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E-Business and the Semiconductor Industry Value Chain: Implications for Vertical Specialization and Integrated Semiconductor Manufacturers

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1. Introduction

During the past 30 years, the global semiconductor industry has experienced rapid rates of technological change, rising costs for production capacity and declining prices for final products. Not coincidentally, this period also has witnessed an increase in vertical specialization in semiconductor design and manufacturing, illustrated by the growth of "fabless" design and marketing firms and their manufacturing counterparts, "foundries," that contract for the production of new product designs. During the past five years, increased vertical specialization has also been associated with an expanded role for equipment suppliers in developing new manufacturing process "modules" that integrate and complement the semiconductor manufacturing tools that they produce. Vertical separation of design and production of semiconductor components also has led to further specialization among design firms that create, license and trade "design modules" for use in integrated circuits (Linden and Somaya 2001).[1] In this paper, we examine the influence of Internet-based eBusiness applications on these trends and consider their effects on global production networks in the semiconductor industry. Although these trends began long before the development of Internet-related "eBusiness" applications, the Internet appears to be accelerating vertical specialization and may provide a fresh impetus to "design module" trading among firms. At the same time, however, Internet applications should enable integrated semiconductor manufacturers to increase their competitiveness and efficiency, and we briefly consider the effects of the Internet on these firms as well.

Although the widespread adoption of eBusiness applications within the semiconductor industry is likely to accelerate the long-term trend of increased specialization throughout the industry value chain, the Internet appears to be a catalyst, rather than primary cause, for such structural change. Ultimately, new Internet applications are likely to reinforce many of the underlying trends that have shaped the evolution of the semiconductor industry for the past three decades. These trends will influence the location of employment, design and production, and

[1] Design firms are either the aforementioned "fabless" semiconductor firms or "chip-less" firms that do not sell any semiconductor products of their own, and instead rely on licensing revenue. Design modules represent a pre-designed function to be implemented in a semiconductor device. These functions include physical library functions, basic blocks and system-level macros. Design modules are also known in the industry as IP blocks, design cores and virtual components (Linden and Somaya 2001).

technology development in the semiconductor design, semiconductor manufacturing and equipment and materials industries.

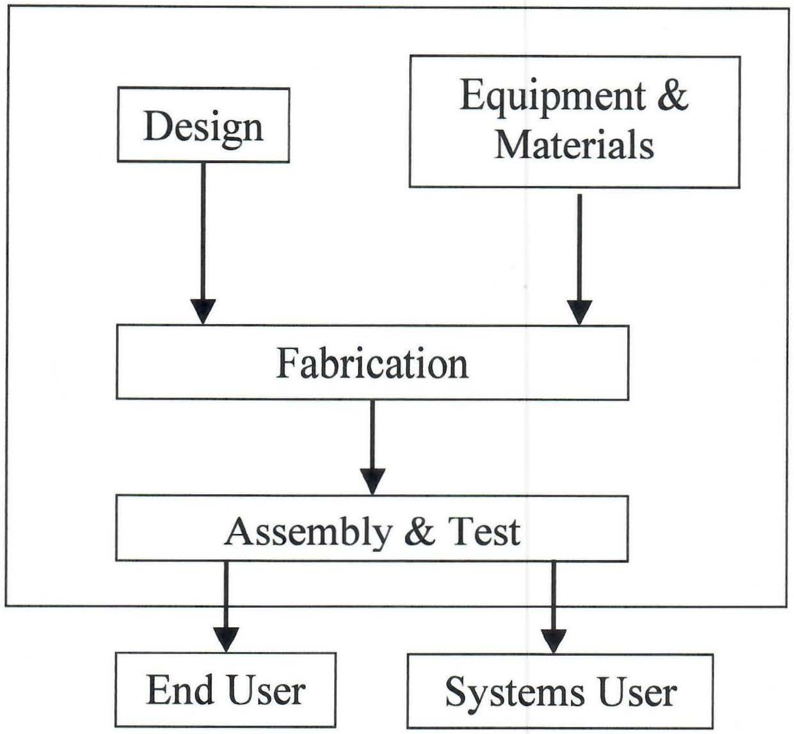
2. Organization Of The Global Semiconductor Industry

Semiconductors in 2000 were a $204 billion global industry (SIA 2001), organized into a number of different product and geographic segments. But the basic sequence of operations required to fabricate semiconductor components is very similar across virtually all of these product segments (Figure 1 provides a schematic depiction). Individual semiconductor "chips" are designed with the aid of advanced software and computer workstations. Chemicals, gases, and materials are combined in an intricate series of operations that utilize complex manufacturing equipment to produce "wafers" containing a large number of "die," each of which (assuming that it does not suffer from fatal defects) forms the basis for a semiconductor chip. Individual die are cut from fabricated wafers, tested for defects, and assembled into complex "packages" that combine wire contacts with insulating material to form the finished semiconductor component.

Although semiconductor design activities are concentrated in specific regions of the United States (including such areas as Silicon Valley, CA; Austin, Texas and northwest Oregon), as well as in Europe and Japan, semiconductor manufacturing is more widely dispersed. Semiconductor chips are sold directly to end-users (e.g. DRAMs or embedded systems), but are more often used as intermediate inputs in electronic systems. The industries that provide manufacturing inputs—with the possible exception of product designs—and purchase finished semiconductor products are dominated by large, multinational organizations. Semiconductors are usually classified by technological sophistication (i.e., leading edge, trailing edge, etc.) and by product type (i.e., memory, logic, discrete devices, etc.).[2]

[2] International SEMATECH' Global Economic Workshop classifies products into five specific groups: (1) Leading edge memory includes DRAMs; (2) Leading edge logic includes microprocessors and DSPs; (3) Other leading edge includes ASICs (PLDs and Standard cells), Flash memory, micro-peripherals and SRAMs. (4) Other ICs includes EPROMs, EEPROMs and other memory and gate arrays, standard logic and analog/linear circuits; and (5) Other semiconductor includes discrete circuits.

Figure 1: Semiconductor Industry Value Chain



2.1. The evolution of industry structure

Although a complete treatment of the history of structural change within the semiconductor industry is beyond the scope of this paper,[3] a selective discussion of the industry's evolution is useful for understanding the implications of eBusiness for structural change in semiconductor production. For the first two decades of the computer and semiconductor industries, large integrated producers, such as AT&T and IBM, designed their own solid-state components, manufactured the majority of the capital equipment used in the production process and utilized internally produced components in the manufacture of electronic computers and computer software that was leased or sold to their customers (Braun and MacDonald 1978). During the late 1950s, "merchant" semiconductor manufacturers entered the semiconductor industry in the United States and rapidly gained market share at the expense of the firms that produced both electronic systems and semiconductor components. Merchant producers remain more significant within the U.S. semiconductor industry than in those of either

[3] More complete treatments of the semiconductor industry's history can be found in Braun and MacDonald (1978), Tilton (1971), Langlois and Steinmueller (2000) and Macher, Mowery et. al (1998).

Europe or Japan. Specialized producers of semiconductor manufacturing equipment also began to appear in the early 1960s.

During the 1980s and 1990s, hundreds of "fabless" semiconductor firms that design and market semiconductor components, relying on contract manufacturers called "foundries" for the production of their designs (the fabless/foundry business model), entered the industry. Fabless semiconductor firms serve a variety of fast-growing industries, especially personal computers and communications, and seek to dominate their markets by offering more innovative designs and shorter delivery times than so-called merchant semiconductor firms. Foundries, in contrast, are firms specialized in semiconductor manufacturing, but may also represent the more traditional integrated device manufacturers (IDMs) with excess fab capacity.

A related structural change within the semiconductor industry has been the emergence of specialized design module providers,[4] Electronic Design Automation (EDA) suppliers[5] and systems houses that compete in the provision of intellectual property (IP) design blocks and systems-on-a-chip (SOC) technology (Linden and Somaya 2001). This networked business model of design and manufacture competes with large integrated firms who have maintained their design and manufacturing capabilities.

Along with increased vertical specialization, consolidation has occurred within the semiconductor and semiconductor materials and equipment industries. As product lifecycles continue to shrink, especially in the computer and communications markets, fabless firms and integrated device manufacturers understand that it is often more economical to acquire, rather than internally develop, new technologies.[6] Partnering with or acquiring design firms, or being acquired by an integrated device manufacturer (IDM) or other larger, fabless firm can help to facilitate product introductions or market entry.[7]

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4 These firms license out product designs known as "IP blocks," "design cores" or "virtual components," but do not market or sell any tangible products. Some of the more successful design module providers are Advanced Risc Machines (ARM), MIPS, and DSP group—all of which license microprocessor-based designs. These firms are successful because they have focused on design niches with multiple applications, developed "architectural" modules that are difficult to duplicate and are based on successive generations, and implemented effective strategies to protect the knowledge assets in place (Linden and Somaya 2001).

5 Besides offering design automation software, EDA firms offer "commodity DM warehouses," whereby a broad range of relatively low value design modules can be licensed. Synopsys and Mentor Graphics are examples.

6 For example, National Semiconductor's purchase of Cyrix helped facilitate the building blocks necessary for systems on a chip (SOC).

7 On the other hand, acquisitions and mergers also aid the acquiring firm by tapping into high growth product markets. The acquisitions by Intel of Level One Communications and Chips & Technologies allowed Intel to enter into the high growth communications market and gain additional silicon content around the CPU, respectively.

2.2. Forces Supporting Specialization

The growth in vertical specialization in semiconductors, particularly during the past 15 years, reflects the influence of market-related and technological factors. The expansion of markets for semiconductor devices means that vertically specialized semiconductor design or production firms can exploit economies of scale and specialization. These scale economies lower production costs, expanding the range of potential end-user applications for semiconductors and creating additional opportunities for entry by vertically specialized firms. The increasing capital requirements of semiconductor manufacturing provide another impetus to vertical specialization. Large fixed costs make it necessary to produce large volumes of a limited array of semiconductor components in order to achieve the economies of scale associated with high throughput. The design cycle for new semiconductor products also has become shorter and product lifecycles more uncertain, making it more difficult to determine whether demand from a single product will fully utilize a fabrication facility, and increasing the risks of investing in a new fabrication facility dedicated to a particular product. Foundries produce a wider product mix and therefore lower these financial risks for both foundry firms and customers who might otherwise have to invest in new capacity to manufacture the devices.

Another factor driving the emergence of specialized design and manufacturing markets are the "network effects" created by the semiconductor industry's standardization around a single production technology and the resulting improvements in complementary design software for the layout and simulation of new semiconductor devices. Manufacturing process technology for digital semiconductor devices is dominated by Complementary Metal Oxide Semiconductor (CMOS) processes, differentiated by feature size, level of interconnects and voltage levels. The emergence of this CMOS standard has facilitated the division of labor between product designers, who are able to operate within relatively stable design rules, and process engineers, who are able to incrementally improve new process technologies (Macher et al. 1998).

Finally, technological innovations have supported vertical disintegration. The "open-standards" architecture of personal computers, which have dominated growth in markets for semiconductor components since the 1980s, contributed to the development of standardized interfaces among components that in turn facilitated the specialized production of individual components, as well as vertical specialization in component designs and component manufacturing. More recently, the advent of partially programmable semiconductor devices has allowed semiconductor designers to incorporate increasing levels of functionality onto devices (system-on-a-chip technology) without sacrificing the applications flexibility required of a true "systems" product. Advances in computer-aided design (CAD) software and tools, as well as high-bandwidth digital communications networks, also have facilitated the exchange of huge amounts of standardized design data among design specialists and between fabless design firms and manufacturing foundries.

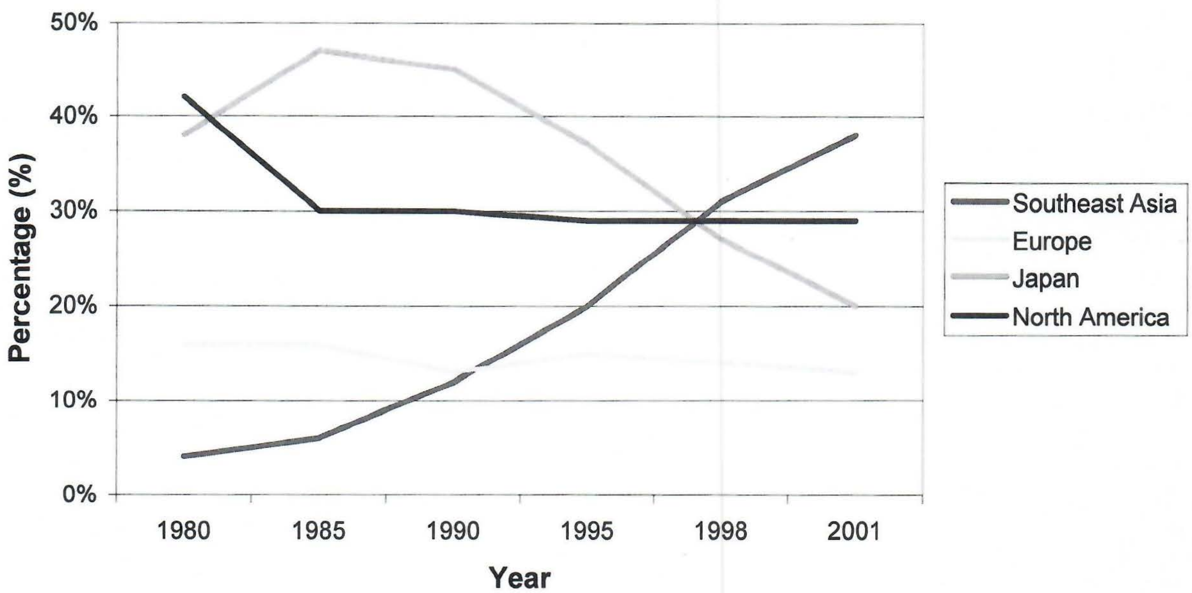
At the same time, however, a number of semiconductor manufacturing companies continue to integrate semiconductor device design and device manufacture. The advantages of such integrated management of design and manufacture appear to be greatest in semiconductor product lines at the leading edge of technology, especially in DRAMs (Macher 2001). In these areas, the demanding requirements for close coordination of design and process innovation mean that intrafirm management of these activities can yield advantages in flexibility, responsiveness, and the "debugging" of new manufacturing methods.

2.3. Implications for the Global Distribution of Semiconductor Design and Production

Regional specialization in different types of products and processes has characterized the semiconductor industry for most of its history. Since the early 1980s, roughly 85 per cent of packaging and testing capacity in the semiconductor industry has been concentrated in Southeast Asia (Leachman and Leachman 2001). The regional concentration of packaging and testing activities in Southeast Asia has been a source of significant volumes of international intra- and inter-company trade within the industry. Since the capital investment requirements for packaging and test activities are roughly one-tenth those of wafer fabrication, however, the networks developed around packaging and testing have involved much more modest flows of investment than has the more recent shift in the global distribution of fabrication capacity.

Wafer fabrication capacity grew at an average rate of 36 per cent per year during the 1980-2000 period (Leachman and Leachman 2001). This rapid growth in overall capacity was combined with the retirement of substantial amounts of "mature" capacity, reflecting the effects of rapid technological change. As a result, the regional distribution of semiconductor manufacturing capacity shifted significantly during these 20 years. Figure 2 depicts trends in the regional distribution of installed fabrication capacity, measured in terms of memory bits and logic gates,[8] from 1980 to 2001. The North American and Japanese shares of fabrication capacity fell significantly during the period, while the share attributable to "Asia/Pacific" (mainly Taiwan, South Korea, and Singapore) increased.[9]

Figure 2: Fabrication Capacity by Region of Location



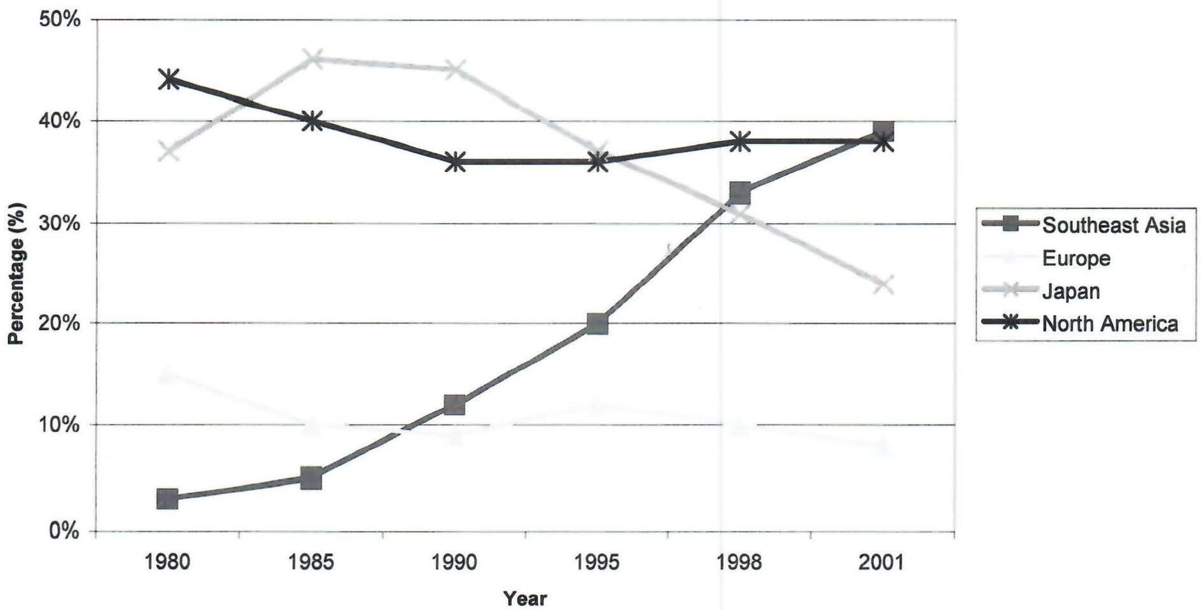
Source: Leachman and Leachman (2001); Henisz and Macher (2001)

Figure 3 presents similar data on manufacturing capacity that are classified by region of ownership, rather than by location. Southeast Asian firms account for the largest share of fabrication-capacity ownership but are followed closely by North American firms. Figures 2 and 3 indicate that North American, Japanese and European firms have expanded their capacity outside of their "home" regions since the mid-1990s, but Southeast Asian firms have tended to invest primarily within their home regions during the same period. The result has been a concentration of fabrication capacity ownership and location in the Southeast Asian region.

[8] There are many possible measures of fab capacity, including the number of wafers processed over a given time period, the total wafer surface area that can be processed, the amount of installed processing equipment, etc. Leachman and Leachman (2001) measure fabrication capacity as the estimated number of electrical functions that are produced by chip manufacturers, where a function is a memory bit or logic gate.

[9] Taiwan and South Korea account for more than 80 per cent of the capacity located in this region.

Figure 2.3: Fabrication Capacity by Region of Ownership



Source: Leachman and Leachman (2001); Henisz and Macher (2001)

The concentration of manufacturing capacity in Southeast Asia, particularly in Taiwan, is attributable in part to the development and success of the foundry business model. Pure play foundries supply roughly 75 per cent of the worldwide foundry market, with IDMs accounting for the remaining 25 per cent.[10] Foundry sales represent a growing portion of overall industry sales and approached $10 billion in 2000 (McClean 2001). Pure-play foundries' manufacturing capabilities still lag those of the most advanced integrated manufacturers in Korea, Japan and the United States, but this gap continues to narrow (Macher et al. 1998).

Although semiconductor manufacturing has become a global enterprise, semiconductor design activities remain heavily concentrated within the U.S. A number of factors help explain the continued U.S. dominance of semiconductor product design. Regional high-technology clusters in areas such as Silicon Valley, Boston's Route 128 and Austin, Texas attract large numbers of product designers and developers due to a density of jobs at established and developing design firms. These centers are often located near universities and other research

[10] IBM Microelectronics (U.S.), LG Semicon (Korea), Samsung (Korea) and Winbond (Taiwan) are notable examples of IDMs who offer contract foundry services.

centers that produce new design techniques as well as new engineering talent. Indeed, U.S. universities' role in the development of new design architectures and new design software for semiconductor components has long outstripped their role as a source of new manufacturing methods, because the cost of constantly re-equipping the necessary facilities exceeds the resources of most academic institutions.

Although its precise effects remain difficult to forecast, growth in vertically specialized fabless/foundry semiconductor production could have significant implications for the geographic location and mix of industry employment. Fabless design firms are likely to remain concentrated in North America, but the most advanced foundries are located primarily in the Southeast Asian countries of Singapore and Taiwan.[11] If Taiwan remains the leading site for pure-play foundries, continued expansion of the fabless/foundry model could result in the some migration of semiconductor manufacturing employment from the United States to Taiwan, even as U.S. design specialists remain fully employed. Nevertheless, a few Taiwanese firms have opened foundries in the United States, and Taiwan's dominant position in the foundry industry faces competition from lower-cost production sites in other areas of Southeast Asia and elsewhere. Indeed, Malaysia and the People's Republic of China are widely cited as important future sites for foundries.[12]

The long-term effects of expansion in the fabless/foundry model on the geographic location of manufacturing capacity and employment thus are uncertain, but on balance, growth in foundries is likely to result in the movement of more capacity and employment from the United States, Japan, and Europe to Taiwan, Singapore, and mainland China. Even more uncertain are the effects of shifts in the regional distribution of production activity on the global distribution of semiconductor design and technology development. At present, the strong agglomeration economies that have supported the regional concentration of these activities in a few areas

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[11] Major pure play foundries include TSMC and UMC (both Taiwan) and Chartered Semiconductor (Singapore). Other pure play foundries include Tower Semiconductor (Israel), Anam (Korea), and WSMC (Taiwan), which was recently bought by TSMC.

[12] 1st Silicon is a Malaysian pure-play foundry startup with a partnership in technology and wafer supply with SHARP Corporation of Japan. Silterra is also a Malaysian foundry startup with a similar technology partnership with LSI Logic. Both 1st Silicon and Silterra have received funding from the Malaysian government. Advanced Semiconductor Manufacturing Corporation (ASMC) is a Chinese foundry startup, and was previously Philips Semiconductor Corporation of Shanghai. It has long-term technology transfer agreements with Philips and Nortel. Central Semiconductor Manufacturing Corporation (CSMC) represents the first pure-play foundry in China and has a joint venture relationship with Huajing Electronics Group Corporation.

around the globe remain strong. But these agglomeration effects may weaken, as more and more semiconductor manufacturing activity is geographically distant.

3. eBusiness In Semiconductor Design And Production

One of the most important effects of the Internet on the global semiconductor industry has been indirect—the Internet has supported the growth of new product segments (e.g., digital signal processing chips, DSPs) that have accounted for a significantly increasing share of total industry output.[13] As the Internet matures, however, it will also affect the coordination and management of design and manufacturing processes. The impact of the Internet and eBusiness on the design and production of semiconductors and on the organization of these activities is the subject of this section. Since many firms are in the early stages of implementing and evaluating eBusiness applications, much of this discussion is necessarily speculative.

3.1. eBusiness and Semiconductor Manufacturing

Some applications of the Internet have already occurred in the fabless/foundry relationship, where fabless firms and foundries rely on Internet links to exchange information about the timing and content of product designs and the manufacturing process. Applications that link the Internet to more complex business processes have been slower to appear. Many companies are using the Internet to integrate sales information with the order tracking, inventory and production management systems utilized in the fab. Some semiconductor manufacturers are also evaluating the use of eBusiness applications for automated procurement, remote diagnostics, and equipment maintenance and repair.

One of the central challenges in managing the "arms-length" interface between a fabless design firm and foundry is coordinating the flow of knowledge to facilitate a smooth and efficient transfer of new designs into production. The transfer of complex design information into production typically relies on the design firm's adherence to the "design rules" laid out by the foundry. A foundry's "design rules" establish a set of parameters and constraints within which the design engineers and architects must work.[14] These rules are incorporated into the

13 DSPs are used in high growth communications markets such as wireless phones and computer networking gear, and are expected to grow from $6.1 billion in revenue in 2000 to $20 billion in 2005, an average annual growth rate of 27 per cent (ForwardConcepts 2001).

14 Design rules also place restrictions on the types of designs that will be manufactured in a foundry or on specific delivery schedules.

tools used by designers and have a significant impact on the final product configuration. It is critical that design firms have current, reliable and accurate information on the design rules that a foundry will support as they approach the completion of a design. In response to this requirement, leading foundries such as Taiwan Semiconductor Manufacturing Company (TSMC) and UMC Group have developed Internet-enabled software products that link designers with information on design rules and new process technologies in the foundry. TSMC has launched two such products. The first is a web-enabled viewer that allows real-time collaboration between geographically separated teams of design engineers and TSMC engineers to reduce the length of design layout reviews and improve design layout efficiency. The second application integrates software from two leading EDA vendors (Synopsis and Avanti) with TSMC's process technologies, providing up-to-date and TSMC-specific design library files and design flow information.[15]

The Internet and eBusiness promise to facilitate collaboration between fabless design firms and foundries by increasing the volume and speed of information transfer and by simplifying the tasks of knowledge management and exchange. Foundries collaborate with the vendors of software tools used by design engineers to embed their design rules into patches that designers can download in order to quickly update the rules that they are using. For example, Mentor Graphics' Calibre software is used to verify that a semiconductor design conforms to physical design and layout rules established by foundries. "Rule Files" for dozens of foundry-specific manufacturing processes at various partner firms including Chartered, IBM, TSMC and UMC can be downloaded through either Mentor Graphics' website or the websites of various foundries.[16] The Internet also aids foundries in the distribution of information about projected changes in design rules and manufacturing processes, making it easier for design firms to plan new designs and conform with future foundry requirements. Each of the major foundries' websites provides a technology "road map" that provides a detailed timeline for the introduction of introduction of new manufacturing processes in each of a variety of design classes such as

15 UMC offers a remote layout viewer similar to TSMC that speeds and simplifies the "design rule check" signoff by the customer (EBAON 05/17/2001). UMC offers other web-based tools it calls "i-Designer," which allows for on-line chip size and cost estimations of various feature sets.

16 See www.mentor.com/dsm/dfm_partners.html for more information.

logic, memory or sensors.[17] This roadmap allows device designers to adapt to future changes in process technologies that affect design rules and specifications.

In addition to facilitating faster transmission of larger amounts of information, the Internet can provide information to foundry customers (fabless firms or systems firms) on the status of orders in real time. TSMC has developed eFoundry, an internet-enabled customer service program that the company hopes will enhance the efficiency of customer booking procedures and service and result in shorter delivery times and improved service (Norris 1997).[18] UMC has similarly implemented a web-based supply chain management system it calls eProject. This system covers the entire semiconductor life cycle, from on-line purchasing through work-in-process and quality reports.

The integration and automation of the entire order-to-delivery process through eBusiness applications can provide information for transactions between foundries and fabless firms that is similar to that obtained by integrated manufacturers from their in-house Enterprise Resource Planning (ERP) software packages. Such information improves the flexibility of production scheduling, reduces inventories, enables the exchange of more accurate information between foundries and fabless firms, and allows the fabless firms more time to make design adjustments. But the realization of these benefits within the fabless-foundry relationship in semiconductor manufacturing requires greater coordination on business process rules and standards for data exchange. Chartered Semiconductor, for example, was the first semiconductor foundry specialist to push for open standards for data exchange between foundries and their customers (Fraone 2000), in order to reduce the burden on customers who face a diverse array of data-exchange standards and systems among competing foundries. Nonetheless, the process of standardization in this area (like many others) has been prolonged and sometimes contentious, in part because of the effects of open standards on interfirm competition. Genuinely open standards facilitate switching by customers among foundries and therefore may significant affect the competitive strength of different foundries. Moreover, any standards for foundry-customer communications

17 For TSMC, visit www.tsmc.com/technology/roadmap.html; For Chartered Semiconductor, visit www.charteredsemi.com/products/index_pop_techsitemap.htm; For UMC, visit www.umc.com/english/process/a.asp.

18 The goal of TSMC's Virtual Fab is to automate the entire process of communications and logistics related to technology, inventory, process, production data, foundry selection criteria, and post-sales support. eFoundry, allows TSMC customers to access engineering information and electronic supply chain information such as purchase orders, work-in-process reports, shipping notices, and other logistical information using the Internet. Customers also have access to yield analysis services, order status, backlog, and wafer sort, QA, SPC, and process reliability data monitoring.

that emerge will require new investments in software and process reengineering by both foundries and their customers.

Although significant, these applications of eBusiness largely facilitate longstanding trends toward higher levels of vertical specialization. Few if any of these applications, with the possible exception of real-time monitoring by customers of their orders in foundries, represent qualitative advances in the technical possibilities for coordination of complex, knowledge-intensive transactions. Nevertheless, the cumulative effect of these many incremental improvements on vertical specialization, as well as the geographic redistribution of manufacturing activity and employment, could well prove significant. By contrast, eBusiness applications in semiconductor design do appear to have created new capabilities that will extend specialization.

3.2. eBusiness and Semiconductor Design

One of the most important developments in eBusiness affecting semiconductor design is the establishment of Internet-based markets to buy and sell "blocks" of intellectual property embedded in semiconductor designs (Linden and Somaya 2001). Internet-enabled design block trading has several benefits, including industry-wide access to best-in-class designs and significant reductions in search costs for available designs. Like other eBusiness applications in semiconductors, design trading faces significant obstacles, including intellectual property ownership conflicts, design support disputes that reflect interdependencies among individual design blocks, and valuation disagreements.

Several industry alliances have recently formed to address many of these transaction cost-related obstacles. A broad coalition of industry participants formed Virtual Socket Interface Alliance (VSIA) in an attempt to establish open, "plug and play" compatibility standards ("virtual sockets") in semiconductor designs. VSIA is largely comprised of leading EDA software vendors, design module vendors, and several Japanese electronics firms. Lower reuse costs and design trading costs are the goals of this promising, but as-yet incomplete, standardization effort (Linden and Somaya 2001).[19] A second coalition called the Virtual Component Exchange (VCX) was formed through a joint initiative of the Scottish economic

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[19] See the VSIA website at www.vsi.org/about.htm for more detailed information. The VSI Alliance is chartered to define, develop, authorize, test and promote open standard specifications relating to data formats, test methodologies, and interfaces.

development agency, "Scottish Enterprise," and a few major players from VSIA.[20] VCX hopes to create a legal and institutional framework around the on-line trading of design modules, a task that requires development of standard contracts, monitoring systems, matchmaking services, and customized arbitration services, among others. Finally, RAPID (Reusable Application-Specific Intellectual Property Developers), was established by firms that develop and sell silicon IP in order to, among other initiatives, develop a catalog standard for featuring commercially available design modules on the Internet.[21] But once again (and similarly to the experience of the RosettaNet consortium that is discussed below), the development of these standards is taking longer than anticipated by many of the proponents of Internet-based markets.

Several Internet business models related to semiconductor design are currently in direct competition with each other. Some trading sites have begun to provide pre-tested cell libraries that represent the basic building blocks from which modules and entire chip designs are constructed via the Internet. Altera and Mentor Graphics maintain their own sites, in contrast to the VCX model of a multi-company trading site. Portals, or electronic malls for design module and other cell library providers, also provide Internet-based trading of design modules.[22] Design billboards that allow customers to post specific design problems in hopes of inviting feedback are also growing in popularity.[23]

One of the most interesting Internet-enabled developments is the complete outsourcing of the design environment.[24] A hosted design environment vendor provides Electronic Design Automation (EDA) and related development tools, including IT and system administration support, to customers via a standard Web browser, allowing geographically dispersed teams to collaborate around the clock. Security and data integrity are managed through a system of firewalls, physical access security, customer-dedicated hardware configurations, and data encryption and user authentication techniques. The availability of high bandwidth access,

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20 VCX received financial support from Scottish Enterprise as part of the agency's regional development initiative in semiconductors. The exchange also received backing from ARC Cores, ARM, Cadence, Mentor Graphics, Motorola, TSMC, UMC Group and Chartered Semiconductor. See the VCX website at www.vcx.org for more detailed information.

21 See the RAPID website at www.rapid.org for more detailed information.

22 SiliconX and ToolWire are two examples of portals.

23 HelloBrain is an example of a design billboard.

24 Synopsys Inc.'s Internet Enabled Systems product is an example of a hosted design environment.

scaleable, centralized computer systems and thin client technology[25] provide the tools necessary for a complete hosted design environment (HDE) via the Internet (Heideman 2001).

Whatever the form or environment, Internet-enabled trading of design solutions should support further specialization by design firms in developing application-specific blocks of intellectual property and will encourage the use of fabless firms' design services. By enabling design firms to specialize still further, the availability of IP design blocks from foundries or other design firms should increase the efficiency, cost-effectiveness, and time-to-market of fabless designers.

Foundries are also playing an important role in Internet-enabled design trading. TSMC and UMC now offer Internet-based services that provide "design solutions," blocks of design-related intellectual property that cover specific functions or operations on chips, to foundry customers. Firms from outside the pure play foundry market are also participating in this opportunity. IBM Microelectronics, for example, offers its customers an Internet-based custom chip design tool to accelerate the introduction of complex chips for high-performance servers and other networking gear.[26] This Internet-enabled design system provides a secure, real-time, on-line collaboration environment that allows customers to share chip information with IBM engineers and access to design kits, software tools and related product information. Many fabless design firms are also trying to assemble a portfolio of design solutions from third parties. As their customers (especially those seeking wireless communications solutions) seek higher levels of integration, the trading of "design blocks" among fabless firms is likely to grow. The growth of this trade will be accelerated and will expand to new product classes through expanded application of the Internet.

The Internet is an ideal location for "virtual marketplaces" for intangible goods such as a semiconductor product designs. The increasing complexity of many semiconductor designs and the continually increasing ability to place more components onto a single chip has facilitated the creation of these markets. As the pace of progress in manufacturing has outstripped product designers' abilities to create designs from scratch that take advantage of manufacturing

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[25] Thin Client Technology enables any computer to access Windows- or Unix-based applications from any web browser over the Internet (or Corporate Intranet) without having to install the applications on the client desktop system. Applications instead reside on servers, which pass only the screen, keyboard and mouse information to the client desktop system.

[26] This on-line custom chip design system offers a secure environment that is available anytime, anywhere in the world, helping customers cut costs, increase productivity and speed custom production of chips for the eBusiness infrastructure.

capabilities in a reasonable period of time, reusable IP from Internet-enabled exchanges allows firms to focus their efforts on higher-level integration and bring completed products to market more quickly. The Internet also enables suppliers of design blocks to simulate the integration and performance of their various design components prior to the submission of a completed design to a foundry. The ability of the Internet to support this type of simulation represents an important qualitative advance in technical capabilities that should facilitate trading in design-related intellectual property.

The Internet and eBusiness are important catalysts in the emergence of new IP markets, allowing potential customers to obtain information, prototype designs, simulate and test performance and complete transactions. Nevertheless, as in all applications of eBusiness, many obstacles remain to the creation of new intellectual property markets. Semiconductors are notoriously complex products to design and manufacture, and performance of specific chip-level designs, let alone the performance of design modules that are combined in novel ways, is very difficult to simulate or forecast. The presence of such unexpected interactions among design blocks makes it impossible for IP vendors to give complete performance specifications for their design blocks on any but a customer-by-customer, product-by-product basis, eroding many of the purported advantages of design trading. Although Internet-based exchanges now include provisions for simulating the performance of design blocks and the interactions among these design blocks, "thick" IP markets will require the creation of standard contractual and pricing practices, along with standards for benchmarking, reporting and interfacing with other design blocks. As we have noted previously, negotiations over such standards are fraught with complexity and conflicting incentives among the parties.

The inherently "footloose" nature of trade in intellectual property also may affect the future location of fabless-firm design activities. Although the advantages of regional agglomeration appear to be quite strong in semiconductor design activities, expanded design trading and "horizontal" specialization could reduce the currently high levels of regional concentration of semiconductor design. Areas such as Silicon Valley or Austin could lose design-related employment as a result of this intra-national or international dispersion of design activity, although there is little evidence of any such erosion at present.

4. eBusiness in the Equipment and Materials Industry

The semiconductor equipment and materials industry provides capital equipment and raw materials to semiconductor producers. The equipment industry serves a global market that generates almost $50 billion in revenues (SEMI 2000). Japan and North America account for more than 50 per cent of global bookings (orders), while these two countries along with Taiwan account for more than two-thirds of global shipments (SEMI 2000). The equipment and materials industry is less concentrated than semiconductor device manufacturing, largely because the complexity of the semiconductor manufacturing process allows many small firms to occupy technically specialized niche markets.[27] During the 1990s, however, large equipment companies, such as Applied Materials and KLA-Tencor, began diversifying their product lines and offering more complex "process modules," recipes and process technology knowhow, with their products. Process modules complement and integrate tools from several steps within the overall manufacturing process and help manufacturers reduce the uncertainty characteristic of complex equipment upgrades that often require significant debugging of the complex interrelationships among tools and recipes.[28] The trend toward integrating equipment and "process modules" predates widespread application of the Internet by these firms, but their eBusiness strategies incorporate and extend this integration process.

There are a variety of ways in which eBusiness may influence the semiconductor equipment and materials industries. First, in one of the most widely anticipated applications of eBusiness in the equipment industry, the Internet can be used to remotely monitor, upgrade, and repair equipment located in customer facilities. Second, the Internet may facilitate "virtual collaboration" (Chesbrough and Teece 1996) among smaller equipment providers. Third, the Internet may have an influence on secondary markets for semiconductor equipment. The Internet

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27 Some idea of the contrasting structure of the semiconductor equipment and semiconductor manufacturing industries (the latter includes integrated design manufacturers, foundries and fabless firms) is conveyed by the size of the membership of Semiconductor Equipment and Materials International (SEMI), the leading international trade association for semiconductor equipment and materials firms. Approximately 2100 firms are members of SEMI (SEMI 2000), while the market research firm Strategic Marketing Associates estimates that the semiconductor manufacturing industry (defined as above) contains approximately 375 firms (SMA 2000).

28 Equipment vendors argue that the integration of process module recipes and software with equipment hardware enables their customers to reduce operating costs, achieve faster process development and production "ramp up," and increase overall productivity. Both KLA-Tencor and Applied Materials have established equipment and process integration centers that aid in the development, evaluation and optimization of process modules for the production environment. Applied Materials is working closely with Ericcson and ThermaWave, among other vendors, in process module development. KLA-Tencor has recently introduced a process module control solution for copper interconnects that is comprised of defect-reduction tools,

provides an excellent medium for buying and disposing of used semiconductor equipment, as well financing these products and other services.

4.1. Remote Diagnostics

The term "remote diagnostics" refers to the ability of equipment suppliers to monitor, modify, and upgrade the equipment and associated process modules in use at customer facilities over the Internet. The first demonstrations of this technology took place in 2000 and 2001, and it is available on only a few of the newest pieces of equipment from major equipment manufacturers. Equipment providers hope to be able to monitor a number of installations from a single site and to use the data acquired through monitoring to improve their understanding of product performance in various manufacturing processes, eventually using Internet-based recipe downloads to upgrade and enhance their products in customer fabs. As one example of the use of remote diagnostics, KLA-Tencor and Teradyne Inc. announced plans to integrate eDiagnostics technology into automated IC-test systems so that field and factory engineers can provide real-time, online support to customers (SBN 05/10/2001).[29] AMD, a major manufacturer of microprocessors, recently announced that it is evaluating Teradyne's eDiagnostic software for test systems (SemiconductorFabTech 10/31/2001).

Remote diagnostics offer considerable potential to improve equipment maintenance and utilization, but this application of eBusiness also has encountered obstacles. Widespread application of remote diagnostics requires that complex data-security issues be resolved through new technical means.[30] Semiconductor manufacturers also may be unwilling to reveal to suppliers the sensitive product and manufacturing information that is necessary for remote diagnostics to operate. Widespread implementation of remote diagnostics also raises difficult issues of competitive strategy and positioning for both equipment suppliers and semiconductor manufacturers, since supplier access to firm-specific manufacturing data could shift the locus of learning in the manufacturing process toward the equipment provider. Such a shift in the locus of

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parametric control systems, and classification/analysis software. This process module optimizes the lithography, deposition, etch and chemical mechanical planarization (CMP) process modules needed to create copper devices.

29 Brooks Automation has also agreed to buy and incorporate KLA-Tencor's eDiagnostics technology into its automation equipment.

30 According to companies such as IBM, which claims to have a mature internal eDiagnostics infrastructure, it is often the difficulty of working with suppliers to resolve tough issues such standards and security that slows adoption more than the technical challenges. See www-1.ibm.com/services/strategy/cnslt_pov/e_diag1.html for more information.

knowledge accumulation would increase the diffusion of the formerly proprietary manufacturing knowledge of leading manufacturers to competitors through the equipment suppliers, potentially threatening the competitive position of some manufacturers.

Standards development is another thorny issue for both semiconductor device manufacturers and equipment providers. Although large equipment providers such as Applied Materials have developed proprietary standards that operate across a range of equipment types, smaller equipment vendors will probably favor some type of open-standards alternative for the industry.[31] As we noted earlier, open standards lower switching costs, a factor that in this context will facilitate substitution by device manufacturers among different suppliers, giving manufacturers greater competitive leverage over suppliers. The adoption of remote diagnostics and the development of new standards for communicating with semiconductor manufacturing equipment also have implications for the evolution of business relationships between fabless design firms and manufacturing foundries.

Remote diagnostics, like the trend towards horizontal consolidation and the emergence of fabless firms and foundries, are likely to blur some of the distinctions between large semiconductor equipment firms and their customers. As we discuss below, equipment firms may need to broaden their product lines in order to participate in this development; alternatively, the Internet could facilitate collaboration among equipment firms to achieve the same goal. In any case the issues of information sharing and interface standards will remain critical and contentious in the evolution of remote equipment maintenance. In addition, some manufacturing firms will resist the "commoditization" of their formerly proprietary capabilities and knowhow, as well as the potential for increased entry by competitors that such information sharing may produce.

4.2. Virtual Integration

Small, specialized equipment and materials companies have a variety of potential responses to the efforts of larger competitors' strategies of product integration through complete process module development. Consolidation is one alternative, but another possibility is Internet-enabled collaboration among independent firms to provide more integrated products. To the extent that eBusiness makes possible seamless collaboration among a set of independent firms in

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[31] In December 1998, Applied Materials purchased Consilium, a supplier of Manufacturing Execution Systems (MES) software. Consilium is a proprietary platform, and according to the company web site, "As part of Applied's 'Total Solutions' strategy, the companies provide… seamless integration with fab management software…"

the design and integration of their various products, independent vendors may be able to replicate many of the advantages of larger firms. Some have speculated that the Internet and eBusiness will help firms realize the benefits of "virtual integration" (Chesbrough and Teece 1996). The integration of information technology may not only allow materials and equipment providers to adapt to changing market circumstances more effectively, but also help them address difficult questions in areas like pricing and new product development.

The trend towards horizontal consolidation within the equipment industry has been motivated by the benefits of offering an integrated product line and simplifying the management of expensive capital equipment upgrades for device manufacturers. The Internet and eBusiness applications, however, could help firms form "virtual collaborations." Small equipment and materials firms might coordinate on a common hosted Enterprise Resource Planning software platform, making their sales and purchasing processes resemble those of a single integrated supplier to benefit high-volume customers. The benefits of "virtual collaboration" through an integrated software platform can also extend to purchasing, where order consolidation helps give the purchasing clout of a larger enterprise. Although sharing performance data may prove difficult, the smaller firms may find it in their interest to jointly support open standards for equipment interface in opposition to any proprietary alternatives. Even these initiatives, however, face a number of transactional hazards.

It remains difficult to predict the effects of eBusiness applications on the likelihood or effectiveness of "virtual integration" among independent equipment suppliers. eBusiness does not offer effective solutions to the long-recognized difficulties of collective action and rent sharing that will influence the ultimate feasibility of such close, complex horizontal collaboration among equipment firms.

4.3. Internet-based Equipment Markets

A third application of the Internet and eBusiness that will influence the evolution of the semiconductor manufacturing and equipment industries is the emergence of on-line markets for the purchase of new and used equipment. Semiconductor equipment is a long-lived and expensive durable good that depreciates rapidly due to short semiconductor product life cycles, and equipment purchases represent a significant fraction of the cost of setting up a semiconductor manufacturing facility. As information goods, financial products are well-suited to the Internet, and the transactional structure and financing of new equipment purchases will undergo change as a result of the expanded use of the Internet. Companies such as Lendx already host electronic markets for the commercial lending transactions typically used to finance semiconductor equipment (Mehra 2001).

The Internet now support limited secondary markets in used and refurbished equipment. The member companies of the Surplus Equipment Consortium/Network (SEC/N), a trade association for the used equipment segment of the semiconductor industry, are working with the International SEMATECH Surplus Equipment Council to resolve a variety of issues related to the used and surplus equipment markets. Besides coordinating with member companies on issues that affect the used and surplus equipment markets, SEC/N utilizes the Internet to develop and disseminate standardized measures of the quality and future useful life of used equipment and serves as a focal point for information and assistance in locating used equipment, spare parts and services. KeyAssets.com, an independent online B2B marketplace for surplus manufacturing equipment, also has recently entered the semiconductor equipment marketplace. This company remarkets high-value used and surplus semiconductor equipment via the Internet utilizing a detailed database of available equipment and services. By providing pictures of each piece of equipment, detailing the required support services, and creating an exchange format for transactions that includes complete audit services and escrow accounts, KeyAssets seeks to lower the costs and complexity of doing business in a fragmented market. It is difficult to measure sales volume on these exchanges, but by December 2001, more than 400 pieces of equipment were listed for sale on the KeyAssets.com web site.

Nevertheless, the high cost of semiconductor equipment, the frequent need for substantial customization of this equipment, and the need to certify its quality and performance all are likely to limit the emergence of used equipment "spot markets." But eBusiness applications will enhance the ability of manufacturing and equipment firms to track used equipment, dispose of it, and gauge the "market value" of in-plant capital. The Internet should lower the search costs associated with dealing in used semiconductor equipment, just as it has in markets for other goods ranging from beanie babies to automobiles. Significant hurdles need to be overcome in order for a well functioning market to result, however, as the current marketplace lacks any standards, SEC/N's efforts notwithstanding.[32]

Implementing eBusiness markets in the financing of used equipment also faces obstacles. Conflicts over standards, interfaces, and the rules of the market are inevitable when a "new" market threatens to change the bargaining power of incumbents. Nevertheless, the gradual emergence of a more liquid market in financing and used capital equipment is likely to encourage the separation between design and manufacture along with lateral integration among equipment producers.

4.4. Implications for the Structure of the Semiconductor Manufacturing Industry

The ability of the Internet to support the development of remote diagnostics, virtual integration among equipment providers, and new markets for financing and used equipment markets will influence the global distribution of manufacturing and trade in semiconductors. An expanded role for equipment suppliers in developing and supporting process modules will interact with and accelerate the growth of the vertically specialized fabless/foundry model of semiconductor manufacturing. If more of the formerly tacit knowhow embodied in specific process modules becomes bundled with purchases of semiconductor processing equipment, entry by new manufacturing firms should become easier in specific semiconductor product segments, intensifying competitive pressure on existing manufacturers. Over time, the semiconductor products for which such process modules are most widely available could migrate away from both the advanced industrial centers of semiconductor production in the United States, Japan and Western Europe as well as centers of foundry production such as Taiwan to lower-wage areas. The expanding role of equipment firms in the development and provision of process modules thus may have far-reaching effects on the international distribution of employment and industry structure in semiconductor manufacturing.

5. Adoption of eBusiness Applications

Although the discussion above suggests that eBusiness will influence structural change in the semiconductor industry, realization of this potential requires widespread adoption of

[32] The SEC/N has created the Equipment Condition Index (ECI), a list of 21 categories that generally describes a spectrum of levels of equipment conditions. These categories range from "never used" to "de-installed" and "cannibalized." Many Internet sites and listing services are incorporating the ECI in their businesses to define their equipment.

eBusiness practices and standards. As with other information technologies, both vertically specialized firms and integrated device manufacturers will have to make extensive modifications of internal business practices to take advantage of eBusiness applications. Adoption of these technologies will also require the development of significant in-house expertise to evaluate and to modify particular applications. In this section, we present two types of evidence on the pace and pattern of adoption of eBusiness applications, summarizing the results of a recent survey of semiconductor equipment firms and briefly discussing the development of RosettaNet, a consortium that seeks to develop eBusiness standards and protocols for the electronics industry.

5.1. eBusiness in the semiconductor equipment industry: results of a survey

In the spring of 2001, the authors conducted a survey on the use of eBusiness applications at semiconductor equipment firms. With the support of Semiconductor Equipment and Materials International (SEMI), a trade association representing equipment and materials firms throughout the world, we contacted nearly 650 firms from the total SEMI membership of more than 2000 enterprises with an on-line survey instrument. Usable replies were provided by 65 firms, which produced a response rate of slightly more than 10 per cent.

Table 5.1 shows that nearly all of the SEMI member firms that completed the survey (63 out of 64) have built a corporate website. The majority of these companies have had a website in place for more than two years. However, use of the Internet for eBusiness applications other than dissemination of basic corporate information is much less widespread. Only 56 per cent (34 out of 63) of the companies reported that they have deployed eBusiness applications. Not surprisingly, as Table 5.2 shows, the majority of companies (24 out of 34) that report adopting eBusiness applications have less than two years of experience with these new business processes.[33]

[33] The data also show that the earliest creators of corporate websites tended to be earlier adopters of other eBusiness applications.

Table 5.1: Internet Use and Deployment

	Active Corporate Website[34]		Adoption of eBusiness (by Age of Website)[35]	
	(#)	(%)	(#)	(%)
<1 Year	4	6.3	0	0
1-2 Years	11	17.5	5	45.5
2-4 Years	27	42.9	16	59.3
>4 Years	21	33.3	13	65.0
Total	63	100.0	34	55.7

[34] The specific question asked in the survey was *"How long has your company had a corporate website?"*

[35] The specific question asked in the survey was *"Does your firm use eBusiness applications?"*

Table 5.2: Experience with eBusiness Applications

	Use of eBusiness Applications[36]	
	(#)	(%)
<1 Year	11	32.4
1-2 Years	13	38.2
2-4 Yeas	6	17.6
>4 Years	4	11.8
Total	34	100.0

Several survey respondents commented that the benefits of eBusiness applications were greater when these applications covered higher volumes, e.g., larger sales volumes. As one anonymous respondent noted, "firms must sell one million widgets in order to exploit eBusiness." Table 5.3 indicates that larger companies were more likely to implement eBusiness applications. Further support for this "economies of scale" argument concerning the benefits of eBusiness adoption for larger firms is provided by the simple correlation between the revenue codes and the self-reported adoption of eBusiness applications, which was approximately 0.3.[37] Other proxies for size, such as the number of employees and age of the firm, are positively correlated with eBusiness adoption but do not appear to be significant after controlling for revenues.[38]

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36 The specific question asked in the survey was *"How long has your company used eBusiness applications?"*

37 The positive relationship between company size and eBusiness adoption remains significant in simple regressions that control for other variables, such as the age and geographic location of the firm.

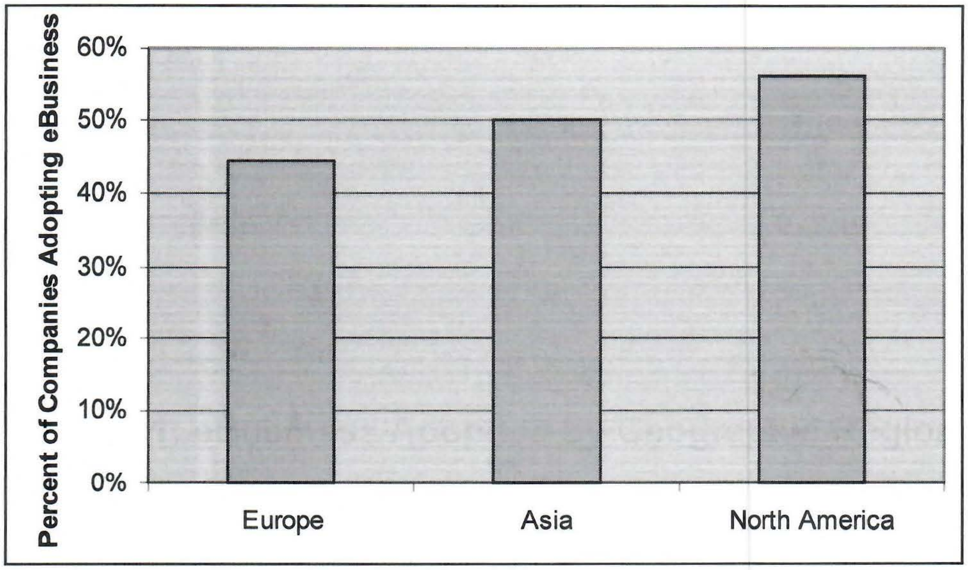
38 The OECD noted a strong correlation between firm size and use of the Internet, especially use of the Internet for more complex business transactions, in its 2001 report on the "digital divide," which finds much lower penetration rates of Internet usage and eBusiness applications among smaller firms in Norway, Netherlands, and Austria (OECD, 2001, p. 25).

Table 5.3: eBusiness Adoption by Revenue Category

Revenue Category	Non-Adopting Firms	Adopting Firms	Adopting Firms/ Total Firms
Less than $1mm	5	1	16.7%
$1-$5mm	1	3	75.0%
$5.1-$10mm	3	5	62.5%
$10.1-$25mm	8	2	20.0%
$25.1-$50mm	1	3	75.0%
$50.1-$75mm	0	2	100.0%
$75.1-$100mm	0	1	100.0%
$100.1-$500mm	3	9	75.0%
$500mm and up	1	2	66.7%
Unlisted	5	5	50.0%
Total	27	33	55.0%

We found weaker evidence of differences in the extent of adoption of eBusiness by SEMI member firms according to geographic location. Figure 5.1 shows the proportion of firms that reported the adoption of eBusiness applications within each of the three major geographic regions. The figure shows that respondents are split fairly evenly between adopting and not adopting eBusiness applications within each region, although North American companies are slightly more likely to adopt eBusiness applications than their European and Asian counterparts. Despite this indication of inter-regional differences in adoption patterns, a simple linear regression that controlled for firm size failed to show a statistically significant relationship between geographic location and self-reported eBusiness adoption. This result, which is somewhat surprising in view of other evidence of significant international differences in adoption of eBusiness applications, may reflect the small size of our sample of twelve Asian and nine European firms.

Figure 5.1: eBusiness Adoption by Geographic Region



The survey also queried respondents about obstacles to the adoption of eBusiness applications. Overall, a lack of industry standards, confusing information about the expected benefits of new applications, and a shortage of IT personnel were most commonly cited as important obstacles; intellectual property and transactional security problems were less frequently singled out. Table 5.4 provides the mean level of agreement with a series of statements about obstacles to eBusiness implementation along with the standard deviation for responses concerning each of the obstacles to adoption. The emphasis on the lack of industry standards in impeding adoption is consistent with our earlier discussion of the importance and difficulty of establishing such standards on an industry-wide basis.

Table 5.4: Obstacles to eBusiness Adoption

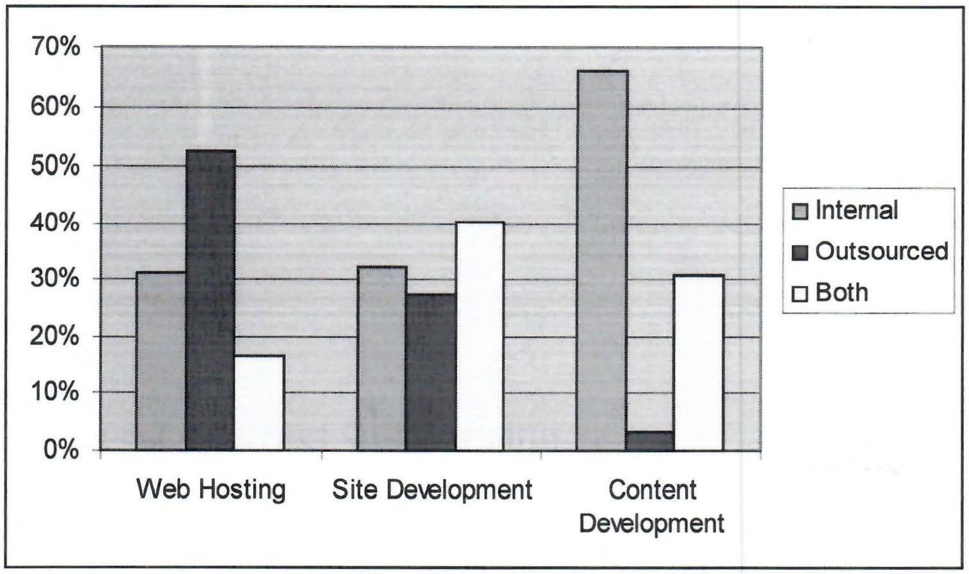
eBusiness Adoption Obstacle[39]	Mean	S.D.
a. The industry lacks sufficient standards for the adoption of eBusiness applications that involve significant inter-firm collaboration.	4.95	1.60
b. The adoption of eBusiness applications invites significant new competition into our product and/or service markets	3.22	1.68
c. The internet and eBusiness applications reduce the differentiation or uniqueness of your products and services in comparison to our competitors' offerings	2.91	1.67
d. The internet and eBusiness applications threaten our firm's intellectual property or do not provide adequate safeguards of critical knowledge	3.16	1.75
e. The internet and eBusiness applications have inadequate transactional security in place (i.e., firewalls, etc.)	3.54	1.87
f. Our firm lacks the personnel and expertise required to successfully implement eBusiness solutions or finds them prohibitively expensive	4.37	1.80
g. There is insufficient reliable information on effective eBusiness strategies to make an informed decision about their use	4.00	1.62
h. There is too much confusing information available on eBusiness strategies from external sources	4.42	1.73
i. Customers will find it easier to switch to other suppliers as a result of their use of web-based business methods	3.29	1.81

Finally, respondents were asked a series of questions about their use of outsourcing as opposed to internal development of Internet and eBusiness applications. The responses summarized in Figure 5.2 show that reliance on outsourcing declines steadily as one moves from web hosting to content development. More than 50 per cent of SEMI member respondents utilize external developers for web hosting applications. Content development, by contrast, is largely done internally, with more than two-thirds of the SEMI respondents choosing this development approach. Interestingly, site development exhibits a roughly even split between internal development and outsourcing. These differences appear to be driven by at least two factors. First, the proprietary character and specificity of much of the firm-specific content may require

[39] Respondents were asked to indicate the importance of these obstacles on a 7-point scale, where 7 indicates great importance and 1 indicates little or no importance.

internal development. Second, the skills that are needed for development of web-hosting applications may support specialization in this function by external vendors that are able to provide this service at a lower cost.

Figure 5.2: Internet Outsourcing



These survey results underscore the importance of firm-size-related differences in the extent of eBusiness adoption among semiconductor equipment firms, with smaller firms lagging behind their larger counterparts. Lower rates of adoption among smaller firms appear to reflect the perception that the benefits of adoption are smaller for lower volumes of transactions or sales, as well as the greater difficulties faced by smaller firms of obtaining reliable information on benefits, costs, and implementation strategies from external sources. Surprisingly, the survey revealed little evidence of significant geographic differences in the rate of adoption of eBusiness applications, although our limited sample of non-U.S. respondents means that this finding should be interpreted with great caution. Outsourcing of eBusiness applications development is most prevalent for relatively generic applications such as web hosting, while more idiosyncratic, firm-specific website content relies on internal development expertise, something frequently lacking in smaller equipment firms. Finally, respondents highlighted the lack of standards and insufficient reliable information on applications as the most important obstacles to adoption by respondents of eBusiness applications. RosettaNet, an eBusiness consortium that we discuss in the next section, illustrates the centrality and difficulty of standards development for eBusiness applications.

5.2. RosettaNet: The Politics of eBusiness standards

RosettaNet is a consortium of more than 400 firms from the semiconductor manufacturing, electronic components and information technology industries that was established in 1998 to define a set of eBusiness standards and protocols. Unlike the Covisint venture in the automobile industry, RosettaNet is *not* an "electronic marketplace" for the sale of components by supplier firms to large assemblers or systems firms. Instead, RosettaNet has the arguably less ambitious goal of simply defining the "rules" for electronic commerce in this industrial sector, with no clear intention of creating a unified market that links all of its members. But standards that would enable purchasers to shrink inventories, manage supply chains more efficiently, and collaborate electronically with suppliers in the development of new products could generate huge cost savings. According to one estimate, the electronics industry currently operates with an average inventory of 65 days' worth of parts, more than six times the 10-day supply utilized by Dell Computer, widely acknowledged to be the most efficient manufacturer of personal computers.

RosettaNet has encountered a number of significant obstacles in its standard-setting work. For example, the creation of a uniform standard for identifying component parts has proven to be extremely contentious and difficult. Yet without some universal product code, duplication in purchasing systems and parts inventories will remain a serious obstacle to automating electronic transactions. Indeed, even simple concepts such as "price," "shipping," and "modem" have proven to be difficult to define. In part, these difficulties reflect the fact that agreeing on a particular definition will require many member firms to revise their business processes and internal organizational structures. As a result, RosettaNet has also attempted to develop standard business processes, a project that if anything has proven to be even more difficult than defining such concepts as "price."

For many participating firms, especially suppliers, the standardization activities of RosettaNet have considerable potential to reduce their firm-specific competitive advantage and the rents associated with maintaining idiosyncratic capabilities. As we noted earlier, RosettaNet standards may "commoditize" some portion of the value chain within these industries, and thereby facilitate entry by new firms and the accompanying loss of profits. The large number of firms and diverse industrial sectors that are linked through RosettaNet also complicate any such standardization activities, simply because of the sheer number and diversity of firms, components, and technologies. In addition, implementing RosettaNet's standards will require an extensive suite of eBusiness software. Yet the consortium's halting progress has failed to create the sort of "bandwagon" that is typically needed to attract the efforts and investments of developers of such complementary software. Finally, smaller firms within RosettaNet have found it very difficult to sustain their participation, for reasons that are very similar to those highlighted as obstacles to eBusiness adoption in the survey of equipment producers that was discussed earlier.

The RosettaNet experiment thus underscores the complexity and obstacles to rapid or widespread adoption of eBusiness applications. The creation of "electronic markets" and the associated "disintermediation" of related transactions will require large investments in complementary technologies, agreement among participating firms on difficult (and for some firms, threatening) issues concerning standardization of components and processes, and extensive internal organizational change to complement the development of these new ways of doing business. As a result, large firms throughout the electronics industry appear to be developing firm-specific eBusiness procedures and purchasing routines for procurement activities. To the extent that these firm-specific approaches develop more rapidly and are perceived to be more effective than RosettaNet, the goal of industry-wide standards will become much more difficult to achieve.

6. Implications of eBusiness for Integrated Device Manufacturers

All of the developments discussed above pose significant challenges and opportunities for integrated device manufacturers (IDMs). The ultimate effects of the Internet and eBusiness on the structure of the semiconductor industry depend on the nature of the response by IDMs to eBusiness. One of the most critical competitive challenges facing IDMs that face competition from foundries is the need to improve performance in the development and introduction into high-volume manufacturing of new process and product designs. Integrated firms have a natural advantage in the coordinated adaptation necessary to undertake these technology upgrades, because of the presence of a host of communication channels and managerial instruments within these firms that are unavailable through market interactions. Vertically specialized firms will benefit from the adoption of eBusiness to the extent that it supports comparably rich communications and coordination among non-integrated companies. The Internet accordingly may improve integrated firms' management of the complex knowledge flows that underpin the effective introduction of new manufacturing processes, but the marginal benefits from the use of Internet-based technology to coordinate the introduction of new design rules and technology upgrades are likely to be greatest for the non-integrated fabless/foundry model of production.

The use of the Internet to coordinate supply and production should prove beneficial to both vertically specialized and integrated firms. There is little reason to believe that integrated device manufacturers cannot replicate any eBusiness-enabled improvements to the supply chain systems used by non-integrated firms. In fact, integrated manufacturers may realize many of these benefits more rapidly than vertically specialized firms, if economies of scale or coordination issues slow the adoption of eBusiness strategies within fabless and foundry firms. The ability of the Internet to support "Intranet" applications to monitor manufacturing yields and equipment performance at widely dispersed production sites can improve integrated firms' performance in the development and introduction of new manufacturing process technologies. Moreover, for those areas where eBusiness does yield greater benefits to non-integrated structures, integrated manufacturers may selectively dis-integrate, redeploying their assets as stand-alone operations and creating intrafirm markets or otherwise exposing former subsidiaries to market forces (e.g., through selective "spinoffs" in which a substantial minority stake is acquired by outside investors). For example, Internet-based trading in design blocks can be used by IDMs to outsource a portion of their design activities, enabling the more efficient use of in-house design talent, or to create new revenue streams using older "off-the-shelf" designs. The same applies to the use by integrated device manufacturers of the Internet to obtain process modules, along with manufacturing equipment, from suppliers of equipment.

The emergence of new eBusiness-enabled markets is likely to encourage increased vertical specialization, perhaps even within IDMs (in the sense described in the preceding paragraph). In addition to creating opportunities for entry in less capital-intensive intermediary roles, such as financing or fab management, Internet-enabled markets increase the opportunities available to non-integrated firms. Used equipment markets increase the residual value of durable capital. Markets for design-related IP encourage firms to look outside their own boundaries for opportunities to purchase or reuse intellectual property. Nonetheless, building these new markets raises a host of difficult business and organizational questions that extend far beyond the technological complexities associated with, for example, supply-chain integration. The need for creation of standards, agreement on transaction fees, and availability of data will prevent new markets from springing up immediately to revolutionize the current industry structure.

Rather than spelling their extinction, the Internet thus can support greater efficiency in the management by IDMs of the development and deployment of product and process technologies. Integrated device manufacturers may come to resemble a collection of independent enterprises. But the use of the Internet by IDMs to sustain their competitiveness requires that they better understand the sources of competitive advantage for the vertically specialized production model. To compete effectively with foundries in the manufacture of the products that they continue to design internally, the integrated firms must improve their management of device design, process development, and the introduction of new manufacturing processes and device designs into high-volume manufacture [See Hatch and Mowery (1998); Appleyard et al.(2000)]. This involves a clearer assessment of their in-house capabilities; development of clearer criteria for outsourcing decisions, recognition that outsourcing can be undertaken with higher efficiency and lower cost through the Internet; and improved management of intra-firm product and process technology development and transfer.

7. CONCLUSION

During the past 30 years, the structure of the global semiconductor industry has undergone a process of progressive vertical specialization, which has resulted in the entry by specialized firms in semiconductor design, manufacture, equipment production, and most recently, process development. Entry by specialized firms has had the most significant consequences for the relationship between semiconductor device design and device manufacture. This form of vertical specialization also has contributed to the rapid growth of semiconductor manufacturing capacity in Southeast Asia and the creation of new forms of international production networks linking design and manufacturing specialists. Vertical specialization affecting the development of new process technologies by equipment manufacturers has begun much more recently and remains a prospect rather than a reality.

Vertical specialization in the semiconductor industry predates widespread use of Internet-enabled "eBusiness" strategies and methods. With some exceptions, such as the ability of the Internet to support design simulation in "design block" exchanges, eBusiness appears to be facilitating and accelerating these longstanding trends and their effects on the geographic distribution of manufacturing capacity rather than creating qualitatively new possibilities. In addition, of course, many of the opportunities created by eBusiness applications should prove equally advantageous to integrated device manufacturers and vertically specialized firms. Overall, however, the Internet appears likely to support the longstanding trend of vertical specialization that has led to significant migration of semiconductor manufacturing capacity to Taiwan and Singapore. The opening of the People's Republic of China to foreign investment and China's accession to the WTO also will have far-reaching implications for growth in semiconductor manufacturing capacity (much of which will be foundry-based) outside of the United States, Europe, and Japan. But as this example suggests, the primary cause of any expansion in foundry production in the PRC will be political and economic reform—the Internet will play a facilitating, not a causal, role.

An important question concerns the effects on the location of semiconductor design and R&D activities of the "outmigration" of semiconductor manufacturing from the regions that historically have been the sites of these activities (notably, California, Oregon, and Texas within the United States). Can design and semiconductor R&D remain vigorous when separated by considerable distances from production sites? This question requires more intensive analysis of longitudinal data. Nonetheless, semiconductor design activities have remained concentrated within California's Silicon Valley in the wake of the departure of the vast majority of semiconductor manufacturing activity from this region. Design agglomerations rely on close contact with academic researchers and customers for semiconductor devices at least as much if not more so than they depend on contact with manufacturing process technologists. The growth of vertically specialized design firms, as well as the enhanced communications and information-exchange possibilities created by the Internet, should favor the continued vigor of existing agglomerations of semiconductor design activity, although the outlook is more uncertain for semiconductor R&D devoted to process technology. Paradoxically, then, the least capital-intensive activity within the semiconductor design and production "value chain" may well be the least "footloose," even as the highly capital-intensive manufacturing process migrates to new sites. The growth of this geographically dispersed value chain nevertheless means that international networks of information exchange and flows of products, people, and capital are likely to expand considerably, especially in the Pacific Rim.

Our discussion of the applications and adoption of Internet-enabled eBusiness methods highlighted a set of obstacles that are well known to any student of the adoption of "general purpose technologies" (Bresnahan and Trajtenberg 1995; Mowery and Simcoe forthcoming). The need for industry-wide standards has proven to be a significant impediment to the development of various Internet-enabled markets for semiconductor designs or equipment. Similar standards-related issues, as well as data-security concerns, have hindered wider use of eDiagnostics or Internet-enabled "process upgrades" by equipment suppliers of manufacturing equipment and processes in customer fabs. Less visible, of course, are the obstacles to Internet adoption posed by the need for far-reaching internal reorganization of business processes within the firm, an issue that is likely to prove especially significant in the adoption of eBusiness methods by integrated device manufacturers. Finally, our survey of equipment manufacturers confirms other survey evidence in suggesting that smaller firms face particular challenges in adopting Internet-based eBusiness applications. All of these factors suggest that the adoption of eBusiness and the realization of its productivity benefits or cost efficiencies are likely to occur more slowly than anticipated.

This survey of the effects of the Internet on semiconductor production networks is necessarily tentative, inasmuch as it provides a "snapshot" of a very rapidly changing process. In addition, hard data on the outlines of our snapshot are lacking. It seems likely that many of the far-reaching structural shifts likely to characterize the global semiconductor industry during the next decade have deeper roots than the Internet alone, and are likely to proceed in the face of even the significant obstacles to Internet adoption outlined above. Nevertheless, better data and additional research on these issues are sorely needed.

8. REFERENCES

Appleyard, M., N. Hatch and D. C. Mowery (2000). Managing the Development and Introduction of New Manufacturing Processes in the Global Semiconductor Industry. The Nature and Dynamics of Organizational Capabilities. G. Dosi, R. Nelson and S. Winter, Oxford University Press.

Braun, E. and S. MacDonald (1978). Revolution in Minature: The History and Impact of Semiconductor Electronics. Cambridge, Cambridge University Press.

Bresnahan, T. F. and M. Trajtenberg (1995). "General Purpose Technologies: Engines of Growth?" *Journal of Econometrics* **65**: 83-108.

Chesbrough, H. W. and D. J. Teece (1996). "When is Virtual Virtuous? Organizing for Innovation." *Harvard Business Review*: 65-73.

EBAON (05/17/2001). UMC introduces Remote Layout Viewer. Electronic Business Asia Online News.

ForwardConcepts (2001). DSP Market Bulletin, Forward Concepts.

Fraone, G. (2000). Chatting about chips. Electronic Business.

Hatch, N. W. and D. C. Mowery (1998). "Process Innovation and Learning by Doing in Semiconductor Manufacturing." *Management Science* **44**(1): 1461-1477.

Heideman, W. P. (2001). "The Internet Provides Untapped EDA Resources." *Fabless Forum* **8**(1).

Henisz, W. J. and J. T. Macher (2001). Technology, Competition and Politics: Plant Location Decisions in the Global Semiconductor Industry, 1995-2000. Georgetown University Working Paper. Washington, DC: 1-56.

Langlois, R. N. and W. E. Steinmueller (2000). "Strategy and Circumstance: The Response of American Firms to Japanese Competition in Semiconductors, 1980-1995." *Strategic Management Journal* **21**(10/11): 1163-1173.

Leachman, R. C. and C. H. Leachman (2001). Globalization of Semiconductor Manufacturing. U.C. Berkeley Competitive Semiconductor Manufacturing Research Program Working Paper.

Linden, G. and D. Somaya (2001). System-on-a-Chip Integration in the Semiconductor Industry: Industry Structure and Firm Strategy. R.H. Smith School of Business Working Paper. College Park, MD: 1-46.

Macher, J. T. (2001). Vertical Disintegration and Process Innovation in Semiconductor Manufacturing: Foundries vs. Integrated Producers. Georgetown University Working Paper. Washington, DC: 1-38.

Macher, J. T., D. C. Mowery and D. A. Hodges (1998). "Reversal of Fortune? The Recovery of the U.S. Semiconductor Industry." *California Management Review* **41**(1): 107-136.

McClean, B. (2001). IC Foundries: A Driving Force in the IC Industry. Semiconductor FabTech. **12:** 17-19.

Mehra, P. (2001). Exchanges in the New Economy: Transforming the World of Work. Perspectives on Business Innovation. Cap Gemini Ernst&Young Center for Business Innovation (www.businessinnovation.cgey.com). **6:** 7-15.

Mowery, D. C. and T. S. Simcoe (forthcoming). The History and Evolution of the Internet. Technological Innovation and Economic Performance. B. Steil, R. R. Nelson and D. Victor, Princeton University Press.

Norris, R. (1997). "The Virtual Fab: A Foundry's Ultimate Goal." *Fabless Forum* **4**(2): 18-19.

SBN (05/10/2001). KLA-Tencor, Teradyne to integrate e-diagnostics in test systems. Semiconductor Business News.

SEMI (2000). SEMI Member Database, Semiconductor Equipment and Materials International.

SEMI (2000). Worldwide Semiconductor Equipment Market Statistics by Category, Semiconductor Equipment and Materials International.

SemiconductorFabTech (10/31/2001). AMD and Teradyne engage in an e-diagnostics trial program to provide interactive online customer support capabilities for automated test equipment. Semiconductor FabTech.

SIA (2001). STATS: Global Billings Report History (Actuals), 1990-Present. Semiconductor Industry Association Industry Statistics Report**:** 1-6.

SMA (2000). International Fabs on Disk, Strategic Marketing Associates.

Tilton, J. E. (1971). International Diffusion of Technology: The Case of Semiconductors. Washington, DC, Brookings Institution Press.