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

David C. Mowery and Jeffrey T. Macher

**David C. Mowery** is a **Milton W. Terrill Professor** of Business Administration, and Director, Ph.D. Program, Haas Business School, University of California, Berkeley. His publications include: Mowery, D. and Richard Nelson (eds.), *Sources of Industrial Leadership: Studies of Seven Industries*, New York: Cambridge University Press, 1999, and major books on the global semiconductor, software and aircraft industries.

**Jeffrey T. Macher** is an **Assistant Professor** with the McDonough School of Business, at Georgetown University, Washington, D.C.

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## **I. INTRODUCTION**

During the past 30 years, the global semiconductor industry has been characterized by rapid rates of technological change, rising costs for production capacity, and declining prices for its products. These trends have produced far-reaching structural change within the global semiconductor industry during the past 15 years. Even before the widespread use of Internet and Intranet-based techniques for managing information, manufacturing processes, and technology development, longstanding trends toward increased vertical specialization and reduced vertical integration had produced new business models in the semiconductor industry. These new business models include the development of “fabless” design and marketing firms, which rely on “foundries” for the production of their designs. Other examples of these tendencies toward higher levels of vertical specialization include the expanded role of equipment firms in the development of manufacturing process “modules” to complement their tools.

The Internet and associated e-commerce applications are likely to accelerate these trends, which could affect the long-term location of employment, production, and technology development in the semiconductor manufacturing and in the semiconductor equipment industries. At the same time, however, the powerful management tools created by Internet and Intranet applications provide significant opportunities for integrated semiconductor manufacturers. At present, however, e-commerce applications by both vertically specialized and vertically integrated semiconductor manufacturing firms are in their infancy—although many firms are exploring such applications, “best practices” still are being developed.

## **II. E-COMMERCE AND VERTICAL SPECIALIZATION IN SEMICONDUCTOR MANUFACTURING**

Although its ultimate effects on semiconductor manufacturing will take considerable time to be realized, we believe that extensive applications of Internet and Intranet solutions in the

semiconductor industry are likely to accelerate and extend trends toward “vertical specialization” that have been prominent for much of the past 15 years. Similar trends have been significant within the overall electronics industry for much of the past 50 years. For the first two decades of the computer and semiconductor industries, integrated producers such as AT&T or IBM manufactured much of the equipment for producing solid-state electronic components, as well as the components themselves, and the electronic computers and the computer software that utilized these solid-state components. Since at least the 1960s, however, specialized firms have entered the production of manufacturing equipment. Independent software vendors now are major producers of computer software. Many of the U.S. computer firms that formerly manufactured all of their semiconductor components in-house have either withdrawn entirely from this activity or have specialized in the production of a smaller assortment of semiconductor devices for sale to other firms and for internal use. In their place, semiconductor manufacturing, especially in the United States, has come to be dominated by specialized manufacturers of semiconductor devices, most of whom develop manufacturing processes (but not manufacturing equipment) and device designs in-house, in addition to producing these components for sale on the market.

During the past 15 years, however, the dominance of semiconductor manufacturing by firms that integrated semiconductor device design, process technology development, and manufacturing has been challenged by two developments that represent the latest stage in this long-term trend toward higher levels of vertical specialization:

1. A large number of “fabless” semiconductor firms, specializing in the design and marketing of semiconductor components, have entered the industry.
2. Complementing and making feasible the fabless strategy, a number of firms have entered the semiconductor industry as specialized manufacturers—the so-called “foundry” firms.

Although a few U.S. integrated manufacturers have begun to devote a portion of their production capacity to foundry manufacturing, the most advanced foundries are concentrated in East Asia, primarily in Taiwan. The majority of the specialized design firms, however, are located in the United States. The rapid growth of this vertically specialized form of production therefore may have significant implications for the future location and mix of semiconductor industry employment in the United States and foreign economies. If Taiwan retains its place as the leading site for semiconductor foundries, continued expansion of the “fabless/foundry” model of semiconductor production could result in the offshore migration of U.S. semiconductor manufacturing employment, even as U.S. design specialists remain fully employed in the specialized design firms. At the same time, however, several U.S. integrated semiconductor manufacturers have established foundries to utilize portions of their mature manufacturing capacity, and a few Taiwanese firms have opened specialized foundries in the United States. In addition, Taiwan’s dominant position in the foundry industry could be eroded by competition from lower-cost production sites in Asia and elsewhere. The long-term consequences of the growth of the vertically specialized model of production for the location and skill mix of employment in semiconductor device manufacture and design thus are quite complex.

As we noted earlier, this vertically specialized form of semiconductor manufacturing has grown rapidly through much of the 1990s. One of the central challenges in the “arms-length” interface between fabless design firm and foundry is managing the flow of knowledge so as to facilitate a smooth and efficient transfer of new designs into production. The transfer and transition into production of such complex design information typically relies on the design firm’s adherence to “design rules” laid out by the foundry—i.e., restrictions on the types of designs that will be manufactured in a foundry on a specific delivery schedule. These design rules are determined by the foundry’s manufacturing capabilities and capacity. For the foundry operator, updating and maintaining these design rules so as to remain near the technological

frontier and competitive with other foundries without losing the ability to quickly “ramp up” new designs is a demanding task. We believe that the ability of Internet and e-commerce links to increase the volume and speed of information transfer between foundries and designers will simplify the tasks of knowledge management and exchange.

In addition to facilitating the more rapid transmission of larger amounts of information, the Internet can provide new types of information on the status of orders in real time, and can be used to expand the flexibility and simplicity of foundry-based design rules. Firms such as Taiwan Semiconductor Manufacturing Company (TSMC), a leading foundry manufacturer and a participant in this research project, now are using the Internet to provide real-time updates in order status, manufacturing capacity, and other key logistical variables. TSMC is expanding its Internet-based services to provide “design solutions,” blocks of design-related intellectual property that cover specific functions or operations on chips, to foundry customers. In the future, TSMC and other state-of-the-art foundries may provide real-time tracking of high-priority production lots for customers over the Internet.

Within the “fabless” segment of the semiconductor industry, Internet-based applications also will have far-reaching effects. We plan initially to focus on two of these effects. First, business-to-business Internet applications will strengthen the relationship between design firms and foundry manufacturers, by facilitating more rapid exchange of design and production information. As the example of TSMC illustrates, Internet applications also will enable foundries to make available to designers selected blocks of intellectual property that are robust design solutions and conform to the production technologies within the foundries. Second, the ability of foundries such as TSMC to assemble a portfolio of such design solutions from third parties, relying on business-to-business Internet applications, is replicated within the fabless firm segment. As their customers (e.g., those seeking wireless communications solutions) seek much higher levels of integration—so-called “system on chip” design solutions—trading of “design

blocks” among fabless firms also will grow. The growth of this trade will be accelerated and will expand to new product classes through the application of the Internet to these activities.

Internet-enabled trading of design solutions should support further specialization by design firms in developing specific blocks of intellectual property and will facilitate the use of fabless firms’ design services by an expanding array of customers from various electronic-systems industries. By enabling design firms to specialize still further, the availability of such design blocks of intellectual property from foundries or other design firms should increase the efficiency, cost-effectiveness, and time-to-market of these fabless firms. In addition, the management of these complex commercial relationships will require the development of intellectual property management strategies that are likely to be relevant to Internet-based trade in “intangibles” in other industries as well.

Finally, the inherently “footloose” nature of this type of trade in intellectual property raises interesting questions for the future location of fabless-firm design activities. Will they remain primarily in the United States, or will portions of the design activity migrate offshore in ways similar to portions of the computer software industry? Are existing regional agglomerations, such as Silicon Valley or Austin, likely to lose design-related employment as a result of “intra-national” dispersion of design activity? These are among the issues we hope to examine in our research on the effects of the Internet on the specialized design firms.

### **III. E-COMMERCE IN THE SEMICONDUCTOR EQUIPMENT INDUSTRY**

A related development that contributes to increased vertical specialization within the semiconductor industry is the growing role of suppliers of semiconductor manufacturing equipment in the development of new process modules (a series of steps covering a specific operation, such as etch, lithography, or implant), including processing recipes and knowhow. Several large U.S. equipment suppliers (e.g., Applied Materials) have expanded their activities

beyond developing and marketing new pieces of complex manufacturing equipment to provide complete “process modules” along with such equipment. The ability of equipment suppliers to monitor, modify, and upgrade these process modules in customer facilities will be enhanced by greater use of business-to-business Internet applications for lot tracking, yield analysis, and data capture and transmission that can enable equipment producers to monitor a number of installations from a single site.

Equipment suppliers also may develop the capability to upgrade process modules that are already deployed in manufacturing facilities through Internet-based recipe downloads, further expanding their role in the manufacturing performance of customer fabs. In addition, specialized design firms can use the Internet to obtain more extensive, richer information on equipment performance in real time, enabling these fabless firms to develop product designs that are compatible with the design rules that emerge from the evolving capabilities of semiconductor manufacturing equipment and their associated process modules.

Like the emergence of the “fabless/foundry” model of semiconductor manufacturing, efforts by equipment suppliers to expand their role in the development and support of process modules predate widespread application of the Internet. But Internet-based applications should expand and accelerate leading suppliers’ role in process module development and support.

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. As and if more of the formerly tacit “knowhow” embodied in specific process modules is bundled with purchases of semiconductor processing equipment, entry by new firms should become easier in specific product segments, intensifying competitive pressure on existing foundry firms. Over time, the semiconductor products for which such process modules are most widely available and easily applied could migrate to lower-wage economies and away from the more costly centers of foundry production such as Taiwan. The

expanding role of equipment firms in the development and provision of process modules thus could have far-reaching effects on the international distribution of semiconductor-related employment.

In addition, the ability of fabless design firms to develop design solutions that conform to the manufacturing capabilities of foundries will be facilitated by the greater availability and “codification” of the processing steps association with the expanded role of equipment suppliers. Finally, as in the trading of “design blocks” of intellectual property, a better understanding of techniques for the management of trade in this form of intellectual property should be relevant to e-commerce in other technology-intensive industries.

#### **IV. IMPLICATIONS FOR INTEGRATED DEVICE MANUFACTURERS**

All of the developments discussed above pose significant challenges for integrated manufacturers of semiconductor devices. But the Internet also creates opportunities for these firms to maintain or strengthen their competitiveness vis-à-vis specialized design and manufacturing firms. One of the most critical competitive challenges facing integrated device manufacturers is the need to improve their performance in the development and introduction into high-volume manufacturing of new process and product designs. The Internet and Intranet can improve integrated firms’ management of the complex knowledge flows and interactions that underpin the effective introduction of new manufacturing processes, and therefore can strengthen integrated firms’ competitiveness in key product areas. But this requires a deeper understanding of best practices in the development and introduction of new manufacturing processes, as well as a clearer understanding of the ways in which Internet and Intranet applications can support these activities

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. Internet-based trading in design blocks can be used by integrated device manufacturers to outsource a portion of their design activities, enabling the more efficient use of in-house design talent. This type of outsourcing may prove to be especially important in developing and designing "system on chip" devices. 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.

Rather than spelling their extinction, the Internet thus can support greater efficiency in the management by integrated manufacturers of the development and deployment of product and process technologies. But the use by integrated manufacturers of the Internet to sustain their competitiveness requires that they better understand the sources of competitive advantage for the vertically specialized production model (fabless firm/foundry manufacturer). 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., 1999). This involves a clearer assessment of their in-house capabilities; a better-informed set of criteria for outsourcing decisions, recognizing 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.

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