New Product Development in a Global Knowledge Network: The Notebook PC Industry[1]

Jason Dedrick and Kenneth L. Kraemer
Personal Computing Industry Center
University of California, Irvine

Prepared for the Sloan Industry Centers Annual Meeting
Cambridge, MA

December 15, 2005

[1] This research is part of the Global Knowledge Networks project (GII) and has been supported by a grant from the Sloan Foundation.

I. INTRODUCTION

Businesses are increasingly relying on knowledge networks to support innovation and create competitive advantage. The scope of knowledge required in many industries is far greater than any individual can master, so firms must tap into networks that cross organizational and national boundaries. Some of these networks are global in scale, linking firms and individuals from around the world to create new knowledge and develop new products and services.

The design and development of notebook computers illustrates the use of global knowledge networks to extend the innovative capabilities of the firm. Branded PC makers rely on a network of component suppliers and original design manufacturers (ODMs) to bring new notebook models to market and incorporate new technologies into those products. The industry is global, but product development and manufacturing are concentrated almost entirely in the U.S., Japan, Taiwan and China.

Although the proportion of outsourcing differs from firm to firm, it is substantial in all firms, as shown in Table 1. Brand name PC companies are outsourcing not only manufacturing, but much of the new product development process to the Taiwanese ODMs. These ODMs are now the key operational part of the industry's supply chain, linking component and peripheral suppliers to meet the product requirements of the branded companies.

Table 1. PC Makers Outsourcing to Taiwanese Firms

PC companies	**% of production outsourced 2005** [b]	**Taiwanese ODM suppliers** [a]
Apple	100	Quanta, Asus, Elite
Dell	92-93	Quanta, Compal, Wistron
HP	100	Quanta, Compal, Wistron, Inventec, Arima
IBM*	40	Wistron, Quanta
Acer	100	Quanta, Compal, Wistron
NEC	100	Arima, FIC, Wistron, Mitac
Sharp	n.a.	Quanta, Mitac, Twinhead
Sony	60	Quanta, Asus, Foxconn
Toshiba	>70	Quanta, Compal, Inventec
Fujitsu-Siemens	50	Wistron, Mitac, Uniwill, Quanta, Compal

Sources:
[a]You-Ren Yang & Chu-Joe Hsia, 2004. They quote this table from report of Ministry of Economic Affairs, Taiwan. Cited in Yang, 2005.
[b]Digitimes, 2005
*Note: IBM's PC business is now part of Lenovo, but this information is for IBM prior to its acquisition.

By looking closely at the product development process in one industry, we are able to understand better how global knowledge networks can be organized, how knowledge work is organized within and between firms, why different activities are located where they are, and what the implications are for companies and countries. We have studied new product development in the notebook PC industry through collection of secondary data and through interviews with PC makers and ODMs in the U.S., Japan, Taiwan and China.[2]

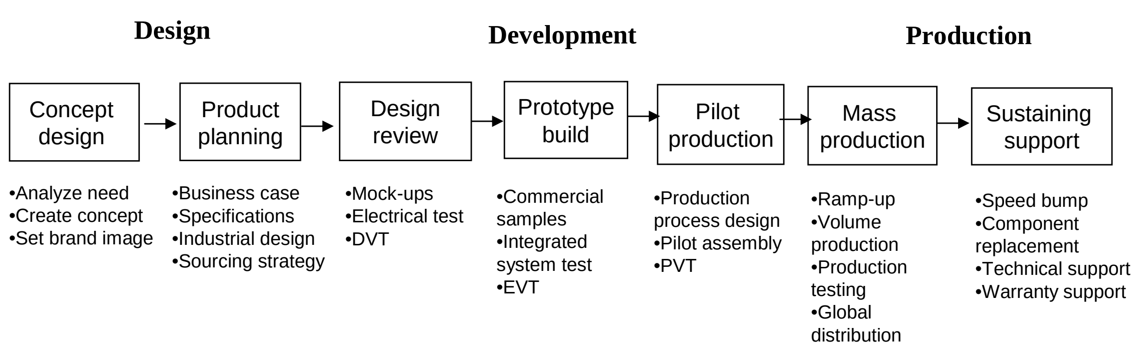
In this paper, we first describe the new product development process for notebook PCs, then discuss the organization and coordination of the process, then look at the location of development activities geographically. We conclude by considering implications of the globalization of new product development for firm strategy and competition and for U.S. employment.

II. THE DESIGN AND DEVELOPMENT PROCESS

The product development cycle for notebook PCs consists of three major phases: design, development and production. These phases take roughly a year for an entirely new product, and less for upgrades of existing platforms. Products may stay in production for about a year, and are under warranty coverage for 1-3 years. This means that there may be knowledge work required for up to five years for a single product. Our focus is on the first year, from initial product planning through ramp up to full-scale production.

Following the principles of Wheelwright and Clark (1992, 1995), notebook PC makers have organized new product development into specific activities and outputs, with gates to pass before proceeding to the next phase. In the notebook PC industry, this process is organized into two design phases, three development phases, and two production phases, as shown in Figure 1 and discussed below.

Figure 1. Phases and Activities in the Product Life Cycle



Design Phases

<u>Concept design</u>. All PC makers engage in concept design, where an effort is made to define a new product based on market forecasts, technology roadmaps, and customer needs. Concept design is led by a multidisciplinary team comprising people from product marketing, market intelligence, industrial design (ID), and physical design disciplines. The output is usually a

[2] This paper draws on the following: Dedrick and Kraemer (1998, 2004 and 2005), Kraemer and Dedrick (2002, 2005)

design requirements document that identifies the target market, desired features (size, weight, battery life, screen size, components), industrial design language and resources required to develop the product.

Product planning. In this phase, a planning team translates the market data, user requirements and product features into a business case for the product with estimates for costs, units, price, revenues and margins. The industrial design language is translated into mock-ups of the product thru sketches and cardboard or styrofoam models. A least one firm uses computer-generated 3D models. Mock-ups of the components are placed within a chassis (actual or mock-up) to determine physical feasibility and layout. Discussions are held with the development group regarding technical feasibility and potential development issues.

The output is a detailed product plan where, as one planner put it, "the project is nailed down from words to numbers." The plan presents the business case including segmentation by market and region, cost, margins and other financials. It includes a detailed product and marketing plan including product timing, resource requirements, and commitments of different functional areas, and also includes a design validation plan to control the development stage. The outcome of this phase is a decision to build the product, which is made by the most senior executives in product planning, marketing and design/development. A product management team is then assigned to the product to manage the product through development, mass production and sustaining support.

Development Phases

Design review. Design review is conducted to test whether the concept design can be built physically. It involves creating a working motherboard and a working mockup of the product with its components and software drivers from the specified bill of materials. The physical chassis for the components and the display is built from the industrial design with attention to mechanical issues such as the display hinge strength and cover closure fit, and functionality issues such as input and output locations for ease of use. The result is a hand-tooled chassis and working mock-up of the system that will boot and operate, but might not be stable. There might be one or more of these "engineering samples," each involving different design tradeoffs to be evaluated by the product management team.

The gate for design review is a design verification test, or DVT. The design review might result in new specifications for components, functionality, software or physical layout because new technologies become available or system integration problems require changes. If any open issues can be resolved reasonably in the next phase, the product is moved to the next phase.

Prototype build. In this phase, the chassis, motherboard, components, electrical system and software are put together into an integrated physical system and tested. This is when issues such as heat dissipation, power management, and battery life are tested and the whole system is "stressed" under extreme operating-like conditions related to running time, vibration, shock, and pressure in test laboratories. These tests indicate where key design changes are needed. The output is a small production lot (50-100) of commercial samples that represent a stable, reliable product for hands-on review by the development team and prospective users.

The gate for this phase is the EVT, or engineering verification test. The prototypes must pass reliability and quality criteria and the physical samples must meet criteria for fit and finish. These test data and samples are reviewed by the project management team at a gate meeting with the developers to determine whether the product can proceed to the next phase.

Pilot production. The final development phase involves preparation for mass production. The production process is designed and a pilot production line is set-up to produce around 500-1,000 units that will enable a test of the process. There is also an out-of-box test of the quality of the units produced, wherein a sample of 100-200 units are taken out of the box and tested as if a user were setting up the system.

The gate for this phase is the PVT, or production verification test, where standards of quality, production time, and out-of-box reliability must be met before ramp-up to mass production. The final "go" decision on production is made jointly by the manufacturing, development and project management teams.

Production Phases

Mass production requires manufacturing engineers to plan and manage the production process and requires test facilities and quality engineers to continually improve product and process quality. Over time, these engineers come to know the product extremely well and are best positioned to provide sustaining engineering support that was previously provided by the original development teams.

Sustaining support deals with changes that occur because of introduction of a faster processor, failing or end-of-life components, or improved components. The sustaining engineers also provide the highest level of technical support when problems occur during use over the product's 2-3 year warranty period.

III. ORGANIZATION AND COORDINATION

This formalization of the development process has enabled a shift from in-house design and development to either outsourcing or joint development with ODMs. The nature of the process creates clear points at which development can be handed off from the PC maker to an ODM (Sturgeon, 2002). The driving forces behind the shift to outsourcing are the competitive pressure to reduce costs, the growing capabilities of ODMs, and the perceived commoditization of notebooks. The notebook market may not be as price driven as the desktop market, but cost reduction is still an imperative for all PC vendors. Given the lower cost structure of Taiwanese ODMs, and the desire of PC makers to reduce headcount and fixed costs, there is a strong incentive to outsource product development.

The ODMs have developed specialized knowledge in notebook design that only a few PC makers can match or exceed. Historically, companies such as IBM, Sony and Toshiba have used their internal design capabilities to differentiate their products and gain competitive advantage.

However, there is a general belief expressed during field interviews that the ability to use hardware design to differentiate in ways that matter to customers is waning.

There are three ways in which design and development are organized between PC vendors and ODMs. First is in-house design, in which the PC maker uses its own design and development teams throughout the process. Second is joint design/development, in which the PC maker develops product specifications, sometimes with input from an ODM, then works with the ODM in the development, testing and production engineering processes. The third approach is when the ODM designs a generic product and the PC maker simply selects the product off the shelf and sells it under its own name.

We have found no data at the industry level on this, but based on interviews and on market share of leading notebook vendors, we would estimate the following shares: in-house design and development: 20%; joint design and development: 60%; and off-the-shelf: 20%. This varies considerably by company, as only a few PC makers have in-house development teams, and those vary in depth of capabilities. It also varies by product line, as PC makers are more likely to outsource design of second generation or low-end products and more likely to buy off-the-shelf for a product they want to get to market quickly.

The trend reported by the companies and outside observers is toward greater use of ODMs, but mostly through joint development. The ODMs might prefer to design their own product and be able to sell to multiple customers, but this part of the market will probably remain limited to low-end products, or to smaller PC vendors who lack any design capabilities. As one PC vendor stated, "On occasion we will buy off the shelf products from ODMs, but doing it is risky because you can't control anything about the product."

ODMs are said to be capable of architecture design, mechanical and electrical engineering, and component selection, but the PC maker needs to protect its brand, product look and feel, and procurement leverage, which can be done by retaining industrial design, product management, high level architecture, and test monitoring. Quality control is very important for a product that is very light, thin and complex, yet takes a lot of abuse ("no one calls us and says they left their desktop on top of their car and drove away"). So PC makers oversee this closely. They also work with Intel, AMD and other suppliers for strategic procurement decisions. They want to control which components are used across the different series and models within each series to reduce cost, reduce complexity, and provide for serviceability.

Interaction of Firms

Throughout development, the PC maker may be involved to various degrees in overseeing the process. All PC makers audit the design implementation, but ODMs say that some PC makers are much more hands-on than others.

The extent of oversight in the process also declines over time as a relationship with the ODM develops. One PC maker said that when working with inexperienced ODMs, they have to spend about one month working with them early on and also assign an engineer full time on site. When working with experienced ODMs, they only need to visit them at check points for entry and exit.

Since most of the cost in a notebook PC is in the components, an important issue is procurement, i.e., who selects the suppliers and negotiates prices. Larger PC makers have enough volume to get the best prices on major components such as microprocessors, memory, drives, panels, batteries and graphics chips. They also want to be able to control the relationship with key suppliers. Smaller vendors might allow an ODM to negotiate, since the ODM has a much larger production volume than the PC maker. For less critical parts such as resistors, cables, fans etc., the ODM is more likely to handle procurement since it sits close to the supply network in Taiwan or China.

There is not a consensus as to the value created from in-house development or the relative ease of working with in-house teams versus ODMs. One PC company that does both in-house design and works with ODMs says the process is very similar either way. Another PC maker that uses ODMs for all design argues that the results are similar to in-house design as long as the process is closely controlled.

Internal Coordination

The product and functional teams constitute the internal organization for knowledge creation and deployment in both the vendor and ODM organizations. The product management team is the central coordinating structure across design, development and production. One team handles a product from concept through the first 90 days of production, when the product is transitioned to sustaining engineering. The matrix organization of design and development teams facilitates sharing of knowledge across development phases, engineering disciplines and product platforms. Product teams handle single products throughout the process, but coordinate with other product teams on things like selection of components to reduce procurement costs and simplify the task of supporting a number of product lines. Engineering teams coordinate across platforms and products on solutions to system integration issues.

The formal gates at the end of phases in the design and development cycle facilitate information sharing because they document key outcomes of the preceding phase. Design teams meet with development engineers before, during and after handover; development teams meet with manufacturing engineers; and manufacturing teams meet with sustainability engineers. All product/process reviews are mechanisms for both formal and informal collaboration and information sharing.

External Coordination

The joint development process is very much like a PC maker's internal process. When using an ODM, a contract is executed with specifications, tests, timing and gates, and it becomes the framework for coordination. Vendors and ODMs agree that coordination tends to be more formal in these instances and is more costly than internal coordination.

Vendors and ODMs have formal meetings only 4-5 times over an 8-12 month design/development cycle. Usually one meeting occurs during design, whereas the others occur at the end of each stage of development. However, there might be many more face-to-face meetings between individual designers or engineers to work out specific issues or problems. As put by one ODM, “there is somebody from (the PC maker) here about every two weeks throughout the design and development process. Sometimes it is product managers, sometimes industrial designers and other times electrical, mechanical or software engineers. The engineers usually stay a week and work closely with our engineers. Engineers also come to Taiwan or China to see production once it gets rolling. They want to be sure things are going OK and they want to see how things are being done in detail.” By being physically present, they can see any problems directly and jointly solve them much faster than having to communicate via telecommunications as it is critical not to miss product launch dates in the time-based competition of the industry.

In new relationships, the PC maker and ODM spend considerable time “educating” one another, but this declines with successful experience and development of trust. One vendor uses visitors from headquarters to convey management culture, engineering practice, or technical matters to their ODM. Another uses temporary assignment of ODM engineers to headquarters or to the development organization. ODMs complain that some PC makers do too much monitoring, thereby increasing the ODM’s costs.

Management across cultures is often an issue as vendor and ODM frequently have different styles. One vendor described Taiwanese companies as wanting to have harmony, avoid conflict and look for alignment quickly, whereas Americans are more comfortable with debate, conflict and negotiation. Communication also differs according to this vendor: “Americans hit the key point and then explain the details, whereas Taiwanese build the story and then get to the main point. We have to ask them, ‘What’s your one page slide?’ We have started to use templates to get them to go through our process. We also have classes on conflict management and communication.”

Knowledge Management and Dissemination

The structures and processes for knowledge management include quality teams, design reviews, shared databases, engineering change requests and newsletters to disseminate knowledge. One vendor uses quality teams not only to ensure that quality is built into design and development, but to distill lessons learned from production and customer use that have implications for future design. Help center calls, critical customer situations and problems/solutions encountered during development and production are entered into a problem management database covering all active products. This database is culled by the quality team for lessons learned which are then disseminated via “lessons learned” newsletters, quality champions in product team, subsystem design teams (mechanical, electrical, software) and the manufacturing procurement organization. We did not determine how much the problem management database is used, but the lessons learned newsletter was described as a big success.

While it is not clear how much the knowledge repositories are used, it is clear that product management databases are used throughout the design, development and early production phases, and passed on to the sustaining engineering team. These databases contain documents, drawings, analyses and tests that are used on a daily and weekly basis throughout the process. They are the official record for confirming product specifications, engineering change requests, product review meetings and the stream of decisions that emerge from these activities. All product and functional teams contribute to them and use them in the course of their activities.

Information Technology

Design, development and production occur in different geographies and information technology (IT) plays a key role in coordination. Communication may be synchronous and asynchronous forms, but the latter is more frequent because of time differences.

All forms of IT are used for coordination: fax, scanners, email, instant messaging, telephone, collaboration tools and design tools. Email is used on a daily basis both for messaging and for sharing files such as documents, open-issue lists, drawings, bill of materials, photographs, and 3D images. Weekly telephone conferences are used for updating and review. Person to person calls are used for urgent issues. One ODM uses NetMeeting internally, but not with customers. One vendor uses the Notes platform to create a shared file where all materials related to a particular product are posted throughout the full product lifecycle and available to anyone with access privileges.

The industry is reportedly becoming aligned on tools for design, with vendors and ODMs having either the same tools, or viewing capabilities for each others' tools. One ODM feels that the tools increase productivity a little, but views them more as a necessary evil—something pressed on the ODMs by the major vendors rather than being a real need. The cost of a single seat for a CAD program, for example, can be $50,000 plus 20 percent annually for maintenance. Consequently, the ODMs may buy only a few seats, share the software among their engineers and not always implement the updates.

The extent to which 3D tools are used for industrial design is unclear as yet. One vendor indicated they do not use such tools, relying more on hand sketches of design features and scanned photos of physical mock-ups. They consider the latter a quicker and more flexible approach. The 3D tools seem to be more appropriate for tooling and the design of plastic moldings and enclosures.

IV. LOCATION OF KNOWLEDGE WORK

The geographic location of new product development activities is influenced by the skill requirements associated with different stages of the process, the cost of those skills in different locations, and the benefits of having some activities located in close proximity to others. One effect of the need for proximity is that the shift of production to China is pulling that latter stages of development there, and may pull other processes as well. This production "pull" is reinforced by the availability of low cost engineers in China.

Skills, Cost and Proximity

Each of the phases 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 people who can talk to marketing people and to technologists, and anticipate how customer demand and technology trends are converging. In terms of proximity, it is important to be located in leading markets where new technologies are developed and are adopted first.

At the product planning stage, skills include product and project management, industrial design, and business skills such as accounting and procurement. For industrial design, there are general skills taught in universities, but experience in certain product types is important, as is a feel for the aesthetic sensibilities of different markets. The requirements of this stage favor proximity to leading markets to understand these aesthetics.

Development

At the design review and prototype stages, a variety of mechanical and electrical engineering skills are required. Specialized skills are needed in thermal, electromagnetic interference, shock and vibration, power management, materials, radio frequency, and software. These require a combination of formal training and experience working in a particular engineering specialty, as well as working on the 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 virtually all products are both developed and manufactured by the same firm, either a PC maker or an ODM.

Production

Mass production requires process engineering, manufacturing, and operations management skills. Each plant has its own complement of engineers, and if the skills are not available locally, they must be brought in. In time, local engineers can be trained to take over most functions; hence skills will both be needed and will 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 lifecycle, which might only be evident after products are in the field for some time.

Availability of Skills

Skill levels vary significantly in different locations. In the U.S., there are 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 electronics products such as notebooks and cell phones.

In Japan, there are industrial designers that are very good at designing for the Japanese market, but also have 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 these products. It also has strong process and manufacturing skills. Taiwan still mostly lacks marketing skills and industrial design skills that would allow 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. A large number of engineers are produced 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."

Relative costs vary greatly among the countries. Compared to engineers in China, the base salary in Taiwan is about twice as high, while in Japan and the U.S. it is six to eight times as high (Table 2). Within China, multinationals from the U.S., Japan or Europe pay considerably higher salaries than Taiwanese or mainland Chinese companies (Table 3). Obviously there are strong economic advantages to moving to China, but differences in productivity can negate the direct cost differences.

Table 2. Comparative Costs of Electronic Engineers by Location

	Average base salary
United States	$82,000
Japan	$63,000
Taiwan	$20,000
China	$10,000

Source: For U.S., Bureau of Labor Statistics Occupational Employment Statistics, 2005
For Japan, Quan, 2002
For Taiwan, EE Times, 2003 and interviews with ODMs in Taiwan
For China, PR Newswire, 2004 and interviews with PC makers and ODMs in Taiwan and China.

Table 3. Engineering Salaries in China by Home Base of Notebook PC Company

Company home base	Base salaries paid in China
U.S.	$15,000 (6-7 years experience) $7,500 (new graduates)
Japan or Europe	Similar to U.S. companies
Taiwan	$5,000 (new graduates)
China	$5,000 (new graduates)

Source: Interviews with PC makers and ODMs in China, Taiwan and Japan

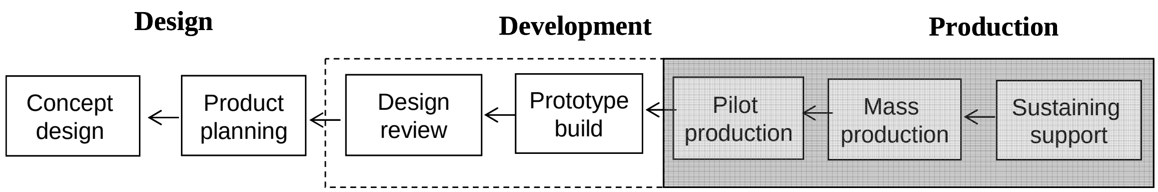
Based on a survey of Taiwanese IT firms, Lu and Liu (2004) found that the main reason these companies were moving R&D (primarily development) to China was the availability of well-educated and cost effective local engineers. This finding is supported by our own interviews with Taiwanese companies. As 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 (2004) found that the second major location factor for R&D (after access to engineers) is proximity to the manufacturing site. This is particularly true given the importance of design-for-manufacturability in notebook PCs. Historically, we have seen product development follow manufacturing from the U.S. to Taiwan as PC makers outsourced development to Taiwanese ODMs (Kraemer and Dedrick, 2005). Some U.S. PC makers have given up their internal development capabilities while others relied on ODMs from the time they entered the notebook business.

Now, with nearly all manufacturing located in China, another shift is happening. Production and sustaining engineering clearly benefit from proximity to manufacturing, as production problems can be addressed immediately on the factory floor and engineering changes in existing products can be tested 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 arises 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. The effect of this production "pull" is seen in Figure 2.

Figure 2. Production "Pull" of Development Activities



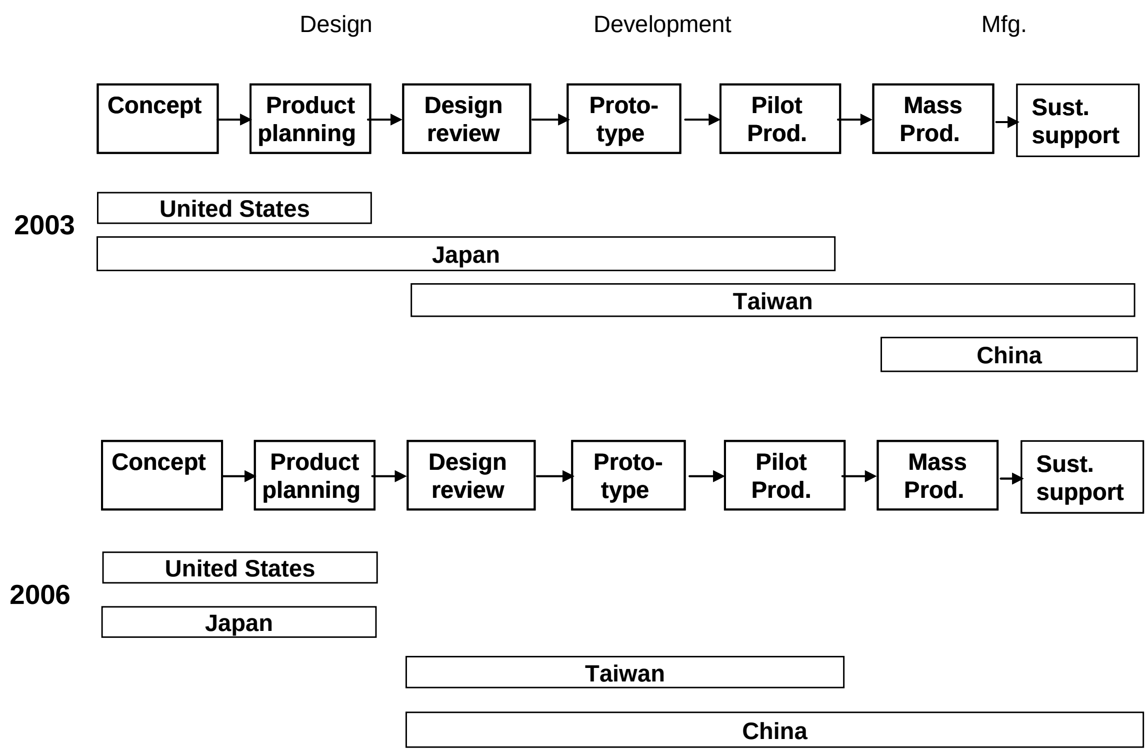
Trends in Location of Product Development

As a result of "production pull" as well as the large pool of lower cost engineering skills, there is an ongoing shift of product development activities to China. During our 2004 visit, one major ODM 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 in order to move more development there. As one manager said, "China is a gold mine of human resources, but if you don't get in and train them you won't be able to take advantage of it."

By 2006, it was expected that more of the new product development process and the associated engineering tests will be conducted in China by many notebook makers. These will be relocated from Taiwan and in some cases Japan (Figure 3).

The shift of product development to China is not only distinguished by which activities are moving, but also by the type of products that are being developed. Some ODMs are moving product updates to China. However development of completely new products and platforms is still done by the ODMs in Taiwan, or by PC makers such as IBM and Toshiba in Japan.

Figure 3. Location of Product Development for Notebook PCs



Source: Market Intelligence Center, Institute for the Information Industry, Taiwan, and company interviews

A near term division of labor for product development is likely to be as follows: concept design and product planning in the U.S. and Japan; applied R&D and development of new platforms in Taiwan; product development for mature products, and all production and sustaining engineering in China.

As China gains experience, it is likely to capture more of the process and new products, 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 for world markets (although it might be for specialized markets). And unless intellectual property protections are strengthened, China is not likely to become a center for advanced component-level R&D, e.g., in microprocessors, LCDs, or wireless technologies. As of now, China's PC market is still only about one-third the size of the U.S. market, and does not have leading edge users who are defining what features and standards are developed for the global market.

However, as China's PC market continues to grow, it may become the leading market at least for the Asia-Pacific region, and definition and planning of products suitable for the region may be done there. In particular, China might be a leading market for very low cost PCs that would be affordable to millions of consumers for whom even $500 is too expensive. Given that China now has nearly 300 million cell phone users but well under 100 million PC users, there clearly is an untapped market there. A functional PC in the $100 range could tap this market, and also be affordable to millions more consumers around the world who currently do not use PCs. Such a price level could not be reached with current PC technology standards, however, as the cost of commercial operating systems and microprocessors alone can exceed $100. Efforts to build very low cost PCs in places such as Brazil and India have failed so far, but the opportunity is there and China's position as a low cost manufacturing center make it a logical place for such a development.

V. IMPLICATIONS OF GLOBALIZATION OF KNOWLEDGE WORK

The restructuring of new product development both organizationally and geographically has implications for competition in the PC industry, and for employment. We look at the impacts on firm strategy and competition and then focus on implications for employment in the U.S.

Implications for Strategy and Competition

The notebook PC market has continued to grow at double digit rates even as desktop sales have declined. As long as the U.S., Europe and Japan remain the major markets, and common designs can be used across those markets, U.S. and Japanese vendors will continue to lead the industry. In China, the dynamics could be different, given the strong position of Lenovo and other local companies. By tapping the capabilities of the ODMs, Chinese companies are already offering cheap notebooks, and China is likely to be a market where low price is more important than distinctive design for many years.

There is a debate about whether the notebook is becoming so commoditized that one cannot differentiate products with hardware design. The vendors we interviewed believe this is becoming the case, but they also believe that differentiation is critical. Some believe that the opportunity to differentiate is shifting to software and services. Others believe the opportunity is in market segmentation. However, with new technologies continuing to be introduced and notebooks gaining much wider popularity in consumer markets, there may still be room to differentiate through design for some time. Less clear is whether in-house development teams are still a source of competitive advantage, or whether such differentiation can be achieved just as well through joint development with ODMs.

Strategically, the vendors are outsourcing an activity that had been a source of product differentiation for some, but appears to be less so today. In doing so, they gain cost savings that go directly to their margins. And, they can concentrate on high-level concept design where this is still opportunity for product differentiation through targeting the right markets, rapidly incorporating new technology, strengthening brand image and bringing new products to market faster than competitors.

In operational terms, there are few risks from joint product development. ODMs work under contract to meet product specifications and test criteria, and vendor product managers monitor their work to ensure they do. When problems occur, they work cooperatively to solve them. Some ODMs do not share all of their processes with notebook makers. One Taiwanese ODM indicated that they have their own tests and processes that they do not share with the vendors because it is proprietary technology that they see as a competitive advantage over other ODMs. They share the results so the vendor sees the advantage, but not the processes or test equipment.

The bigger potential concern is that an ODM will reveal information about one customer to another, since the major ODMs work for multiple PC makers. One vendor mentioned an ODM showing them a design done for a competitor, mainly out of pride in the design, but otherwise this was not mentioned as a concern. Another executive mentioned that he was able to learn quite a bit through interaction at industry events where people in the small community sometimes are quite talkative. Overall, the risk of joint development is probably reduced by the long-term nature of the relationships; if an ODM was seen as unreliable it would risk future business with existing customers, and probably with other potential customers given the closeness of the community.

Implications for U.S. Employment

The shift of production out of the U.S. since 2000 has been dramatic, with output falling by over 30% in four years, while China's production tripled. The impact of falling production on U.S. jobs has been significant. Total hardware industry employment fell from 322,000 in 1998 to 210,000 in 2005, with production jobs falling from 126,000 to 87,000 (Bureau of Labor Statistics, 2000-2005). The decline in employment is likely to slow as PC makers need to keep the production of bulkier desktop PCs and servers in the U.S., especially to handle customized orders and government contracts. Also, headquarters and marketing functions have remained in the U.S.

The loss of design and development work will have less impact on U.S. jobs, simply because there are not as many jobs at stake. We estimate total number of knowledge workers (e.g., market analysts, product managers, industrial designers and all types of engineers) across major vendors and leading countries in notebook design and development to be on the order of 15,000 to 20,000. Some of these jobs are moving, mainly from the U.S. to Taiwan and from Taiwan and Japan to China. While we do not know the number of jobs the U.S. has lost, we do know that it is retaining the high-end knowledge work so far, thanks to its position as the leading market and its advanced skills in concept design, product management, marketing and brand management.

More important than the number of jobs involved in the PC industry is what the shift of knowledge work might portend for other industries in which much larger numbers of jobs are involved. Product development, design, R&D and other innovative activities account for many jobs in industries such as software, IT services, electronics, aerospace, automobile, clothing, and pharmaceuticals. In some cases, these activities may be pulled along with manufacturing, or they may 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, there will be an incentive for firms to develop products specifically for the Chinese market in order to be more competitive there. These factors will be enhanced by the combination of incentives and regulations used by the Chinese government to attract and encourage such knowledge activities as it tries to become a center of innovation rather than just a manufacturer of the innovations of others. On the other hand, for software and services, China is far behind India and faces competition from other locations such as Ireland, Israel, and the Philippines.

REFERENCES

Bureau of Labor Statistics (2000-2005). Employees on Nonfarm Payrolls by Major Industry Sector and Selected Industry Detail, Seasonally Adjusted. Washington DC: Department of Labor. http://www.bls.gov/ces/home.htm#tables

Bureau of Labor Statistics (2005) Occupational Employment Statistics, Washington, DC: Department of Labor. http://www.bls.gov/oes/

Dedrick, Jason and Kenneth L. Kraemer (1998), *Asia's Computer Challenge: Threat or Opportunity for the U.S. and the World*? (New York: Oxford).

Dedrick, Jason and Kenneth L. Kraemer (2004), Knowledge Management across Firm and National Boundaries: Notebook PC Design and Development, Irvine, CA: Personal Computing Industry Center. http://www.pcic.gsm.uci.edu/notebookpc.pdf

Dedrick, Jason and Kenneth L. Kraemer (2005). The Impacts of IT on Firm and Industry Structure. *California Management Review*, *47*(3), pp. 122-142.

DigiTimes, January 2005. Taiwan notebook industry overview. http://www.digitimes.com/NewsShow/NewsSearch.asp?DocID=000000000000000000000000002804&query=TAIWAN+NOTEBOOK

EE Times (2003). "EE Times-Asia Salary and Opinion Survey reveals mixed fortunes for Asia's Engineers," http://corporate.globalsources.com/INFO/PRESS/ARTICLES/OCT2303.HTM

Kraemer, Kenneth L. and Jason Dedrick (2002), Enter the Dragon: China's Computer Industry. *IEEE Computer*. 35(2), pp. 28-36.

Kraemer, Kenneth L. and Jason Dedrick (2005). Offshoring in the PC Industry. Irvine, CA: CRITO, working paper.

Lu, Louis Y.Y. and John S. Liu (2004). R&D in China: An Empirical Study of Taiwanese IT Companies. *R&D Management*, 34(4), pp. 453-465.

PR Newswire (2004), Salaries of Mainland China Electronic Engineers Rising By Up To 12 Percent - Global Sources Survey http://www.prnewswire.co.uk/cgi/news/release?id=130057

Quan, Margaret (2002), "EE compensation, increases vary worldwide" *EE Times*, http://www.eet.com/story/OEG20020926S0024

Sturgeon, Timothy J. (2002). Modular Production Networks: A New American Model of Industrial Organization. *Industrial and Corporate Change*, 11(3).

Wheelwright, Steven C. and Kim B. Clark (1992). *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality*. New York: Free Press.

Wheelwright, Steven C. and Kim B. Clark (1995). *Leading Product Development: The Senior Managers Guide to Creating and Shaping the Enterprise*, New York: Free Press.

Yang, Y. R. & C. J. Hsia (2004). Local Clustering and Organizational Governance of Trans-border Production Networks: A Case Study of Taiwanese IT Companies in the Greater Suzhou Area. *Journal of Geographical Science*, 36, pp. 23-54.

Yang, Yung-kai (2005). Taiwanese Notebook Computer Production Network in China and the Implication for the Upgrading of Chinese Electronics Industry. Unpublished PhD Thesis, Manchester Business School, University of Manchester.