Can Chinese IT Firms Develop Innovative Capabilities Within Global Knowledge Networks?

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by

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prepared for international workshop "Greater China's Innovative Capacities: Progress and Challenges", co-sponsored by Stanford University and Tsinghua University, May 20-21, 2006, in Beijing, China

Abstract

Key words

Acknowledgements

Introduction

The rapid growth of China's information technology (IT) industry has attracted worldwide attention -- China is now the largest exporter of IT goods, surpassing the US (up from 10th in 2000). But how sustainable is this success? Will China be able to move beyond its current status of a low-cost export- oriented global factory, and upgrade its IT industry through innovation?

China's opportunities to build innovative capabilities in the IT industry differ from those faced earlier by Japan and East Asian NIEs. In the first place, China has a unique combination of competitive advantages that comprise a booming market for electronics products and services; the world's largest pool of low-cost and easily re-trainable knowledge workers[1]; the emergence of sophisticated lead users and test-bed markets; and concerted policy efforts (both at the national and regional level) to strengthen China's innovation system. As a late-late comer, China has the additional advantage that its policy-makers can learn from past achievements and mistakes of earlier latecomers (in Asia and elsewhere).

At the same time, the international environment within which China seeks to develop is dramatically different from that of previous East Asian success stories. Most importantly, China's technological development over the past twenty years has been inseparable from the expansion of global knowledge networks. These networks have emerged as globalization has been extended beyond markets for goods and finance into markets for technology and knowledge workers (Ernst, 2006a).

China is far more integrated into global knowledge networks than were Japan and Korea at a similar stage of their development. *Formal corporate networks* link Chinese firms to global customers, investors, technology suppliers and strategic partners through foreign direct investment (FDI) as well as through venture capital, private equity investment and contract-based alliances[2]. And *informal global social networks* link China to more developed overseas innovation systems, primarily the US, through the international circulation of students and knowledge workers.

Deep integration into these networks arguably facilitates knowledge diffusion and learning (Ernst, 2005c and 2002a). Hence, progress in and challenges to China's innovative capabilities need to be assessed in the context of these networks. This raises three questions that are at the center of this paper: Can Chinese IT firms exploit these unique advantages? Does their integration into global knowledge networks facilitate or constrain their efforts to develop innovative capabilities? And precisely what type of capabilities are they developing?

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[1] "Knowledge workers", a term originally coined by the late Peter Drucker (arguably the most perceptive observer of industrial capitalism), in this paper is defined to include science and engineering personnel, as well as managers and specialized professionals (in areas like marketing, legal services and industrial design) that provide essential support services to research, development and engineering.

[2] An additional important development, not addressed in the paper, is the integration of Chinese IT firms into international standard-setting alliances. See Garcia and Burns, 2006, and Suttmeier et al, 2006

The findings of the paper can be summarized as follows:

- A company's initial business model can shape its integration into global knowledge networks. In turn, this integration can influence the evolution of its business model and its approach to the development of innovative capabilities.

- A high integration into global knowledge networks can expose Chinese IT firms to leading-edge technology, management approaches, intellectual tools and sources of knowledge.

- Familiarity with peculiar features of China as a market and production site can help Chinese IT firms to exploit these unique advantages.

- Successful Chinese IT firms have not attempted to jump right into "technology leadership" strategies, to compete head-on with global technology leaders through "radical" innovations. Instead, they appear to have focused on "incremental" and "architectural" innovations that allow them to pursue "technology diversification" strategies.

These findings contradict a pessimistic literature that provides a backward-looking appraisal of the weakness in China's innovative capabilities[3]. They also contradict fears, sometimes played up for political purposes, that Chinese firms could successfully create "radical" innovations that would challenge U.S. technology leadership[4]. A central proposition of the paper is that Chinese IT firms seem to make most progress in areas that escape the attention of both pessimists and proponents of China's emerging technology threat.

Part one presents the overall picture of China's integration into both formal corporate and informal social global knowledge networks.

In part two, I draw on the literature on Asian innovation systems to highlight systemic determinants, the importance of international knowledge sourcing, the role of Asian governments and firms. I use a broad definition of "innovative capabilities" to emphasize that, in addition to technological knowledge and R&D, complementary "soft" entrepreneurial and management capabilities are of critical importance to compensate for China's initial disadvantages.

In part three, I use the case of Lenovo, a large and successful Chinese IT firm, to explore how changes in the business model affect integration into global knowledge networks, and to highlight implications and challenges for the development of innovative

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[3] For instance, Nolan, 2001; Steinfeld, 2004; Gilboy, 2004; Rosen, 2003; and Dedrick and Kraemer, 2005.

[4] See, for instance, the congressional hearing of the US -China Economic and Security Review Commission,held at Stanford in April 2005 on China's High Technology Development, at: http://www.uscc.gov/hearings/2005hearings/transcripts/05_04_21_22.pdf

capabilities[5]. Specifically, I examine how Lenovo's initial focus on the China market has shaped its integration into formal corporate networks with customers, technology suppliers and strategic partners, and how this has changed, once the company decided to "go global", by acquiring IBM's PC division. I also discuss the role of venture capital and private equity investment, as well as that of informal social networks.

Part four introduces two concepts to examine what specific innovative capabilities have been developed by Lenovo and other Chinese IT companies - a taxonomy that distinguishes *incremental, modular, architectural* and *radical* innovations (Henderson and Clark, 1990), and the concept of "*disruptive technologies*" (Christensen, 1997). The taxonomy provides an analytic framework for distinguishing innovative capabilities by complexity, while the concept of "disruptive technologies" deepens our understanding of the market constraint to innovation. Both concepts are normally used to analyze strategic options for incumbent market leaders. I turn this analysis around to examine why a combination of "incremental" and "architectural" innovations makes more sense for Chinese IT firms than "modular" or "radical" innovations.

1. China's Integration into Global Knowledge Networks

1.1. Formal corporate networks through foreign direct investment

China's rise as the primary global electronics factory reflects its integration into global production, sales and R&D networks that industry leaders (primarily from the US) and their Taiwanese junior partners have established through *foreign direct investment* (FDI). This has generated deep integration with global customers, technology suppliers and strategic partners.

Since 2003, China is the world's largest recipient of FDI, overtaking the US, traditionally the largest recipient. Incoming FDI has averaged 5% of GDP in China over the past decade; during Japan's and Korea's high growth periods, incoming FDI was never as much as one half of one percent of GDP. FDI is more than ten times as important in China as in these earlier latecomers, and nowhere more so than in high technology exporting. In 2003, foreign-invested enterprises (FIEs) produced 55% of China's total exports, but fully 85.5% of high-technology exports. And Taiwan-owned FIEs produced 60 % of China's exports of computers and handsets.

In addition, practically all global IT industry leaders have begun to conduct R&D in China, as part of aggressive innovation offshoring strategies (Ernst, 2005a). A recent survey of the world's largest R&D spenders showed that by 2004 China had become the third most important offshore R&D location after the United States and the United Kingdom, followed by India (sixth) and Singapore (nineth) (UNCTAD 2005).[6] Much of

[5] A related paper will examine findings for two small semiconductor firms (Vimicro and Verisilicon) that use knowledge acquired in Silicon Valley to conduct R&D in China (Ernst, 2006 b). And case studies of Huawei can be found in Ernst and Naughton (2005) and Ernst, 2006 c.

[6]The UNCTAD sample consists of the first 300 firms of the R&D scoreboard of the 700 top worldwide R&D spenders, published by the UK Department of Trade and Industry (DTI).

the R&D offshoring to Asia is concentrated in the electronics industry, with China dominating hardware R&D for hardware. Last but not least, leading Chinese IT companies (e.g., Huawei and Lenovo) are now constructing their own global R&D networks, often in close collaboration with global industry leaders.

As for non-equity forms of R&D internationalization ("offshore outsourcing"), China is now the third most important location behind the United States and the United Kingdom, but ahead of Germany and France. The same survey projects that China will be a more attractive location for future foreign R&D than even the United States.

1.2. Venture capital and private equity investment

More recently, *venture capital* and *private equity investment* have added a new and critically important dimension to China's integration into formal corporate knowledge networks[7]. Venture capitalists in Silicon Valley now require start-ups to present an "offshore outsourcing" plan as a precondition for funding. The emerging business model is to keep strategic management functions like customer relations and marketing, finance, and business development in Silicon Valley, while increasingly moving product development and research work to offshore locations (Ernst, 2006a).

A typical example is a start-up company in Shangdi Information Industrial Base in Beijing's Haidian District that specializes in mixed-signal chip design (Interview 092105). The company was founded by Chinese engineers who hold Ph.D. degrees from leading U.S. universities and who have worked as senior project managers in leading U.S. semiconductor companies. The company has received venture capital funding for developing chip designs in both China and Silicon Valley. A fully integrated design team in Beijing develops decoder chips customized for the new Chinese AVS (audio-video signal) standard. Of the more than 60 engineers at the Beijing facility, 90 percent hold at least Masters degrees. Five senior managers based in Santa Clara handle relations with customers and with suppliers of design tools and design building blocks.

Since the turn of the century, fund raising in private equity has rapidly increased, and is now also targeting China's high-tech industries. Much of these new forms of network integration take place behind the scenes, and hence are difficult to document[8].

Rough indicators of evolving role of VC and private equity in China: CBR; Zero2IPO; Martin Bloom

Viewed from the broader perspective of economic development, the expansion of VC and private equity investment is a double-edged sword. There is concern that, as long as it remains unregulated, the expansion of private equity funding may endanger the stability of financial systems[9]. As they obtain important management information in advance,

[7] Definitions VC versus private equity investment
[8] Sources: data from consulting firm Greenwich Associates; article on TPG, FT, 3 April 2006; …
[9] See article on the absence of regulations of private equity funds ("Buy-Out Groups Consider Setting Up Trade Body", FT, 10 April 2006. Page1)

private equity firms can use such information to avoid losses or to unfairly take profits through insider stock trading, transferring losses to ordinary shareholders[10]. Yet, as shown below, both venture capital and private equity investment may act, under certain conditions, as carriers of knowledge on markets, technology and best practice management approaches.

1.3. Informal social networks

Equally important is China's growing integration into *informal* global knowledge networks through the international circulation of students and knowledge workers. Since the opening of its economy, China has become intricately linked to more developed overseas innovation systems, first through a massive brain drain of its students and, more recently, through a reverse brain drain that brings returnees and overseas Chinese knowledge workers back to China. The primary link of course has been with the US, and its universities, its high-tech industries and its financial sector.

In 2005, China had more than 61,000 students in American universities, more than any other country except India[11].

Add table with latest NSF figures

But China now also relies on a growing circulation of students and knowledge workers with other Asian countries (especially Taiwan), as well as with Japan and Europe.

data

As demonstrated below, China's integration into these informal global knowledge networks provides an important enabling factor for the development of its innovative capabilities. Exposure to professional peer group networks, China's large *diaspora* of skilled migrants, and "IT mercenaries" (from Taiwan, Hong Kong, the Philippines, as well as Japan, the US and Europe) and can help to diffuse complex and often tacit knowledge about technology and management. In addition, these informal social networks can provide much needed experience and links with markets and financial institutions, and they can become an important source of reverse brain drain.

2. Defining Innovative Capabilities

How do we define "innovative capabilities" in a world in which even a very large country like China finds itself deeply integrated into both formal corporate and informal social global knowledge networks? An important challenge is to define this concept in a way that reflects globalizing markets for technology and knowledge workers and the resultant transformations in the international innovation system (Ernst, forthcoming).

2.1. Systemic determinants

[10] An example is the recent indictment of Warburg Pincus's Korean office on charges of insider trading ("Warburg Pincus faces Won 26 bn fine", FT, 19 April 2006:16).
[11] Data, courtesy of the U.S. Council of Graduate Schools, march 2006

Unfortunately, much of the literature on Asian innovation systems is based on empirical evidence that predates these transformations[12]. However, that literature does provide important insights. It demonstrates, for instance, that peculiar features of economic structures and institutions offer quite distinct possibilities for learning and innovation, and hence should be reflected in the design of innovation strategies.

This is in line with a key finding of the study of innovation systems - peculiar features of economic structures and institutions offer quite distinct possibilities for firm-level learning and innovation and hence shape the firm's technological and economic performance[13]. Of course, Edith Penrose`s important proposition remains true - "... a firm´s rate of growth is limited by the growth of knowledge within it"[14]. But equally important are the systemic impacts of the external economic structures and institutions into which a firm is embedded.

Specifically, the economic structure (of a country, an industry and a region) is an important determinant of a firm's specialization (i.e. its product mix), its learning requirements as well as the breadth and depth of its capabilities. Institutions, on the other hand, shape the efficiency of firm-level learning - they define how things are done and how learning takes place. An important concern is the "congruence" (Freeman, 1997:13) of different subsystems, which is necessary to create a *virtuous* rather than a *vicious* circle.

In Asia, empirical studies within this research tradition have focused primarily on how firm-level development of resources and capabilities is shaped by industry structure and government policies, and the resultant idiosyncratic approaches to innovation management. An important finding is that the analysis of capabilities needs to move beyond the boundaries of the firm to capture its increasing reliance on external knowledge sources. For instance, Jefferson and Kaifeng (2004) identify 23 indicators ("attributes") that potentially enhance the productivity and profitability of firm-level R&D operations, under four headings: openness/competition, human capital, feedback links of R&D networks, and peculiar features of institutions. And Rasiah (2003) attempts to extend the concept of capabilities to include what he calls "systemic and institutional dimensions", i.e. the role of "intermediary organizations" such as chambers of commerce and government-business councils in generating feedback links between innovation agents.

2.2. International knowledge sourcing

More recently, research has emphasized the critical importance of the international dimension. A central proposition of this literature is that much of the success of Asian export-led industrialization was due to international knowledge sourcing – Asian latecomer companies have upgraded their technological capabilities in manufacturing

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[12] For instance, Bell and Pavitt, 1993; Kim Linsu, 1997; Nelson and Pack, 1999; Lall, 2000; Hobday, 1995; Ernst, Ganiatsos, Mytelka, 1998; Ernst and O'Connor, 1989 and 1992

[13] For instance, Freeman, 1987; Nelson, 1993; Lundvall, 1992; Mowery and Nelson, 1999.

[14] Penrose, 1959/1995, Foreword, 3d edition, "The Theory of the Growth of the Firm", pages XVI and XVII.

through integration into global production networks (GPNs) that multinational corporations have established to integrate their geographically dispersed production, sales and R&D sites[15]. It is argued that Asian countries were able to overcome their initial disadvantages through strategies "…to leverage knowledge and technologies from their more advanced competitors … (that) utilize the existing and latent inter-firm connections of the global economy" (Mathews, 2002: p.VIII).

These studies provide empirical evidence that, through integration into GPNs, Asian firms were able to tap into the world's leading markets, especially in the United States, and compensate for the initially small size of their domestic markets. Network participation also has provided access to leading-edge technology and best-practice management approaches. This, in turn, has created new opportunities, pressures, and incentives for Asian network suppliers to upgrade their technological and management capabilities and the skill levels of workers (Ernst and Kim 2002).

In addition, as latecomers to innovation, Asian economies (even the most successful ones), are constrained by weak domestic research capabilities and a narrow portfolio of home-grown intellectual property (Ernst, 2002a). Hence, they have little choice but to seek for ways to attract and expand R&D by global firms.

A related important finding is that, as Asian economies progress in their industrial development, they continue to rely on international knowledge sourcing through global production and R&D networks. In a case study of Malaysia's electronics industry, Ernst (2004) demonstrates that attracting foreign R&D may not only compensate for initial weaknesses of the domestic knowledge base. Such international knowledge sourcing may also facilitate the adjustment of business organization and strategy to abrupt changes in technology and markets. The study concludes that, under certain conditions, attracting R&D by global firms may catalyze the development and the diffusion of innovative capabilities *ahead* of what the market would provide.

2.3. Foreign R&D labs

To examine how foreign R&D labs may contribute to the development of local innovative capabilities, it is important to distinguish between "home-base-exploiting" and "home-base-augmenting" overseas R&D labs (Kuemmerle, 1996). "Home-base-exploiting" overseas R&D has been around for a long time. Its *raison d'etre* is to adapt technology developed at the company's home base for commercialization in overseas markets. The key requirement for overseas R&D is the adaptation of products, services, and production processes to local needs and resource endowments.

By contrast, "home-base-augmenting" overseas R&D in Asia has become considerably more important since the 1990s. Its rationale is "external knowledge sourcing," that is to say, tapping into new knowledge from an increasing number of overseas local innovation clusters, to transfer that knowledge back to the home base (Kuemmerle 1997: 66), and to combine these diverse technologies to create new products and processes (e.g.,

[15] Ernst, 1997; Borrus, Ernst and Haggard, 2000; Sturgeon, 2002.

Granstrand, Patel and Pavitt, 1997). Hence, augmenting overseas R&D requires far more than adaptive engineering. It includes product development as well as applied and fundamental research.

The following taxonomy (Ernst, forthcoming) helps to capture the evolution of R&D labs established by global electronics firms in China. "Satellite" R&D labs, the least developed type of lab, combine elements of "home-base-exploiting" and "home-base-augmenting" R&D. These labs are of relatively low strategic importance, as evidenced by their vulnerability to budget cuts decided by headquarters.

"Contract" R&D labs describe the pure-play version of "innovation offshore outsourcing." For these labs, China's role is confined to the provision of lower-cost skills, capabilities, and infrastructure. While dense information flows link these labs with R&D teams at headquarters and other affiliates, knowledge exchange remains tightly controlled, and highly unequal. The highest stage, "(more) equal partnership" labs, is reserved for those R&D labs of global firms that are charged with a regional or global product mandate. For these labs, barriers to knowledge exchange are supposed to be much lower, and may eventually give way to full-fledged mutual knowledge exchange.

Recent research documents that satellite and contract R&D labs continue to dominate (e.g., von Zedwitz 2004; Gassmann and Han 2004; Li and Zhong 2003). However, there are also examples of (more) equal partnership arrangements, especially related to the development of China's alternative standards in mobile telecommunications, open source software, and digital consumer electronics (Ernst and Naughton 2005; Garcia and Burns 2006).

2.4. Role of Asian governments and firms

But the study of Asian innovation systems also highlights the critical role that Asian governments and firms are playing as promoters and new sources of innovative capabilities. In fact, integration into global corporate knowledge networks increases the need for strong national innovation systems.

In order to reap the potential benefits from network integration, Asian countries must have in place vigorous policies to reduce potentially high costs that may result from "brain drain" (both domestic and international), when global firms are crowding out the local market for scarce skills. Other sources of network integration costs include a possible deterrence effect of global labs on local R&D; the acquisition by global firms of innovative local companies; and the disproportionately high benefits that may accrue to a foreign parent company.

In other words, integration into global corporate knowledge networks can only produce sustainable long-term economic benefits, if policies exist to develop strong local companies that can act as countervailing forces to the accumulated strengths of global firms. But the literature also emphasizes that, for Asia to cope with the complex challenges and opportunities of network integration, new policies are required that are very different from earlier top-down "command economy"- type industrial policies that were typical for the "East Asian development model".

2.5. A broad definition of "innovative capabilities"

To establish what are realistic options for Chinese IT firms to build innovative capabilities within global knowledge networks, it is necessary to open the black box of "innovative capabilities". I suggest to use a broad definition of "innovative capabilities" to emphasize that, in addition to technological knowledge and R&D, complementary "soft" entrepreneurial and management capabilities are of critical importance to compensate for China's initial disadvantages.

Especially useful for our purposes is research that has developed operational data sets for measuring firm-level innovative and R&D capabilities. Important contributions include Lall (1992), Ernst and O'Connor (1992), Rasiah (1995), Bell and Pavitt (1995), Hobday (1995), and Ernst, Ganiatsos, Mytelka (1998). The latter study, prepared for the United Nations Conference on Trade and Development (UNCTAD), developed the first comprehensive taxonomy of firm-level capabilities required for *production, investment, minor change, strategic marketing,* establishing *inter-firm linkages,* and *major change*. This taxonomy, which suggested a sequential ordering of priorities for capability formation, was largely confirmed in that study's comparative analysis of how electronics and textile firms have developed their capabilities in Taiwan, Korea, Thailand, Indonesia and Vietnam.

The study's emphasis on *strategic marketing* capabilities was corroborated by recent case studies of Lenovo and China's handset industry (Xie and White, 2004 and 2005) that highlight the role of distribution channels and close interaction with end users as preconditions for developing innovative capabilities. Ariffin (2002) documents the role of *minor change* capabilities and *inter-firm linkages*, while the importance of *major change* capabilities is emphasized by Amsden and Tschang (2003), who have classified different categories of R&D by their technological complexity.

Building on this literature, I define "innovative capabilities" broadly to include the skills, knowledge and management techniques needed to create, change, improve and commercialize successfully "artefacts", such as products, services, equipment, processes and business models (Ernst, forthcoming). R&D plays an important role, but equally important are complementary "soft" capabilities beyond the fields of science and engineering. Research on successful innovations demonstrates that "the technology is the easy part to change. The difficult aspects are social, organizational, and cultural" (Norman, 1998).

Lester and Piore (2004) emphasize that higher education in science and engineering tends to place too much focus on analysis, while neglecting interpretation and knowledge integration. In their view, innovation requires both analysis and interpretation. But analysis is much easier to teach and understand than interpretation. The purpose of analysis is to solve problems. One divides the problem into a series of discrete and separable components and assigns each one to a knowledgeable specialist. Analysis works best when alternative outcomes are well understood and can be clearly defined and distinguished from one another. But innovation hardly ever fits this pattern. Uncertainty and unpredictability are its defining characteristics. Analysis therefore needs to be complemented by interpretation, for instance "a new insight about a customer, a new idea for a product, a new approach to producing or delivering it."(Lester and Piore, 2004: 9).

In short, in addition to R&D, I suggest to emphasize the following complementary "soft" innovative capabilities:

- to sense and respond to market trends before others take note ("entrepreneurship");
- to recruit and retain educated and experienced knowledge workers who are the carriers of new ideas (an invention or discovery);
- to raise money required to bring an idea quickly to the market (the litmus test of innovation);
- to deliver unique and user-friendly industrial designs (which is of critical importance especially for fashion-intensive consumer devices, like mobile handsets);
- to develop and adjust innovation process management (methodologies, organization and routines) in order to improve efficiency and time-to-market; and
- to manage knowledge exchange within multidisciplinary and cross-cultural innovation projects.

3. Lenovo - Leveraging Linkages with Global Industry Leaders

Lenovo provides a telling example of the hybrid ownership patterns that characterize China's IT industry (Ernst and Naughton, 2005) [16]. It also demonstrates that a company's initial business model ("focus on the China market") can shape its integration into global knowledge networks, and that, in turn, this integration can influence the evolution of its business model and its approach to the development of innovative capabilities.

In terms of their contribution to innovative capabilities, Lenovo's most evident network linkages are with customers, technology suppliers and strategic partners. The company has leveraged linkages with global industry leaders, first to establish domestic market leadership, and later to expand into global markets. These linkages have culminated in the acquisition of IBM's PC division, which has also raised the role of private equity investors. Informal social networks are important, but they are more difficult to document.

3.1. Ownership

Founded in 1984, as a spin-off of the Chinese Academy of Sciences, this is a "state-owned, privately-run" company whose state oversight virtually disappeared since its has been "corporatized" and listed on the Hong Kong Stock Exchange in 1994. Originally called New Technology Developer Inc., the company was renamed Legend in 1988, after its successful Chinese-character PC card. In 2003, the company was renamed again -

[16] Two excellent sources on the origins and evolution of the company are Lu (2000) and Feng and Elfring (2004).

“Lenovo” was chosen on suggestion of an international brand consulting firm as a logo that could be used without restrictions in global markets.

Figure 1

Figure 1 describes the current ownership structure - the Lenovo Group Ltd is part of the Hong Kong-listed conglomerate Legend Holdings Ltd, together with Digital China Holdings Ltd, which focuses on distribution and services, and Legend Capital, one of China’s leading corporate venture capital investors. As will be described below, the company also has received substantial private equity investment.

Two persons have shaped the company’s initial business model - Chen Chunxian and Liu Chuanzhi. And both have played an important role in transmitting and absorbing critical commercial knowledge from foreign sources, and in adapting that knowledge to the harsh business environment of China. Chen Chunxian was a CAS researcher who, during three visits to the US, had examined the experience of high-tech start-ups along Route 108. He decided to set up a privately run “new technology department” along Zhongguancun Road. This model was adopted by the Academy’s Institute of Computing Technology (ICT)

Liu Chuanzhi, who was born in Shanghai into a family with a long tradition in banking, was influenced by the experience of his father who, after working at the Bank of China had become a lawyer and moved to Hong Kong to become a specialist in intellectual property law. The young Liu was a graduate of the Xi’an Military Institute of Telecommunications and Engineering. During the Cultural Revolution, he, like many other college graduates, was sent to the countryside. In 1984, he found himself stuck in a low-paid computer scientist position and was frustrated that the institute’s research was not turned into something practical. His main motivation in founding the company was to commercialize ICT research.

By 1984, when Legend was founded, Deng XiaoPing’s call for reform was well established. Yet, all the necessary ingredients for creating a successful start-up company were missing, and there were no established role models of how to overcome the substantial and deeply entrenched barriers to entrepreneurship. This left little alternatives but to start small, by buying and selling whatever could be sold. Rather than proceeding from manufacturing to sales and then to R&D, the company had to start as a trading company. In a way, this reverse sequencing of capability development was typical for the business practices established by Hong Kong traders. Most importantly, it was instrumental in focusing attention on collecting critical knowledge about peculiar features of the China market.

3.2. A focus on the China market

The result is, that until recently, Lenovo’s primary focus has been on the China market. After the mid-1980s, that market expanded rapidly. By 2005, it was still growing seven times faster than the US market. And despite the entry of Dell and HP, Lenovo has remained the market leader for eight consecutive years, with a 2005 share of about one-third of the China market.

Lenovo owes its success at home to the development of products and services that are user-friendly; less over-engineered and less expensive than those provided by global market leaders; and that contain unique performance features that address peculiar needs of China's markets. As demonstrated in part four, these are all characteristics of "disruptive technologies", as defined by Christensen (1997). Specifically, Lenovo's strength in China reflects a business model, developed by the company's founders, that combines the following elements:

- familiarity with specific market characteristics and user requirements in China;
- a superior domestic distribution network and information management;
- advanced industrial design capabilities;
- strong brand names;
- reliance on China's competitive cost structure; and
- access to well-educated and trainable knowledge workers.

Learning from global market leaders

Much of Lenovo's success at home was made possible by learning and capability development through linkages with global market leaders. Specifically, the company's integration into global knowledge networks was shaped by its decision to enter the China market as a distributor of foreign products rather than as a manufacturer[17]. Back in 1985, the company began to distribute computers by HP, IBM and AST. Especially from HP, Lenovo acquired the basics of modern business management: "Legend learned to be more sensitive to the market and to market trends, and it learned the value of working with established procedures." (Feng and Elfring, 2004:37).

In fact, much of the company's management philosophy and organization was shaped by insights that Lenovo's current chairman Yang Yuanqing gained from his close association with HP. This covers the introduction of formal decision-making procedures, the transition from a functional organization to business units, and the use of performance evaluation and incentives. Generous share options were used to recruit top university graduates and to poach aggressive young Chinese executives from leading global corporations. But the most important lessons were the critical importance of establishing a superior distribution network and the early introduction of an efficient, IT-enabled controlling system that would help to control inventory and accounts receivables.

Another important international source of knowledge were extensive contacts with Taiwan's IT industry. For instance, before establishing its manufacturing base in Guangdong Province, Legend's top management took an exploratory trip to Taiwan that included extensive brain-storming discussions at Acer and other leading Taiwanese PC

[17] This decision was imposed by the company's failure to secure a manufacturing license from the Ministry of Electronics Industry (MEI). Instead, licenses went to companies that were part of the "MEI family", like Great Wall which was then the largest domestic producer.

companies (Feng and Elfring, 2004:88). This visit was instrumental in committing the company to its focus on the China market. In contrast to Taiwan, where a small market has forced companies to embark on global subcontracting strategies[18], the China market was big enough to sustain a brand. It was hoped that at a later stage, the experience gained in the China market could be used as a base for developing a brand internationally.

In addition, the company brought in McKinsey consultants, who, according to one observer, "almost lived in the company for several years, building Western-style management and logistics systems." (McGregor, 2005: 290). Since 2000, Legend also started to talk to a group of private equity investors at General Atlantic, originally looking for advice on how to spin-off Legend's distribution and software activities, resulting in the 2001 listing of Digital China on the Hong Kong Stock Exchange (Primack, 2006). The chairman of General Atlantic, Steven A. Denning, is a member of the Board of Trustees of Stanford University, but also serves on the Advisory Board of the School of Economics and Management at Tsinghua University. This apparently has helped to establish contact with Liu Chuanzhi, the founder of Legend, who as chairman of Legend Holdings, retains control behind the scenes.

As we will see below, these kind of informal social networks are important, but they are more difficult to document than linkages through international circulation of students and knowledge workers. For instance, among the eight most senior Chinese executives of today's Lenovo group, only one, Mary Ma, has done her graduate studies overseas (at King's College of the University of London). But this reflects her responsibility as Senior Vice President and CFO for finance and investor relations. And none of these eight most senior Chinese managers lists overseas work experience in their CVs.

This China-centered education and work experience obviously reflects the barriers to international studies and work experiences faced by Lenovo's founding generation. But it also highlights a peculiar strength of Lenovo. As the company is a spin-off of the Chinese Acadmey of Sciences - Lenovo's senior managers have retained strong ties to the academic research community, which may help it to absorb quickly R&D from universities and national labs. In addition, a new generation of future senior managers (many of them poached from leading global corporations) is likely to present a very different picture - their education and work experience is much more exposed to international knowledge networks through overseas graduate studies, travel and work[19].

Developing Innovative Capabilities

As its own capabilities extended beyond the mastery of the basics, Legend engaged in deeper cooperation with a core group of technology suppliers and strategic partners to develop and upgrade its innovative capabilities. This willingness to learn from global industry leaders was captured by the company slogan: "Research and development stands

[18] As documented in Ernst, 2000, Acer had to pay a heavy price for its early attempt to develop a global brand.

[19] **Cite examples from interviews**

on the shoulders of giants." (Feng and Elfring, 2004:127). In addition to IBM and HP, that core group now also included Intel, Microsoft, Hitachi, Siemens, and Texas Instruments. Of particular importance has been the relationship with Intel. One of the reasons that allowed Legend to gain market share was its decision to use only the best of Intel's microprocessors, and Intel was quick to select the company as its first strategic partner in China. As a result, most of the company's executives have participated in Intel's organizational training programs.

Another important knowledge network has developed around capabilities in industrial design and materials. A second reason for Legend's success in the China market was its decision in 1998 to introduce a laptop (the Tianxi model) for consumers and small businesses, melding a stylish design (a pastel-colored, shell-shaped body) with performance features that effectively addressed user requirements of these market segments[20]. The Tianxi model was introduced after two years of intensive R&D that involved some of the leading global players in materials, such as GE Plastics and Nike, and well-known design firms such as Palo Alto-based IDEO and Portland-based Ziba Design.

3.3. Going Global

However, by around 2004, the company realized that it had to expand beyond its China base, if it wanted to avoid a premature slow-down in its growth. Lenovo's domestic market leadership came under attack by Dell and HP, who benefited from support by Taiwanese contract manufacturing partners. This has intensified price competition. It also has exposed two fundamental weaknesses of Lenovo:

- A heavy reliance on China's price-sensitive and low-margin markets for computer products and services, together with insufficient size and hence limited economies of scale and scope could squeeze the company's profit margins.

- Over time, this could limit the funds available for expanding R&D to develop proprietary products and services needed for product differentiation as well as for diversification into new product markets like handsets and servers. It could also constrain funding for the huge investments required to develop a global brand recognition.

The most immediate challenge arguably is to overcome size limitations. With revenues of HK$ 22.555 billion (roughly US$ 2.9 billion) in 2005, the company is much smaller than global industry leaders. And a telling indicator of the company's lack of exposure to global markets is that, as of March 31, 2005, only 57 of its 9,682 employees were employed outside China (mostly in Hong Kong).

Lenovo's response consisted of a four-pronged strategy:

- develop a distinct global brand;

[20] Plastics News Report, 9 December 2005

- expand the company's global market share as rapidly as possible, including lead markets in the US, Europe and Japan[21];
- attack the weak spot of global market leaders and their Taiwanese junior partners, by offering "disruptive technologies", i.e. products and services that are less over-engineered and expensive than those of global market leaders, and that contain unique performance features that reflect specific characteristics of the target markets[22]; and
- leverage linkages with global industry leaders to accelerate the development of the company's innovative capabilities and to gain insights in how to penetrate the extremely demanding global lead markets (especially the US).

3.4. Acquiring IBM's PC division

In December 2004, Lenovo acquired IBM's PC division - a move so daring that it shook the industry. This take-over of an American icon, albeit a highly unprofitable part of Big Blue, provides "the best laboratory in which to study a blended Chinese and Western management model (McGregor, 2005: 289).

Ownership and private equity investors

There is no doubt that the complex ownership structure of the new company will create tensions. Management will have to struggle to comply with potentially quite different interests.

Lenovo was reported to pay $ 1.25 billion for IBM's PC division and assume debt, which brings the total cost to $1.75 billion. As part of the deal, IBM will gain an 18.9 percent stake in Lenovo, providing it with sufficient influence over decision-making. The remaining ownership shares are 46% for the Chinese government and 35% for Lenovo and its shareholders.

Little is known about the identity of these shareholders. However, we do know that private equity investors apparently now play an important role in decision-making. In fact, private equity investors were instrumental in bringing about the IBM PC acquisition, by providing critical information and by helping Lenovo navigate stormy US political waters. According to one source,

> "Liu (Chuanzhi) called General Atlantic, and asked for help determining if such an acquisition would make sense. If Lenovo were to bid and win, Lui told GA, the private equity firm would be welcomed in as an equity participant on the deal. GA agreed, conducted due diligence, and told Lui that the acquisition would, indeed, make sense."(Primack, 2006)

[21] According to Lenovo Group chairman Yang Yuanqing, "(w)e will make money but we don't focus on profit, we focus on growth", adding that this phase may last at least two years. (quoted in *Network World*, 9 December 2005)

[22] An example are Lenovo's first computers sold under its own brand outside China – the Lenovo 3000 J series Desktops and 3000 C Notebooks. These models target lower performance at a lower price for overseas markets. See discussion in part four.

As part of its acquisition of IBM, Lenovo received a $350 million private equity commitment from Texas Pacific Group ($ 200million), General Atlantic ($ 100 million) and Newbridge, TPG's Asian affiliate ($50 million). The entry of these new investors will shrink IBM's eventual share in Lenovo to 13.4%, down from the 18.9% reported when the acquisition was announced (*China IT Weekly*, 1 April 2006). Upon full conversion of preferred shares and after share issuance to IBM, the private equity investors are expected to hold around 12.4% of Lenovo's capital.

As a result, the private equity investors are now involved "in much of the decision-making…(and)… are treated as partners instead of like minority investors." (Primack, 2006). It is too early to judge how this will affect the long-term development of Lenovo's innovative capabilities.

Implementation challenges

The challenges of implementing this acquisition are mind-boggling - to compete in a business with slim margins and fierce competition, while patching together complicated supply chains, sales networks and information systems. The new Lenovo needs to retain IBM Think Pad customers, while developing its own distinct global brand image.

An equally important challenge is to retain cost leadership. The new company has four times the revenue of the old Lenovo, but it has six times the staff cost of the China group alone and only twice the profit. With one stroke, Lenovo's workforce was more than doubled, from around 9,000 to almost 21,000. Of those 10,000 originally from IBM, 40% are currently based in China and 25% in the U.S..

For its US-based workforce, Lenovo has promised that their compensation and benefits would remain identical or fully comparable to their IBM package[23]. For instance, the average salary at its new R&D center in Morrisville/North Carolina is reported to be $ 70,000 a year plus benefits (*The Herald Sun*, 28 October 2005). As Lenovo now has to pay US salaries to its ex-IBMers, it will not be easy to retain its cost leadership. This may also have negative consequences for Lenovo's efforts to strengthen innovative capabilities. Paying US wages will not only increase Lenovo's cost of R&D, but it also might create tensions within its China-based R&D workforce.

It did not take long for management to respond. On March 20th, 2006, the company announced that it will cute five percent of its 21,000 staff, with lay-offs concentrated on ex-IBM employees outside China (of whom 16% will loose their jobs).

An additional important challenge is to develop a new corporate identity that would help to bring together two vastly different work forces, in terms of demographics and behavior. The average age of Lenovo employees is 27.5 years, half of them joined the company in 2002. Many senior Lenovo managers are promoted within a few years, some even got three promotions within a year; while IBM executives are older and more experienced. In addition, IBMers are used to a management style that is highly structured

[23] *Workforce Management*, special issue on IBM, July 2005.

(some would say "bureaucratic") and may not be easy to reconcile with Lenovo's peculiar blend of authoritarian top-down decision-making and Silicon Valley-type remuneration packages.

A clash between conflicting management cultures seems unavoidable. An indicator of such tensions is that the first president and CEO of the new Lenovo was retired after only a few months. Stephen M. Ward had spent over 26 years with IBM, most recently as Senior Vice President, responsible for IBM's PC division. His style of management apparently did not match well with the rapid pace of change typical for Lenovo. The new CEO, William J. Amelio, had also worked in IBM's PC division since 1979, but had then left in 1995. Arguably his greatest attraction for Lenovo has been his most recent position with Dell (since 2001) where, as Senior Vice President for Asia-Pacific and Japan, he had shaped Dell's aggressive market penetration strategies.

Opportunities

However, this diversity of management cultures could also become a rich source of learning and capability development. One could argue that, at least on paper, there are substantial synergies that could help to shape a new, hybrid business model and that this in turn could give rise to the creation of a unique set of innovative capabilities.

There are indeed potential synergies in product, market segment and geography. For instance, despite the success of the Tianxi laptop, only 18% of Lenovo's pre-acquisition revenues came from laptops, while for IBM's PC division that share was 60%. While for IBM, corporate customers represented almost 60% of revenues, 83% of Lenovo's revenues came from small businesses and consumers. Most importantly, Lenovo expects to benefit from IBM's global presence to overcome its lack of experience in overseas markets.

A greater exposure to global informal knowledge networks starts at the level of top executives. Seven out of the 15 most senior executives of Lenovo now are non-Chinese, two of whom were educated in India, one in Canada and one (of Greek origin) in Australia. Of particular importance is the international exposure in their work experience. For instance, Ravi Marwaha, Senior Vice President for Geographies, has worked in India and Australia, and has served as president of the Indo-American Chamber in Bangalore. And Bill Matson who, as Senior Vice President for Human Resources, bears responsibility for blending the merged company's diverse labor forces, has graduated at Cornell University in Industrial and Labor Relations, and has 24 years of experience with IBM on global human resources management.

Through its acquisition, Lenovo expects to gain access to a worldwide network of highly skilled computer sales and distribution employees who know tax laws and invoicing practices in 66 countries. The same is true for R&D. After the acquisition, Lenovo's R&D workforce has increased from 1,100 to 1,800. This represents about 9.5 % of Lenovo's total workforce, and about 18 % of its non-manufacturing workforce (there are about 10,000 people in the manufacturing department). In sheer quantitative terms, Lenovo thus has now more resources available for an expansion of R&D.

Especially noteworthy is the addition of two IBM R&D labs, in Yamato/Japan and North Carolina. Both new centers could help to initiate a process of globalizing Lenovo's R&D network. Before the acquisition, Lenovo's R&D was almost completely China-centered, with main centers based in Beijing, Shanghai and Shenzhen[24]. Obviously, Yamato and North Carolina could help to improve the portfolio of R&D projects and to raiseR&D productivity and revenues.

Yamato is credited with developing IBM's highly rated ThinkPad family of laptops, and hence may be an important asset for Lenovo. After the acquisition, Lenovo continues to use the experienced Yamato R&D team to focus on notebook development, in addition to its work on RFID (radio frequency identification) technology.

As for North Carolina, rather than using IBM's facilities in the Research Triangle Park, Lenovo decided to invest US$84m to build a new R&D campus in nearby Morrisville that will house more than 2,200 employees. This would increase Lenovo's North Carolina headcount by around 400[25]. This new research center will focus on the development of desktop computer, software, product definition and quality control.

Finally, the acquisition of IBM PCD has strengthened Lenovo's portfolio of brands and patents. An important part of the takeover agreement is that Lenovo is allowed to use the IBM brand for five years, and that includes the successful "Think" brand. IBM has promised to support Lenovo with marketing and with its IBM corporate sales force.

In addition, by acquiring IBM PCD, Lenovo was able to add around 1,500 patents to its own accumulated 1,000 patents. Assuming that a significant share of the former IBM patents are registered at the USPTO, this could help Lenovo to overcome its almost exclusive reliance on patenting in China, and to gradually internationalize its patent portfolio. As of June 2004, Lenovo had registered 787 patents in China, entering for the first time the top ten list of the most competitive intellectual property owners in China. But a search in the USPTO patent data base showed that, from 1976 to present, Lenovo had registered only 34 patents.

In short, one could argue that the acquisition of IBM's PC division provides a unique, albeit very costly opportunity for Lenovo to strengthen those innovative capabilities that are necessary to support its global market expansion. Immediate benefits include technical support from IBM R&D labs, access to global market intelligence and distribution know-how, and accelerated learning for further development of Think Pad laptops through collaboration with the Yamato lab. The acquisition of 1,500 IBM patents might also generate additional income for Lenovo (enterprises that had paid IBM licensing fees for using the patented items are now paying Lenovo).

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[24] **Brief description what these centers are doing.**

[25] Construction on the new facility is scheduled to be completed by January 2007. The building of the new facility was announced by North Carolina Governor, Mike Easley, who revealed that Lenovo is to benefit from a $750,000 grant from the One North Carolina Fund, as well as up to $8.4m in tax incentives from a Joint Development Investment Grant if it meets employment and performance targets.

It is an open question, however, to what degree Lenovo will succeed to use its access to a set of proprietary IBM innovations (especially in key component technologies) to strengthen and upgrade its own innovative capabilities. This may happen only, if Lenovo manages to reorganize the former IBM PC labs. But this obviously will take time.

4. Assessment of Innovative Capabilities

4.1. Argument

The study of innovation has long focused on the distinction between "incremental" and "radical" innovations (Nelson and Winter, 1982; Tushman and Anderson, 1986). But an analysis that explores how technology affects competitive dynamics needs to move beyond that simple dichotomy. By adding "architectural" and "modular" innovations, Henderson and Clark (1990) and Baldwin and Clark (2000) have provided an analytic framework for distinguishing innovative capabilities by complexity. And the concept of "disruptive technologies" (Christensen, 1997) deepens our understanding of the market constraint to innovation.

These concepts are normally used to analyze strategic options for incumbent market leaders. The main concern of Henderson and Clark is to highlight the threat to incumbent market leaders - "architectural innovations destroy the usefulness of the architectural knowledge of established firms, and since architectural knowledge tends to become embedded in the structure and information-processing procedures of established organizations, this destruction is difficult for firms to recognize and hard to correct." (Henderson and Clark, 1990: 9). And, as captured in the subtitle of his widely quoted 1997 book, Christensen seeks to establish "When New Technologies Cause Great Firms to Fail."

I turn this analysis around and apply it to latecomer innovation strategies. I argue that both concepts can also be used to examine how Chinese IT firms might seek to leverage participation in global knowledge networks to develop their own innovative capabilities and what barriers they might face. Specifically, I argue that Chinese IT companies face two challenges that are not easy to reconcile.

- On the one hand, they continue to lag substantially behind industry leaders in terms of size and a much narrower base of knowledge and capabilities. Hence, Chinese firms need to focus pragmatically on what is feasible.

- On the other hand, however, if Chinese IT firms would be content with just competing as lower-cost suppliers of "me-too" products, this might leave them in a low-margin "commodity price trap"(Ernst, 2001 a and 2001b). To avoid this trap, they need to provide unique products and solutions, addressing important user needs that incumbent market leaders have neglected.

Both the innovation taxonomy and the concept of disruptive technologies can help to shed light on ample opportunities for innovation that exist below the level of "radical" innovations. Successful Chinese IT firms have not attempted to jump right into "technology leadership" strategies, to compete head-on with global technology leaders through "radical" innovations. Instead, they appear to have focused on "incremental" and "architectural" innovations.

There is a powerful economic rationale behind such strategies. As for "incremental" innovations, intense price competition in most IT markets implies that Chinese firms are under tremendous pressure to improve on cost, time-to-market and performance. This normally can be achieved through relatively minor changes to the existing product or production process. At the same time, "architectural" innovations are of great interest as they could create "disruptive" technologies that face substantially lower entry barriers than "sustaining technologies" that are pursued by incumbent market leaders.
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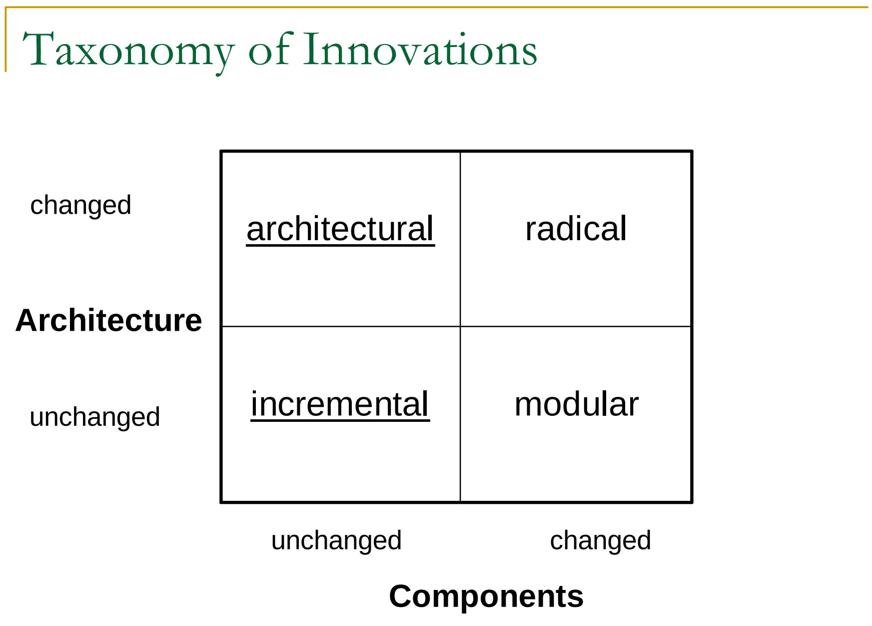
4.2. A taxonomy of innovations

Table … classifies innovations in terms of their contributions to changes in component technology and/or to changes in the architecture of an artifact. That artifact may be a product or a service. Four types of innovations are distinguished: incremental, modular, architectural and radical

This taxonomy builds on the framework for defining innovations, introduced by Henderson and Clark (1990). However, I have adjusted it to fit the specific research agenda of this paper. For Henderson and Clark, the main concern was to emphasize that incumbent market leaders are threatened not only by "radical" innovations, but also by "architectural" innovations that "change the way in which the components of a product are linked together, while leaving the core design concepts (and thus the basic knowledge underlying the components) untouched." (ibid: 11).The authors use the decline of Xerox and RCA to illustrative the destructive power of "architectural" innovations.

The focus of this paper is different. I need a taxonomy that helps to examine what specific innovative capabilities have been developed by latecomers such as Chinese IT firms. Specifically, I want to know how this process has been affected by vertical specialization and the resultant integration of Chinese firms into global knowledge networks. Hence, the taxonomy should provide guidance on how innovations differ in the capabilities they require, and how they differ with regard to opportunities for and barriers to learning and capability development.



Source: adapted from Henderson and Clark, 1990

"Incremental" innovations
"Incremental" innovations take both the dominant component design and architecture for granted, but improve on cost, time-to-market and performance. Their purpose is to exploit as much as possible the potential of a given "design", by introducing relatively minor changes to an existing product or process (Nelson and Winter, 1982). These innovations do not require substantial inputs from science, but they do require considerable skill and ingenuity, especially in what I called earlier complementary 'soft' entrepreneurial and management capabilities.

Examples are improvements in the organization of manufacturing, distribution and support services, like Dell's "direct sales" model and its integration of factory automation and supply chain management. Other examples are new approaches to subcontracting arrangements, pioneered especially by Taiwanese IT firms, like original design manufacturing (ODM), foundry services (for integrated circuit fabrication), and design implementation services[26]. Incremental innovations may also involve continuous improvements in industrial design that help to attract the attention of customers and that enhance the user-friendliness of a product and its performance.

Chinese IT firms have strong reasons and are well placed to pursue "incremental" innovations across all stages of the value chain. They are operating in extremely price-sensitive markets, especially in China, but also as suppliers to global industry leaders. At the same time, barriers to develop "incremental" innovation capabilities are relatively low, as tools and methodologies are familiar, and as investments tend to be low and

[26] For an analysis of the economics of design implementation services, see Ernst, 2006 b.

predictable. Most importantly, incremental innovations can build on existing operational and engineering skills of Chinese IT firms for adjusting the organization of production and R&D, as well as the management of supply chains, customer relations and information systems.

"Modular" innovations

"Modular" innovations introduce new component technology and plug it into a fundamentally unchanged system architecture. This type of innovation has been a defining characteristic of the PC industry - within each generation of the Wintel architecture (combining Microsoft's Windows operating system and Intel's microprocessors), specialized suppliers have introduced new component technology, for instance for memory, storage and display devices.

"Modular" innovations have been made possible by progress in the division of labor in product development ("design" in the parlance of innovation economists). The starting-point is technical change - "(m)odularity is a particular design structure, in which parameters and tasks are interdependent within units (modules) and independent across them." (Baldwin and Clark, 2000: 88). But equally important are implications for the organization of innovation projects and the development of capabilities.

The computer industry is frequently cited as an important breeding ground for this new model of industrial innovation (e.g., Langlois and Robertson, 1992; Baldwin and Clark, 2000). Modular design has made it possible to transform products into decomposable building blocks, i.e. standard interchangeable components. Together with the widely shared Wintel architecture, this has given rise to a massive process of vertical specialization, segmenting an erstwhile vertically integrated industry into closely interacting horizontal layers (Grove 1996).

Many activities that a computer company used to handle internally are now being farmed out to multiple layers of specialized suppliers. This has given rise to rapid market segmentation and to an ever-finer specialization within each stage of the value-chain. Global firms have been the main beneficiaries. As they accumulate experience in managing global distribution and production networks and learn from successes and failures in inter-firm collaboration, they have been able to expand vertical specialization beyond assembly and lower-end component manufacturing.

An important new development is that vertical specialization is being pushed deeper and deeper into higher-end value-chain stages, including product development and research (e.g., Ernst, 2005a, 2005b).This has enabled incumbent market leaders to disintegrate the innovation value chain as well as to disperse it across firm boundaries and geographic borders, giving rise to "innovation offshoring" through global innovation networks (Ernst, 2006 a).

But modularity has also created opportunities for industrial latecomers, as demonstrated by the success of a handful of large Korean and Taiwanese firms in high-precision components like integrated circuits and flat-panel displays[27] However, barriers to modular innovations are substantial - high technological complexity requires top scientists and experienced engineers in component and materials technology, as well as in embedded software and interface standards. In addition, investment requirements are very substantial (around $ 3 billion for a state-of-the-art semiconductor fabrication plant), as are risks of failure.

“Architectural” innovations

“Architectural” innovations are “innovations that change the architecture of a product without changing its components” (Henderson and Clark, 1990: 9). These innovations use existing component technology, but change the way components are designed to work together.

We know from Henderson and Clark why such innovations are a threat to incumbent market leaders. But what enables industrial latecomers to pursue “architectural” innovations? By definition, latecomers like Chinese IT firms continue to lag behind industry leaders in the breadth and depth of their R&D and innovative capabilities. Their strength however is that they are familiar with peculiar characteristics of China’s markets and institutions, and that they are exposed to user requirements that global industry leaders have neglected. Having started as distributors of foreign products and services, Chinese firms have been exposed to China’s insatiable but largely untouched demand for products and services that are not over-engineered and hence are less expensive, but provide essential performance features.

Chinese firms can use this knowledge to penetrate China’s large mass markets, *not by following but by breaking new ground in product development*. This requires a change in the architecture of a product or service. To implement that new architecture, however, Chinese firms do not need to develop the necessary components, nor do they have to change them. The afore-mentioned vertical specialization of industrial manufacturing and R&D has given rise to global markets for technology and knowledge workers. This enables Chinese firms to buy in the relevant component technology from specialized suppliers.

“Radical” innovations

Finally, “radical” innovations involve both the use of new component technology and changes in architectural design. Radical innovations challenge established market leaders, since they destroy the usefulness of the leaders’ capabilities.

But barriers to radical innovations are very high - they require breakthroughs in both architectural and component knowledge. Examples include the discovery of new drugs, or the invention of the Internet. In China, an intriguing example is the development of the world’s first commercially operated nuclear “pebble bed” reactor that offers the hope of cheap, safe and easily expandable nuclear power stations[28].

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[27] For instance, Ernst and O’Connor, 1992; Ernst, 1994; Hobday, 1995; and Ernst, 2000.

[28] “China in Drive for Nuclear Reactors”, Financial Times, 8 February 2005: 4.

These innovations receive the greatest attention in the business press and in the public proceedings of policy debates. High margins through premium pricing and strong market entry deterrents are among their powerful attractions. However, radical innovations require dense interaction with leading-edge science. They also require an extremely broad base of capabilities in a society - top scientists and engineers are needed who work at the frontier of basic and applied research in a broad range of disciplines.

In short, radical innovations are extremely costly and risky, and failure can destroy even large, well-endowed companies. This implies that radical innovations are beyond the reach of most IT companies in China, with the possible exception of state-supported mega-projects for instance for military and space projects.

4.3. The market constraint - disruptive technologies

In a case study of the hard disk drive industry, Christensen (1993) demonstrates that established, vertically integrated market leaders typically lead in the adoption of new component technology, while successful new entrants rely on architectural innovations. Christensen identifies two possible explanations:

- First, while technological complexity (and hence risk, time, and investment expense) are much lower for architectural design than for the development of new key components, architectural innovations tend to have much more far-reaching implications for market shares and profitability of innovating firms.

- Second, the key to successful innovation is whether there are enough customers who are willing to pay for these new technologies and who can profit from using them.

The concept of "disruptive technologies" (Christensen, 1997) deepens our understanding of the market constraint. "Disruptive technologies" under-perform relative to established products in mainstream markets today, but they may be fully performance-competitive in the same market tomorrow. "Disruptive technologies" differ from "sustaining technologies" which improve the performance of *established* products that mainstream customers in mainstream markets have traditionally valued.

Disruptive technologies bring to a market very different products - they have features that initially only a few fringe (and generally new) customers value. Products based on disruptive technologies tend to be cheaper, simpler, smaller, and, frequently, more convenient to use. Incumbents market leaders typically fail to notice "lower-end" markets that may erode their market leadership, because they promise lower margins; because their most profitable customers generally do not want products based on disruptive technologies; and because the required break from routine requires a different organization from sustaining technologies. Most importantly, developing disruptive technologies requires an organization of innovation projects with substantially lower overheads than is typical for market leaders.

The concept of “disruptive” technologies has important implications for our topic. Chinese IT firms that are new entrants to a particular product market may face relatively low entry barriers for developing “disruptive” technologies, compared to the very high entry barriers that they would face for “sustaining” technologies. In addition, disruptive technologies require changes in the architecture of a product or service, i.e. “architectural” innovations. But disruptive technologies may not require changes in component technology. An additional advantage is that “architectural” innovations offer substantial opportunities for market share expansion, profitability and potential follow-up innovations (Christensen, 1993). Disruptive technologies thus are within reach for industrial latecomers.

The ability of Chinese IT firms to profit from architectural innovation may seem counter-intuitive, but it follows from their familiarity with peculiar features of Chinese markets and their capacity to complement missing pieces of knowledge through their integration into global knowledge networks. Over time, Chinese IT firms have learned to slice up the value chain of innovation more finely, in collaboration with multiple global knowledge network partners, as described earlier in this paper.

In short, in addition to “incremental” innovations, a focus on “architectural” innovations, using widely available existing component technology, makes more sense for Chinese firms than “modular” or “radical” innovations. A combination of “incremental” and “architectural” innovations would make it possible for Chinese IT companies to pursue a strategy of “technology diversification” (Ernst, 2005d). Defined as the expansion of a company’s or a product’s technology base into a broader range of technology areas (Granstrand, 1998: 27), this strategy focuses on applied research and the development of products that draw on component and process technologies that are not necessarily new to the world or difficult to acquire.

“Technology diversification” carries several advantages for Chinese IT firms. They can build on strengths in distribution, supply chain management and manufacturing. They also can leverage their experience in providing lower- cost integrated solutions to customers who have limited resources and who require strong support services. Most importantly, technology diversification could enable Chinese IT companies to leverage their participation in global knowledge networks. Since technology diversification often requires the exchange of knowledge with foreign parties, Chinese firms could use their accumulated capabilities to implement, assimilate, and improve foreign technologies.

4.4. Illustrative Examples

The following examples illustrate the diversity of innovative capabilities that Chinese IT firms are developing. They also indicate that the more successful these firms are, the more they tend to focus on a judicious combination of incremental and architectural innovations that provide integrated solutions and help customers to maximize their returns on investment throughout the life cycle of these systems. Modular innovations are less frequent, and radical innovations are reserved for state-supported mega-projects.

The examples however also demonstrate how difficult it is to pigeon-hole a particular innovation into one specific category. Caution is required in the use of the innovation taxonomy. As emphasized by Henderson and Clark (1990:13), "…(t)he distinctions between radical, incremental,…(modular)…and architectural innovations are matters of degree. The intention here is not to defend the boundaries of a particular definition, particularly since there are several other dimensions on which it may be useful to define..(different types of)…innovation." This reflects the systemic nature of innovation that requires a combination of diverse and evolving capabilities.

Radical innovations

Lenovo's super computer projects may be interpreted as an example of a "radical" innovations. The first project was the *DeepComp 1800 supercomputer*, introduced in 2001, which, based on 526 Intel Xeon processors , was ranked 51^{st} by 2002. This was followed, in November 2003, by the DeepComp 6800 model that was ranked 14^{th} worldwide, and was jointly funded by the Ministry of Science and Technology and the Chinese Academy of Sciences. There were expectations that a commercialized version of this machine could be used during the 2008 Beijing Olympic Games for a precise 36-hour weather forecast on a specific area within just 30 minutes of computing work (which now requires 40 hours). Markets were also expected to exist for computing data from oil fields, in disease control centers and physics labs. It is unclear however to what degree these expectations will materialize.

Finally, the most recent project, the *1000 TFLOPS supercomputer*, which was started in 2005 and scheduled for completion before 2010, is supposed to be nearly ten times more powerful than the world's fastest supercomputer. The underlying rationale was clearly more political than commercial, as shown from the following quote: "China will need more supercomputing power in the years ahead to maintain its economic growth and development, China cannot rely on other countries to develop a supercomputer that meets its needs."(InfoWorld, 28 July 2005).

In short, for latecomers like Chinese IT firms, "radical" innovations pose a difficult challenge - investment requirements are huge and require substantial government support, while markets are likely to be limited. There may however be indirect commercial benefits, as successful completion of a radical innovation project may help to establish a company as a serious player and foster its brand image.

Incremental innovations

Turning to the other extreme, Chinese firms typically have made a conscious effort to develop "incremental" innovations that would enable them to improve on cost, time-to-market and performance across its product range and value chain stages. This includes for instance substantial improvements in the management of product development, quality control, supply chains and customer relations, but also in the underlying information management.

Take Lenovo. An important reason for recruiting William J. Amelio, the former head of Dell's Asian operations, as the new CEO, undoubtedly reflects an attempt to tap into his expertise on distribution and supply chain management, and to absorb and improve the Dell model.

Another example are built-in and easy-to-use "Lenovo Care" support tools in the company's 3000 series desktops and laptops that provide automatic updates and offer one-button system recovery. Drawing on IBM's ThinkVantage technology, Lenovo has further improved and integrated these tools, with the result that the J-series gets ravish reviews as a smart, versatile and affordable choice for small businesses - one of the few market segments in the PC industry that display reasonable growth.

Modular innovations

"Modular" innovations are more difficult to find. Presumably this reflects their higher complexity and investment thresholds.

Huawei provides a few examples of projects to develop new component technology that can be plugged into a fundamentally unchanged system architecture. The company has substantially strengthened its capabilities in software development - with its R&D lab in Bangalore playing an important catalytic role. According to China's Ministry of Information Industry (MII), Huawei is now one of the three largest domestic Chinese software enterprises (together with ZTE and Haier).

And Huawei has invested heavily in the development of ASIC chips (including state-of-the-art SoC designs with 130 nm process technology), embedded software and shared platforms for communication and networking equipment (Ernst, 2006c). Until recently, Huawei's internal semiconductor design unit supplied no more than 10% of the chips the company needs. This share is now expected to increase substantially. After the company has spun-off its independent chip design company Hi-Silicon, Huawei reports the completion of design projects for nearly 100 types of ASIC chips, including so-called IP cores for 3G mobile systems.

For Lenovo, a possible example of a modular innovation that relies on the introduction of new materials is the 'roll-cage' technology developed by the company for its new Thinkpad Z series laptops. This technology provides extra physical protection, by fusing a magnesium alloy skeleton into the chasis of the laptop. Coupled with the existing titanium exterior, the laptops are supposed to better survive falls, bumps, and other shocks.

Architectural innovations

Let us now turn finally to "architectural" innovations. In China, an early example is the development of China's electronic switching system HJD04 - the innovation consists in developing a system architecture that optimizes performance features in line with the specific features of the national telecommunications network structure and the specific needs of the service providers (Shen, 1999). Other examples include: the development of

Chinese-language electronics publishing systems by the Founder Group Company, a spin-off from the Institute of Computer Science and Technology of Beijing University (Lu, 2000: chapter 4); and the development of the unique Chinese video compact disk (VCD) technology and the successful transition to Chinese DVD system technology (Lu Fang and Ling Mu, 2003).

While these architectural innovations use existing component technology, they nevertheless introduce substantially new and distinct features to existing system architectures. Two recent examples are Lenovo's Tianxi laptop and Huawei's development of a new integrated IP service platform ME 60.

Tianxi laptop (Lenovo)

Lenovo's Tianxi laptop computer provides a telling example of a product tailored to meet peculiar needs of the Chinese market. This project was able to build on earlier efforts to develop, against all the odds, the domestic computer market for private consumers and small businesses. Global firms were uninterested, and for apparently good reasons - in the mid-1990s, an ordinary PC cost RMB 13,000, the equivalent of one or two year's salary for an ordinary family (Feng and Elfring (2004: 61).

Legend started by developing a home computer for the Chinese family. The cheapest model, priced at RMB 3,000, did not even have a hard disk. Gradually, through trial-and-error, the company found out what Chinese consumers really wanted. Using Intel's new Pentium processors, while global companies still shipped PC with the older 486 processors to China, Lenovo was able to provide user-friendly features through in-house design of ASICs and add-on cards.

The focus of the Tianxi project was to provide Internet access at affordable price and with little fuss, and within an attractively designed box. A defining characteristic was its "one-touch-to-the Net" button that enabled national roaming. Through a special arrangement with China Telecom, the Internet registration process was dramatically simplified, which was very attractive for Chinese users, as they did no longer have to go to the PTT to get an account - a process that was famously complicated. Buyers of the Tianxi received a year of free Internet access. In addition, a special pen allowed Tianxi users to write Chinese-character emails.

It is important to emphasize that, while global industry leaders and their Taiwanese partners had superior technology, they were unable to address the specific needs of Chinese consumers. The Tianxi provides an example of an "architectural" innovation that was difficult to copy, because it draws on context-specific and tacit knowledge. As long as global industry leaders were unwilling to invest in local R&D labs, they are unable to compete on those terms.

To sustain this strength, Lenovo has made great efforts to add substantial improvements in price-performance ratios through a combination of improvements in hardware, software and industrial design.Take for instance the Lenovo Tianyi F20 which was introduced in December 2005, seven years after the first model of this series had been developed. This model won the prestigious Germany's IF product design award for 2006. In the week after this model of the Tianyi was released, Lenovo's share price on the Hong Kong market doubled.

In addition, the Tianyi F20 provides important improvements in performance, such as

- a three-cell battery and a six-cell battery solving one of laptop users' top worries, battery life;
- access to popular broadband applications like video communication, interactive video applications and online payments, with collaborative applications among various digital home appliances;
- a unique 13.1-inch liquid-crystal display that gives a better picture than the existing 12-inch PCs; and
- with a travel weight of only two kilograms, the Tianyi F20 is slimmer and lighter than the ordinary 14-inch PCs.

Designing these diverse performance improvements and applications into the system is a demanding architectural task and requires complex system integration capabilities.

Huawei's integrated IP service platform ME 60

The last example is Huawei's integrated IP service platform ME 60. This is the first integrated multi-service platform on the market that enables telecommunications operators to substantially improve the quality of service and the security of their IP services at a reduced cost of operation.

Current IP networks do not offer the security and quality of service that operators need to be able to offer these networks to their customers, while traditional networks are incapable of supporting bandwidth-hungry multimedia services such as IPTV. Operators have a number of consumer and business products in the market, such as DSL, cellular, ATM[29] IP VPN[30], and central office exchange services. To improve service quality and security, these products need to be aggregated and run over a common IP core[31]. The ME60 is the "Swiss army knife" that enables operators to aggregate multiple services from various networks into one IP core and that improves the operators' real-time control over these services..

In technical terms, this system is quite an achievement. As a 10-Gigabit multi-service control gateway[32], the ME is an edge router that sits between the IP core and the access network (which may be fixed or mobile).

[29] Asynchonous Transfer Mode

[30] Virtual Private Network – allows secure remote connection with own organization's network over Internet.

[31] The IP core, also sometimes called backbone, is the primary path of an IP network traffic. It connects smaller segments of a network and has a high concentration of traffic.

[32] A gateway is the entrance to another network. The gateway allows equipment with different protocols to communicate together.

But equally important is the systems' capacity to provide, at reasonable cost of operations, customized solutions to problems that thus far have obstructed the progress of IP networks. A defining characteristic of the ME-60 is its ability to deliver tailor made products as a response to customers' specific needs. This is quite unusual in the network equipment industry, where incumbent industry leaders typically provide standard solutions.

The main explanation for the incumbents' focus on standard solutions are their very high development costs. This reflects the fact that global industry leaders have their major R&D operations located in high-cost industrialized countries. In addition, many of their products are over-engineered – they provide leading edge technology that exceed by far the needs of most users. These high R&D costs necessitate a business model that seeks to reap economies of scale through "mass-manufacturing" of standard, and fairly inflexible solutions.

Huawei's approach is very different. The key to the success of the ME60 system seems to be Huawei's capacity to integrate multiple system components into a versatile and flexible system. A distinguishing feature of the ME 60 is its high level of integration through a single software system. This makes it possible to integrate the capabilities currently separated in different network parts like broadband remote access server, firewalls, which until now had no communication standards.

This capacity to provide integrated solutions does not seem to be widely shared in the network equipment industry. According to industry experts, Cisco, the industry leader, could only build such a system by teaming up with other companies like Ericsson.[33] While Cisco has major advantages in market reputation and product quality, its products apparently lack the integration of multiple functions that is characteristic for the ME60. According to the same source, Alcatel, another global industry leader, may only be able to build a similar system if it had the capacity to develop broadband remote access servers.

Conclusions

This paper demonstrates that, under certain conditions, a high integration into global knowledge networks can provide unique advantages for the development of innovative capabilities in industrial latecomer societies like China.

Specifically, the paper demonstrates that a company's initial business model can shape its integration into global knowledge networks. In turn, this integration can influence the evolution of its business model and its approach to the development of innovative capabilities. The paper also demonstrates that a high integration into global knowledge networks provides ample learning opportunities for Chinese IT firms, by exposing them

[33] Huawei unveils god box, Unstrung, 21.06.2005, http://www.lightreading.com/document.asp?doc_id=76055

to leading-edge technology, management approaches, intellectual tools and sources of knowledge.

However, the paper also emphasizes that exploiting these unique advantages requires conscious efforts on the part of Chinese firms. They must develop strategies that allow them to translate familiarity with peculiar features of China as a market and production site into an appropriate set of innovative capabilities.

The paper demonstrates that successful Chinese IT firms seem to make most progress in areas that escape the attention of both pessimists and proponents of China's emerging technology threat. The successful companies have not attempted to jump right into "technology leadership" strategies, to compete head-on with global technology leaders through "radical" innovations. Instead, they appear to have focused on "incremental" and "architectural" innovations that allow them to pursue "technology diversification" strategies.

The paper does not address implications for government policies. It is clear however that there is ample scope for policies to facilitate and promote the development of firm-level innovative capabilities (Ernst, 2005 d and 2000). In fact, integration into global knowledge networks is likely to increase the need for policies to develop strong national innovation systems that can create new sources of innovation.

Finally, the main message of the paper is one of cautious optimism. I am optimistic because Chinese knowledge workers are now exposed to the same intellectual tools and sources of knowledge as American knowledge workers, and because they combine this with an underdog's curiosity to learn from industry leaders. Caution, on the other hand, reflects an important insight of the study of innovation - successful innovations require fundamental adjustments in institutions and behavior. These adjustments are time-consuming in any country, and even more so in China, because of the uncertainty and instability created by its recent transition to capitalism.

References

Amsden A.H. and F.T. Tschang, 2003, "A New Approach to Assessing the Technological Complexity of Different Categories of R&D (with examples from Singapore)", Research Policy, April 2003, vol. 32, no. 4, pp. 553-572

Arrifin, N, 2000, Internationalisation of Innovative Capabilities: The Malaysian Electronics Industry, PhD thesis, Science Policy research Unit, University of Sussex

Baldwin, C.W. and K.B.Clark, 2000, Design Rules: The Power of Modularity, MIT Press, Cambridge, Mass

Bell, M. and K. Pavitt, 1993, "Technological Accumulation and Industrial Growth: Contrasts Between Developed and Developing Countries", Industrial and Corporate Change, Vol. 2., pages 157-210

Bell, M. and K. Pavitt, 1995, "The Development of Technological Capabilities", in: I. Ul Haque et al, eds, Trade, Technology and International Competitiveness, The World Bank, Washington, D.C., pp. 69-101

Borrus, M., D. Ernst and S. Haggard, 2000, "Cross-Border Production Networks and the Industrial Integration of the Asia-Pacific Region", in: Borrus, M., D. Ernst and S. Haggard (eds.), International Production Networks in Asia. Rivalry or Riches?, Routledge, London

Christensen, C.M., 1993, "The Rigid Disk Drive Industry: A History of Commercial and Technological Turbulence", Business History Review, vol. 67 (Winter), pp. 531-588

Christensen, C.M., 1997, The Innovator´s Dilemma. When New Technologies Cause Great Firms to Fail, Harvard Business School Press, Boston, Mass.

Dedrick, J. and K.L. Kraemer, 2005, "Is Production 'Pulling' Knowledge Work to China? A Study of the Global Computer Industry", manuscript, Personal Computing Industry Center, University of California at Irvine

Ernst, D., 1994, *What Are The Limits To The Korean Model? The Korean Electronics Industry Under Pressure*, A BRIE Research Monograph, The Berkeley Roundtable on the International Economy, University of California at Berkeley, Berkeley, California.

Ernst, D., 1997, *From Partial To Systemic Globalization. International Production Networks In The Electronics Industry*, report to Sloan Foundation, published as *The Data Storage Industry Globalization Project Report 97-02* (San Diego, California: Graduate School of International Relations and Pacific Studies, University of California at San Diego,).

Ernst, D., 2000, "Inter-Organizational Knowledge Outsourcing. What Permits Small Taiwanese Firms To Compete In The Computer Industry?" in special issue, "Knowledge Management In Asia," *Asia Pacific Journal of Management,* August.

Ernst, D., 2001a, "Catching-Up and Postcrisis Industrial Upgrading: Searching for New Sources of Growth in Korea's Electronics Industry", chapter 5, in: F.C.Deyo, R.F. Doner and E. Hershberg, eds., *Economic Governance and the Challenge of Flexibility in East Asia*, Rowman & Littlefield Publishers, Lanham etc

Ernst, D., 2001b, "Responses to the Crisis: Constraints to Rapid Trade Adjustment in East Asia's Electronics Industry", chapter 12, in: H.J. Chang, G. Palma and D.H. Whittaker, eds, *Financial Liberalization and the Asian Crisis*, Palgrave, Houndmills, Basingstoke

Ernst, D., 2002a, "Global Production Networks And The Changing Geography Of Innovation Systems: Implications for Developing Countries," *Economics of Innovation and New Technologies* , Vol. XI, No. 6

Ernst, D., 2004, "Global Production Networks In East Asia's Electronics Industry And Upgrading Perspectives In Malaysia," in: Yusuf, S., Altaf, M.A. and Nabeshima, K. (eds.), *Global Production Networking And Technological Change In East Asia* (Washington, D.C.: World Bank and Oxford University Press).

Ernst, D. 2005a, "Complexity And Internationalization Of Innovation: Why Is Chip Design Moving To Asia?" in *International Journal of Innovation Management*, special issue in honor of Keith Pavitt, Vol. 9, No. 1, pp. 47-73.

Ernst, D., 2005b, "Limits To Modularity - Reflections On Recent Developments In Chip Design," *Industry and Innovation,* Fall.

Ernst, D., 2005c "The New Mobility Of Knowledge: Digital Information Systems And Global Flagship Networks," in Latham, R. and Sassen, S. (eds.), *Digital Formations: IT And New Architectures In The Global Realm* (Princeton, New Jersey: Princeton University Press).

Ernst, D. 2005d, "Pathways To Innovation In Asia's Leading Electronics-Exporting Countries - A Framework For Exploring Drivers And Policy Implications," special issue, "Competitive Strategies of Asian High-Tech Firms, *International Journal of Technology Management*, Vol. 29, No. 1/2, pp. 6-20.

Ernst, D., 2006a, *Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks*, a special report prepared for the East-West Center and the U.S.-Asia-Pacific Council, East-West center, Honolulu

Ernst, D., 2006 b, Developing Innovative Capabilities in Chip Design. Insights from the US and Greater China, manuscript, East-West Center, Honolulu

Ernst, D., 2006 c, "Building Innovative Capabilities within Global Knowledge networks - the Case of Huawei", manuscript, East-West Center, Honolulu

Ernst, D., forthcoming, *INNOVATION OFFSHORING - Asia's Emerging Role in Global Research and Development Networks*, book manuscript, East-West Center, Honolulu

Ernst, D., Ganiatsos T., and Mytelka, L. (eds.), *Technological Capabilities And Export Success - Lessons From East Asia* (London, United Kingdom: Routledge Press, 1998).

Ernst, D. and Kim, Linsu, "Global Production Networks, Knowledge Diffusion And Local Capability Formation," *Research Policy*, Vol. 31, No. 8/9, 2002, pp. 1417-142

Ernst, D. and Naughton, B., *China's Emerging Industrial Economy - Insights From The IT Industry*, paper prepared for the East-West Center Conference, "China's Emerging Capitalist System," August 10-12, 2005, Honolulu, Hawaii.

Ernst, D. and D. O'Connor, 1989, Technology and Global Competition. The Challenge for Newly Industrialising Economies, OECD Development Centre Studies, Paris, 149 pages

Ernst, D. and O'Connor, D. [1992], Competing in the Electronics Industry. The Experience of Newly Industrialising Economies, Development Centre Studies, OECD, Paris, 303 pages

Feng, S. and J. Elfring, 2004, *The Legend Behind lenovo. The Chinese IT company that dares to succeed*, Asia 2000, Hong Kong

Freeman, C., 1987, Technology Policy and Economic Performance: Lessons from Japan, Pinter Publishres, London

Freeman, C., 1997, "Innovation Systems: City-State, National, Continental and Sub-National", mimeo, Science Policy Research Unit (SPRU), University of Sussex, December

Garcia, D. L. and Burns, K., "Globalization, Developing Countries, And The Evolution Of International Communities Of Standard Setting Practice," paper prepared for China's Technology Standards Policy Workshop, Tsinghua University, Beijing, China, January 6, 2006.

Gassmann, O. and Han, Zheng, "Motivations And Barriers Of Foreign R&D Activities In China," *R&D Management*, Vol. 34, No. 4, 2004, pp. 423-437.

Gilboy, G.F., 2004, "The Myth Behind China's Miracle", *Foreign Affairs*, Jul/Aug;

Granstrand, O., "Towards A Theory Of The Technology-Based Firm," *Research Policy*, 1998.

Granstrand, O., Patel, P., and Pavitt, K., "Multi-Technology Corporations: Why They Have 'Distributed' Rather Than 'Distinctive Core' Competencies," *California Management Review*, Vol. 39, No. 4, 1997, pp. 8-25.

Grove, A.S., 1996, *Only The Paranoid Survive: How To Exploit The Crisis Points That Challenge Every Company And Career* (New York, N.Y.).

Henderson, R.M.. and K.B.Clark, 1990, "Architectural Innovation: The Reconfiguration of Existing Systems and the Failure of Established Firms", Administrative Science Quarterly, March, 9-30

Hobday, M., 1995, *Innovation in East Asia: The Challenge to Japan*, Edward Elgar, Aldershot

Jefferson, G.H. and Z. Kaifeng, 2004, "An Investigation of Firm-Level R&D Capabilities in East Asia", chapter 10 in: Yusuf, S., Altaf, M.A. and Nabeshima, K. (eds.), *Global Production Networking And Technological Change In East Asia* (Washington, D.C.: World Bank and Oxford University Press

Kim, L., 1997, Imitation to Innovation: The Dynamics of Korea's Technological Learning, Boston: Harvard Business School Press

Kuemmerle, W., 1996, *Home Base And Foreign Direct Investment In R&D*, unpublished Ph.D. dissertation (Boston, Massachusetts: Harvard Business School).

Kuemmerle, W., 1997, "Building Effective R&D Capabilities Abroad," *Harvard Business Review*, March-April, pp. 61- 70.

Lall, S., 1992, "Technological Capabilities and Industrialisation", World Development, Vol. 20 #2: 165-186

Lall, S., 2000, "Technological Change and Industrialization in the Asian Newly Industrializing Economies: Achievements and Challenges", in: L. Kim and R.R. Nelson, eds, Technology, Learning and Innovation. Experiences of Newly Industrializing Economies, Cambridge University Press, Cambridge

Langlois, R.N. and P.L.Roberston, 1992, Networks and Innovation in a Modular System: Lessons from the Microcomputer and Stereo Component Industries", Research Policy, 21: 297-313

Lester, R.K. and Piore, M.J., *Innovation – The Missing Link* (Cambridge, Massachusetts: Harvard University Press, 2004).

Li, Jiatao and Zhong, Jing, "Explaining The Growth Of International R&D Alliances In China," *Managerial And Decision Economics*, 24, 2003, pp. 101-115.

Lu Fang and Ling Mu, 2003, "Indigenous Innovation, Capability Development and Competitive Advantage: The Origins and Development of the Competitiveness of Chinese VCD/DVD Industry", unpublished paper, presented at the Annual Meeting of the Business History Conference, University of Massachusetts at Lowell, Mass

Lu, Qiwen, 2000, *China's Leap Into The Information Age: Innovation And Organization In The Computer Industry*, (Oxford, United Kingdom: Oxford University Press, 2000).

Lundvall, B.A., (ed.), 1992, National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, Pinter Publishers, London

Mathews, J.A., 2002, Dragon Multinational. A New Model for Global Growth, Oxford University Press, Oxford etc

McGregor, J., 2005, *One Billion Customers. Lessons from the Front Lines of Doing Business in China*, Free Press, New York etc

Mowery, D.C. and R.R. Nelson (eds.), 1999, Sources of Industrial Leadership. Studies in Seven Industries, pp. 79- 132, Cambridge University Press, Cambridge

Nelson, R. R. (ed.), 1993, National Innovation Systems: A Comparative Analysis, Oxford University Press, London etc.

Nelson, R.R. and H. Pack, 1999, "The Asian Miracle and Modern Growth Theory", The Economic Journal, 109, pp. 416-436

Nelson, R. and S. G. Winter, 1982, An Evolutionary Theory of Economic Change, Harvard University Press, cambridge,Mass.

Nolan, P., 2001, *China and the Global Business Revolution*, Palgrave, London

Norman, D.A., *The Invisible Computer* (Cambridge, Massachusetts: MIT Press, 1998).

Penrose, E., *The Theory Of The Growth Of The Firm, Third Edition* (Oxford, United Kingdom: Oxford University Press, 1995).

Primack, D., 2006, Lenovo gives TPG, General Atlantic a China Presence, *Buyouts*, 6 March

Rasiah, R., 1995, Foreign Capital and Industrialization in Malaysia, Macmillan, Basingstoke

Rasiah, R., 2003, Export Experience and Technological Capabilities: Evidence from East and Southeast Asian Firms, mimeo, Institute for New Technologies, United Nations University, Maastricht, Netherlands

Rosen, D.H., 2003, "Low-tech bed, high-tech dreams", China Economic Quarterly, Q4;

Shen, Xiaobai, 1999, The Chinese Road to High Technology. A Study of Telecommunications Switching Technology in the Economic Transition, St. Martin's Press, New York

Steinfeld, E.S., 2004, "Chinese Enterprise Development and the Challenge of Global Integration, in: S. Yusuf, M.A. Altaf and K. Nabeshima (eds.), *Global Production Networking and Technological Change in East Asia*, a co-publication of the World Bank and Oxford University Press, Washington, D.C.;

Sturgeon, T., 2002, "Modular Production Networks: A New American Model of Industrial Organization", Industrial and Corporate Change, Vol. 11/#3

Suttmeier et al, 2006

Tushman; M.L. and P. Anderson, 1986, "Technological Discontinuities and Organizational Environments", *Administrative Science Quarterly*, 31: 439-465

UNCTAD, "UNCTAD Survey on the Internationalization of R&D," *Occasional Note*, December 12, 2005.

US -China Economic and Security Review Commission, congressional hearing held at Stanford in April 2005 on China's High Technology Development, at: http://www.uscc.gov/hearings/2005hearings/transcripts/05_04_21_22.pdf

von Zedwitz, M., "Foreign R&D Laboratories In China," *R&D Management*, Vol. 34, No. 4, 2004.

Xie, W. and S. White, 2004, "Sequential Learning in a Chinese Spin-Off: The Case Of Lenovo Group Ltd", *R&D Management*, 34: 407-422

Xie, W. and S. White, 2005, "Windows of Opportunity, Learning Strategies and the Rise of China's handset Makers", INSEAD Working Paper, Singapore

Word count (3 May 06): 15,223