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Design Engineering or Factory Capability? Building Laptop Contract Manufacturing in Taiwan

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The development of high-tech industries in East and Southeast Asia is commonly viewed as a linear progression from manufacturing to design capabilities. By examining the three earliest laptop projects in Taiwan, however, this article shows how important these producers' early design engineering capabilities were to attracting customers and to bridging to successful production. Also, manufacturing was not necessarily simpler than design.

Taiwan's laptop industry emerged in the late 1980s and occupies a critical position in the world today. In 1996, Taiwan's companies produced 32 percent of the world's laptops, and the share rose to about 50 percent in 1999, surpassing Japan to become the top laptop producing country. The laptop business, similar to that of semiconductors, at this time had become a star industry that commonly occupied the business or technology sections in daily newspapers in Taiwan. In 2011, laptop manufactures from Taiwan held about 90 percent of the global market share (although their subsidiary factories were in China after 2001), with Quanta Computer producing about 56 million units, Compal Electronics 40 million units, and Wistorn 32 million units for a total of about 200 million units worldwide in that year.[1] These major producers were involved in not only manufacturing, but also the design of most Wintel computers(i.e., computers that use Microsoft's Windows operating system and Intel's processor).

This article traces the birth of the laptop industry in Taiwan. While electronics production and its contribution to the economic growth in East and Southeast Asia are well known, the prevailing view of the development of the high-tech industries in this region is that each industry evolves from inexpensive labor and assembly and then is "upgraded" to incorporate design or even R&D capabilities. In exploring the beginnings of Taiwan's laptop industry, I will demonstrate that the companies did not "progress from (local) manufacturing to (global) design" but rather based their businesses on a foundation of capable design engineering that looked to the world from the beginning. I argue that this manufacturing was not necessarily simpler than design, and this early design engineering mediated the cross-organizational and cross-regional process of creating laptops to assure the final success in production.

The Relationship between Design and Manufacturing

Although a great deal of research explores the roles of knowledge and innovation in production, such as in the scientific management of Taylorism,[2] the mass production and standardization of Fordism, the use of flexible mass production,[3] the lean production and just-in-time model of Toyotism,[4] and the use of interchangeable parts,[5] industrial policy scholars still largely view manufacturing as less innovative or less significant than R&D. For example, while recognizing Asia's contribution in global production, Dieter Ernst nevertheless argued that Asia was "starting" to emerge from the role of the global factory to participating in global innovation networks in his

2006 article,[6] which could be construed to imply that factories lack innovation in their own right.

However, certain scholars have begun to emphasize the importance of manufacturing activities. In *Made in the USA*, Vaclav Smil argued that there are two persistent myths concerning modern manufacturing. The first sees it as a "progressively less important endeavor."[7] The second regards modern manufacturing as a largely dispensable activity, "a matter of a secondary importance that can be taken care of by simply importing whatever is needed from the cheapest foreign sources and paying for the purchases by earnings from high value-added services whose contribution now dominates GDPs of all affluent countries."[8]

Rebutting the notion that the loss of American manufacturing is a desirable evolutionary step toward a pure service society, Smil argued that no advanced economy can prosper without a robust and active manufacturing sector. For Smil, manufacturing does matter, and "manufacturing has been the principal driver of technical innovation, and technical innovation in turn has been the most important source of economic growth in modern societies."[9] The history of manufacturing in America, Smil explained, is in fact a nation-building story.

Nevertheless, manufacturers are still often portrayed as playing only the role of implementing design plans. In other words, there seems to be a hierarchical relation between the design knowledge and manufacturing knowledge. A statement such as "Designed by Apple in California, Assembled in China"[10] suggests that the relation between design and production is hierarchical and disconnected.[11] Similarly, when media experts, scholars, and industrial analysts described the history of Taiwan and Asia's high-tech industrial development, they tend to portray a linear progression from manufacturing to design. For example, it is commonly stated that Taiwan's electronics or IT industry developed from OEM (original equipment manufacturer)[12] to ODM (original design manufacturer),[13] and thus its capability evolved from manufacturing to also include design. (The ODM model signifies that the contractor is responsible for product design in addition to volume production, and OEM involves only manufacturing services.) For example, Jenn-Hwan Wang said that the technology capabilities of Taiwan's information computer firms has gradually upgraded from OEM to ODM, and certain companies have even begun selling products under their own brands.[14] Ernst also provided an image of linear progress for Asian electronics companies: "while vertical specialization initially focused on final assembly and lower-end component manufacturing, increasingly it is being pushed into higher-end value-chain stages, including product development and research."[15]

This hierarchical view of the relationship between design and production, however, can be problematic. For example, manufacturing semiconductor products is so difficult that it often shapes the direction of product designs.[16] Some scholars even argue that the most "upstream" activity in the semiconductor industry is manufacturing rather than design.[17] We should also note that one reason that Silicon Valley surpassed the East Coast of the US in the high-tech industry was because they engineered innovative manufacturing techniques. "The manufacturing capabilities made Silicon Valley," as Christophe Lécuyer concluded.[18] Hence, there is no reason to dismiss manufacturing.

Therefore, we should question if this image of progression "from manufacturing to design" is overgeneralized, especially when this overgeneralization has unconsciously influenced ideas, from how we make policy decisions to how we write history.

The Roots of the Laptop Industry in Taiwan

The development of laptop production in Taiwan was in part rooted in the electronics industry that flourished there beginning in the 1960s, followed by the rise of the calculator and PC (desktop) industries starting in the 1970s, which were buttressed by Taiwan's developmental state strategies and other social structures.

The Rise of Taiwan's Electronics Industry

Taiwan's government switched its focus to export-oriented industrialization in the mid-1960s from its earlier import-substitution strategy. This was a time when many Asian and Latin American countries were still adopting the latter strategy, which aimed to replace foreign imports with domestic products.[19] General Instrument (1964) and Philco (1965) established the first foreign electronics companies in Taiwan.[20] Afterward, Taiwan opened its first export processing zone in southern Taiwan in 1966. The export processing zone model was considered to be a success because it attracted many foreign companies to establish factories to produce radio, television, telephone, and other consumer electronics components for export.

Among them, the television set industry was considered to be the first mature electronics industry established in Taiwan, and it provided an intensive learning experience for Taiwan to produce large-volume products.[21] With the increase of wages in Taiwan, and the appreciation of new Taiwan dollars after the late 1980s, many foreign companies such as RCA and Zenith from the United States as well as Orion and Funai from Japan retreated from Taiwan after the decline of the radio and television industries. Nevertheless, these foreign companies still trained many local employees in the electronics industry.[22] Also, some foreign consumer electronics companies such as Philips remained in Taiwan and evolved to produce computer monitors and terminals.[23] In the meantime, computer-related companies such as IBM, Digital, Wang Laboratories, and Texas Instruments also came to Taiwan to set up either large branch offices or factories, which resulted in a spillover of technology to the local industry.[24]

These interactions with foreign firms not only integrated Taiwan into a globalized division of labor in electronics production, but they also helped the gradual formation of local parts and components suppliers in Taiwan. Later these local suppliers developed into a solid cluster and became critical to supporting further development in the IT industries in Taiwan.[25] The cluster of electronics components suppliers, usually small- and medium-sized enterprises, provided an environment that nurtured frequent technological information exchanges among the industrial participants in Taiwan.

Although it enjoyed economic growth by adopting the developmental state strategies,[26] Taiwan faced a series of diplomatic setbacks and other challenges. The Taiwanese government thus attempted to transform its industry from labor-intensive to technology-intensive in the 1970s.[27] The government fostered both the semiconductor and IT industries, although it had much more financial and central support for the semiconductor industry, partly because semiconductor production had a higher technology barrier and required much higher capital investment and thus was less accessible for individuals who wanted to establish their own businesses. In the early 1970s, the government initiated an important technology transfer project of semiconductors from the United States. Also during this time, Unitron, San-Ai, Qualitron, Inventec, Mitac, Multitech, and other calculator or computer system companies began to appear, all of which were founded by local people and local capital in the private sector.

Engineer-Entrepreneurs and the Calculator Industry

The calculator industry in Taiwan played an important role in paving the way for laptops. It is even stated that the calculator industry was the “mother of the notebook computer industry” in Taiwan.[28] First, among several of the largest notebook companies today, either the main founders or the companies themselves originated in the calculator industry: Compal and Inventec began as calculator companies, and the two main founders of Quanta, Barry Lam and C.C. Leung, both started their businesses in the calculator industry. The main founder of Acer/Wistron, Stan Shih, also began his career in two calculator companies.

The 1970s and 1980s were a time of active entrepreneurship in Taiwan. The postwar prevalence of education had largely changed Taiwan’s population structure. The well-educated newer generation included groups of engineering students who started their own electronics companies one after another when they encountered the rise of the IT industry, and the Taiwanese government’s welcomed developing small- and medium-sized businesses in its postwar society.

Second, the calculator industry was asserted to begin the trend to change from OEM to ODM in Taiwan’s electronics industry, and it also created a more significant and influential learning path than that of the television industry.[29] The calculator industry in Taiwan in the 1970s had begun to show an energetic engineering capability as engineers used reverse engineering to copy foreign calculators (primarily from Japan). They also tried to make design improvements before producing their new products. Due to the relatively low overall cost of their products compared with the Japanese products, many American importers bought Taiwan's calculators. Even Japan began to outsource to Taiwan in the early 1980s.[28]

Through imitation and observation, the calculator companies in Taiwan gradually learned how to design integrated systems. They caught the new wave of using LSI (large-scale integration) chips to develop new electronics end products.[30] They also acquired different techniques from their Japanese component suppliers to become experts at integrating a great number of parts and components into a small space.[31] Scholars have argued that the competitive foundation of these Taiwanese calculator companies relied mainly on "detailed design capability" rather than on low-wage shop-floor workers because the cost for basic workers' was higher than that in some other countries.[32] That is, during this period, the advantage from engineering capability seemed to surpass that of cheap laborers or factories.

Early PC Industry: Selling, Imitating, and Innovating

Following the boom of calculator companies, the personal computer started to emerge in Taiwan. In 1974 and 1976, two of the earliest local computer companies Mitac and Multitech (renamed Acer in 1987) were founded. Both companies sustained themselves primarily by selling foreign components and computer products and promoting and commercializing the application of microprocessors. For example, Mitac was the local agent for the Q1 commercial computer and Intel's microprocessors, while Acer was the local agent for Zilog's and Texas Instruments' microprocessors.[33] By selling foreign computers and components, they gradually acquired sufficient knowledge to design computers.

Important events for the development of Taiwan's computer industry occurred in the early 1980s. As the popularity of arcade video games spread from Japan, many Taiwanese engineers seized the opportunity to construct similar machines. Taiwanese makers were able to successfully replicate the arcade games from the United States and Japan. They could soon produce a game for an inexpensive price.[34] But in 1982, the Taiwanese government began to ban arcade video games in the domestic market, mainly due to the negative effects of having young people playing gambling machines in arcades. After the domestic ban, there were no guarantees that game machines would generate profit only through the limited export market; therefore, these companies and their employees faced a transition crisis that led a number of makers to change to another new business: cloning the popular Apple II.

The business of cloning the Apple II became a worldwide phenomenon with its launch in 1977. Apple II was an appealing product on the market more for its ease of use and flexibility than for the significant inventions that were occurring at places like IBM or Xerox.[35] Between 1982 and 1984, Apple initiated more than 50 lawsuits in 16 countries.[36] However, according to Apple, Taiwan accounted for 75 percent of its infringement problems.[37] Many players in Taiwan used reverse-engineering techniques to copy the machine and produce Apple II compatibles, although some claimed that their products were not identical copies.[38] In an era that had weak regulations regarding computer intellectual property (which was also unclear even in the US at the time),[39] Taiwan saw a boom in **partial** "imitations." Following Apple's legal actions, many Taiwanese players temporized and shifted their efforts again, this time making IBM PC clones.

At that time, in addition to dismantling related machines from the market, many engineers used what they called the "bible" from IBM, or an IBM technical manual with which they could check technical details, including circuit designs and BIOS (basic input/output system), which was available because IBM adopted an open standards strategy for personal computers.[40] The building of IBM clones also faced legal problems in 1984, however, when Acer exported their PCs to the United States. Acer had commissioned ERSO (Electronics Research & Service Organization) of ITRI (Industrial Technology Research Institute), a semi-government-supported organization to develop an IBM-compatible BIOS for their PCs, but IBM still claimed copyright infringement. Later, by using the cleanroom method to redevelop an IBM-compatible BIOS, ITRI successfully solved the infringement issue with IBM. ITRI's BIOS was licensed to five PC companies in Taiwan, which partially facilitated the boom of the PC industry in Taiwan.[41]

Imitating or Innovating in Taiwan’s Early PC Era

Whether or not Taiwanese companies were copying or pirating technology during this early time of the desktop development in Taiwan has been a controversial issue, especially when companies and organizations had different levels of involvement with and references to existing products and technologies in a legally unclear era. For example, organizations such as ITRI and Acer argue that they did not copy others’ products, but rather they made an effort to create their own products that were compatible to IBM’s.

It is less contested to say hat imitation was “part of” the important industrial learning strategy in 1970s and 1980s in Taiwan. But imitation is not equivalent to counterfeiting or reproduction, which is open to legal action, so it is not necessarily illegal or unacceptable.[42] Imitating can be part of a learning process and helps cultivate the ability for future innovations, and can be legal.[42] A company’s ability to absorb advanced technology also affects the learning result.

Overall, before the development of Taiwan’s laptop computer industry, there had been an accumulation of knowledge from several sources:

- the early consumer and other electronics industry after the mid-1960s, which involved foreign technology spillover, talent training, and the formation of local parts suppliers;

- calculator firms’ growing integration capabilities and early computer companies’ introduction and knowledge acquisition of foreign computers and microprocessors in the late 1970s; and
- desktop clones and other computer product development experiences in the early 1980s.

It was under such half imitation and half self-reliance that the community of Taiwanese producers enhanced its design engineering capabilities that contributed to the development of its early computer (desktop) industry, which would not have been possible without a large group of young and capable engineers, their active entrepreneurship, and a cluster of local parts suppliers.

Three Approaches to Designing the First Laptops in Taiwan

In the late 1980s, the regions that had either major PC brands or PC-related manufacturing bases included the U.S., Japan, German, Taiwan, South Korea, Singapore, and Hong Kong, but the main players that could attract the world were still only the U.S. and their strong rival at that time, Japan. In particular, in the smaller electronics products like laptops, Japan had shown its excellence and competitiveness. It was thus no surprise that the two countries became Taiwanese companies’ main sources of inspiration in their products and business. However, these companies were was by no means a passive follower, with an ample supply of local engineers, local parts suppliers, and early experience in the electronics industry, they actively created products to grow their business.

In the early period of laptop innovation and production, companies in Taiwan showed at least three different paths to innovations.[43] These paths all contributed to the later expansion of Taiwan’s international laptop industry, and they all relied heavily on the design engineering effort.

Trial-and-Error Method (Quanta, 1988–1989)

A company with annual revenues of about US$30 billion in 2014, Quanta was founded in a small apartment in Taipei in May 1988.[44] Despite such a modest beginning, Quanta’s founders Barry Lam and C.C. Leung already had years of experience in making calculators, first at San-Ai Electronics (1972) and later at Kinpo Electronics (1973–1987).

In 1980, in addition to the calculator business, Lam considered it was time to develop a computer business at Kinpo. Two years later, Kinpo received orders for computer monitors and terminals from Qume (later part of ITT), a US company that was founded by an overseas Chinese David Lee. Kinpo then started a new company Compal to manufacture Qume's monitors and terminals. A big fire in 1987 in Compal's factory partially forced Lam and Leung to leave the Kinpo group, where they had worked for more than 15 years. Thus, they rented a small apartment in Taipei to start their new company Quanta in 1988.[45]

Initially, it was unclear what type of products Quanta should develop. Leung, now the vice chairman and president of Quanta, said that the only thing they knew was that miniaturization of computers would be a promising direction because LSI and a new display technology (twisted-neumatic LCD) had resulted in smaller calculators, and personal computers were shrinking in size as well.[45]

They wanted to design smaller computers, but one problem was that none of the engineers at Quanta, eight in total, had made a computer before. Still, they were familiar with many of the components suppliers from their early experiences with calculators. Some of these engineers were good at software, others at hardware, while still others were good at mechanical parts or EMI (electromagnetic interference). Thus, the eight of them worked together to design their first computers.[45]

According to another early employee, whom I will call Rob,[46] the group collected available information, drew on the IBM "bible," dissembled other companies' computers, and explored the components and design layouts adopted by those products. They then discussed what they could do based on the knowledge they acquired. More specifically, lacking computer design experience, the engineers first studied the motherboards of desktops that were made locally because they were less expensive. The engineers took the domestic products apart to see how the motherboards were designed. Later, they began to dismantle foreign notebook-sized products, mainly from Japan's Toshiba and the US's Zenith and attempted to design their own laptop-type product.[46]

Dismantling others' products is a common practice in the electronics industry, especially because hardware itself is such an information-rich object. But Rob said that their goals when analyzing those machines were to refer to the system placement (such as the components' locations and how they were linked together), the components used, and the ways in which the machines were assembled. He said they did not conduct reverse engineering or replicate others' machines.[47] In Rob's interpretation, the term reverse engineering has a connotation of replication or counterfeiting, which was not what they did, although reverse engineering can have a broader meaning, such as "the process of extracting the knowledge or design blueprints from anything man-made."[48]

Thus, there is interpretive flexibility in the meaning of reverse engineering. In fact, there are various related terms to refer to similar practices, and they are often confusing or misused. Elliot Chikofsky and James Cross thus defined and clarified six terms that refer to analyzing and understanding existing systems: forward engineering, reverse engineering, redocumentation, design recovery, restructuring, and reengineering.[49] They indicated that reverse engineering involves identifying a system's components and their interrelationships and creating representations of the system in another form or at a higher level of abstraction. For Chikofsky and Cross, reverse engineering in and of itself does not involve changing the subject system or creating a new system based on the reverse-engineered subject system. It is a "process of examination, not a process of change or replication."[50] Therefore, if we use the Chikofsky and Cross definition, what Quanta did could be regarded as reverse engineering, but that is still a label Rob would like Quanta to avoid because it seems to imply merely replication.

One of the special features of the Quanta machine was that it consisted of many existing components designed for much larger desktops because, at that time, laptop-specific parts were mostly unavailable on the market. Leung said that if there had been no specialized support from components suppliers, such as Conner from the US, which sold Quanta their new 3.5-inch drive (rather than the 5-inch format that was dominant at that time), Quanta might not have made a small-sized product, especially when they were still such a new small company.[45]

Quanta's customers also believed that its first product was fairly a work of "genius" (in Chinese, the word has both a positive and a satirical meaning of doing something unexpectedly or illogically) because they unexpectedly compressed everything from desktops into laptops, but the machine worked. Leung explained that there was no special tip: they just tried every possible way to squeeze in the components, which became highly condensed, on the printed circuit boards.[45]

When Quanta decided to make a laptop computer in July 1988, it took only a little over a month for them to produce a model that they thought they could sell in late August. But it took another three months for them to debug the machine because “every part had a problem.” Still, they gained a more reliable computer by solving these problems one by one.[51] For example, during the design process, Quanta developed their own power management system and embedded controllers for the keyboard because these were not defined by IBM. They also had to solve the application compatibility of the LCD because they used a 640 × 400 panel, which was different from the popular 720 × 348 panel used in desktops. Finding suitable batteries and reducing electromagnetic interference were also major issues at that time.[52]

Quanta’s machine sold at a very competitive price, which resulted primarily from engineering efforts rather than cheap assembly workers. The Quanta team found a specific way to reduce their cost. There were two types of printed circuit boards. One used SMT (surface mount technology), which directly mounted the components onto the surface of printed circuit boards with solder paste before conveying the board into the reflow soldering oven to bond the components in their places. The other method used through-hole technology, which affixed components with wires inserted into holes in the printed circuit boards. Leung said SMT machines were used for high-density products with smaller components, but SMT lines were so expensive that few companies in Taiwan at that time could afford them. Thus, Quanta had no choice but to design the laptop with the economical but clumsy (with crowded wires) through-hole technology.[45,53]

With its first working laptop (see Figure 1), Quanta received an order from the Dutch company Tulips and then later from the US company Packard-Bell, both famous brands then. Quanta both designed and manufactured these laptop-sized computers rather than being a pure assembler that waited for the design blueprints or details from its clients. Quanta shipped only a few thousand units, but the price of more than $2,000 per unit yielded a large profit for this small start-up. Shortly thereafter, Quanta modified the first model slightly when designing its second model and received even larger orders.[45]

Figure 1. Quanta’s first laptop-type computer QC201, 1988–1989. It weighed about 16 lbs and included Intel’s 80286 microprocessor, the MS-DOS operating system, and a black-and-white 9.5-inch LCD. (Courtesy of Quanta)

This initial success did not guarantee Quanta’s survival. The company was continually looking for other products and responded accordingly. In 1989, Compaq Computer launched one of the earliest A4-size portable computers (the Compaq LTE, one of the first computers to be widely known as a “notebook computer”).[54] Quanta strived to design a machine in a few months that was similar to Compaq’s. Consequently, Quanta became one of the first companies in Taiwan to make a notebook-sized computer. This QC328 machine (shown in Figure 2) was mass produced in September 1990 and was sold to many customers, including the Dutch company Philips, in a significant volume. Quanta claims this laptop was the most important machine in terms of the small start-up’s initial sustainability as it established a solid foundation for its future business.[55]

Figure 2. Quanta’s first A4-sized notebook QC328 PC-AT, with Intel’s 80286 microprocessor, an 8.5-inch black-and-white LCD, 20-Mbyte hard disk drive, and 1-Mbyte system memory. (Courtesy of Quanta).

In designing their laptops, Quanta’s engineers used a trial-and-error approach and endeavored to mobilize the available resources from around the world, including technical documents, artifacts, and component supply networks. There was little reliance on low-wage shop-floor laborers or efficient assembly lines in the factory. Indeed, when a laptop product had only tens of thousands of units sold over months, with substantial profit, there was as yet no need to worry much about mass production and efficiency.

Sharing Jobs, Knowledge, and Technical Objects (Notebook Alliance, 1990)

Not long after Quanta produced its first laptops, the government began to value the product’s commercial potential. In 1990, the Notebook Alliance, convened by the Computer and Communication Research Laboratories (CCL) at ITRI, was initiated to help more companies join this rapidly growth industry. The goals of this project included increasing the competence of the national notebook industry, facilitating collaboration among companies, saving the repeated modeling development fees, and standardizing laptop components.[56] Peter Wang, a senior manager at ITRI who had been familiar with computer projects at ITRI, recalled that they regarded the standardization of laptops and the horizontal division of labor as crucial because this strategy would enable various small- and medium-sized enterprises in Taiwan to "become a company" in order to "fight together with others."[57] The alliance indeed attracted many companies. As long as they funded a share of the investment and joined the division of labor, these companies would gain a "common motherboard" from the collaborative project.

According to the alliance manager from CCL, Sid Wang,[58] the development fee for such a product was about US$400,000 to $800,000. By sharing the fee, each company could save a great deal of money. More than 200 companies attended the first meeting, and 46 companies joined the alliance with a total investment of US$2.1 million for this development project. All parties signed the alliance contract in July 1990. To codevelop the product, the company members then divided into groups focusing on topics such as the motherboard, mechanical engineering, keyboards, power, components testing, and electromagnetic interference.[59] They spent only four months developing a prototype machine to be presented at the ComdexFall exhibition, a large international computer trade show held annually in November in the United States.

The composition of the alliance was complex, from PC and notebook companies to components, consumer electronics, and small trade companies as well as some new companies.[60] Some famous consumer electronics companies in Taiwan such as Tatung and TECO joined the project, but computer companies like Quanta, Compal, and Acer did not. Leung explained that, because Quanta already had developed workable machines, there was no reason to join the project, especially when other companies might acquire Quanta's know-how through this product alliance.[45] A few computer companies thought this alliance was problematic because it was too open, as any company could attend. One top R&D manager from Compal, whom I call Stuart,[61] explained **in an interview** why Compal did not join:

> **Stuart:** *What we wanted then was ... to design [a system] by ourselves, not through others.*
>
> **L.-F. Lin:** *At that time you thought that the alliance was not useful?*
>
> **Stuart:** *Once everyone had the common design, all you could do was just to compete on prices. But at that time, the prices of notebooks were very good. It was not a problem to have a gross margin of 30%. However, once you chose to do the common product, the blue sea would then just become the red sea.*
>
> **L.-F. Lin:** *But they still could get the technology, right?*
>
> **Stuart:** *They didn't get any technology. The only thing they got was the components of that design. So they just needed to put them together and change the chase—then you would have a white-box computer. The know-how was not in their hands, and when you had problems, you couldn't solve them.*[62]

The final result was indeed unfavorable because the alliance caused a price war; in the end, price became the only way to distinguish between the different companies' products. It was difficult to evaluate technological **acquisitions** for them. Each alliance company member's technological capabilities differed before they joined, so they contributed and absorbed different degrees of technology from this collaborated project. Some were only small trading companies, whereas others had large business and R&D capabilities, such as Tatung. The division of labor of the project was such that, if a company was good at making motherboards, it could contribute to designing the motherboard, and the alliance would pay them for the R&D work.[63] In addition to each member's own technology, the main core technology for the notebook project was from ITRI. In fact, ITRI's CCL had a laptop computer project in 1989, before the notebook alliance, that was based on its early experience in a personal computer project. Therefore, CCL had the system hardware technology and operational system software technology.[64]

Regarding technology sharing in this industrial alliance, a CCL senior engineer, Houng-Ching Shyu, said that he believed that ITRI's technology was the strongest, and ITRI's very mission was to transfer the technology to the companies.[63,65] Overall, there was a dispute over how much technological advancement could be gained by joining such an alliance, but it was clear that few companies wanted another price war from selling similar products based on a common model. Consequently, the next year when ITRI wanted to form a slim notebook consortium, it did not succeed.[66]

Despite the criticism that too many companies were allowed to join the alliance, Sid Wang said that 46 companies in the alliance might have in fact been too few because, according to statistics, there were thousands of PC-related companies in Taiwan at that time. Indeed, the concentration of global shipments from only a few major Taiwanese players after the late 1990s contrasts with the situation earlier in the decade, when there were more than 100 notebook system providers. It was similar to an early gold-rush-like pursuit in the desktop motherboard market, which attracted more than 200 players in Taiwan, resulting in severe competition and price wars.[67] This also gives us a sense of how active start-ups and small- and medium-sized enterprises were in Taiwan in the golden era of the PC's rapid growth.

It was argued that the alliance at least resulted in the training of many people for the laptop industry and that it facilitated the industry's development in Taiwan by helping standardize laptop components. A final contribution of the notebook alliance was that the Comdex event helped Taiwan gain a reputation around the world for being good at making notebooks because there were tens of Taiwanese companies exhibiting and selling their laptops in the early period of the emerging market.[61,68]

This notebook alliance illustrates a second approach to designing and manufacturing the initial laptops in Taiwan: forming a horizontal alliance across company boundaries in order to quickly and inexpensively obtain a sellable machine and facilitate the standardization of laptop components. If Taiwan's companies could not compete with foreign computer firms in size or finance, they could at least do it collectively and collaboratively by sharing jobs, resources, risks, knowledge, and even the finished artifact itself. This notebook alliance also shows an effort to design a laptop rather than relying on factories, assembly lines, or cheap labor.

Learning through Partnership (Acer/Wistron, 1991–1992)

Acer's entry into the laptop business seemed to overpower Quanta in several respects.[69] According to Fred Lin,[70] one of the cofounders of Acer Computer, when Acer saw how impressive Compaq's notebook-sized computer (Compaq LTE) was, they seriously considered entering the market. Acer was founded in 1976, much earlier than Quanta, by Stan Shih, his wife Tsu-Hua Yeah, and five other partners. Most of them were engineers, with little wealth in their backgrounds. But by 1988 when Quanta was founded, Acer had become successful with desktop computers and was already a star company in Taiwan when its stock became publically available.

Knowing that Acer planned to create its own notebook-sized computer, a laptop designer Kazuhiro Miyashita from America's Data General in Japan (Nippon) came to discuss a possible cooperative project with Acer. Miyashita would be the head of the R&D team that designed the Data General/One laptop computer when he was in Nippon Data General,[71] but he had left that company for personal reasons. His electronics engineering expertise was well established, and to Acer managers, he seemed to know every technical aspect of notebooks. Indeed, when Data General/One was launched in 1984, *Byte* magazine featured this product on its cover and praised how cutting edge it was, weighing only 10 pounds and with a full-sized LCD that few vendors would promise to make at that time, for a competitive price of less than $3,000.[71,72] After the Acer project, Miyashita would also become the top manager of several Taiwan's display component firms and obtain dozens of international patents.[73]

Upon evaluation, Acer decided to form a joint-venture company, Long Chi, to design a whole new notebook.[70,74] Miyashita was the general manager of Long-Chi, with a special technological share.[70,74] Fred Lin said they formed a new company because, if they did everything internally in the much bigger mother company Acer, it might take longer. Long Chi was assigned to do the high-level design, while Acer was responsible for the detailed design.

Acer thought highly of this new project and dispatched important engineers and managers to it. Within Acer, Fred Lin asked Shung Chang, a director of quality control in the factory, to be the notebook factory director. Chang had received a PhD in the United States, had worked in a famous US electronics company for a long time, and had joined Acer not long before. Fred Lin also assigned Kung-Ming Lee, another PhD from National Taiwan University who had joined Acer in 1978, to be the head of R&D. Several excellent Acer design engineers such as

Jackson Lin were also invited to join the team.

Acer's internal target was to design and produce an advanced notebook that would be similar to Compaq's LTE product within one to one and a half years.[70] This plan not only matched Acer's existing culture of pursuing advanced products, but it also aligned with Miyashita's inclination toward developing leading technology. When asked if they dismantled Compaq's machine, Fred Lin answered, "Of course we dismantled it, even Miyashita dismantled it."[75] Similar to Rob's account from Quanta, Acer did not interpret this as reverse engineering and copying. Acer's retired Chief Technology Officer Jackson Lin said that it was not meaningful to conduct reverse engineering at the computer system level, which was not hard for laptops because they did not have to go down to the level of chipset analysis. What they did was product competition analysis and "forwarding thinking"—they needed to design a more advanced machine than their competitors', especially when the market changed quickly. Therefore, they had to know their competitors' products in order to put their own laptops in a better position. The goal of disassembling other machines was to explore and analyze the components and materials used, the number of components, the size of the printed circuit board, the detailed layout, and the component suppliers. Then they could formulate a design breakthrough either in function or in cost structure.[76] Again, the Chikofsky and Cross taxonomy would classify this practice as reverse engineering, which is a "process of examination, not a process of change or replication."[50] Acer aimed to surpass rather than replicate existing laptops, and it did not interpret this practice as reverse engineering.

Similar to Quanta, one difficulty with developing early laptops for Acer also came from the component issue because most components were designed for desktop use only. For example, Acer had to use Intel's microprocessors for desktops, just as Quanta did. These microprocessors tended to have higher power consumption, which in a compact space with limited dissipation causes an over-heating issue and shortens battery life. They also had to find smaller-sized resistors and capacitors and more layers of printed circuit boards from local component suppliers, whose flexible and efficient support had provided an advantage for building computer businesses in Taiwan. Some of the components, such as the LCD, power module, and battery pack, were custom designed by Japanese suppliers for this Acer project. Other challenges included reliability, electromagnetic interference shielding, software compatibility, sturdiness after dropping, and power management for longer battery life. The first notebook-sized model by Acer, AnyWare 1120 NX (see Figure 3[77]), was delayed for seven to eight months due to these various challenges.[70,78]

Figure 3. Acer's first notebook PC, Anyware 1120 NX, with Intel 386SX 16/25 MHz microprocessor, 3.5-inch 1.44-Mbyte diskette drive, 20/40/60 Mbyte hard disk drive, dual battery with hot-swap design, 9.5-inch VGA LCD display, and Microsoft operating system: MS-DOS and GW-BASIC. It supported an external card memory, and the thickness was less than one inch.[77] *(Courtesy of Jackson Lin)*

The sales of Acer's first notebook model were disappointing to the company after it was released on the market in late 1992. The technology was evolving so quickly that the delay made certain functions of their originally advanced model obsolete. After spending more than US$1 million, Acer finally stopped investing in Long-Chi (but continued the laptop business internally), claiming the new company kept "burning money" and did not run smoothly. However, Acer had gained valuable experience from this cooperation, such as the ability to define key questions, plan a system's architecture, manage quality, and solve problems. In total, Acer was in the red for four years in the laptop business, and it did not begin to be profitable until the fifth year.[79]

Observations

The three early laptop development projects just described show three different paths to laptop innovation. Quanta mobilized its limited man-power and resources and implemented a trial-and-error method. It was able to commercialize its first laptops by referring to IBM documents, analyzing machines on the market, and innovatively squeezing components and parts from desktops into a laptop design. Quanta's goal was to have a workable product as soon as possible that could be sold to international clients.

By contrast, Acer drew upon a more formal organizational effort and financial investment. It cooperated with a laptop expert from Japan, recruited people with PhDs, and invested heavily in the project. As a later entrant than Quanta and other local or foreign firms in the laptop business, Acer aimed for a more advanced machine and set high standards for a product that was to be sold under Acer's own brand.

Lastly, the Notebook Alliance organized by a semi-governmental research institute in 1990 illustrates another path. The 46 companies formed a horizontal alliance to quickly and inexpensively create a commercially viable machine and to push for standardization of laptop components in Taiwan. They shared jobs, resources, risks, knowledge, and even the finished artifact to reach their goals. This comprehensively collaborative approach is relatively rare in the development of the personal computer in the world.

Within a decade, Quanta would climb to the top position in the sector in Taiwan and in the world, and Acer would also perform well in the laptop industry. At this early point, however, neither company knew how long it would continue in this business, let alone know that they would become major global laptop producers.

Based on these early efforts, both Taiwanese companies attracted orders from a few leading brands after the early 1990s. During that time, through their cooperation with companies including Apple, Dell, and IBM, the Taiwanese producers would further learn and advance their project management, products' development process, and quality control as well as greatly enhance their manufacturing capabilities and techniques, which were all beyond the scope of the product-level design involved in the early period.[80] Nevertheless, without these early workable laptops, these companies would not have been able to obtain the orders from leading firms and thus the learning experience from them.

Emerging Through Design Engineering

During the initial period, the Taiwanese producers' product design engineering capabilities were a more prominent feature than their small-scale and unremarkable production facilities. Few producers waited passively for foreign companies to give them product design ideas in order to begin the manufacture process. On the contrary, they first designed and made products to attract foreign firms, which could in turn buy and sell these products by simply attaching their logos to the ready-made products. The development of those earliest laptops demonstrates how Taiwan emerged in the industry primarily through capable design engineering, especially in the areas of electrical engineering, mechanical engineering, and software engineering, all of which were crucial for constructing computers. Their strengths in the three kinds of engineering made me use the term design engineering to refer to their capability in this article.

In addition to the three early laptops I discussed here, other important laptop companies, such as Twinhead Computer and Inventec, also gained laptop contract orders from US firms based on their design engineering. Twinhead's cofounder Yi-Cheng Chen in particular was a famous computer designer in Taiwan. His company designed and produced laptops and had top-ranked brand-name business in Taiwan in the 1990s. Richard Lee, now the chairman of Inventec, has indicated that after Inventec's calculator and telephone factories moved to Malaysia in the late 1980s, there were hundreds of engineers left in Taiwan. Consequently, Inventec decided to move into the notebook business in order to utilize these employees because they thought it was a business that required an intensive engineering effort.[81] Shortly after entering the laptop business, Inventec received ODM orders from the US companies Zenith in 1990 and Dell in 1992.[82]

Several other larger laptop firms in Taiwan in the 1990s, such as FIC, MSE, Clevo, GVC, and Asus, all expanded their business from desktop motherboards to laptops, mainly because they had already developed design engineering capabilities with motherboards. Having design engineering capabilities alone was not sufficient to succeed in the international market, but it was a necessity.

Acer's main founder, Stan Shih, has asserted that Taiwan's computer and laptop industry was established mainly on design capabilities. Taiwanese companies had especially solid design experience with PC motherboards. Shih asserted that Taiwan's major companies emerged because of strong design abilities rather than simply transferring foreign technology to its computer production:

> *There were people visiting Taiwan for ODM. It was ODM, not OEM. Taiwan had no opportunity to do OEM [in the beginning]. OEM was not the reason we made computers. Quanta did well [with] notebooks because they designed a good product, not [because of] providing only manufacturing.*[83]

> *If there were no design capability, there would have been no contract manufacturing for Taiwan. How would Taiwan get product orders [if Taiwan didn't have design capability]? China could do that, or the nearby EMS companies in the U.S would just take [those orders].*[83]

Furthermore, Max Fang, the former general manager of Dell Computer's international purchase office in the Asian Pacific region, commented that the foreign laptop companies relied heavily on Taiwan's design capabilities from the beginning. For example, the first notebook order Dell gave to Taiwan in 1989/1990 was a joint-development project.[84] Thus, the main advantage of Taiwan at that time was that it had excellent, experienced, but relatively inexpensive pool of engineers in the broader electronics industry.

Unimpressive Manufacturing Factories

Although the producers took divergent paths in constructing their first products, none of the companies stressed that their manufacturing capability or factories were excellent. Initially, everything was very basic in Quanta's factory, which had about 50 operators and fewer than five production-related engineers.[85] At first, they had only one production line in a small plant without expensive SMT (surface mount technology) machines. Quanta's early factory was mocked by Apple, Dell, and even its own employees. One of Apple's former managers who visited Quanta's factory said that it was horrible because it did not even have a restroom.[86] Max Fang, a former Dell manager, said that when Dell first went to visit Quanta, they viewed it as a second- or third-tier manufacturer.[87] A later Quanta factory manager also said that, when he was interviewed for a job in Quanta, the factory's roof was leaking, and it made him wonder if he should join the company.[88]

Acer's factory was not much better. An early laptop factory manager, whom I call Duane,[89] remembered that the new laptop factory was not well equipped compared with the desktop division in Acer, and he even had to buy electric fans to cool it down in the summer when others had air conditioners. Acer had only one production line in the factory, with merely tens of operators. Although it was not expensive to design a prototype or a laptop, the investment in mass production was significant.[70] Thus, it is clear the entry barrier was higher in manufacturing than in design at that time for these companies.

As a former senior R&D employee in an American company, Duane recalled that when he volunteered to manage the laptop factory in Acer he at first had thought that factory production would be easy, but it turned out to be completely the opposite. "Manufacturing is not simple at all, you have to know so many details" about many things.[89] A top manager in Compal's R&D, whom I call Stuart, also mentioned that he had not realized how complex the laptop manufacturing system was until he came to Compal. It was much more complex than his early job in integrated circuit design because it required time and opportunities to learn manufacturing techniques. For instance, Compal built up its systematic manufacturing capabilities with the help of ITT when Compal was producing monitors and terminals for the US company after 1982.[61,91] Stuart indicated that the mechanism that bridged the engineering and manufacturing systems was so complicated that he hoped that each company engineer, including design engineers, would work hard to figure it out.[61] Thus, it would be naive to say that computer manufacturing is simple and easy compared with design.

In the late 1980s, laptop factories in Taiwan primarily involved small-scale manual assembly, but today not only are professional managers and various types of engineers in their Chinese factories, but also expensive equipment and computerized, robotic, and automated technologies are adopted in the advanced large-scale manufacturing. Therefore, the idea of progressing from manufacturing to design is doubly problematic. First, from the outset, the Taiwanese laptop producers' design engineering was much stronger than their production capabilities. In fact, it seemed that product innovation was easier for this group of engineers and managers, and professional manufacturing and process innovation were more difficult to capture, so that they needed to gradually learn these things from the larger projects with the leading firms. Second, laptop manufacturing was not always simple because it was possible to produce a product in different ways. Initially, laptop production in these companies was relatively low tech and primarily manual (using skilled workers). Since then, it has become increasingly sophisticated, like their factories in China today. In fact, manufacturing in Taiwan has made huge progress over the last 20 or so years. Instead of the laptop industry in Taiwan progressing from manufacturing to design, progressing from design to manufacturing might be a more accurate description.

We have also seen that it is a myth that manufacturing is simple and not innovative when compared with design. The common low-value-added image of computer production perhaps comes from the lower status of Asian contract manufacturers in the industry, rather than due to a lack of innovation. When we analyze the activities of design and of manufacturing, we should be sure to place them into the proper context, rather than examining them in a social and historical vacuum. In many situations, design could be overvalued and manufacturing undervalued.

Conclusion

How do we explain the seemingly paradoxical phenomenon that US companies were sourcing manufacturing services from Taiwanese companies, which initially had better design capabilities than manufacturing techniques? Also, if contract manufacturing and assembly were so simple and mainly required low-skilled workers, why did the brand-name companies not choose their manufacturing partners from other countries that had even cheaper labor and overall costs, especially when many countries were eager to join this rising global industry? The phenomenon of brand-name companies selecting manufacturers by considering the partner's design capability demonstrates how crucial the link was between design and manufacturing in the rapidly changing computer industry. The chosen partners might not have had sophisticated or well-established manufacturing capabilities, but they had solid design engineering teams, whose functions partially overlapped with those of the brand names' own design teams to ensure the two parties could connect smoothly and integrate design and manufacturing well in an cross-organizational and cross-regional industrial alliance. The direction of this link is not arbitrary, however. My research indicated that the brand-name firms did not choose manufacturing partners that had, for example, excellent marketing capabilities, because that function would impede a brand's core value.

Overall, I argue that these Asian computer producers did not "progress" from manufacturing to design at all. First, by examining the three earliest laptop projects in Taiwan, which involved not only engineer-entrepreneurs consulting documents from the US, analyzing products from the US and Japan, and working with experts from Japan, but also local approaches including assembling computers in unexpected ways and sharing task and objects among dozens of partners who hoped to quickly seize the great opportunity. I show how important these producers' design engineering capabilities were to attracting their initial orders from Western firms and establishing a solid foundation for their future development. Second, I also show that laptop manufacturing is not necessarily less difficult or less valuable than design. In fact, what distinguishes these producers today, in addition to their continuous design engineering capabilities, are their advanced manufacturing engineering and techniques as well as their integrated processes and practices that closely link design and manufacturing, which are dramatically different from those situations in the early period.

The broader implication of this argument is that, when forming a production alliance, instead of offering only a complementary function such as efficient or economical factory assembly, it might be equally or even more crucial for the contract producer to provide overlapping and thus bridging functions to their partners in order to assure the success of a complex cross-boundary alliance. More Importantly, if a place wants to attract more factories and related jobs, having more design engineering workforce might be a good start.

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References and Notes

1. Seehttp://www.digitimes.com/news/a20130130RI400.html. The top six laptop manufactures from Taiwan in 2011 were Quanta, Compal, Wistron, Pegatron, Foxconn, and Inventec. These six major companies produced about 80% of the worldwide laptops.
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3. See D.A. Hounshell, *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States*, Johns Hopkins Univ. Press, 1985; Jones, *Forcing the Factory of the Future*.
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6. D. Ernst, "Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks," special report., East-West Center, 2006.
7. V. Smil, *Made in the USA: The Rise and Retreat of American Manufacturing*, MIT Press, 2013. p. 9.
8. Smil, *Made in the USA*, p. 11.
9. Smil, *Made in the USA*, p. 13.
10. This tag is on the 2011 iPad 2.
11. This implication could be misleading. For example, Tim Cook, the current CEO of Apple said, "We have executives that have stayed in dorms. It's not unusual. Honestly, this wasn't to see what life was like in a dorm. It was that we worked so closely with these manufacturing partners and in the manufacturing plants [that] it's convenient to do… The truth is we couldn't innovate at the speed we do if we viewed manufacturing as this disconnected thing. It's integrated. So it's a part of our process." J. Tyrangiel, "Tim Cook's Freshman Year: The Apple CEO Speaks," *Bloomberg Businessweek*, 6 Dec. 2012.
12. The electronics industry has two different and confusing usages for the term OEM. One use distinguishes it from ODM, as I discussed in the text. The other use refers to brand-name companies such as Dell or HP. Here, I refer to the first meaning.
13. The ODM model signifies that the contractor is responsible for product design in addition to volume production, and OEM involves only manufacturing services. In addition to OEM and ODM, which are mainly Taiwanese companies, the industry also includes EMS (electronic manufacturing service) suppliers, which are largely headquartered in North America (except Foxconn, which is a Taiwan-headquartered EMS and component giant). Sturgeon and Lee compared the ODM and EMS models, indicating that while EMS firms do not provide design services, their product scope is much wider, including computer, telecom, datacom, and medical instruments. By contrast, ODM or OEM companies usually concentrate on a single or only a few product services. T.J. Sturgeon and J.-R. Lee, "Industry Co-Evolution: A Comparison of Taiwan and North American Electronics Contract Manufacturers," *Global Taiwan: Building Competitive Strengths in a New International Economy*, S. Berger and R.K. Lester, eds., M.E. Sharpe, 2005. See also Ernst, "Innovation Offshoring."
14. J.-H. Wang, *The Limits of Fast Follower: Taiwan's Economic Transition and Innovation*, Juliu Books, 2010, p. 106 (in Chinese).
15. Ernst, "Innovation Offshoring," p. 14.
16. R. Knox Bassett, *To the Digital Age*, Johns Hopkins Univ. Press, 2002; C. Lécuyer, *Making Silicon Valley: Innovation and the Growth of High Tech, 1930–1970*, MIT Press, 2005; H. Choi, "The Boundaries of Industrial Research: Making Transistors at RCA, 1948–1960," *Technology and Culture*, vol. 48, no. 4, 2007, pp. 758–782.
17. J.-H. Wang and J.-M. Chen, "Why the Models of Organizational Development between the Taiwanese Semiconductor and Computer Industry are Different?" *Proc. Ann. Conf. of Taiwan Assoc. of Sociology*, 2006. p. 26 (in Chinese).
18. See Lécuyer, *Making Silicon Valley*, p. 297.
19. Balassa argued that, except for England and Hong Kong, all countries went through their initial stages of import substitution in their early stages of development, with different degrees of protection. After the initial import-substitution stages, some East Asian countries such as Taiwan and South Korea switched to a export promotion strategy in the 1960s, whereas many others including Latin American countries continued the import-substitution strategy until the first energy crisis (1973–1974): See P.C.Y. Chow, "From Dependency to Interdependency: Taiwan's Development Path toward a Newly Industrialized Country," *Taiwan in the Global Economy: from an Agrarian Economy to an Exporter of High-Tech Products*, P. C. Y. Chow, ed., Praeger, 2002, pp. 241–277. For East Asian countries' transition details, see Y. Ren, *The Postwar Economic Development of*

Japan and East Asian Countries, Showwe Information, 2009 (in Chinese). Ren said that Taiwan's transition to export orientation was due to the limited domestic market scale, the demand for foreign currency, and the termination of American aide (1951–1965).

20. See W.-W. Chu and A.H. Amsden, *Beyond Late Development: Taiwan's Upgrading Policies*, Chinese translation ed., Linking Publishing, 2003; See also the Taiwan Electrical and Electronic Manufacturers' Association website at www.teema.org.tw/about-teema.aspx?unitid=92 (in Chinese).
21. Chu and Amsden, *Beyond Late Development.* Taiwan shipped 7.9 million units of television sets in 1978, which was its peak time.
22. Y. Sato, "Diverging Development Paths of the Electronics Industry in Korea and Taiwan," *Developing Economies*, vol. 35, no. 4, 1997, pp. 401-21. Quoted in Chu and Amsden, *Beyond Late Development*, pp. 29–30.
23. Chu and Amsden, *Beyond Late Development*.
24. Wang, *The Limits of Fast Follower*.
25. See Wang, *The Limits of Fast Follower*; M.-L. Pan, "Local Ties and Global Linkages: Restructuring Taiwan-based Production Networks in the Apparel and Computer Industries," PhD dissertation, Duke Univ., 1998. The study of industrial clusters has been an important focus in economic sociology, economic geography, and business studies. See, for example, A. Marshall, *Principles of Economics*, MacMillan, 1920; M.E. Porter, "Clusters and the New Economies of Competition," *Harvard Business Rev*., vol. 76, no. 6, 1998, pp. 77–90; P.R. Krugman, *Geography and Trade*, MIT Press, 1991; A. Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Harvard Univ. Press. 1994; S. Manning, "Customizing Clusters: On the Role of Western Multinational Corporations in the Formation of Science and Engineering Clusters in Emerging Economies," *Economic Development Quarterly*, vol. 22, no. 4, 2008, pp. 316–323.
26. See C. Johnson, *MITI and the Japanese Miracle*, Stanford Univ. Press, 1982; Chu and Amsden, *Beyond Late Development*.
27. The challenges included the following: Taiwan exited from the United Nations in 1971, Japan broke off diplomatic relations with Taiwan in 1972, and the first global oil crisis occurred in 1973. See S.-C. Hong and Y.-H. Hwang, "Research Institutes Drawing on Resources to Facilitate Industrial Development," *Industrial Technologies and ITRI: The Visible Brain*, C.-T. Shih, ed., Industrial Technology Research Inst., 2003, pp. 105–135 (in Chinese).
28. Chu and Amsden, *Beyond Late Development*, p. 35.
29. Chu and Amsden, *Beyond Late Development*, pp. 35–41.
30. For the development of LSI and the rise of metal-oxide-semiconductor technology, see Bassett, *To the Digital Age*.
31. Chu and Amsden, *Beyond Late Development*. Learning by doing has been an important topic in economics. See K.J. Arrow, "The Economic Implications of Learning by Doing," *Rev. Economic Studies*, vol. 29, no. 3, 1962, pp. 155–173; A. Young, "Learning by Doing and the Dynamic Effects of International Trade," *Quarterly J. Economics*, vol. 106, no. 2, 1991, pp. 369–405.
32. Chu and Amsden, *Beyond Late Development*, pp. 35–41. For the statistics about wages, see S. Yusif, *Innovative East Asia: The Future of Growth*, World Bank Publications, 2003, p. 24. In 1985, the annual average wage in manufacturing in Taiwan was $3,832, higher than South Korea's at $3,719, Hong Kong's at $3,464, Philippines' at $1,431, and China's at $379. In 1993, the numbers became Taiwan $13,014, Korea $13,237, Hong Kong $8,580, Philippine $2,999, Malaysia $4,868, Thailand $2,242, and China $581. Thus, Taiwan's average wage in manufacturing was higher than many other Asia's developing countries in 1993 when the laptop industry was in its early years.
33. See the companies' milestones on their official websites, Shih's personal website at www.stanshares.com.tw/stanshares/portal/stanshih/career.htm, and Wang, *The Limits of Fast Follower*.
34. "Where Could the Arcade-Game Industry Go?" special report, *Economic Daily*, 9 Mar. 1982 (in Chinese).
35. See P.E. Ceruzzi, *A History of Modern Computing*, MIT Press, 1998. The Apple II's spreadsheet application VisiCalc was a hit though. For Apple II's development, see also M. Campbell-Kelly and W. Aspray, *Computer: A History of the Information Machine*, 2nd ed., Westview Press, 2004.
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39. Although the US today is the main actor promoting intellectual property rights, Kim indicated that for more than 100 years (beginning in 1886) the US refused to attend the Bern Convention, which aimed to protect copyright laws. The US argued that, as a developing country itself, it needed to conveniently gain the advanced results from foreign countries. Also, it was not until 1976 and 1978 that Japan and Switzerland admitted product patents. See L. Kim, *Imitation to Innovation: the*

Dynamics of Korea's Technological Learning, Harvard Business School Press, 1997; Chinese translation ed., Yuan-Liou Publishing Co., 1998.

40. "Rob" (senior manager), interview by L.-F. Lin, 31 Dec. 2010; "Floyd" (senior manager), interview by L.-F. Lin, 23 July 2011; J. Lin, interview by L.-F. Lin, 25 May 2010. Before he retired in 2015, J. Lin was Acer's chief technology officer. Quotation marks for interviewees' names indicate pseudonyms.
41. Shih, *Re-engineering Acer*, pp. 81–86. For a detailed account of ITRI's effort in developing its own BIOS, also see T. Lin, "The Social and Economic Origins of Technological Capacity." A cleanroom in the manufacturing sector or scientific laboratories refers to a room with a controlled, low level of pollutants in order not to affect the product or process proceeding in the room. The cleanroom method in the ITRI context means that, when ITRI wanted to create an IBM compatible computer, they dispatched two engineer teams. One team was responsible for studying IBM's PC-AT technical manual and giving its specs to the second team, whose engineers had never studied IBM's manual. The second group of engineers was isolated in a room where they created their own version of circuit design and BIOS based on the specs (J. Lin interview, 2010).
42. For example, it is claimed that, to a large degree, South Korea achieved rapid industrial development through imitation. See Kim, *Imitation to Innovation*.
43. The word "laptop" can have two meanings. One is a narrower term that means the middle-weighted products between heavier portable and lighter notebook PCs in 1980s–1990s. The other is a broader term used in the US to represent today's 11- to 15-inch **notebook-sized** products. In Taiwan, however, "notebook" is more commonly used to represent today's products. In this paragraph and most other places, laptop refers to the broader meaning. To avoid confusion, when referring to the early middle-weighted "laptops," I use laptop-type computers.
44. Revenue from information products surpassed that of consumer electronics products in Taiwan in 1988 as well. See www.teema.org.tw/about-teema.aspx?unitid=92 (in Chinese).
45. C.C. Leung, interview by L.-F. Lin, 7 Sept. 2010.
46. "Rob" interview, 2010.
47. "Rob," correspondence with L.-F. Lin, 28 Jan. 2015 and 4 Feb. 2015.
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49. E.J. Chikofsky and J.H. Cross, "Reverse Engineering and Design Recovery: A Taxonomy," *IEEE Software*, vol. 7, no.1, 1990, pp. 13–17.
50. Chikofsky and Cross, "Reverse Engineering and Design Recovery," p. 15.
51. Leung interview, 2010, p. 22. The first laptop from Quanta was said to be officially launched in Nov. 1988. See *Quanta's*, Dec. 1998, p. 17, which was the company's internal magazine in the 1990s.
52. "Rob" correspondence, 28 Jan. 2015; *Quanta's*, Dec. 1998.
53. Later in Aug. 1989, Quanta began to equip SMT machines. See *Quanta's*, Dec. 1998, p. 17.
54. Just as there are disputes about which computer was the first portable computer, similar disputes concern the first A4-sized notebook computer. My interviewees tended to regard Compaq's product as the first at that time.
55. For the date of its mass production, see *Quanta's*, Dec. 1998, p. 17. According to the same magazine, p. 18, Quanta shipped about 20,000 laptops in the first year and 50,000 units in the second laptops. Other information is from "Rob" interview, 2010.
56. "Notebook PC Common Model Project Deployment Plan," *IT Information*, Aug. 1990, p. 18 (in Chinese).
57. P. Wang, interview by L.-F. Lin, 28 Oct. 2010, p. 2; P. Wang and H.-C. Shyu, interview by L.-F. Lin, 29 Oct. 2010. Shyu is a senior engineer at ITRI. A few scholars thought positively on this alliance, although they believed some aspects could have been improved. They thought it was a successful industrial alliance model of Taiwan's small- and medium-sized enterprises, which needed strategic alliances to enter the international market. See Y.-M. Yu, "The Analysis of the First Generation Notebook Computer Development Alliance," *Economic Daily*, 10 Aug. 1991.
58. See S. Wang, "The Case Study and the Research of Continuous Participatory Requirements in the Notebook Strategic Alliance of Republic of China," master's thesis, Graduate School of Management Sciences, National Chiao-Tung Univ., 1991 (in Chinese).
59. See Yu, "The Analysis of the First Generation Notebook Computer Development Alliance."
60. Wang, "The Case Study and the Research of Continuous Participatory Requirements in the Notebook Strategic Alliance of Republic of China," p. 52.
61. "Stuart," interview by L.-F. Lin, 9 Nov. 2010.
62. "Stuart" interview, 2010, pp. 19–21.
63. P. Wang and H.-C. Shyu interview, 2010.
64. Hong and Hwang, "Research Institutes Drawing on Resources to Facilitate Industrial Development," p. 115.
65. Wang, "The Case Study and the Research of Continuous Participatory Requirements in the Notebook Strategic Alliance of Republic of China," mentions that 50 percent of the common fund was given to ITRI, 45 percent to the development committee of the alliance, and 5 percent to the industrial association TEEMA.
66. C.-T. Chuang, "Development Fund Raising Insufficient, Companies' Opinions Diverged, Slim Notebook Development Alliance Terminates," *Economic Daily*, 4 Sept. 1991.

67. S.-H. Hsu (chairman of Compal), interview in *Global Entrepreneur*, 8 June 2010; C.-J. Wang, “The Closure Rate is Super-High in the Notebook Industry,” *Economic D*aily, 5 June 1994.
68. See also Hong and Hwang, “Research Institutes Drawing on Resources to Facilitate Industrial Development.”
69. Acer was separated into two companies in 2001. One kept the Acer brand-name business, while the other was spun off and renamed Wistron, which kept the design and manufacturing services.
70. F. Lin, interview by L.-F. Lin, 8 Mar. 2010.
71. See G. Williams and K. Sheldon, “The Data General One: A 10-pound Battery-Powered Portable That’s Fully Compatible with the IBM PC,” *Byte*, vol. 9, no. 12, 1984, pp. 102–109.
72. The Data General/One laptop was a cross-regional laptop project. Miyashita proposed the project as a Japanese branch employee, and it was approved by the US headquarters. This project involved the Japanese team, the design team in Massachusetts, and a third-party software partner in northern California. *Byte* said this product was significant and blew away experts because it was predicted that a similar product would take two to three more years to arrive and it would weigh up to 25 pounds and cost up to $5,000.
73. Miyashita has stayed in Taiwan since then, and he joined or started electronics companies that produce advanced components for LCD. As of 3 Feb. 2015, he had received 65 patents (as a sole inventor or co-inventor) in display-related technologies in the world, including Taiwan, the US, Japan, and Europe: www.patentmaps.com/inventor/miyashita_kazuhiro_1.html . A few of the patents were obtained when he was still with Data General.
74. F. Lin, email with L.-F. Lin, 3 Feb. 2015.
75. F. Lin, email with L.-F. Lin, 2 Feb. 2015; F. Lin interview, 2010, quote on p. 19.
76. J. Lin, email with L.-F. Lin, 4 Feb. 2015.
77. The detailed product specs were from Jackson Lin, email with L.-F. Lin, 29 Jan. 2015.
78. J. Lin, email with L.-F. Lin, 2 Feb. 2015.
79. J. Lin interview, 2010.
80. The argument is based on multiple interviews with the Taiwanese companies conducted for my dissertation: L.-F. Lin, “The Dynamics of Design-Manufacturing Laptops: How Taiwanese Contract Manufacturers Matter in the History of Laptop Production,” PhD dissertation, Cornell Univ., 2015, chap. 1, part II.
81. R. Lee, interview by L.-F. Lin, 30 Sept. 2010. He said, in 1987 the new Taiwan dollars faced a dramatic appreciation, and the exchange rate with the US dollar changed from 40:1 to 27:1. The dramatic change of Taiwan’s currency greatly impacted the export industry because Taiwan became a much more expensive place for foreign companies to source products. Because telephone sets production was still labor intensive, Inventec decided to move its factories to Malaysia.
82. Lee interview, 2010. The relationship between Dell and Inventec did not last long, however. Instead, Inventec and Compaq later formed a robust partnership in the laptop business until Compaq was bought by Hewlett-Packard in 2002.
83. S. Shih, interview by L.-F. Lin, 2 July 2009, p. 6.
84. M. Fang, interview by L.-F. Lin, 2 July 2009. He said that, when Dell gave contract manufacturing orders to Taiwan’s companies, all of them included design services. Earlier they had outsourced to Hong Kong’s Wang Company the manufacturing of a laptop that was designed by Dell itself.
85. J. Fong, email with L.-F. Lin, 1 Feb. 2015. Fong’s information came from C.C. Leung.
86. “Louis,” interview by L.-F. Lin, 1 Oct. 2011.
87. M. Fang, interview by L.-F. Lin, 19 Mar. 2010.
88. “Christopher,” interview by L.-F. Lin, 19 July 2012.
89. “Duane,” interview by L.-F. Lin, 29 Jan. 2015.
90. “Duane” interview, 2015, p. 1.
91. “Yao,” interview by L.-F. Lin, 7 Sept. 2010; David. Lee, interview by L.-F. Lin, 11 Dec. 2010. David Lee founded Qume in 1973, which was acquired by ITT Corporation in 1978.

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This article explores how Taiwanese laptop contract manufacturers established the foundation of their businesses between the late 1980s and mid-1990s. It casts doubt on the traditional view of a linear progression from manufacturing to

design capability in Asia. By examining the three earliest laptop projects in Taiwan, however, this author shows that manufacturing was not necessarily simpler than design and how important these producers' design engineering capabilities were to attracting customers and establishing a solid foundation for their future development.

history of computing, laptop production, Taiwan contract manufacturers, design engineering