 presents a simple conceptual map of the shift from the vertically integrated organizational form of the modern corporation to the value-chain modularity that characterizes the modular production network. Note that R&D remains a vital function for each firm in the modular network, where it is specialized into product and process applications.

Seen from the perspective of the late 20th century, Schumpeter's conception of effective organizational strategies was too narrow. His focus on the organizational strategy of vertical and horizontal integration and ever-increasing firm size is understandable given the industrial structure prevalent at the time of his writing. Today a wider range of organizational strategies should be recognized. At the same time, Schumpeter was right that industry organization can be deployed *as a strategy in its own right* and is not simply a function of other strategies, as Chandler would have it (see below). Industry organization, the social division of labor, if you will, has been and is now a central force in capitalist development (Sayer and Walker, 1993: 159; Miles *et al.*, 1997).

3.2 *Alfred Chandler's implicit theory of the firm: economies of speed*

In his seminal 1977 book, *The Visible Hand*, Alfred Chandler does not offer a general theory of organizational change. The task he set out for himself was to describe and explain the rise of the modern corporation on the US industrial landscape between 1840 and 1920. The giant corporation did not reflect any abstract law of economic truth, but a set of *strategies* employed by those in control of the firm. However, an implicit theoretical argument can be distilled from Chandler's work because he did present the modern corporate form as providing certain advantages over earlier modes of capitalist development. According to Chandler (1977), the advantages of the large multidivisional corporate form—and likewise of internal organization—over market transactions are: (i) transaction costs are lower inside the firm because they can be better routinized; (ii) information on prices and supply is more accurate when transmitted inside the firm; and (iii) better coordination of inputs and outputs through the productive apparatus leads to better utilization of plant and equipment and increased throughput. Although Oliver Williamson would later try to formalize Chandler's theory of the firm based on the first advantage, reduced transactions costs (see below), Chandler is clear that the third set of advantages of internalization, more intensive capital utilization and faster throughput, are the most important to his explanation of the modern corporation (Chandler, 1980).

According to Chandler, the elaborate control hierarchies and the large size of the modern corporation arose to solve the problems of fixed costs. In a high-volume production environment, the time needed to put management, labor, machine and supply systems in place creates a lag between product innovation and initial sales that increases the risk of investment. If investments in fixed costs are to prove profitable, plants need to come on-stream quickly and equipment utilization rates need to be continuously high. Because faster throughput leads to higher productivity and greater returns on investment, the likelihood that the firm's products will succeed in the marketplace is greater. Chandler called the advantage of high throughput 'economies of speed'. It wasn't increases in the 'optimum scale' of 'indivisible' production technologies as much as the need to ensure maximum utilization of plant and equipment that spurred vertical integration over time (Lazonick, 1991).

Ongoing efforts to improve economies of speed form Chandler's central explanation for the tendency for the internal economies of the modern corporation to grow. The argument proceeds as follows. Because investments in high-volume plant and equipment require increased throughput, expanded managerial structures are needed to better plan and coordinate the flow of materials and payments through the system. Vertical integration follows from the need to better control the flow of inputs purchased outside the firm on the market, resulting in backward integration into materials and components, and the sale of outputs through intermediaries, resulting in forward integration into distribution. High throughput depends on uninterrupted sources of supply and unimpeded sales, so functions formerly mediated by the market tend to accumulate within the boundaries of the firm. Put another way, variable costs tended to decrease and fixed costs tended to increase, resulting in vertical integration. Management's role, to use a metaphor, is to dredge the channels upstream and downstream from the productive apparatus of the firm, increasing the volume of flow. During the early 20th century the deployment of new, more productive capital equipment, such as highly mechanized continuous process equipment for cigarette manufacturing, heightened the throughput problem by acting as a powerful pump in the center of the channel. The pump could be damaged either if the channel is allowed to run dry or if the outlet is allowed to back up.

The addition of upstream and downstream functions to the existing corporate structure added to the problem of fixed costs, to which the modern corporation responded by further increasing its managerial organization. Newly added functions were upgraded and streamlined to match the throughput needs of existing operations. The dynamic created by successive rounds of investment in high-volume facilities, vertical integration and organizational expansion propelled the modern corporation to ever greater size and scope, *as long as markets continued to expand to absorb such growth in output.*

I argue that the rise of international competition in the 1970s and 1980s negated this assumption for many US electronics firms. Yet, the problem of fixed costs as outlined by Chandler persists. More productive, expensive and difficult-to-master production technologies have come on the scene in electronics manufacturing since 1985 (see Sturgeon, 1999), requiring greater throughput and more intensive utilization of plant and equipment than ever before. But because no amount of advertising, product innovation,or new market development can ensure capacity utilization rates great enough to easily justify new investments in plant and equipment, productive capacity has begun to build up outside, not inside, innovating firms. The firms that supply these production services, the contract manufacturers, specialize in coordinating the flow of inputs and outputs through their factories, relieving the brand-name firm of the need to invest in in-house fixed capital as well as the R&D activities related to process innovation. Because the new equipment is highly flexible and relatively standardized it can effectively be shared across the supplier's customer base. This generic capacity maintains economies of speed despite the market uncertainty faced by any single brand-name firm. Furthermore, because cash outlays for investments in plant and equipment and (at least temporarily) for the purchase of materials are the responsibility of the contract manufacturer, the brand name firm needs only to risk the increasingly substantial investments required to develop and market new products.

Recent moves toward upstream integration by the largest electronics contract manufacturers fit well with Chandler's argument. Companies such as Flextronics and Sanmina (both based in San Jose) have recently developed in-house capabilities to provide inputs that are specific to the products they manufacture, such as bare circuit-boards and plastic enclosures. In part, these investments have been made because they have set up integrated operations in places with poorly developed supply-bases, such as East Europe and Mexico, but they have also been undertaken to ensure a supply of inputs that are specific to particular products, thus maintaining economies of speed. What also supports Chandler's argument is that there has been very little or no upstream integration by contract manufacturers into standardized components such as passive semiconductors and power supplies. Still, the critical deviation from Chandler is that the economies of scale and speed that build up in modular production networks surpass those of any single firm because they reside externally and can effectively be shared the industry as a whole.

More than most historiography, Chandler's inquiry is influenced by the concerns of economists, such as efficiency, economies of scale and the emergence of oligopolistic market structures. But unlike the economists with whom he is in conversation, Chandler's project is not to make absolute theoretical statements about the evolution of capitalism. Chandler's training as a historian gives him an evolutionary approach. Effective administrative control over a geographically dispersed corporate structure could *only* arise after the railroad and telegraph systems had been put in place in the 1880s. Manufacturers integrated forward into distribution and marketing *only* in those industries and cities where existing sales channels were inadequate (e.g. where they could not provide for specialized needs such as technical sales, after-sales service or refrigeration of perishable goods) (Chandler, 1980). Chandler's analysis was derived from examination of a specific set of firms during a specific time period; he left it to others to formally abstract his findings into a more general predictive theory of industry organization. It has been Oliver Williamson who has most notably taken up this task.

3.3 Frequency, uncertainty and asset specificity in the modular network: a critique of transaction costs theory

Pivotal to explaining and predicting firm and industry structure is the question of whether a firm 'makes or buys' a given input or service. The story of the rise of the modern corporation is one of companies successively choosing the 'make' option over the 'buy' option, causing firms to become larger, more integrated and more diversified over time. It is a short step to extrapolate from a tendency of firms in a particular sector or institutional setting to choose one option over the other to a general pattern of industry organization. Why would firms choose to internalize functions previously purchased from other firms through the market?

In 1937, as the debate about the modern corporation was taking off, Ronald Coase began explore the make versus buy tradeoff within the framework of neoclassical theory. In so doing he was essentially asking a question new to mainstream economics: what determines the size of firms? While he maintained his confidence that the price mechanism governed the interaction of firms in the market, he noted that 'men', not prices, allocated resources within the firm. 'If a workman moves from department X to department Y, he does not do so because of relative prices, but because he is ordered to do so' (Coase, 1937: 387).

Coase argued that firms existed because there were costs to using the market.

Accurate knowledge (i.e. perfect information) cannot be assumed, and buyers cannot always specify exactly what they want from sellers ahead of time. The time and effort involved in negotiating and concluding each purchase through the market also has a cost. Within the firm, one open-ended contract can effectively substitute for many, reducing ‘marketing costs’ (i.e. transaction costs) and increasing efficiency.[15]

Oliver Williamson (1975, 1981, 1985; Williamson and Ouchi, 1981) built a powerful theoretical framework on Coase’s notion that there are costs to using markets. His project has been to ‘operationalize’ the concept of transaction costs as a way to predict when a firm would choose the make option over the buy option. Williamson calls for an economic theory that treats the firm not as a production function, but as a ‘governance structure’ defined in its extent by transaction costs. If transaction costs are high, the internal governance structure of the firm will grow; if transaction costs are low, the governance structure will not grow.

Williamson’s first step to building his framework is to ask: what basic assumptions should we hold about market transactions? For these Williamson reaches to the Hobbesian roots of classical political economy, arguing that the self-interested behavior of economic actors could extend to ‘opportunism’, meaning tactics of guile and deceit (Granovetter, 1985). Such cheating in economic relations requires another assumption: that the party being cheated remains unaware, at least at first, that they are being done in. Williamson refers to the assumption that economic actors cannot know everything in advance as ‘bounded rationality’.

Here Williamson is introducing two elements that directly challenge the assumptions of standard neoclassical economics: that self-interested behavior would be checked to gentlemanly levels by competition and that economic actors would have access to perfect information about the conditions of the market (i.e. real prices). Williamson argues that, under certain conditions, bounded rationality and opportunism can raise the cost of doing business, resulting in transaction costs. Transaction costs are a determining factor in industry structure because they affect when a firm will make or buy a particular input or service. Higher transaction costs lead firms to internalize functions, while lower transaction costs (or zero transaction costs as assumed by standard neoclassical theory) result in industry structures where amalgams of smaller

[15]Just as did Chamberlin (1933), Coase rejected the idea that large firms signified absolute market failure. For Coase, firms existed because markets could, in some cases, operate more efficiently *inside* the firm; a portion of the market was simply absorbed by the firm. By adapting the concept of the market to the realm inside the firm, one of the key distinctions of the word ‘market’ was lost: that it signifies economic relationships *between autonomous economic actors*. Using the cost of ‘markets’ to explain the make versus buy choice became meaningless when the term ‘market’ was made so plastic it could be applied to either internal or external transactions. In his rush to adapt the firm to the tenets of the neoclassical paradigm, Coase failed to account for his own observation that, ‘If a workman moves from department X to department Y, he does not do so because of relative prices, but because he is ordered to do so.’ The field of strategic management addresses such questions by explicitly acknowledging the agency of managers.

firms interact through arm's length, price-based market transactions—the Marshallian norm.

Williamson's next step is to operationalize the assumptions of opportunism and bounded rationality in a way that can predict when a firm will make or buy a particular input. He introduces three independent variables: frequency, uncertainty and asset specificity. The threat of opportunism, under conditions of bounded rationality, raises the risk of higher costs unexpectedly coming to light. In such an uncertain environment, optimal actions cannot be defined because the element of risk is involved. Influenced by legal scholars writing on contract law (e.g. Alchian and Demsetz, 1972; Jensen and Meckling, 1976; MacNeil, 1978), Williamson's chief examples of uncertainty are contracts where price could not be agreed upon ahead of time because the nature of the transaction was too complex or uncertain to pre-specify all contingencies. Such 'relational contracting' exposes both parties in the transaction to risk. Williamson argues that contracting firms will avoid assuming risk by internalizing uncertain transactions, as long as the costs of doing so are not too high.[16] In the transaction cost framework, infrequent transactions will tend to take place in a market context. The costs of building internal capacity to provide a good or service that is rarely required cannot usually be justified unless it is unavailable on the market. If, on the other hand, market transactions for the same input become too frequent, the risk of opportunism on the part of the supplier becomes greater (because of increasing asset specificity—see below), therefore triggering the internalization of the function.

The third and most important independent variable that Williamson offers as a tool to predict outcomes in the transaction costs framework is asset specificity, by which he means the degree that capital assets (e.g. machinery, routines or skills) are specific to the transaction in question, i.e. assets that are specialized, dedicated or customized to make a specific product. If asset specificity is high, then it is likely that the activity will be internalized. Of the three independent variables in Williamson's framework, asset specificity is assigned the greatest causal power. More than frequency or uncertainty, Williamson argues that 'a considerable amount of explanatory power turns on' the notion of asset specificity (Williamson, 1981: 1546):

> . . . neither frequency nor uncertainty—individually or in combination—justifies the creation of internal organization (with its associated transaction-specific governance structure). (Williamson and Ouchi, 1981: 352)

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[16]The likely strategy for the supplier firm under such conditions is not theorized in Williamson's model. The entire project of organizational theory is skewed in this manner. As buyer firms integrate and become larger, it is assumed that supplier firms shrink and disappear. In a static, 'zero-sum' economy this would be true, but in a dynamic, growing economy, suppliers continue to grow with their customers over time. The supplier firm does not have the option, in most cases, of internalizing risky transactions (a.k.a. integrating forward) because it would be eliminating its market by competing directly with its customer(s). In practice, suppliers try to protect themselves from risk by decreasing their dependence on any single customer and diversifying their customer base. The groundwork for the emergence of external economies in electronics production has been the continued growth and increasing competence of supplier firms over time.

Williamson identifies several kinds of asset specificity: *site specificity*, a condition in which, for whatever reason, there are benefits to be gained through physical proximity (e.g. an engine plant located near an auto assembly plant to reduce transport costs); *physical asset specificity*, where machinery is dedicated to a particular product; and *human asset specificity*, where skills and routines are product-specific. Although Williamson does not affix it with a formal title, he identifies a fourth dimension of asset specificity (Williamson, 1981: 1546) that I will call *relational specificity*, which Williamson and Ouchi describe as follows:

> Additional [to site, physical, and human] transaction specific savings can accrue at the interface between supplier and buyer as contracts are successively adapted to unfolding events, and as periodic contract renewal agreements are reached. Familiarity here permits communications economies to be realized: specific language develops and nuances are signaled and received in a sensitive way. Both institutional and personal trust relationships evolve. In consideration of the value placed upon economies of these kinds, agents who engage in recurring, uncertain, idiosyncratic transactions have a strong interest in preserving the exchange relation. Autonomous contracting modes give way to internal organization as the value associated with exchange continuity [i.e., long term relationships] increases. (Williamson and Ouchi, 1981: 353)

The notable thing about this passage, besides its move toward the 'socialized notions' of economic life offered by sociologists and network theorists (e.g. Granovetter, 1985), is its *historical* dimension. Williamson never states that assets *always* become more specific over time, but he strongly suggests that the tendency exists. Consider the following passage:

> The production cost advantage of markets decrease and the (comparative) governance costs of markets increase as assets become *progressively more specific*. Thus as assets *become more fully specialized* to a single use or user, hence are less transferable to other uses or users, economies of scale can be as fully realized when a firm operates the asset under its own internal direction as when its services are obtained externally, by contract. And the market's advantage in pooling risks likewise shrinks. Simultaneously, the transactions in question take on a stronger bilateral character, and the governance costs of markets increase relatively. . . . What may have been (and commonly is) an effective large-numbers-bidding situation at the outset is sometimes *transformed* into a bilateral trading relation thereafter. (Williamson, 1981: 1548, italics mine, except in the last instance)

Williamson assumes that specific assets, particularly of the relational kind, tend to build up over time with repeated contracting as the parties to the relationship accrue transaction-specific attributes. Although he does not formally acknowledge the assumption of the tendency of asset specificity to increase over time as he does with his assumptions of opportunism and bounded rationality, it is on this *pseudo-assumption* that the historical, evolutionary element of Williamson's theory rests. It is through this device that Williamson attempts to weld his argument to Chandler's empirical case by using his transaction-cost theory to explain the rise of the modern corporation.[17] Because he drew heavily on Chandler's account of the modern corporation, Williamson's operational mechanism is slanted toward the 'make' side of the make/buy equation and it is the assumption that there is a tendency for asset specificity to increase over time that tips the scales. In Williamson's model, the emergence of the modern corporation is a result of a general tendency for firms to choose the 'make' over the 'buy' option because asset specificity tends to build up over time. This attribute of transaction costs theory is not surprising. From the vantage point of the 1960s, 1970s and even the 1980s, the chief problem for organizational theory was to explain the accretion of more and more functions within the modern corporation, first in its 'U-form' (vertically integrated), then in its 'M-form' (multidivisional), and on to its conglomerate and multinational incarnations. If we accept Williamson's assumption that asset specificity tends to build up over time, and also accept his argument that high asset specificity results in internalization, the expanding size and scope of the modern corporation becomes the only possible outcome .

Now let us rehearse the transaction cost framework with the empirical case of contract manufacturing in the US-led electronics industry. First, frequency is very high, suggesting internalization. Brand-name electronics firms are using contract manufacturers for an increasing percentage of their production needs. Indeed, an increasing number of lead firms have little or no internal manufacturing capacity at all. When the level of outsourcing approaches 100%, frequency nears its theoretical maximum. Here we see that, in this instance at least, frequency is largely a descriptive variable because it simply changes in proportion with levels of outsourcing.

Second, uncertainty in the electronics industry varies depending on the kind of uncertainty considered. In terms of *market uncertainty,* the electronics industry is extremely volatile. Market leaders are unseated with stunning regularity, particularly in fast-moving product categories such as laptop computers and modems. Through increased outsourcing, lead firms are passing investment risks out of house to their contractors, who can lower their risk and maintain consistently high plant and equipment utilization rates by balancing and spreading production volumes across their customer base. Ongoing market volatility has been one of the driving forces of increased contract manufacturing in electronics. As such, the case of contract manufacturing in the electronics industry falsifies this element of the transaction cost framework, which predicts internalization in the face of uncertainty.

But at the more constrained level of *contract uncertainty* that Williamson focuses on,

[17]In response to Williamson's efforts in the regard, Chandler clearly maintains that economies of speed (the need for high throughput) have more to do the rise of the giant corporation than the need to economize on transaction costs (Chandler, 1980).

the predictive power of the model is borne out, because electronics design and manufacturing technology have become increasingly codified and standardized. As information technology for product design and supply-chain management have become more effective, production processes have become more capital intensive, and elaborate quality regimes have been put in place on the factory floor, the ability of contractors to specify in advance the methods and costs of production has dramatically improved. That modular production networks have arisen in an environment of increasing process codifiability and standardization supports Williamson's third hypothesis that extensive market relationships require low asset specificity. Because contract manufacturers can reprogram their computer-controlled production equipment to serve any of their customers the key assets in the transaction remain general, and do not become specific.

Thus, the case of outsourcing in the US-led electronics industry falsifies Williamson's fourth *pseudo*-assumption that asset specificity tends to increase over time. As codification has increased, and as both customer and contractor firms have sought to limit interdependence through volume spreading (both lead firms and contractors report efforts to keep each other's business at or below 20% of total volume), customer firms have not become locked into a bilateral trading relationship with their contractors, or vice versa. Although the frequency and (market) uncertainty of the transactions have been high, lead firms have little incentive to build internal manufacturing capacity. We need to ask which is the dominant historical trend: increasing asset specificity or increasing process codifiability and standardization? Although Williamson has argued the former, I argue that the latter trend is fairly clear, especially with the rise of digital design, communication and factory automation technologies.[18]

Figure 2 summarizes some of the key points of this section's discussion by comparing the modular production network form to the other organizational forms that have been put forward in the literature on industry organization. The key organizational innovation embodied by the modular production network is that it divorces the size of the firm developing new products from manufacturing scale economies. In the Marshallian form and both the unitary and multidivisional forms of the vertically integrated modern corporation, manufacturing scale economies are closely associated with firm size. In the modular network form, industry structure is vertically disintegrated as in the Marshallian form, but process commodification and scale and scope economies are achieved by specialization on a base process that cuts across product categories. In the modular network, base processes enable horizontal integration (along with attendant scale economies) to be built-up while overall industry structure remains vertically disintegrated. While some brand-name firms retain

[18]Langlois and Robertson (1995: 69) make a similar argument: 'When markets offer a high level of capabilities relevant to an entrepreneurial opportunity, and especially when that opportunity permits innovation to proceed in autonomous rather than systemic fashion, the result mat be economic growth within a vertically and horizontally specialized structure.'

	Marshallian Form	Unitary (U) Form	Multidivisional (M) Form	Modular Network Form
Size of innovating firm	small	medium to large	large to very large	small, large, and very large
Geographic scope of operations	small (clustered in discete industrial districts)	small (single location)	large (multiple locations)	small or large (outsourcing linkages can span industrial dictricts)
Manufacturing scale economies	small	medium to large	large	large
Number of products	few	few or many	many	many
Number of processes	few	few or many	many	few
Organizational form	vertically and horizontally dis-integrated	vertically integrated	vertically and horizontally integrated	vertically dis-integrated and horizontally integrated
Internal functions	design, mfg., **or** sales (firms can change roles)	design, mfg., **and** sales	design, mfg., **and** sales **x** no. of divisions	design **and** sales, **or** mfg. (firms do not change roles)

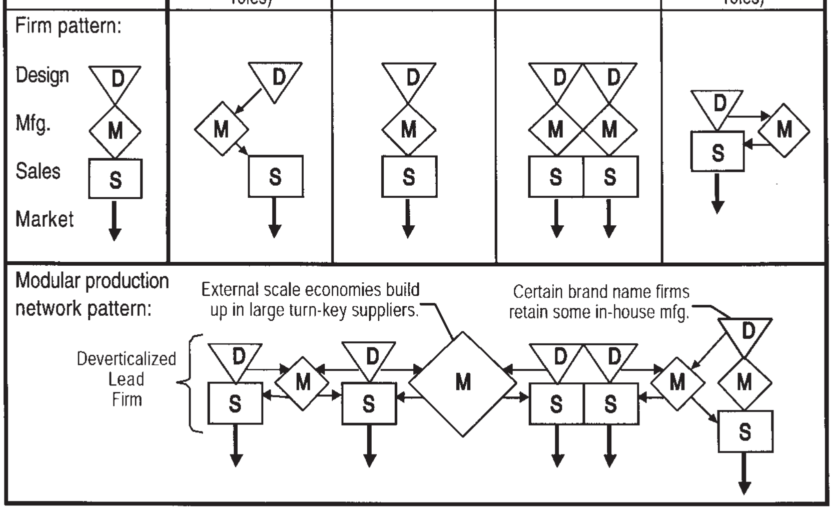

Figure 2 The modular network form compared to other organizational forms.

internal manufacturing capacity for specific reasons, such as fear of intellectual property loss, tight integration between process and product innovation, retention of process expertise to qualify outsourcing partners, etc., the emergence of large, globally operating contract manufacturers facilitates the build-up of external economies of scale and scope.

It is hoped that the discussion here can begin to open up the debate on what drives transitions as profound as the shift from the vertically integrated modern corporation to the modular production network. It will become clear in the following section that a discussion and analysis of new 'network' forms of industrial organization is well underway. It would be unfortunate, however, if the forces that have led to the perceived organizational shift fail to become part of the debate. The broad intellectual project should be to join the two eras with a dynamic theory of industrial organization (see Fine, 1998, for an useful step in this direction). The question may or may not be as simple as one of, as Ronald Coase put it, at age 89, 'whether the costs of transacting decreases as fast as the costs of organizing' (Coase, 2000).

4. Building a new paradigm for industrial organization: production network models

As the competitive crisis of the Anglo-American modern corporation intensified during the 1980s, its image as the pinnacle of capitalist development became tarnished. Perhaps the modern corporation had grown too large, too sluggish and too inwardly focused to respond adequately to the 'new competition' (Best, 1990; Schoenberger, 1997). Scholars interested in industry organization, theories of the firm and economic development began to look for a new, more adaptive model. Alternatives have been provided from a wide range of disciplines, including law, sociology, geography, political science, management and economics. Because of the diversity of interests and methodologies within these disciplines, the literature on production networks tends to be eclectic and additive. Some of this literature has used the transaction cost framework to argue that network forms are a middle ground between the Marshallian firm and the modern corporation.[19] Others reject the efficiency assumptions of neoclassical economics to argue that markets are embedded in social life, and are therefore not strictly governed by the logic of efficiency. The strongest thread that can be discerned in this work is its focus on the ongoing tolerance of *thick linkages* in inter-firm relationships. The new production network models come in various forms, some geographically and culturally specific, such as the Japanese, Italian and German models, and some conceptual, such as abstract models of network organization, agglomeration economies and industrial districts. This section contrasts these models with the findings from the empirical case of contract manufacturing in the US-led electronics industry in an effort to add a distinctive production network model to those already in place.

4.1 Network theories of the firm

Network theorists (e.g. Powell, 1990) do not argue, as I have in the previous section, that

[19]Using the transaction cost formula to derive 'intermediate' organizational forms we should expect intermediate levels of transaction frequency, uncertainty, and asset specificity. While Williamson is on record as arguing that firms would tend to get larger over time (Williamson, 1981; Williamson and Ouchi, 1981) his later work (1985) deals with the fact that intermediate forms of industry organization do exist. On the subject of distribution pattern, he remains neutral.

network forms of organization can function without the build-up of specific assets. Instead, they argue there are mitigating factors, such as trust and social norms, that allow external economies to persist in the face of asset specificity. Asset specificity need not lead to vertical integration over time and therefore to the ever-increasing size and scope of firms because trust, reputation and mutual dependence dampen opportunistic behavior.

Granovetter (1985) has enjoined Williamson at the most basic level, drawing 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. 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, Williamson's driving force for the accretion of production functions within the 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 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 offered by Williamson.[20]

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

[20]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.

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 generated in the first place is simply 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). 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 (1986) 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, 1986).[21] 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).

While I do not disagree with this argument, mine is different. Trust, reputation and long-term relationships are not the only way to buoy external economies. As industries grow, open and *de facto* standards tend to emerge, codification increases and the capabilities of the supply-base deepens. These characteristics of industrial development make it is possible for assets to become *less* specific over time, allowing outsourcing relationships to be maintained without an intensely relational or hierarchical character, as long as the firms providing the industry with external capacity maintain a merchant character through volume spreading.

4.2 Nationally specific models of industrial organization

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. I divide these networks into two broad categories, *captive production networks* (e.g. Japan and Korea) and *relational production network* (e.g. Italy, Germany and those of 'overseas

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

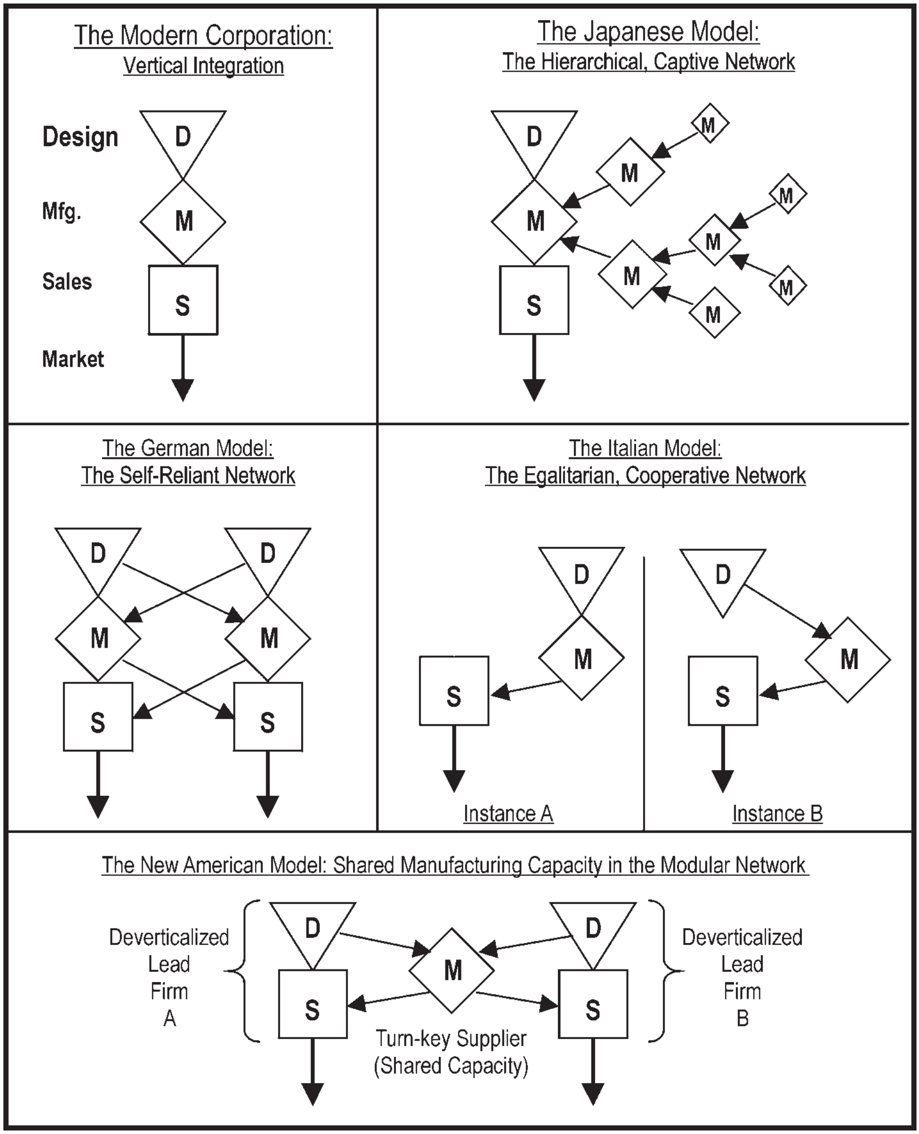

Figure 3 Country-specific production network models: where the modular production network model fits.

Chinese' in East Asia). The basic organizational characteristics of the various models are well known; I have summarized them conceptually in Figure 3.

I describe the production networks led by Japanese firms as *hierarchical, captive networks* because they rely on 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, created by steady technological upgrading in the supply base and close coordination of 'just-in-time' deliveries, and flexibility in the face of market volatility, created 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).

Relational 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, relational production networks tend to be embedded 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.

Geographers (e.g. Scott 1988a,b, 1999; Storper and Walker, 1989) have noted 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 (Katzenstein, 1989; Sabel, 1989; Herrigel, 1993); clusters of apparel assembly subcontractors and home-workers clustered around the fashion design centers of New York, Los Angeles and Paris (Sassen, 1987, 1988; Bonacich *et al.*, 1994; Gereffi, 1994; Taplin, 1994, 1996); the family-based business networks of overseas Chinese in East Asia (Borrus, 1995, 2000; Ravenhill, 2000); and even Silicon Valley (Saxenian, 1991, 1992, 1994; Luthje, 1997) are examples of places where robust relational production networks operate. Here, I will briefly outline the characteristics of the most emblematic of relational production networks, those from Germany and Italy.

In Germany networks of small and medium-sized firms interact through dense contracting relationships while jealously guarding their *self-reliant* stance in the marketplace by retaining a strong end-product focus. Generally speaking, most small and medium-sized German firms (known as the *Mittlestand*) are willing to provide design, production or marketing services to other firms that need it if they have excess capacity, but few choose to forego developing and selling end-products and make design or production services their sole business, although there are some signs that such a *full service konzept* is becoming more popular (*Markt & Technik*, 1993). This end-product focus has led even small German firms to remain remarkably vertically integrated, as depicted in Figure 3. In the German model vertical integration inhibits productive capacity from pooling in large merchant suppliers, and as a result large external economies of scale fail to develop.

Figure 3 identifies the Italian model as an *egalitarian, cooperative network* because of the close association that is required to maintain a very elaborate social division of labor. The firms in the network are functionally specialized, and change partners within the network easily. Like the modular production network model, flexible production equipment facilitates organizational flexibility and allows a wide variety of products to be produced for a variety of customers (Piore and Sabel, 1984), and allows productive capacity to be easily redeployed if market share changes hands (Brusco, 1982). But unlike the modular network, the Italian model stresses long-term, trust-based relationships based on social and spatial propinquity that make the external boundary of the network impermeable to economic actors from the outside. Organizational flexibility is high and there are barriers to entry for actors within the industrial district, but because the relationships within it are idiosyncratic, external scale economies fail to build up and the district fails to develop as a node on a global-scale production network.

Walter Powell (1990) has offered a schematic comparison of the Marshallian firm, which he labeled as 'market', the modern corporation, which he labels as 'hierarchy', and the relational network, which he labels as 'network'. In Table 3, I present an elaborated version of this schematic, relabeling Powell's 'network' organizational form as 'relational network' and adding my own category of 'modular network' as a way to build a new network model in contrast to the relational model put forward by most network theorists. Instead of 'thickly relational' interactions between firms, as in the relational network, turn-key contracting allows for looser, 'thinly relational' interactions because the supplier specifies its own processes, purchases its own inputs and retains an autonomous financial stance *vis-à-vis* its customers.

In the modular network, supplier firms take a 'full service' stance toward their customers, providing turn-key services that require very 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

Table 3 Stylized comparison of organizational forms: where the modular network fits

	Organizational forms			
Key features	Market	Hierarchy	*Relational* network	*Modular network*
Normative basis	contract-property rights	employment relationship	complementary strengths	*contracting–complementary strengths*
Means of communication	prices	routines	relational	*'thinly relational' prices, codified transactions*
Volume of information and goods flowing across linkage	*low*	*NA*	*high*	*medium*
Degree of interdependence in market	*low*	*NA*	*high*	*medium to low*
Methods of conflict resolution	haggling—resort to courts for enforcement	administrative fiat-supervision	norms of reciprocity—reputational concerns	*competitive switching, multiple partners*
Degree of flexibility	high	low	medium	*high*
Degree of adaptability within system	*high*	*low*	*high*	*high*
Degree of adaptability of overall system architecture	*high*	*low*	*low*	*high*
Amount of commitment among the parties	low	medium to high	medium to high	*medium to low*
Tone or climate	precision and/or suspicion	formal, bureaucratic	open-ended, mutual benefits	*precision, competitive, pragmatic*
Actor preferences or choices	independent	dependent	interdependent	*limited dependency*
Mixing of forms	repeat transactions contracts as hierarchical documents	informal organization market-like features: profit centers, transfer pricing	status hierarchies multiple partners formal rules	*tight linkages and long term relationships contractors as buffer capacity*
Spatial aspect	*clustered or dispersed*	*dispersed*	*clustered*	*clustered and dispersed, linked nodes*

Source: adapted from Powell (1990: 300). Italic entries added to original.

enabled by the use of highly formalized inter-firm linkages, such as the transfer of digital design files from customer to contractor. However, transactions may be very frequent and important to both parties in the modular network, with a great deal of value and codified information flowing across the inter-firm link. This feature points to 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 arm's 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.

5. Production networks and economic performance

Harrison (1994) has argued that the competitiveness of US industry has been weakened by the failure to adopt a 'network' model of production organization. US 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. US 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, US 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 US workers and a worsening competitive crisis for US industry.

That business practices such as downsizing, wage suppression and the hiring of contingent workers have had negative impacts on many US 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, is completely unconvincing.[22] Even in situations where predatory supplier–relations are still in force, such as they are between the largest US automakers and their suppliers (Helper, 1991), US firms have improved product quality, lowered costs, reduced cycle times and improved their standing on world markets.

Increased market volatility, in particular, has accelerated the deverticalization of firm structure and led to the growth of various network forms of production organization. Shortening lifecycles and increasing product complexity place severe pressure on the capacity of the firm in all areas, from R&D to manufacturing to marketing and sales. In response to this pressure, firms in a wide range of sectors and from a wide variety of places have sought to outsource an increasing number of 'non-core' functions to spread the risk of market volatility among a larger number of network players. By tapping production networks, lead firms are finding new ways to exert substantial market power without the fixed costs and risk of building and supporting a gigantic corporate organization. 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

[22]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.

markets (Powell, 1990; Cooke and Morgan, 1993).[23] There are, however, aspects of both relational and captive 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 captive production networks leads to disadvantages because mutual dependence makes it more difficult, costly and time consuming to begin and end supplier relationships. 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, excessive accumulations of debt to keep the system running during extended economic downturns, and limitations in the scale and scope of external economies. Relational networks are also flexibly rigid in that the trust required to enter the system takes a long time to build up.

While I concur that the internal structure of captive and relational production networks—both based on long-term relationships—may well be more adaptable than the governance structures of integrated firms, substantial rigidities may exist if the overall architecture of the network is itself resistant to change. In contrast to the captive and relational network offered by much of the network literature, I offer a different network model, the modular network. Figure 4 depicts the characteristics of modular production networks that lead to superior economic performance. The most important difference between modular networks, which are rooted in the US institutional context, and the other nationally specific network models that appear in the literature (Japan, European and overseas Chinese), is their relatively open character. 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 widely accepted standards that enable the codifiable transfer of specification across the inter-firm link. These preconditions lead to generic (not product-specific) capacity at suppliers that has the potential to be shared by the industry as a whole and highly codified links between lead firms and suppliers that allows the system to attenuate the build-up of thick tacit

[23]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 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).

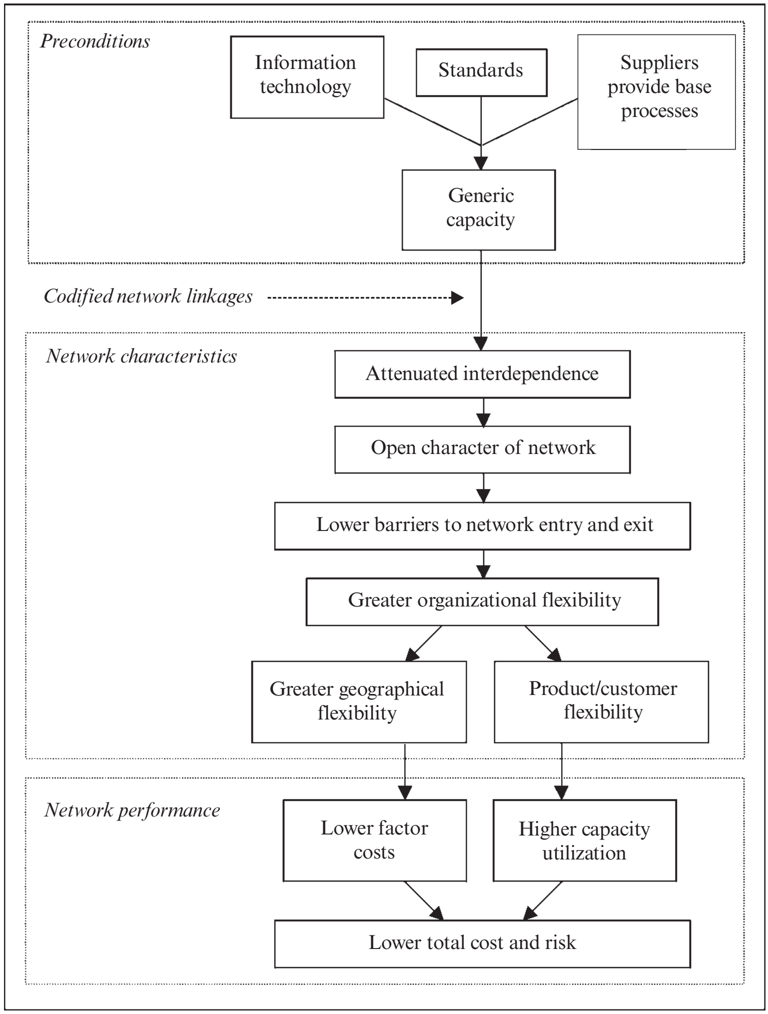

Figure 4 Performance benefits of modular production networks

linkages between stages in the value chain. Codified linkages allow the system to operate without excessive build-up of asset specificity and mutual dependence.[24]

The performance advantages that flow from the openness of modular networks stem

[24]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.

from the agility (flexibility) of the system along two fronts: geographic and product/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, (i) the network can more easily be extend and withdrawn from specific locations (what I am calling geographic flexibility), and (ii) the suppliers can be more easily shared by a variety of lead firms and/or products. 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 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.

In an economy increasingly integrated on a global scale, captive networks and 'stand-alone' relational 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 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, particularly in established centers of the electronics industry such as Silicon Valley, Scotland and Singapore. 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.

Of course, modular networks are not a panacea. As suppliers gain in financial strength, technical and operational competence, and geographic reach—and as brand-name firms become extremely reliant on them—the possibility arises for suppliers to take the further step of developing their own end-products in competition with their customers (Teece, 1996; Fine, 1998). This is not an idle concern. In the 1970s and 1980s, US consumer electronics firms began to use Japanese firms to manufacture their products. Eventually, US firms lost control of product definition and were reduced to affixing their brand names to products designed and manufactured by the Japanese. These same Japanese firms now dominate most consumer electronics markets and US consumer electronics firms have all but disappeared. Another concern stems from the merchant character of modular networks. If suppliers work for brand-name firms that are in direct competition with one another, the specter of technological leakage to

Table 4 The determinants of external scale economies

External scale economies build-up when:	External scale economies do not build-up when:
Suppliers have a wide range of customers	Suppliers have a narrow range of customers
Suppliers use generic process technology	Suppliers use proprietary process technology
Suppliers focus on a functional specialty	Suppliers make products of their own
Suppliers take a full-service approach to their specialty	Suppliers are dependent on customers for parts, equipment, complementary processes, and technical help

competitors and loss of intellectual property arises. The experience of outsourcing a product's manufacturing only to find a counterfeit version appearing on the market months later is not unknown. Finally, the outsourcing of broad swaths of activities formerly performed in-house raises the possibility that brand-name firms will lose process expertise that makes them more astute buyers of external services and, more importantly, may turn out to be critical to ongoing success in product development.

The key competitive advantage of modular production networks is the build-up of external economies of scale. Table 4 summarizes the factors that determine the formation of external economies. External economies build up when suppliers have a wide range of customers, use generic process technology, focus on their functional specialty, and take a turn-key approach to providing a full range of services related to that specialty. Vertical integration, relational production networks and captive production networks all place grater limits on the build-up of external scale economies.

6. Concluding remarks: a world convergence of organizational paradigms?

What does the rise of modular production networks tell us about the evolution of late capitalism? Firms and industrial systems that have historically been rooted in their respective national economies have become increasingly interlinked as global-scale production networks have emerged. As competition between nationally based production systems has become more pronounced, so too has the rate of organizational change as firms from one nationally based system adapt to new competitive pressure from another by adopting, however imperfectly, the organizational characteristics that are perceived as providing competitive advantages for their rivals. Since nationally rooted organizational characteristics cannot be imitated without being altered to fit their new context, powerful forces of innovation have been unleashed as attempts at imitation have been combined with home-grown institutions to create new, more powerful approaches to organizing production.

If we posit that such adaptation cycles are becoming shorter over time, and that globalization means that there are fewer ‘isolates’ in the world economic system, it follows that that the changes we are seeing today might culminate with global industrial structure converging around a common organizational model. The process of convergence, if indeed it is occurring, may not be linear or unidirectional, but characterized by accelerating rounds of competition, adaptation and transformation. National differences will persist to be sure, but over time, national production systems could well co-evolve to become more compatible and interlinked with one another, further increasing global economic integration as global-scale production systems overlap and thicken in a self-reinforcing dynamic.

By thinking in terms of such broad historic sweeps, we may be able to locate the modern corporation as a peculiarly American organizational innovation that spread more or less intact to Europe (Franko, 1976) but triggered organizational transformation in Japan, where the tenets of mass production were adapted to smaller markets (Sayer, 1986). The result was ‘lean production’, a system so productive that, in many important manufacturing industries, such as steel, autos and electronics, it triggered a competitive crisis among the leading industrial firms in the United States and Europe (Womack *et al.*, 1990). Similarly, US electronics firms have now grafted some of the elements of lean production—namely a highly deverticalized industry structure—on to their own production system, creating a new, highly adaptive system that spreads risk, lowers factor costs, conserves fixed and human capital, and builds up large external economies of scale. In the electronics industry, at least, it is clear that the modular production network model has put a great deal of pressure on competing networks emanating from Europe and Japan. Recent interviews conducted with senior managers at several of the largest electronic systems firms in Japan revealed a great deal of concern about ‘the American model’, and it appears that a period of questioning and experimentation is well underway there. While it is impossible to imagine that the Japanese electronics industry will refashion itself in the exact image of the US electronics industry, it is clear that the process of organizational innovation is in full swing. We should not be surprised if a highly competitive hybrid, ‘post-modular’ organizational form emerges in Japan or elsewhere to help drive the process of industrial transformation in the world economy forward.

Acknowledgements

A preliminary version of this paper appeared as Berkeley Roundtable on the International Economy Working Paper 92A, 1997.

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References

Abernathy, F., J. Dunlop, J. Hammond and D. Weil (1999), *A Stitch in Time: Lean Retailing and the Transformation of Manufacturing, Lessons from the Apparel and Textile Industries.* Oxford University Press: New York.

Alchian, A. and H. Demsetz (1972), 'Production, information costs, and economic organization,' *American Economic Review*, **62**, 777–795.

Aoki, M. (1987), 'The Japanese firm in transition,' in K. Yamamura and Y. Yasuba (eds), *The Political Economy of Japan.* Stanford University Press: Stanford, CA.

Appelbaum, E. and R. Batt. (1994), *The New American Workplace: Transforming Work Systems in the United States.* ILR Press: New York.

Apple Computer (1996), 'Apple enters into agreement to sell Fountain manufacturing facility to SCI Systems,' press release, 4 April.

Arrow, K. (1964), 'Control in large organizations,' *Management Science*, **10**, 397–408.

Baldwin, C. and K. Clark (1997), 'Managing in the age of modularity,' *Harvard Business Review*, September–October, 84–93.

Baran, P. and P. Sweezy (1966), *Monopoly Capital.* Monthly Review Press: New York.

Berle, A. A. and G. C. Means (1934), *The Modern Corporation and Private Property.* Macmillan: New York.

Best, M. (1990), *The New Competition : Institutions of Industrial Restructuring.* Harvard University Press: Cambridge, MA.

Best, M. (2001), *The New Competitive Advantage: The Renewal of American Industry*. Oxford University Press: Oxford.

Biewener, J. (1997), 'Downsizing and the new American workplace: rethinking the high-performance paradigm,' *Review of Radical Political Economics*, **29**, 1–22.

Bloomberg News (2000), 'NEC to sell cell phone plants in Mexico, Britain,' December 12.

Bonancich, E., L. Cheng, N. Chinchilla, N. Hamilton and P. Ong (eds) (1994), *Global Production: The Apparel Industry in the Pacific Rim.* Temple University Press: Philadelphia, PA.

Borrus, M. (1995), 'Left for dead: Asian production networks and the revival of US electronics,' University of California at Berkeley, Berkeley Roundtable on the International Economy Working Paper no. 100.

Borrus, M. (2000), 'Exploiting Asia to beat Japan: production networks and the comeback of US electronics,' in D. Encarnation (ed.), *Japanese Multi-Nationals in Asia: Regional Operations in Comparative Perspective.* Oxford University Press: Oxford.

Borrus, M., D. Ernst and S. Haggard (eds) (2000), *International Production Networks in Asia; Rivalry or Riches?* Routledge: London and New York.

Bradach, J. and R. Eccles (1989), 'Price, authority, and trust: from ideal types to plural forms,' *Annual Review of Sociology*, **15**, 97–118.

Brusco, S. (1982), 'The Emilian model: productive decentralization and social integration,' *Cambridge Journal of Economics*, **6**, 167–184.

Brusco, S. and C. Sabel (1983), 'Artisanal production and economic growth,' in F. Wilkinson (ed.), *The Dynamics of Labor Market Segmentation.* Academic Press: London, pp. 99–113.

Brusco, S. and E. Righi (1989), 'Local government, industrial policy and social consensus: the case of Modena (Italy),' *Economy and Society*, **18**, 405–424.

Chamberlin, E. (1933), *The Theory of Monopolistic Competition.* Harvard University Press: Cambridge, MA.

Chandler, A. (1977), *The Visible Hand: the Managerial Revolution in American Business.* Belknap/Harvard University Press: Cambridge, MA.

Chandler, A. (1980), 'The growth of the transnational industrial firm in the United States and the United Kingdom: a comparative analysis,' *Economic History Review*, **33** (2nd series), 396–410.

Coase, R. (1937), 'The nature of the firm,' *Economica*, **4**, 386–405.

Coase, R. (2000), 'Talking about tomorrow: Ronald Coase,' *Wall Street Journal Interactive*, Millennium Edition: Industry and Economics, 1 January.

Cooke, P. and K. Morgan (1993), 'The Network Paradigm: New Departures in Corporate and Regional Development,' *Environment and Planning D: Society and Space*, **11**, 543–564.

Davidow, W. (1992), *The Virtual Corporation: Structuring and Revitalizing the Corporation for the 21st Century*. HarperCollins: New York.

Dedrick, J. and K. Kraemer (1998), *Asia's Computer Challenge: Threat or Opportunity for the United States and the World.* Oxford University Press: Oxford.

Dertouzos, M., R. Lester and R. Solow (1988), *Made in America: Regaining the Competitive Edge.* MIT Press: Cambridge, MA.

Donaghu, M. and R. Bariff (1991), 'Nike just did it: international subcontracting and flexibility in athletic footwear production,' *Regional Studies*, **24**, 537–552.

Dore, R. (1986), *Flexible Rigidities: Industrial Policy and Structural Adjustment in the Japanese Economy 1970–1980.* Stanford University Press: Palo Alto, CA.

Dunn, D. (1997), 'Ericsson Telecom signs agreement with Solectron,' *Electronic Business News*, 31March, issue 1051, Section: Service & Support.

Electronic Buyers News (1996), 'Apple sells mfg. plant,' 6April, no. 1001, p. 8.

Electronic Trend Publications (2000), *The Worldwide Contract Electronics Manufacturing Services Market: A Comprehensive Study on the Trends, Issues, and Leading Companies in the Worldwide Market for Contract Electronics Manufacturing Services*, 8th edn. Electronic Trend Publications: San Jose, CA.

Electronics Weekly (2000), 'Ericsson shifts phone production to contractors,' 20 October.

Fine, C. (1998), *Clockspeed—Winning Industry Control in the Age of Temporary Advantage.* Perseus Books: New York.

Florida, R. and M. Kenney (1991), *The Breakthrough Illusion.* Basic Books: New York.

Florida, R. and M. Kenney (1993), *Beyond Mass Production: The Japanese System and its Transfer to the US*. Oxford University Press: New York.

Franko, L. (1976), *European Multinationals.* HarperCollins: New York.

Gereffi, G. (1994), 'The organization of buyer-driven global commodity chains: how US retailers shape overseas production networks,' in G. Gereffi and M. Korzeniewicz (eds), *Commodity Chains and Global Capitalism.* Praeger: Westport, CT, pp. 95–122.

Granovetter, M. (1985), 'Economic action and social structure: the problem of embeddedness,' *American Journal of Sociology*, **91**, 481–510.

Green, F. and B. Sutcliffe (1987), *The Profit System*. Penguin: Harmondsworth.

Harrison, B. (1994), *Lean and Mean: The Changing Landscape of Corporate Power in the Age of Flexibility*. Harvard University Press: Cambridge, MA.

Hart, J. and M. Borrus (1992), 'Display's the thing,' Working paper 52, University of California at Berkeley. Berkeley Roundtable on the International Economy.

Helper, S. (1991), 'How much has changed between US automakers and their suppliers?,' *Sloan Management Review*, **32**, 15–28.

Herrigel, G. B. (1993), 'Power and the redefinition of industrial districts: the case of Baden-Wurttemberg,' in G. Grabher (ed.), *The Embedded Firm: On the Socioeconomics of Industrial Networks*. Routledge: London, pp. 227–251.

Hitt, M., B. Keats and S. DeMarie (1999), 'Navigating in the new competitive landscape: building strategic flexibility and competitive advantages in the 21st century,' *Academy of Management Executive*, **12**, 22–42.

Hymer, S. (1976), *The International Operations of National Firms: A Study of Direct Foreign Investment*. MIT Press: Cambridge, MA.

Jarillo, J. (1988), 'On strategic networks,' *Strategic Management Journal*, **9**, 31–41.

Jensen, M. and W. Meckling (1976), 'Theory of the firm: managerial behavior, agency costs and ownership structure,' *Journal of Financial Economics*, **3**, 305–360.

Johanson, J. and L. Matsson (1987), 'Interorganizational relations in industrial systems: a network approach compared with the transaction-cost approach,' *International Studies of Management and Organization*, **27**, 34–48.

Jonas, G. (1997), 'Ericsson, CEMs sign deals,' *Electronic Business News*, 14 July, issue 1066, Section: News.

Jürgens, U. (ed.) (2000), *New Product Development and Production Networks, Global Industrial Experience*. Springer Verlag: Berlin and New York.

Katzenstein, P. (ed.) (1989), *Industry and Politics in West Germany*. Cornell University Press: Ithaca, NY.

Kochan, T. and P. Osterman (1994), *The Mutual Gains Enterprise: Forging a Winning Partnership among Labor, Management, and Government*. Harvard Business School Press: Boston, MA.

Kuhn, T. (1970), *The Structure of Scientific Revolutions*. University of Chicago Press: Chicago, IL.

Langlois, R. and P. Robertson (1995), *Firms, Markets and Economic Change*. Routledge: London and New York.

Lazonick, W. (1991), *Business Organization and the Myth of the Market Economy*. Cambridge University Press: Cambridge and New York.

Levy, F., L. Mishel and J. Bernstein (1996), *Running in Place: Recent Trends in US Living Standards*. Competitiveness Policy Council. Government Printing Office: Washington, DC.

Lorenz, E. (1988), 'Neither friends nor strangers: informal networks of subcontracting in French industry,' in D. Gambetta (ed.), *Trust: Making and Breaking Cooperative Relations*. Basil Blackwell: Oxford and New York.

Lorenz, E. (1992), 'The search for flexibility: subcontracting networks in British and French engineering,' in M. Storper and A. Scott (eds), *Pathways to Industrialization and Regional Development*. Routledge: London and New York, pp. 122–132.

Luthje, B. (1997), 'Industrial restructuring, production networks, and labor relations in the Silicon Valley electronics industry,' unpublished manuscript, Department of Social Sciences, University of Frankfurt.

MacNeil, I. (1978), 'Contracts: adjustments of long-term economic relations under classical, neoclassical, and relational contract law,' *Northwestern University Law Review*, **72**, 854–906.

Malerba, F. and L. Orsenigo (1995), 'Schumpeterian patterns of innovation,' *Cambridge Journal of Economics*, **19**, 47–65.

Markt & Technik (1993), 'Der Vollservice gewinnt an Bedeutung,' *Markt & Technik; Wochenzeitung für Electronik*, 19 February, p. 18.

Meyer, M. and A. Lehnerd (1997), *The Power of Product Platforms*. Free Press: New York.

Miles, R., C. Snow, J. Mathews, G. Miles and H. Coleman (1997), 'Organizing in the knowledge age: anticipating the cellular form,' *Acadamy of Management Executive*, **11**, 7–24.

Mishel, L. and J. Bernstein (1996), 'Trouble in paradise: eroding wages and growing income inequality,' in *Running in Place: Recent Trends in US Living Standards*. Competitiveness Policy Council. Government Printing Office: Washington, DC.

Nelson, R. and S. Winter (1982), *An Evolutionary Theory of Economic Change*. Harvard University Press: Cambridge, MA.

Piore, M. and C. Sabel (1984), *The Second Industrial Divide*. Basic Books: New York.

Powell, W. (1987), 'Hybrid organizational arrangements: new form or transitional development?,' *California Management Review*, Fall, 67–87.

Powell, W. (1990), 'Neither market nor hierarchy: network forms of organization,' *Research in Organizational Behavior*, **12**, 295–336.

Prahalad, C. and G. Hamel (1990), 'The core competence of the corporation,' *Harvard Business Review*, May–June, 79–91.

Quinn, J. and F. Hilmer (1994), 'Strategic outsourcing,' *Sloan Management Review*, **35**(4).

Ravenhill, J. (2000), 'Japanese and US subsidiaries in East Asia,' in D. Encarnation (ed.), *Japanese Multi-nationals in Asia: Regional Operations in Comparative Perspective*. Oxford University Press: Oxford.

Richardson, G. (1972), 'The organization of industry,' *Economic Journal*, **84**, 883–896.

Sabel, C. (1989), 'Flexible specialisation and the reemergence of regional economies,' in P. Hirst and J. Zeitlin (eds), *Reversing Industrial Decline?* St Martin's Press: New York, pp. 17–70.

San Francisco Chronicle (1996), April 30 and August 14.

Sanchez, R. and J. Mahoney (1996), 'Modularity, flexibility, and knowledge management in product and organizational design,' *Strategic Management Journal*, **17**, 63–76.

Sassen, S. (1987), 'Growth and informalization at the core: a preliminary report on New York City,' in M. Smith and J. Feagin (eds), *The Capitalist City*. Basil Blackwell: Oxford, pp. 138–154.

Sassen, S. (1988), *The Mobility of Labor and Capital*. Cambridge University Press: New York.

Saxenian, A. (1991), 'The origins and dynamics of production networks in Silicon Valley,' *Research Policy*, **20**, 423–437.

Saxenian, A. (1992), 'Divergent patterns of business organization in Silicon Valley,' in M. Storper and A. Scott (eds), *Pathways to Industrialization and Regional Development*. Routledge: London and New York, pp. 316–397.

Saxenian, A. (1994), *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Harvard University Press: Cambridge, MA.

Sayer, A. (1986), 'New developments in manufacturing: the just-in-time system,' *Capital and Class*, **30**, 43–72.

Sayer A. and R. Walker (1993), *The New Social Economy: Reworking the Division of Labor*. Blackwell: Cambridge, MA and Oxford.

Schilling, M. (2000), 'Towards a general modular systems theory and its application to inter- firm product modularity,' *Academy of Management Review*, **25**, 312–334.

Schoenberger, E. (1997), *The Cultural Crisis of the Firm*. Blackwell: Cambridge, MA.

Schonberger, R. (1982), *Japanese Manufacturing Techniques*. Free Press: New York.

Schumpeter, J. (1934), *The Theory of Economic Development* [1911]. Harvard University Press: Cambridge, MA.

Schumpeter, J. (1942), *Capitalism, Socialism, and Democracy*. Harper & Row: New York.

Scott, A. J. (1988a), *Metropolis: From the Division of Labor to Urban Form*. University of California Press: Berkeley and Los Angeles.

Scott, A. J. (1988b), *New Industrial Spaces: Flexible Production Organization and Regional Development in North America and Western Europe*. Pion: London.

Scott, A. J. (1999), *Regions and the World Economy: The Coming Shape of Global Production, Competition, and Political Order*. Oxford University Press: London.

Storper, M. and S. Christopherson (1988), 'Flexible specialization and regional industrial agglomerations: the case of the US motion picture industry,' *Annals of the Association of American Geographers*, **77**, 104–117.

Storper, M. and A. Scott (1988), '*The geographical foundations and social regulation of flexible production complexes*,' in J. Wolch and M. Dear (eds), *The Power of Geography*. Allen & Unwin: Boston, MA, pp. 21–40.

Storper, M. and R. Walker (1989), *The Capitalist Imperative: Territory, Technology, and Industrial Growth*. Basil Blackwell: Oxford and Cambridge, MA.

Sturgeon, T. (1999), 'Turn-key production networks: industrial organization, economic development, and the globalization of the electronics manufacturing supply-base,' Ph.D. dissertation, Department of Geography, University of California at Berkeley.

Sturgeon, T. and R. Florida (1999), 'Globalization and jobs in the automotive industry,' final report to the Alfred P. Sloan Foundation, Center for Technology, Policy, and Industrial Development, Massachusetts Institute of Technology, Cambridge, MA.

Sturgeon, T. and J. Lee (2001), 'Industry co-evolution and the rise of a shared supply-base for electronics manufacturing,' Globalization Study working paper 01-002, Industrial Performance Center, Massachusetts Institute of Technology.

Sturgeon, T. and R. Lester (2002), 'Upgrading East Asian industries: new challenges for local suppliers,' paper prepared for the World Bank's Project on East Asia's Economic Future, Industrial Performance Center working paper 002-01.

Taplin, I. (1994), 'Strategic reorientations of US apparel firms,' in G. Gereffi and M. Korzieniewicz (eds), *Commodity Chains and Global Capitalism*. Greenwood Press: Westport, CT and London.

Taplin, I. (1996), 'Rethinking flexibility—the case of the apparel industry,' *Review of Social Economy*, **LIV**, 191–220.

Technology Forecasters (1996), 'Contract manufacturing 1996; state-of-the-industry report,' multiclient market research report, Berkeley, CA.

Teece, D. (1996), 'Firm organization, industry structure, and technological innovation,' *Journal of Economic Behavior*, **31**, 193–224.

Thomas, R. (1994), *What Machines Can't Do: Politics and Technology in the Industrial Enterprise*. University of California Press: Berkeley.

Thomke, S. and D. Reinertsen (1998), 'Agile product development: managing development flexibility in uncertain environments,' *California Management Review*, **41**, 8–30.

Thorelli, H. (1986), 'Networks: between markets and hierarchies,' *Strategic Management Journal*, **7**, 37–51.

Ulrich, K. (1995), 'The role of product architecture in the manufacturing firm,' *Research Policy*, **24**, 419–440.

Venkatesan, R. (1992), 'Strategic sourcing: to make or not to make,' *Harvard Business Review*, **70**(6), 98–108.

Williamson, O. (1975), *Markets and Hierarchies*. Free Press: New York.

Williamson, O. (1981), 'The modern corporation: origins, evolution, attributes,' *Journal of Economic Literature*, **19**, 1537–1568.

Williamson, O. (1985), *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting*. Macmillan: London.

Williamson, O. and W. Ouchi (1981), 'The markets and hierarchies program of research: origins, implications, prospects,' in A. Van de Ven and W. Joyce (eds), *Perspectives on Organization Design and Behavior*. Wiley: New York.

Womack, J., D. Jones and D. Roos (1990), *The Machine that Changed the World*. Rawson Associates: New York.