Is Production Pulling Knowledge Work to China? A Study of the Notebook PC Industry

Jason Dedrick and Kenneth L. Kraemer
University of California, Irvine

China is now the world's largest computer hardware producer and, as a study of notebook PC companies reveals, is beginning to pull knowledge work along with production to its key manufacturing centers. This trend has major implications for employment and competition in large-scale industries both in the US and abroad.

During the past 15 years, China has gone from a minor player in the computer industry to the world's largest hardware producer. As Figure 1 shows, total hardware output soared from $645 million in 1990 to $81 billion in 2004, surpassing US production in that year. China began outpacing the US as well as Japan, Singapore, and Taiwan in 1995; since 2000, Chinese hardware production has tripled while output in the other countries has declined—in the case of the US, by 30 percent.

Accompanying this shift has been the creation of a broad and deep supply chain within China that manufactures many of the parts and components the computer industry uses. In 2004, Chinese PC maker Lenovo bought the PC business of IBM, the company that created the mass market for PCs and once set the industry standard—a development that would have been unimaginable 10 years ago.

The movement of manufacturing to lower-cost locations has been occurring for decades, and China's emergence as the leading computer hardware producer is just the most recent phase of this aspect of globalization. The loss of labor-intensive manufacturing is typical for countries such as the US or even Taiwan as they move toward a postindustrial economy.

While these shifts are disruptive, they are usually accompanied by creation of more knowledge-intensive industries, and potentially the expansion of global markets for those industries. A 1998 review of globalization in the computer industry concluded that US computer makers had gained a strategic advantage by partnering with Asia-Pacific suppliers to remain competitive at home and abroad.[1] This study also indicated that the loss of computer manufacturing jobs in the US was more than offset by the creation of jobs in R&D, product design, software, and IT services.

Today, however, such activities are also globalizing, as companies outsource knowledge work to countries such as Ireland, Israel, India, and now China. This has raised concerns about future economic opportunities in the US, Europe, and Japan, as well as in more recently industrialized economies such as Taiwan. So far, little empirical research has actually captured the scale and scope of these trends, what factors are driving or deterring them, or what the implications are for the firms and countries involved.

To address these issues, we have been studying the globalization of new product development in the notebook PC industry.[2] Our purpose is to understand how this type of knowledge work is organized across firms and across geographies. As part of this study, we have conducted numerous interviews in the US, Japan, Taiwan, and China with leading branded PC makers and Taiwanese original design manufacturers (ODMs).

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CHINA'S COMPUTER INDUSTRY

The growth of China's computer industry has been remarkable but uneven in several ways. First, multinational and Taiwanese firms account for most production and exports; domestic firms control much of the local market but most do not compete beyond their borders.

In addition, China remains entrenched in the low-margin, decreasing-returns segments of the computer industry making commodity PCs, peripherals, parts, and components. Local production remains focused on low-cost assembly, and most domestic firms lack the technology, design skills, and marketing capabilities needed to compete in higher-margin segments of the industry. Inadequate protection of intellectual property also discourages both foreign and domestic firms from doing advanced R&D in China.

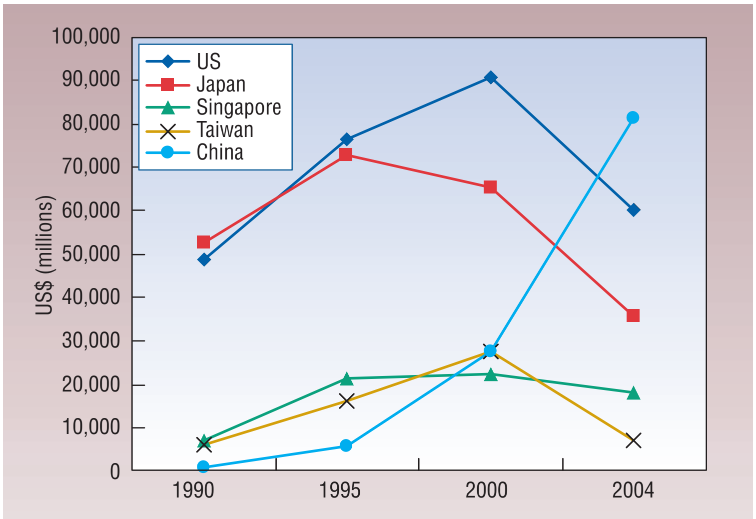

Figure 1. Leading computer-hardware-producing locations, 1990-2004. Source: Reed Electronics Research, **Yearbook of World Electronics Data.**

Taiwanese companies

Taiwanese firms are the world's leading producers of notebook PCs, motherboards, scanners, several types of network equipment, keyboards, add-on cards, optical drives, and monitors.

As Table 1 indicates, the largest segment of Taiwan's computer industry is notebook PC production, as most branded PC makers rely on Taiwanese ODMs for manufacturing and product development. As early as 1995, Taiwanese companies accounted for 27 percent of world notebook production. This figure reached 72 percent by 2004, when the top 10 Taiwanese manufacturers produced more than 33 million of the 46 million notebooks sold worldwide.[3] A PC vendor can now outsource the entire process of developing, manufacturing, delivering, and servicing notebook PCs to an ODM.

Table 1. Top 10 Taiwanese notebook PC manufacturers.

Company	2004 volume (thousands)	Major customers
Quanta	11,100	Gateway, Dell, Hewlett-Packard (HP), IBM, Apple, Sharp, Sony, Fujitsu-Siemens (F/S)
Compal	7,700	Dell, HP, F/S, Toshiba, Acer
Wistron	3,200	IBM, Dell, Acer, Hitachi, F/S
Inventec	2,800	HP, Toshiba
Asus	2,700	Epson, Canon, Sony, Apple, Trigem
Uniwill	1,400	F/S, Samsung, clones
Mitac	1,400	Sharp, F/S, NEC
Arima	700	HP, NEC
FIC	600	NEC
ECS	500	Apple

Source: *DigiTimes*, Jan. 2005.

Taiwan's computer makers and other electronic companies began moving production offshore in the early 1990s in response to rising land and labor costs. While some production went to Southeast Asia, Europe, and elsewhere, most went to mainland China. The role of Taiwanese companies in China is critical, as they have the technical and managerial skills needed to operate high-volume, technologically sophisticated manufacturing processes as well as close working relationships with the major global computer vendors.

The Taiwanese companies have clustered in two regions of China—the Shenzhen area of Guangdong Province, which specializes in desktop PCs, and the Shanghai/Suzhou region that is home to the notebook PC industry. The largest computer hardware producer in China is Taiwan's Foxconn, which employs more than 100,000 Chinese, with 70,000 of those employees in Shenzhen.

Before 2001, the Taiwanese government prohibited the country's notebook makers from doing final assembly of notebooks in China. When the government finally lifted this restriction, the ODMs moved en masse to Shanghai/Suzhou. There they found an amenable location for Taiwanese managers to live where there are good schools and universities, an educated workforce, export processing zones, and access to international air and sea cargo via Shanghai.

Many Taiwanese component suppliers had already relocated to the region by this time, and others soon followed. Nearly 90 percent of the parts needed for a notebook PC—not including the high-value CPUs, hard drives, or displays—are now manufactured in Suzhou.

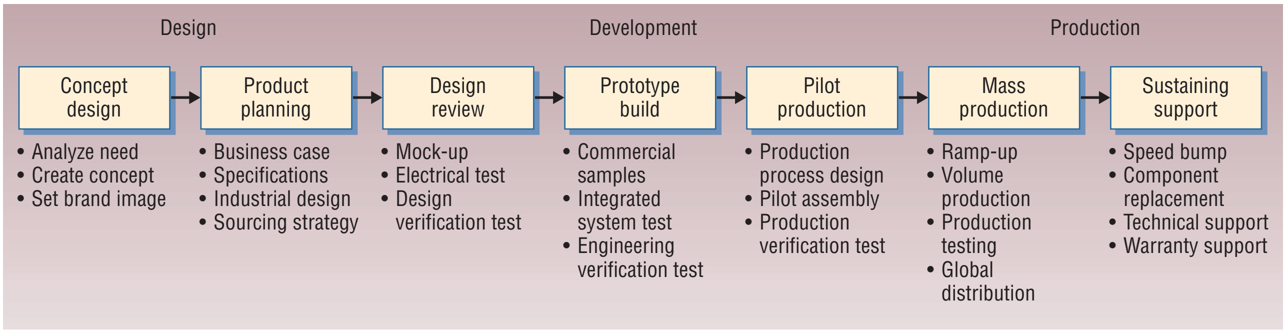

Figure 2. Notebook PC life cycle. Design, development, and production each contain distinct phases with specific activities.

Foreign multinationals

Foreign companies such as Motorola, AMD, Infineon, and Hitachi also have major production facilities in the Shanghai/Suzhou area for notebooks and components such as semiconductors and LCDs. In addition to Taiwanese companies, there is also PC production by foreign multinationals such as Toshiba in Hangzhou, Samsung in Suzhou, and Sony in Wuxi.[1] Outside the two main regions, Dell manufactures PCs in Xiamen.

Local firms

While Taiwanese and foreign companies dominate computer production in China, local firms such as Lenovo, Founder, Huawei, and ZTE are major suppliers of PCs and other hardware to the domestic market, and in some cases, they are becoming exporters as well. Beijing-based Lenovo operates the former IBM facility in Shenzhen, which produces the majority of ThinkPad notebooks for the global market.

NOTEBOOK PC DEVELOPMENT

A PC is based on a modular architecture, meaning that the PC maker and the component maker can develop most components independently and integrate them into a new design with only limited interaction. However, in notebook PCs, both components and system design require more customization. For one thing, developers must package components into a product that is small, thin, light, portable, durable, and energy efficient, and that does not burst into flames from the heat generated during operation. Also, notebook PCs have a fashion element that most desktop PCs lack.

Developing such a product involves solving new engineering problems as developers design new form factors or add new technologies, such as wireless networking. It also requires making choices and tradeoffs to optimize several factors—for example, a bigger battery will run longer but adds weight, while a faster processor will improve performance but generate more heat. Manufacturability likewise is a major issue: As the product must be built in high volumes and at low cost, final assembly must allow packing components and subassemblies into a very tight space quickly and with high reliability. In addition, it should be easy to disassemble and repair the product if necessary.

Product life cycle

Creating a new notebook PC takes about a year and broadly involves three processes: design, development, and production. These processes in turn consist of distinct phases with specific activities, outputs, and gates to pass before proceeding to the next phase, as Figure 2 shows.

Design. *Concept design* consists of envisioning a new product based on market forecasts, technology roadmaps, and customer needs, and creating an initial design specification. *Product planning* involves making a business case for the product, with estimates for costs, units, price, revenues, and margins. The outputs of these phases are a product mock-up, detailed product and marketing plans, a complete design specification, and a bill of materials. At the end of this process, a company decides whether to build the product.

Development. A *design review* determines whether it is physically possible to build the concept design. The review involves creating a working motherboard and a mock-up of the electrical, mechanical, and software systems that will boot up and can be tested.

The *prototype build* involves putting together the chassis, motherboard, components, electrical system, and software and then testing the integrated physical system. The output is a small production lot (50-100) of commercial samples.

Pilot production involves designing the production process and building 500-1,000 units to test the process. The gate for this phase is the production verification test, where the product must meet standards of quality, production time, and out-of-box reliability before ramp-up to mass production.

Production. *Mass production* requires manufacturing engineers to plan and manage the production process, while test facilities and quality engineers must continually improve product and process quality. *Sustaining engineering* deals with changes that follow introduction of a faster processor, failing or end-of-life components, or improved components. Sustaining engineers also provide the highest level of technical support during the product's warranty period.

Organization and division of labor

Notebook design and development is generally organized in one of three ways.

First, the PC maker can employ its own design and development teams throughout the process, perhaps using an outside specialist for a specific task such as industrial design. The most notable practitioners of in-house design are Toshiba and the former IBM PC division that is now part of Lenovo, both of which have development teams in Japan and manufacturing teams in China.

Second, the PC maker can take primary responsibility for design and then hand off the product specifications to an ODM for development and manufacturing. The working relationship in joint design/development is quite close and involves considerable face-to-face interaction. For instance, both HP and Dell have design centers in Taipei that work closely with ODMs in developing new products.

Each phase of new product development requires a different set of skills, and some benefit from proximity to other activities.

Third, the PC maker simply selects a generic product designed by an ODM off the shelf and sells it under its own name. This approach is most common with small PC vendors that lack internal design capabilities or major brands that need to bring a product to market quickly.

Based on interviews and market statistics from leading notebook vendors, we estimate the following shares for the industry: in-house design and development—20 percent; joint design and development—60 percent; and off-the-shelf acquisitions—20 percent. This breakdown varies considerably by company, as only a few PC makers have in-house development teams. It also varies by product line, as PC makers are more likely to buy second-generation or low-end products off the shelf, while those that have internal capabilities focus those resources on more advanced and higher-value products.

LOCATION FACTORS FOR KNOWLEDGE WORK

The availability of persons with the necessary design, development, and production expertise for notebook PC creation varies by geographical location.

Required skills

Each phase of new product development requires a different set of skills, and some benefit from proximity to other activities.

Design. Concept design requires people who know markets and customer demand, as well as technology trends. There also is a need for those who can talk to marketing people and to technologists and anticipate the convergence of customer demand and technology trends. In terms of proximity, it is important to be in leading markets where new technologies are developed and adopted first.

At the product planning stage, required skills include product and project management, industrial design, and business activities such as accounting and procurement. Universities can teach some of these skills, but experience with certain types of products is important, as is having a feel for different markets' aesthetic sensibilities. This stage's requirements favor proximity to leading markets to understand their aesthetics.

Development. At the design review and prototype stages, various mechanical and electrical engineering skills are required. Specialized skills in thermal conductivity, electromagnetic interference, shock and vibration, power management, materials, radio frequency, and software development require a combination of formal training and experience in a particular engineering specialty, as well as working on a specific product type.

At the pilot development stage, the emphasis on manufacturability and producing commercial samples makes proximity to the manufacturing plant valuable. Each model is developed with a manufacturing process and even a particular facility in mind. The link between product development and manufacturing is strong enough that the same firm—either a PC maker or an ODM—both develops and manufactures virtually all products.

Production. Mass production requires process engineering, manufacturing, and operations management skills. Each plant has its own complement of engineers, and if skilled personnel are not available locally, they must be brought in. In time, local engineers can be trained to assume most functions; thus, skills will both be needed and tend to develop as a result of the manufacturing location decision.

Sustaining support requires engineering skills for making and testing minor design changes to accommodate new components or handle upgrades. It also involves monitoring and handling problems that arise in the product during its life cycle, which might only be evident after a product is in the field for some time.

Regional differences

Skill levels vary significantly by location. In the US, workers possess business skills such as market intelligence and product management that are hard to find elsewhere. There are also leading industrial design firms that specialize in small electronic products such as notebooks and cell phones.

Japan has industrial designers who are accomplished at designing for the Japanese market as well as having

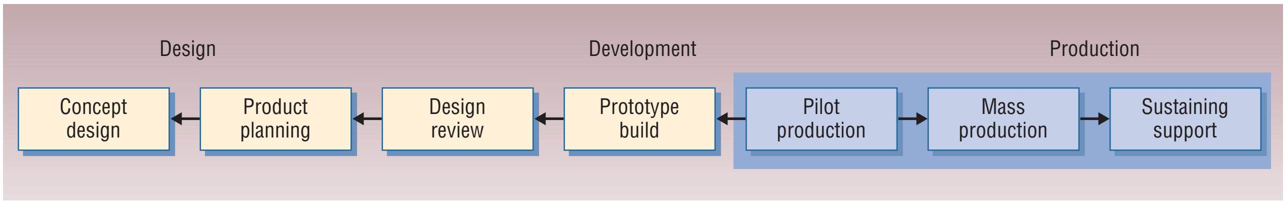

Figure 3. Production pull. As production moves to a low-cost location, it pulls development activities with it.

experience designing for global markets. Japanese design and development teams have deep skills in all design and development areas. Japan also is very strong in process engineering and manufacturing operations.

In Taiwan, mechanical and electrical engineers are available with strong hands-on experience. Taiwan's historical specialization in the PC industry, and notebooks in particular, has created a pool of engineers with a great depth of knowledge in developing these products. It also has strong process and manufacturing skills. Still, Taiwan mostly lacks marketing and industrial design skills that would enable it to take over the concept and product planning stages for leading PC brands.

China has many well-trained mechanical and electronic-design engineers, but they are still developing the hands-on skills that come with experience. Industrial design is weak, and marketing and business skills are very underdeveloped. China produces numerous engineers each year, but quality varies greatly by university.

According to one interviewee, China's engineers "work perfectly at doing what they have been told, but cannot think about what needs to be done; they lack both creativity and motivation. They are good at legacy systems, but not new things; they can't handle 'what if' situations."

CHINA'S EXPANDING DEVELOPMENTAL ROLE

The availability of low-cost engineering talent and production "pull" are responsible for the ongoing movement of knowledge work to China in the notebook PC industry.

Labor costs

Relative employment costs differ greatly among countries. In the US or Japan, an engineer might command $120,000 a year or higher, including benefits and associated overhead. In China, however, a foreign company could hire an engineer for $20,000 a year, a local or Taiwanese firm for even less. Salaries in Taiwan are in between but much lower than in the US. Obviously there are strong economic advantages to moving to China, though productivity differences can negate some of the direct cost savings.

Based on a survey of Taiwanese PC and electronics firms, Louis Y.Y. Lu and John S. Liu found that the main reason these companies were moving R&D to China was the availability of well-educated and cost-effective local engineers.[4] Our own interviews with Taiwanese companies support this finding. As Taiwan's supply of engineers has failed to keep up with demand, the attraction of a large pool of engineers with both linguistic and geographical proximity has been strong. This has enabled Taiwanese engineers to concentrate on more advanced development activities while lower-value activities such as board layout and software coding have moved to China.

Production pull

Some hypothesize that once production moves to a low-cost location, it will pull development activities with it. Lu and Liu found that the second major location factor for R&D, after access to engineers, is proximity to the manufacturing site.[4] Given the importance of design-for-manufacturability, this is particularly true for notebook PCs. Historically, as PC makers outsourced manufacturing to Taiwanese ODMs, product development followed. Some US PC makers have given up their internal development capabilities, while others have relied on ODMs for development from the time they entered the notebook business.

Now, with nearly all manufacturing located in China, another shift is under way. Production and sustaining engineering clearly benefit from proximity to manufacturing, as the manufacturer can address production problems immediately on the factory floor and test engineering changes in existing products in production models from the assembly line. It also makes sense to move pilot production to China rather than maintain an assembly line in Taiwan just for this purpose. Then the question is whether to move the expensive test equipment from Taiwan to China. If so, then there is more reason to relocate the design review and prototype processes as well. Figure 3 shows the effect of this production pull.

Future prospects

During our 2004 visit, one major ODM's staff told us that they did all of their board layout and most packaging design in China, while doing mechanical engineering and software engineering in Taiwan. They were in the process of training people in their electronic engineering methods in China to facilitate moving more development there. As one manager said, "China is a gold mine of human resources, but if you don't train them, you won't be able to take advantage of it."

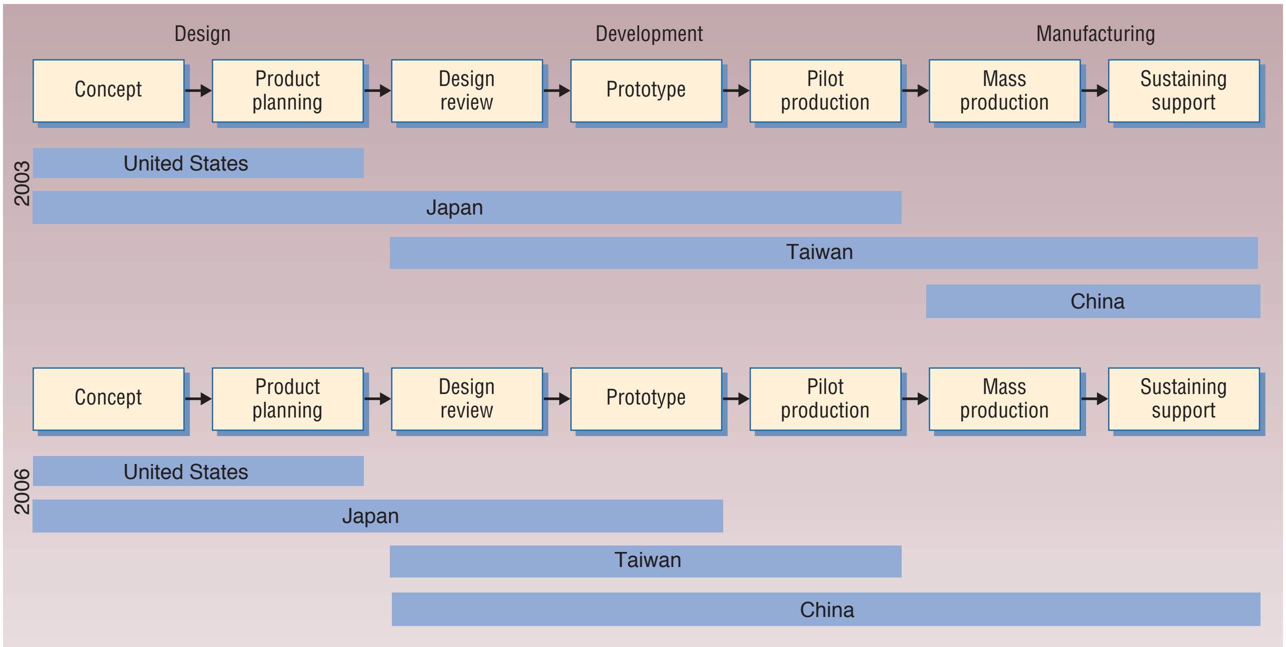

Figure 4. New product development. Many notebook PC makers will likely relocate more new product development processes from Taiwan, and in some cases Japan, to China by 2006. Source: Market Intelligence Center, Institute for the Information Industry, Taiwan.

As Figure 4 shows, many notebook makers will likely relocate more new product development processes and their associated engineering tests from Taiwan, and in some cases Japan, to China by 2006. This shift is not only distinguished by which activities have moved or are moving, but also by the type of products being developed. Some ODMs are moving product updates to China. However, development of completely new products and platforms is still being done by ODMs in Taiwan, or by PC makers such as Lenovo and Toshiba in Japan.

A near-term division of labor for product development is likely to be as follows:

- component-level R&D, concept design, and product planning in the US and Japan;
- applied R&D and development of new platforms in Taiwan and Japan; and
- product development for mature products, and all production and sustaining engineering, in China.

China is likely to capture more of the process and new products as it gains experience, but, unless it becomes a key final market for PCs, it is not likely to capture the market-driven functions of concept design and product planning. Also, unless China strengthens intellectual property protections, it is not likely to become a center for advanced component-level R&D—for example, in microprocessors, LCDs, or wireless technologies.

Currently, China's PC market is still only about one-third the size of its US counterpart, and it lacks leading-edge users to define features and standards for the global market. However, as the market continues to grow and its users become more demanding, it may become the leading market, at least for the Asia-Pacific region.

IMPLICATIONS FOR EMPLOYMENT

The shift in computer hardware production to China from other countries has significantly impacted the global job market. For example, according to the US Department of Labor's Bureau of Labor Statistics (www.bls.gov/sae), total US computer and peripherals industry employment dropped from 236,000 in 2002 to 205,000 in 2005, with production jobs falling from 55,000 to 31,000.

In contrast, computer, math, and engineering jobs in the industry only fell from 92,000 to 89,000 during the same time. Also, headquarters and marketing functions have remained in the US, so business and management jobs have actually increased. Many of the knowledge jobs related to development and manufacturing apparently had already moved offshore by the late 1990s, while the US retained more high-end knowledge work in concept design, product management, marketing, and brand management.

However, these numbers fail to capture the industry's continued growth, with shorter product cycles and proliferating models requiring ever more engineering work, and this growth is not occurring in the US. The fact that Dell and HP both operate design centers in Taipei with hundreds of engineers suggests that even more jobs can potentially move offshore.

Even more important for the US is what the past offshoring of knowledge work in the computer industry portends for future employment in other large-scale industries. For example, product development, design, R&D, and other innovative activities account for many US jobs in software development, IT services, the electronics industry, automobile production, the aerospace industry, clothing manufacturing, and the pharmaceutical industry.

In some cases, these activities might be pulled offshore along with manufacturing, or they might move to places where engineering and other creative skills are abundant and cheap. If so, our research suggests that China will attract a good share of the knowledge work associated with manufacturing industries, given its large pool of engineers and its role as a manufacturing center.

In addition, as China becomes a major market for many goods, firms will seek to develop products specifically for the Chinese market to be more competitive there. The Chinese government will likewise offer incentives to attract knowledge activities as it tries to become a center of innovation rather than just a manufacturer of others' innovations. On the other hand, for software and services, China is far behind India and faces competition from other countries such as Ireland, Israel, and the Philippines.

The competitive impact of China's rise on US companies has been mixed so far. Dell and HP have consolidated their global market leadership, while Apple and Gateway remain strong competitors in the US. However, US companies have had less success penetrating China itself. Dell has captured the fourth spot in China's fast-growing PC market, but its lack of distribution beyond the major cities has hampered growth. Chinese PC makers still hold four of the top five spots, with Lenovo having a dominant share of more than 30 percent.

The shift of design and development to Taiwan and Asia likewise does little to change the competitive environment. Dell and HP have expanded in Taiwan to work more closely with the ODMs, but their joint design/development models already relied heavily on ODMs. The same is true for other US PC makers. If anything, the growing reliance on ODMs makes product design differentiation harder, as all PC makers have access to the same ODM suppliers.

Lenovo's acquisition of IBM's PC business constitutes China's first bid to become a global player in the notebook PC market. Growth by acquisition has a poor track record in the PC industry, but if Lenovo succeeds, it could establish a precedent for Chinese companies to acquire the technical and managerial skills needed to compete in global technology markets. ■

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References

1. J. Dedrick and K.L. Kraemer, *Asia's Computer Challenge: Threat or Opportunity for the United States and the World?*, Oxford Univ. Press, 1998.
2. J. Dedrick and K.L. Kraemer, "Knowledge Management across Firm and National Boundaries: Notebook PC Design and Development," unpublished report, Personal Computing Industry Center, Univ. of California, Irvine, 2003; www.pcic.gsm.uci.edu/notebookpc.pdf.
3. Y. Yang, "The Taiwanese Notebook Computer Production Network in China: Implication for Upgrading of the Chinese Electronics Industry," Personal Computing Industry Center, Univ. of California, Irvine, 2006; www.pcic.merage.uci.edu/pubs/2006/TaiwaneseNotebook.pdf.
4. L.Y.Y. Lu and J.S. Liu, "R&D in China: An Empirical Study of Taiwanese IT Companies," *R&D Management,* vol. 34, no. 4, 2004, pp. 453-465.

Jason Dedrick *is a Senior Fellow at the Center for Research on Information Technology and Organizations (CRITO) and executive director of the Personal Computing Industry Center (PCIC) at the University of California, Irvine. His research interests include the globalization of computer production and use, national technology policies, and the productivity impacts of information technology. Dedrick received a PhD in management from the University of California, Irvine. Contact him at jdedrick@uci.edu.*

Kenneth L. Kraemer *is a professor of information systems at the Paul Merage School of Business and in the Department of Informatics at the Bren School of Information and Computer Science, as well as director of CRITO and PCIC, at the University of California, Irvine. His research interests include the use and impact of information technology in organizations, the globalization of IT production and use, and management of information systems. Kraemer received a PhD in public policy and management from the University of Southern California. He is a member of the ACM. Contact him at kkraemer@uci.edu.*