Technological Innovation in China's High-Tech Industry

Investigating Factors that Influence Technological Innovation

Abstract

China's high-tech industry has witnessed dramatic growth in the past three decades. However, how to transform from "Made in China" to "Designed in China" remains problematic. China's high-tech industry has much weaker performance in terms of technological innovation relative to its export volume and industry size. China's domestic owned high-tech companies generally have inadequate emphasis on technological innovation. This research suggests several hypothetical factors that can influence the performance of technological innovation, and then applies statistical analysis to investigate these factors based on a data sample collected by the third High Performance Manufacturing project conducted in 10 countries since 2005. The analysis provides evidence that six variables influence the long-term or short term performance of technological innovation. At last, with more emphasis on the long term performance which contributes to the sustainable development of technologies, this research presents an application in Chinese "Shanzhai" industry, a special part of electronic industry in China. The analysis suggests that the emphasis on the factors described in the model helped some of these "Shanzhai" companies make progress with their technological innovation.

Introduction: High-Tech Industry in China

China's high-tech industry has witnessed dramatic growth. China's exports of high-tech products grew 33 percent annually from 1995 to 2008, with the value of export products increasing from 10 billion to 416 billion US dollars. High-tech exports, which now make up about 29 percent of total exports, have grown much faster than overall exports. According to an OECD (Organization for Economic Cooperation and Development) report, in 2006, China surpassed EU-27, the US and Japan to emerge as the largest high-tech exporting country with 16.9 percent of global market share in high-tech products. (Xing, 2010)

However, many believe that such dramatic growth in the industry size and export volume does not mean that China is leading the technological development of the world. In a compelling background brief, Yuqing Xing(2010), from the National University of Singapore's East Asia Institute, argued that the rapid expansion of China's high-tech exports is mainly due to the relocation of production capacities by multinational enterprises, and to the proliferation of production fragmentation and outsourcing activities in information and communication technology. China's high-tech exports are dominated by foreign invested firms. The high-tech products for export manufactured by foreign invested firms increased from 74 percent of in 1998 to the peak level of 88 percent in 2006 while the presence of Chinese indigenous firms actually shrank. On the other hand, the high-tech exports are mainly located at the lowest value added segment of the production chains: processing and assembling. In terms of trade forms, 82 percent of high-tech exports belong to processing trade. Under the category of high-tech products, what China's high-tech industry actually exports is low skilled labor rather than technology. The share of processing exports in high-tech products rose from 71 percent in 1993 to its peak of 93 percent in 2003, suggesting that in the ten-year period, China's high-tech exports became more low-skilled and labor intensive. (Xing, 2010) Chinese growing high-tech industry actually benefit more to the outsourcing of foreign countries than to the development of domestic industry. The technological innovation does not seem to have major contribution to such increasing export volume.

Limited Emphasis on Technological Innovation

Although the above data suggests that China's high-tech export exploits cheap labor as a major comparative advantage, there is also evidence that technologies in the high-tech manufacturing have developed. Bosworth and Collins (2003) suggest that China's total factor productivity, namely the efficiency of factor usage, has contributed fully half of the increase in the output per worker in China since 1978. This feature sets China apart from the East Asian miracles of the 1970s and 1980s, when these countries relied heavily on investment in physical capital. Considering such magnitude of gains in total factor productivity, although China's high-tech export relies on low-end manufacturing, the continuous increase in efficiency suggests that China's high-tech manufacturing also frequently updates its technologies.

Efficiency in manufacturing explains why China is attractive to the reallocation and outsourcing of many multinational corporations, when there are cheaper labors in many other countries. However, if China wishes to move upward in the supply chain and become the designer rather than the producer of high-tech products, the domestic high-tech industry needs to lead the technological innovation rather than simply catching up with other's technologies. Many claim that China's high-tech companies do not tend to view the technological innovation as the key competiveness. This research will try to investigate this claim firstly by describing the unbalanced development of China's companies in the semiconductor industry, a key sector of the high-tech industry, and secondly, by looking into the low R&D investment of China's high-tech companies. Then, after arguing that such insufficient emphasis on technological innovation cannot sustain the growth of Chinese high-tech industry, the research will investigate several hypothetical factors of technological innovation with the empirical analysis.

Semiconductor Industry

Peter Dicken (2003) described the microelectronics industry as today's "industry of industries". Its core, the semiconductor has emerged with dominating influence of the past four decades, extending its transformative effects into all branches of the economy and into many aspects of society at large. (Dicken, 2003) The semiconductor involves numerous cutting-edge technologies. Basically every technology applied in the semiconductor manufacturing marks the highest level in its fields, and the level of semiconductor technology can also in many ways demonstrate a country's technological strength in electronic materials. However, the semiconductor industry is still a developing sector in China's fast growing high-tech industry. Ning (2009) in his book *China's rise in the World IT Industry* presented the data, illustrated in table 1, that the size of China's domestic semiconductor industry is minor compared to other major semiconductor industries in developed countries. As a comparison, China's high-tech export is largely made up by electronic products with fewer technologies such as mobile phones, televisions, radio/recorders, monitors, CD drivers, and hard drivers. (Gou, 2006) Then it seems that in more technological intensive sectors, China's companies have limited performance.

Table 1: The industry sizes, world market shares and growth rates of semiconductor industries in major countries in 2003 and 2004

	2003($ million)	2004($ million)	Growth(%)	Global Market Share(%)
US	87,733	105,206	20	46.7
Japan	46,291	53,841	16	25.6
EMEA	21,461	27,298	27	12
S. Korea	14,007	21,988	57	10
Taiwan	8,362	10,820	29	5
China	388	727	87	0.3
Total	178,242	219,880	23	

Source: Calculated from SIA(2004)and Gartner(2005), (Ning, 2009). Note: EMEA, Europe, the Middle East and Africa.

Although China's domestic semiconductor companies are in a technologically intensive industry, they still seem to take cheap labor as their chief comparative advantage rather than the technological innovation. Many believe that most China's semiconductor companies are limited in the stage of the supply chain that requires the fewest technologies, namely the low-end production and the low-level repetition. Rather than progressing through technological progresses to control the core technologies, these domestic owned companies tend to make progress by entering into other fields of low-barrier sectors in order to diversify their production and by continuously exploiting the advantage of China's low-cost and large-scale economy. Despite efforts from both Chinese entrepreneurs and politicians to create a fully developed semiconductor industry with all stages including design, wafer fabrication and chips fabrication, these companies still have not made obvious progresses moving upstream in the supply chain. Table 2 from Falan Yinug (2009) captures the status of China's domestic semiconductor industry. Most China's semiconductor companies are specialized in assembly, testing and packaging, while few companies enter into the higher stages of design and front-end fabrication that involves more sophisticated technologies.

Table 2: Three stages of semiconductor production and the extent of China's participation

Stage	Description of Activity	Characteristics	Leading locations
Design	Design of the semiconductor	- R&D intensive - Abundant high-skilled labor - Strong IPR environment	United States, Taiwan China's participation: Limited
Front-end Fabrication	Construction of semiconductors on silicon wafers using highly sophisticated machinery	very expensive - Some low-skilled labor - Strong IPR environment	United States, Korea, Japan, EU, Taiwan China's participation: Limited
Back-end testing, assembly, and packaging	Testing, assembling, and packaging of semiconductors for final sale to end customers	- Less capital intensive and expensive than front-end fabrication - more labor intensive than front-end fabrication	China, Singapore, Malaysia, Taiwan, the Philippines China's participation: established and robust

(Falan Yinug, 2009)

The status of China’s semiconductor industry demonstrates that domestic technological innovation are weak in fields that involve large R&D spending, high-skilled labor and strong intellectual property right environments. Similar to companies from the semiconductor industry, most China’s high-tech companies still concentrate on fields where they can exploit the cheap labor advantages, and they have not set technological innovation as their key competiveness.

Limited R&D Investments as resources for technological innovation

The OECD (2007) reviews of innovation in China pointed out that China’s national innovation system has undergone fundamental changes since the start of the reform of science and technology system in 1985. However, enhancing the innovation capability and performance of the business sector has been one of the most difficult challenges. The review further addresses that the increase in R&D from the business sector has generally resulted from the conversion of some public research institutes into business entities. From 1998 to 2003, 1050 public research institutes were converted into business entities. Other factors such as the emphasis on the quantity rather than the quality, the availability of cheap but insufficiently skilled labors, and the shortage of encouragement to managers to take risks of innovating also caused the limited performance and low propensity to innovate. In a word, from company’s perspective, R&D activities have been in sufficient.

Zhongwen, Gou(2007), the Vice Minister of Chinese Ministry of Information Industry, argued in a report of innovation in China's domestic electronic information industry, that the investment of China's high-tech companies in the R&D of core technologies has been small. Gou also mentioned that, according to a survey conducted by related authorities to the nation's key companies, more than 70 percent of these companies have technological R&D investment that accounts for less than 1 percent of their total assets, which is far lower than the 10 percent level of major companies in developed countries. Table 3 from Ning (2009) further illustrates that Chinese domestic firms in high-tech industry have much lower R&D expenditures compared to the expenditures in major developed countries. China enjoys a great global market share in both the sector of electronic and telecommunications equipments, and the sector of the manufacture of computer and office equipments. But companies of these two industries did not bring much of their profit from increasing export to invest on their technological innovation.

Table 3: Ratio of R&D expenditure to value added for the IT industry in selected countries

	Electronic and telecommunications equipment (%)	Manufacture of computers and office equipment (%)
China (2003)	5.4	2.5
United States(2001)	37.2	36.7
Japan (2002)	20.4	90.4
Germany (2001)	44.1	19.8
France(2002)	57.2	15.8

Source: Yearbook of China's High-tech Industries 2005. (Ning, 2009)

However, some suggest that the lack of domestic technological innovation can be compensated by increasing foreign R&D in China. Foreign R&D in China has been growing rapidly, particularly since 1997. The number of independent foreign R&D establishments in China has increased to more than 700 in 2005.(Sun, Du and Li, 2006)While some of these research centers develop products for Chinese market, some also conduct original long-term research that can provide services to the Chinese manufacturers which lack R&D capabilities. Although such foreign R&D can help promote productivities in Chinese manufacturing and bring more experience to Chinese engineers, Chinese domestic high-tech companies still need more R&D investments to make technological breakthroughs themselves in order to lead rather than follow the trend of worldwide technological development. The research further adopts a comparison of the percentage of R&D investments to sales revenue of several Chinese companies and companies in developed countries, in order to demonstrate the different levels of emphasis on technological innovation.

Graph 1: Comparison of percentage of R&D investment over net revenue between companies focus on IC Production

Source: Annual Report of the five companies 2005-2008

Graph 1 depicts the comparison between two Chinese companies, two American companies and a European company. These companies are all leading companies of integrate circuits in their countries, and their major businesses are integrated circuits design and production, so comparison can show the low R&D investments in Chinese companies. Companies from developed countries are Intel, AMD and STMicroelectronics. Intel is the world’s largest semiconductor chips maker, based on its revenue since 1991. Intel is also the inventor of the x86series of microprocessors, the processors found in most personal computers. AMD (Advanced Micro Devices) is the second-largest global supplier of microprocessors based on the x86 architecture and the third-largest supplier of graphics processing units. In 2009, AMD ranked ninth among semiconductor manufacturers in terms of revenue. STMicroelectronics is an Italian-French electronics and semiconductor manufacturer. By 2005, the largest European semiconductors supplier was ranked fifth, behind Intel, Samsung, Texas Instruments and Toshiba. On the other hand, the two companies of IC design and production in China are SMIC and Shanghai Belling. Semiconductor Manufacturing International Corporation (SMIC) is founded and developed by Chinese. Although it has investments from many different countries, none of these countries have sufficient influence over the technological development or the management of SMIC. It is one of the leading semiconductor foundries in the world and the largest and most advanced foundry in mainland China, providing integrated circuit foundry and technology services at 0.35um to 45nm. In October 2007, the United States Government enrolled SMIC in its Validated End User (VEU) program, as a trusted customer of regulated U.S. technology, thereby reducing many of the export control barriers for SMIC.(LaPedus, 2007) Shanghai Belling is a domestically owned company. Also a leading Chinese manufacture of integrate circuits, Shanghai Belling started its own 8 inch production line for 0.25 micron integrated circuits since 2001.

The comparison illustrates that even these two leading Chinese semiconductor companies have relatively low R&D investments compared to international leading companies. Although many Chinese high-tech companies are still in their beginning levels (Falan, Yinug, 2009), companies such as SMIC and Shanghai Belling are expected to have sufficient resources for more R&D investments. (For example, SMIC's net revenue reached 1,550 million dollars in 2007. (SMIC Annual Report, 2007)) Although their resources cannot compare with Intel or AMD, their low percentage of R&D investments still suggest that they do not put as much focus on their technological innovation as leading international companies.

Technological innovation as the key competiveness

The above two perspectives support the claim that China's high-tech companies have generally inadequate emphasis on their technological innovation. Most of China's high-tech companies rely on cheap labor and low-end assembly as the major competiveness. After they had made a profit, they still choose to diversify themselves by entering into other fields of low-end assembly, rather than promoting their capabilities of technological innovation. (Ning, 2009)

Many scholars and officials focusing on the high-tech industry have argued that the technological innovation is the key dynamic of the growth of the industry. In high-tech industries, the conventional belief is that firms that possess higher technological knowledge and innovative capabilities have higher competitiveness than those without such capacity. (Makino and Lau, 1998) Although other comparative advantages in China have helped promote the growth of the high-tech industry, the difficulties of technological innovation will ultimately prevent China from becoming a high-tech leader in the world. When most companies cannot independently develop products and technologies nor have their own intellectual property rights, the technologies of their mainstream products and their production process are far behind internationally advanced levels, leading to a series of problems including the lack of sustainability in growth, weak core competiveness, and difficulties encountered in venturing into international market as Chinese companies have to pay patent fees. (Gou, 2006) Their weak technological innovation will ultimately limit the development of Chinese high-tech industry.

Although China's high-tech industry develops relatively fast in its scale, the shortage of independent knowledge property and brand are unfavorable to the sustainable development of China's high-tech industry. Lu and Fei (2001) suggest that China should aim at enhancing the position in the high-tech industrial chain of the whole world, namely encouraging companies to improve their technological innovation as comparative advantage. The development of innovation in high-tech companies will make China upgrade from big high-tech industry country to strong high-tech industry country, and greatly accelerate the improvement of the whole national economy.

In the fast changing world, China cannot anticipate cheap labor as a sustainable method of continuous growth. While China has gained some technological and manufacturing capabilities and achieved enormous success in exporting, the core of global competition has changed from the manufacturing to network-controlling activities. (Ning, 2009) Such change will eventually make China's comparative advantage in the cheap labors and the low cost manufacturing less significant in the international competition. The capability to develop high-technology is essential to sustain China's economic growth. How China's domestic companies should adjust their management and strategy to put more emphasis on technological innovation is vital.

Promoting Technological Innovation

When discussing the improvement of the technological innovation among China's high-tech firms, this research focuses less on resources (since the previous part suggests that most China's high-tech companies have limited R&D investment as resources for technological innovation), but more on the management of the new product development and the strategic planning for technological innovation. Wei Jiang (2002) holds the view that innovation capability is the integrated reflection of production preparation, marketing and management. The improvement in these perspectives can help China's domestic high-tech companies better apply their resources from their sales volumes to enhance their capabilities of innovation. The next part of this research will study literatures to propose several hypothetical determinants of the technological innovation from the perspectives of production preparation, marketing and management. Then the research will study how these determinants influence the technological innovation by conducting a regression analysis based on a sample data from the third High Performance Manufacturing (HPM) project conducted in 238 mid- to large-sized manufacturing plants in 10 countries since 2005 (Peng et al., 2007). The wide coverage of the sample will discover how high-tech companies throughout the world improve their technological innovation. Although, this research focuses on high-tech industry in China, a worldwide data sample can better avoid a biased sample selection, and generate a more universal model that can offer important advice for China's domestic high-tech companies.

Literature Review of Technological Innovation

Researchers have proposed different definitions of innovation to meet different objectives. Van de Ven (1986) has generally defined the innovation as the development and the implementation of new ideas. More specifically, innovation is considered as “a process of generation, adoption, implementation and incorporation of new ideas” (Wan D., Ong, C.H., Lee, 2005). This research of companies’ technological innovation focuses on such process within high-tech companies and new ideas of technologies.

From the firms’ perspective, the ability to quickly introduce new products and to adopt new processes is a crucial way to obtain competitive advantage. According to researchers of technology management, Adler and Shenbar (1990) conceptualized the capability of technological innovation as the capacity to develop new products and to adopt new production process. In marketing researcher’s view, innovative capability is conceptualized into two dimensions: innovativeness and capacity-to-innovate (Hurley and Hult, 1998). The innovativeness belongs to the cultural aspect and is measured in terms of the firm’s willingness to change. It reflects the firm’s innovative capability in the initiation stage of innovation. The capacity-to-innovate belongs to the aspect of outcome and is measured in terms of firm’s rate of technological innovation adoption. It reflects firm’s innovative capability in the implementation stage of innovation. Hence an evaluation of technological innovation should incorporate both firms’ willingness to change and firms’ capabilities of new product development and production process.

This study evaluates the performance of technological innovation with the percentage of new product in the sales of a period of time. A strategy that relies the sales on new products demonstrates that the firm is willing to innovate. The good performance of new products shows that the firm has impressive capability of technological innovation. Various previous researches use similar percentages to illustrate a firm's performance of technological innovation. Robert G. Cooper and Elko J. Kleinschmidt (1995) applied the percentage of sales represented by new products introduced in the past 3 years to measure whether firms in his samples have good performance of technological innovation. Steven Bragg (2002) mentions the percentage of new products introduced in a period among the total available products in that period as an important measurement in high-fashion consumer market. Inspired by these studies, this research measures the percentage of sales in both a longer and a shorter range of time to more specifically describe the new products. The performance of longer range puts more emphasis on whether the plants have been consistently bringing new products and incorporating new technologies in its productions. The performance of shorter range measures whether the plants have been actively keeping up with latest technologies and frequently updating their products. Hence, this research proposes two sets of hypothetical models. Model A describes the long-term performance while model B explains the short-term performance.

Literature Reviews and Hypothesis of Determinants of Technological Innovation

Traditionally, industrial and organizational characteristics explain the difference in innovation capabilities (Cooper, 1979; Damanpour, 1991; Wolfe, 1994). Wan, Ong, and Lee (2005) examined the relationship between six determinants and firms' innovation in Singapore, considering both organizational factors and organizational norms as potential determinants. They are (1) decentralized structure; (2) presence of organizational resources; (3) belief that innovation is important; (4) willingness to take risks; (5) willingness to exchange ideas, and (6) communications channels.

More literatures of resource-based view provide new insights for technological innovation research (eg., Brown & Eisenhardt, 1995; Verona, 1999). In the resource-based view, firms are composed of resources and capabilities (Wernerfelt, 1984). The main argument of this perspective is that firms' resource endowment and their capabilities to use these resources are sources of firms' competitive advantages. It is believed that the capabilities distribute heterogeneously among firms and are difficult to imitate and transfer, which ensure the competitive advantage of firm (Peteraf, 1993). Thus, the resource-based view of firm explains that the variation of firms' performances is owing to their difference in capabilities. Thus the following analysis will focus more on firms' capability to use available resources for technological innovation.

The sample of this study concentrates on high performance manufacturing plants. Their high performances illustrate that these plants have sufficient resources for their technological innovation and help control for the influence of resources. From the perspective of firms' capabilities, this research proposes six hypothetical determinants of technological innovation: long-range plans, involvement of customers, continuous development, manufacturing target, production process, and time cycle. The research brings the hypothesis that these six factors are related to both the long-term and the short term performances of technological innovation. So there are two sets of hypotheses. Set A is for the model of long-term performance while set B is for the short-term model.

Researchers have showed that long-range plans play significant roles in firms' performance. A formal plan anticipates future trends of technology and prepares manufacturing to cater for such future needs. Stanley S. Thune and Robert J. House (1970) conducted research on how the formal long-range planning procedures affect a firms' economic performance. They discovered that positive economic performance and formal planning are strongly related, especially among the medium-size companies in rapidly changing markets. David Herold (1970) attempted to extend the study by Thune and House. His research concluded that formal planners not only outperform informal planners on sales and profits but also outspend informal planners on R&D expenditures. Such higher R&D investments usually contribute to better performance of technological innovation. Therefore, this study proposed the following hypothesis:

H1a: the development of long-range programs has a positive relationship with the long-range performance of technological innovation;

H1b: the development of long-range programs has a positive relationship with the short-range performance of technological innovation.

Many literatures consider the involvement of customers in the new product development as a successful strategy and tactic to improve new product success. Kaulio (1998) pointed out in his research that different methods support the involvement of customers at different phases of the design process, particularly in three phases: the specification phase, concept development and the prototyping. However, contradicting opinions also exist. Peter R. Magnusson (2003) conducted an experiment to access the contributions made by users in comparison with professional service developers in order to examine how the implementation of users' involvement affects the outcome. He realized that involving users makes the ideas more original, holding a higher perceived user value, but the users' ideas are less producible on average. Despite such different opinions, the involvement of customers is generally believed to contribute to the originality and the design of more user-friendly products. Thus, this research brings the following hypothesis:

H2a: the involvement of customers has a positive relationship with long-range performance of technological innovation;

H2b: the involvement of customers has a positive relationship with short-range performance of technological innovation.

Researches point out that continuous improvement in all aspects of the business is essential for meeting the challenge of today's turbulent environments. John Bessant and Sarah Caffyn (1997) reported on a five-year research program exploring the implementation issues in continuous improvement. He found out that the continuous improvement is especially important for technological innovation, and that a firm which keeps continuous improvement has great comparative advantage. During the rapid technological evolution, keeping up with the trend is significant. Also, continuous changes make the products and production processes moving targets, which are harder for followers and competitors to copy. The evaluation of continuous improvement in this research is widely defined as managers' attitude of their production process instead of specific measurements. The third group of hypothesis is:

H3a: the continuous improvement has a positive relationship with the long-range performance of technological innovation;

H3b: the continuous improvement has a positive relationship with the short-range performance of technological innovation.

Wan, Ong, and Lee (2005) brought up the belief in innovation as a determinant of firms' innovation in Singapore. If the firms set creating new product as the chief manufacturing goal instead of obtaining market share or cutting costs, they are expected to have better performance of technological innovation. Hence:

H4a: the manufacturing goal of the new product has a positive relationship with the long-range performance of technological innovation;

H4b: the manufacturing goal of the new product has a positive relationship with the short-range performance of technological innovation.

Besides the innovation of products, some researchers have shown that the innovation of production process is also important. Researchers generally recognize product and process innovation as two major areas of technological innovation (Tushman and Nadler, 1986; Gobeli and Brown, 1994). Product innovation is the improvement and development of new products, while Process innovation is the improvement in the process for product manufacturing (Kanji, 1996). The development of both two processes should be combined to improve firm's performance of technological innovation. In the research of John E. Ettlie and Ernesto M. Reza(1992), they argued that since most of the firms buy new technologies from others for manufacturing operations, it can be difficult for the innovators to achieve competitive advantage because it is difficult to protect them from imitation and circumvention. However, making the production process a unique occasion such as significant restructuring and creating effective new patterns can better secure the firm's leading role of technological innovation. Therefore, besides innovation on product itself, continuous changes of production process also contribute to the performance of technological innovation, whereas, firms tend to have weaker capabilities of technological innovation if they deem their production process fully developed and does not look for improvements or alternatives. This study proposes the following hypothesis:

H5a: the stability of the production process has a negative relationship with the long-range performance of technological innovation;

H5a: the stability of the production process has a negative relationship with the short-range performance of technological innovation.

The time of new product development or cycle time, has become a critical competitive variable, particularly for high-tech manufacturing firms. However, shorter cycle time may contribute to introduce new products faster but achieving shorter cycle time may results from keeping the technical content of the product simple. (Abdul Ali, Robert Krapfel, Jr. Douglas LaBahn, 2003). So these products may lose market shares as better alternatives come to the market. Erik Jan Hultink Henry S. J. Robben (2003) also found out through their research that speed-to-market is more important in the short term than long term. Therefore, different from previous groups of hypothesis, there is only one hypothesis on the cycle time:

H6b: the cycle time has a negative relationship with the short-range performance of technological innovation.

Control Variables

The sample selects plants from 10 countries that have high performance from the industries of electronics, machinery and auto supplies. Their high performances demonstrate similar technological intensity although they are from different countries. But the research will still control for the possible effects that can influence the statistical analysis. It will firstly control for the effect of countries which have different environment for technological innovation. Plants in the samples are in the industries where technologies changes rapidly, but the strategies of technological innovation of these plants may still vary with different industries. Therefore, the research will also control for the effects of different industries. Even within the same industry sector, there are still different technological opportunities. (Wilson, 1977) When the technologies change faster, the existing products will be replaced quickly. Plants that have high-technological opportunities may tend not to put more effort on reducing the production cost but rather keeps up with the latest technology. Therefore, this research also controls for the variables of different technological opportunities. The research adopts two similar criteria: whether the needs and wants of our customers are changing very fast, and whether all of the customers desire essentially the same products. Although, these two questions are practically the same, an industry where customers desire the same products seems to be a little more stable than an industry where wants of customers changes slowly. So the research applies the first question for the model that studies the long-range performance, and the second question is applied to the model for the short-range performance. The variables of industry and the variables of technological opportunities seem to address similar issues, so these variables will be introduced separately to the two models to avoid multicollinearity. Despites the effects of industries and countries, the research also considers that plants’ sizes could influence the technological innovation so it will control for the effects of different annul sales and the number of models produced each year. After controlling for the influence of countries, industries, technological opportunities and plants' sizes, the model is expected to present clearer relationships between the hypothetical factors and the two dependant variables.

Sample and data collection

This research uses the data collected by the third High Performance Manufacturing project that was conducted in 10 countries since 2005 (Peng et al., 2007). These countries give a broad representation of the plants in different areas around the world including Finland, Sweden, Austria, Germany, Italy, Spain, Japan, South Korea, United States, and China. In each country, around 30 firm samples in three industries electronics, machinery, and automobile supplier. Table 3 captures the distribution of industries within each country. These industries involve frequent technological innovations and plants in these industries tend to have more emphases on new product developments. Totally, 238 mid- to large-sized manufacturing plants were selected. These plants were first called to obtain their agreement of participation and identification of potential survey coordinator in the plants. Then a package of 21 questionnaires is distributed to the targeted plants and is expected to be answered by 10 managers, 6 supervisors, and 5 direct labors. (Peng et al., 2007) Most of the selected plants are visited and identified as qualified sample of this study, especially the qualification of high performance. Later, telephone calls are made to encourage the companies to reply. The response rate of this survey is around 65 percent in most countries. (Peng et al., 2007; Huang et al., 2008)

Table 3: Plants in the sample

Country	Electronics	Machinery	Auto Supplier	Total
Finland	14	6	10	30

Sweden	7	10	7	24
Germany	9	13	19	41
Austria	10	7	4	21
Italy	10	10	7	27
Spain	9	9	10	28
Japan	10	12	13	35
South Korea	10	10	11	31
United States	9	11	9	29
China	21	16	14	51
Total	109	104	104	317

Zhiqiang Wang (2009) used the same database for research on the relationship between the project complexity and novelty on one hand and the product design collaboration practices on the other. His research broke down the design collaboration practices to the external involvement of customers and suppliers, and the internal involvement of manufacturing. He focused on the questionnaire of the new product development where there is only one single response to each question on a scale from 1 to 7. The research applies the confirmatory factor analysis, which is a proper method when measuring the effect of several factors and working with categorical variables. In order to have a full view of the relationships among latent constructs, his research applied a structural equation modeling approach to test the proposed relationships. Comparing with the regression, this approach could provide a simultaneous test of the relationships in a multistage model structure. The result suggests that the manufacturing involvement in product design plays a crucial role in dealing with the project complexity. The external involvement of customers and suppliers in the product design reacts to the project complexity indirectly through the manufacturing involvement in product design. In addition, only the external involvement in the product design is important for dealing with the project novelty.

Compared to Wang's study that focuses on the complexity and the novelty, this research focuses on a broader topic of technological innovation measured in the performance of both the short-range and the long-range. The results should be easier for firm directors to apply in their management of innovation since it addresses directly the performance of innovation that many managers worry about. However, many different factors can influence the technological innovation and there are also different ways to evaluate the performance of technological innovation, so there could be more unexplained variation in the regression result. While Wang's study has more sophisticated model and the confirmatory factors analysis is more proper for large number of independent categorical variables that share similar factors among them, regression analysis is a better choice for this research, since it addresses the performance of technological innovation as a numerical dependent variable and involves small number of independent variables. Also, rather than focusing on questions on the new product development, this research draws questions that relate to technological innovation from more questionnaires that involve answers from more representatives of the plants.

This research draws answers from the questionnaires of complexity of environment, manufacturing strategy, quality, technology. All of these questionnaires were sent in 2004 during the third round of High Performance Manufacturing project. So although these answers are from different questionnaires, the time lag can be neglected.

The question that corresponds to the long-range performance of technological innovation comes from the questionnaire of the complexity of environment. It asks the plants' process engineers the percentage of plant sales represented by products introduced in the last five years. The question that corresponds to the short-range performance of technological innovation is in the questionnaire of technology, which asks the process engineers the percentage of sales comprised of new products introduced last year.

The questions for H1 on long-range programs and H5 on manufacturing goals are from the questionnaire of manufacturing strategy answered by process engineers, plant managers and the plant superintendents. The questions for H2 on the involvement of customers and H3 on continuous improvement come from the questionnaire of quality, answered by the direct labors, the quality managers, and the plants' supervisors. The questions for H4 on process development and H6 on time for new product are from the questionnaire of technology, answered by the process engineers, members of the product development team, and the plant superintendents. Except question for H6, which asks how many months it takes, on average, to introduce a typical new product into the plant, the questions of the other hypotheses ask for a rating on a scale from 1 to 7. For each data, the original data collectors in the High Performance Manufacturing project took the average (with 1 decimal) of the three responses. When one of the three was left blank, they took the average of the other two responses, and if two responses were missing, they used the only response directly as the data. However, the database does not show much many of these data are the average of three or the average of two. But the high response rate can in some way guarantee that most of the data are the average of three responses. Generally speaking, although each rating is an ordinal data, the average can serve as a numerical data, which is valid for a regression analysis.

The two control variables of technological opportunities are from the questionnaire of technology, answered by the process engineers, the members of the product development team, and the plant superintendents. Similar to most questions of those hypotheses, they also ask for rating on a scale from 1 to 7. The control variable of product models comes from the questionnaire of the complexity of the environment. The question of how many product models are manufactured at this plant asks the product control manager. The control variable of sales is from the questionnaire of performance answered by the plant accounting manager.

Data Analysis and Explanation

This research uses the multiple linear regression to study the relationship between the independent variables that indicate the hypothetical determinants of technological innovation and the two measurements of performance of technological innovation. Model A evaluates the impacts of the six determinants on the long-range performance controlling for the change of needs. Model B evaluates the impacts of the six determinants on the short-range performance controlling for the degree to which customers' needs are the same. Other controlled variables were dropped because they showed little significance to the regression model, the reason of which will be explained later.

Table 4: regression results:

Variables	Model A:	Model B:
	Coefficients	
Long-term programs	6.65***	3.69**
Involvement of customers	4.4*	-0.62
Continuous improvement	5.61**	2.29
Manufacturing goals	3.28	4.89**
Process development	-6.54**	-0.32
Cycle time		-0.34**
Change of needs	4.64**	
Same needs		-2.09*
	Goodness-of-fit	
Adjusted R^2	0.1066	0.0760
Root MSN	28.626	21.801
Number of Observations	241	220
*****significant value<0.01,**	****significant value<0.05,**	***significant value<0.1**

The regression results show that there is statistical evidence to support H1a, H1b, H2a, H3a, H4a, H5b, and H6b. So in these two models, only long-range programs have clear linear relationship with both dependant variables in both Model A and B. Other variables have positive linear relationship in Model A but not in Model B, or vice versa. The long-term programs benefit both long-range and short-range performance of technological innovation. Since formal plans provide plants with sufficient manufacturing capabilities for future needs, the plants can better react to the technological trends and they can keep putting popular new products into the market. The coefficients illustrate that for each one scale higher of the averaged response, there are on average almost 7 more percent of sales represented by products introduced in the past five years, and almost 4 more percent of sales represented by products last year. So the long-term programs seem to have larger influences to long-range technological innovation. Involvement of customers benefit the long-term performance but there is no evidence that such involvement also contributes to short-term performance. Perhaps, opinions of customers bring more originalities and user-friendly designs, but customers usually do not sufficiently consider whether their suggestions are feasible, as is mentioned in the experiment of Peter R. Magnusson (2003). Thus innovation may need more time to incorporate users' opinions to the feasible production. The coefficient shows that for each one scale higher of the averaged response, there are on average over 4 more percent of sales represented by products introduced in the past five years, so the influence to dependent variable is slightly smaller compared to the influences of other independent variables. Similarly, the continuous improvement and the process development require that the plant allocate part of its resources on other fields than new product development, so the plants may need more times to introduce new product. But their innovative production process and continuous improvement may lead to better performance, so that their new products can generate more sales in the five-year period. Their coefficients of 5.61 and -6.54 respectively show that these two variables have almost equal effects on the dependent variable as the long-term planning does. The question of process development asks if these plants' manufacturing processes stay the same, and the hypothesis is that it has negative relationships with the two dependent variables. So the negative coefficient supports the hypothesis. If the plant focuses on new product as a chief manufacturing goal, it will keep bringing new product to the market. But perhaps the plants need more diverse targets to ensure that their new products can generate sales for longer period of time. So the focus on new product may benefit short-term performance of innovation but its relationship with long-term consistent performance remains ambiguous. The coefficient of 4.89 demonstrates that for each one scale higher from the averaged response, there are on average almost 5 more percent of sales represented by products last year. In addition, these independent variables have similar standard deviations less or equal to 1 from ratings on a scale from 1 to 7, which means that the there are not large variations from the data of independent variables. Then, taking the coefficient of long-range programs in model A as an example, for one standard deviation there are about 7 more present of sales represented by products introduced in the last five years. So, despites the statistical evidences to support these hypotheses, they are not the overwhelming determinants of the performance of technological innovation. Different from the above variables measured in ratings, the variable of cycle time is measured in month. A coefficient of -0.34 suggests that for each month shorter of the cycle time, there is on average 0.34 more percent of sales represented by products last year. Although the coefficient is small, the variable has a standard deviation of 9.25, which means that for one standard deviation there are on average 3.15 more percentage of sales represented by products last year. So the effect of cycle time is smaller than the effect of other independent variables.

Among the four control variables, the regression model only takes technological opportunities into consideration. In order to control the effects of the three industries, the research deletes the variables of technological opportunities and then adds two binary independent variables. But adding these two variables does not improve the statistical significance of other independent variables, perhaps because these three industries share similar environments of technological innovation and the technological opportunity of specific plants is a more effective way to consider the different technological environments. Similarly, the research also adds nine binary independent variables to control for the influence of countries. But the cross-country consideration does not improve the significance of other variables either, probably because each country only has around 30 samples and does not give sufficient amount of data. However, the research observes that the responses from Chinese plants do not have obvious differences from the responses from plants of developed countries in North America and Europe. This result somewhat contradicts the previous claim that Chinese domestic owned high-tech companies have less emphasis on technological innovation than companies in developed countries. One possible explanation can be that the responses from different countries have different criteria. When giving responses, the supervisors or managers may tend to look at companies in their same environments for judgments. A respond of 7 in China might means that this company outperforms other Chinese companies but might not necessarily mean that this company is better than, say, a German company with a response of 6. The control variables of sales and numbers of models do not contribute to better regression results. Perhaps the firm size does not influence the performance of innovation. Kleinknecht(1989) found out through an innovation survey in Netherland that there is no systematic relationship between size and R&D when restricting observations for those firms that have a working R&D departments.

This research conducts further diagnoses with the residual versus fitted value scatter plot. The two plots show no obvious pattern of the residuals. The adjusted R^2 of 0.1066 for model A and 0.076 for model B demonstrate that these two models can explain, to some degree, the variation of the percentage of sales represented by new product in past five years and one year. However, the adjusted R^2 illustrates that model A explains 10 percent of the total variation and model B only explains less than 8 percent. In order to improve the fit of the model, the research tries to add second degree and interaction variables to the model, but these additions do not improve the adjusted R^2 nor the significance of other independent variables, perhaps because most variables are averaged scales from 1 to 7 and do not provide a wide enough range for second degree or interaction variables. So although there is statistical evidence not to reject the above hypothesis, these models cannot fully explain the variation of the performance of technological innovation. More factors within the management of technological innovation, and also factors from other perspectives such as policies and human resources could influence the technological innovation as well. Or, better method to judge a company's management strategies that can provide wide range of numerical variables can also improve the fit of the model.

Applications and Conclusion

Application of the Determinants in Chinese Special Technological Innovation, the "Shanzhai" Industry

Considering the contribution to the general technological innovation, a steady and consistent performance is more preferable. So determinants of long-range performance, namely the formal planning, involvement of customers, continuous development and production process development are more important. In the resource-based view, firms' capabilities to use available resources for technological innovation are difficult to imitate and transfer, which ensure the competitive advantage of firm (Peteraf, 1993). So developments of the above determinants are essential for the performance of a company's technological innovation. Weaker emphases on these determinants may help to explain why Chinese high-tech industry has inadequate technological innovation.

The recent rapid development and flourish of the "Shanzhai" industry in China provide a good application of the above determinants. Originally used to refer to a bandit stronghold outside government control, the term "ShanZhai" has today become the shorthand for fake or pirated products, especially electronics products. Coming from similar backgrounds of copycats, these companies have a great variety of different performances according to how they emphasize on their own technological innovation. The research selects them also because these small companies in "Shanzhai" industry are less stable compared to ordinary enterprises, and they have frequent changes of their production strategies. Thus, their fluctuation makes it easier to form a comparison between those that gradually shift their comparative advantage to technological innovation and those who are always copycats.

The use of "Shanzhai" became popular with the outstanding sales of "shanzhai" cell phones. According to Gartner's data, 1.15 billion cell phones were sold worldwide in 2007, and according to data provided by the Chinese government, 150 million "Shanzhai" cell phones were sold in the same year, thus making up more than one tenth of the global sales."Shanzhai" cell phones can be sold at very low prices compared to normal cell phones. Cell phone factories are able to manufacture at a very low cost mainly thanks to the Taiwanese company Mediatek, which has developed a complete chain of core technologies support for cell phones to sell at a much lower cost than the traditional suppliers of large cell phone companies like Nokia and Motorola. Taking advantage of MediaTek's simple, integrated motherboard and easily changeable user interface, these "Shanzhai" companies do not need their own R&D investment. But instead, they follow tightly the international technological trend such as 3G, iphone, and the latest ipad, copy their design and technology due to the weak intellectual property protection in China, and recreate a similar but substandard product at low cost. They target at domestic mass consumers, strive for very short cycle time on product introduction. (Tse, Edward, Kevin Ma and Yu Huang, 2010) Although, these companies are running in the grey area of the intellectual property right, they are typical China's domestic owned high-tech companies since their chief advantage is their low-cost manufacturing focusing on quantity rather than quality.

Judging from the determinants of the statistics model, the "Shanzhai" companies are expected to have poor performance of technological innovation. Their strategy is to follow the trend of international electronic product, and link their latest technological innovation with the domestic demand. Then, they rarely make formal long-range plan for their own development, since they cannot anticipate their own independent manufacturing needs. Their strongest comparative advantage besides low cost are interesting product features and functions specifically to local requirements. Then although, they work closely with customers in terms of product features, most of their customers come from less developed area and their involvements touch less upon technological innovation. With useful chips form MediaTek and the latest foreign designs, their production process is relatively simple, and they worry little about the continuous development of their production process. However, from the perspective of setting new products as the manufacturing target and shortening cycle time, they seem to have good performance. They follow the trend of latest products and spread the market with their “Shanzhai” version in a very short time, for example most of them put their “Shanzhai” ipad into Chinese market even before the Apple officially starts their sales of ipad in China. But, as is illustrated in the comparison between long-term and short-term model previously in this study, target of new product and reduction of time cycle fail to contribute to the good performance of new products for longer period of time and the consistent performance of technological innovation. These companies’ new products can hardly keep their sales for a longer range of time firstly because their low quality and secondly because newer “Shanzhai” product with similar price will come into market soon. As a conclusion, these “Shanzhai” companies have weak technological innovation judging from the above determinants. They are good examples of a huge and fast growing high-tech industry with limited improvement in core technological innovation. Indeed, most of these “Shanzhai” companies are very short-lived. Other formal high-tech companies in China, though they operate legally and are more stable, will ultimately face similar result as these “Shanzhai” companies without technological innovation as a key competiveness.

However, some “Shanzhai” companies did manage to get through the copycat stage and become mainstream manufacturers with more emphasis on their own innovation. Mobile phone maker Tianyu, for example, whose knockoff handsets target trendy but value-conscious buyers, has emerged from a “Shanzhai” company to a major player of electronic industry in China. With successful “Shanzhai” strategy, Tianyu launched more than a hundred tailored models within a year. The resulting high sales volumes led to rapidly growing market share, and the company soon became China's top domestic handset manufacturer, whose sales in China is now catching up with market leaders Nokia, Samsung, and Motorola. But Tianyu did not stopped there, which could have witnessed its short live like other "Shanzhai" companies. With increasing resources from its growth in market share, Tianyu starts to increase its strength of core technological competence. The company has begun to invest in 3G products, aiming at the next phase of China's telecom development, rather than copying 3G products latest released in other countries. Following a recent agreement with Qualcomm, a leading developer of CDMA wireless technologies, Tianyu will soon be able to develop, manufacture, and sell its popular K-Touch range on a platform compatible with China's upcoming 3G networks. (Tse, Edward, Kevin Ma and Yu Huang, 2010) With such long-range planning to move up to the value chain and away from their "Shanzhai" beginnings, companies like Tianyu have emerged as the industry trendsetters, leading new waves of product or technology development. After acquiring key know-hows through their copycats beginning, Tianyu has strived to upgrade core technological capabilities. They gradually get away from the simple production which is easy to imitate, and aim at continuous development, developing value-added services or differentiated products. Then their strategies will ultimately lead to the improvement of technological innovation, which can truly contribute to a sustainable growth. Tianyu's example demonstrates that a "Shanzhai" companies can become an industry leader in, if it strives to improve its capability of technological. Then other formal high-tech companies in China should realize from Tianyu's example that low-margin production focusing on the stages of supply chain with the least technologies cannot make them competitive worldwide. China's major high-tech companies should also rise from cheap labor exporting to major player of technological innovation in the world.

Conclusion

This research has explored the gap between Chinese fast growing high-tech industry and the relatively poor technological innovation in core technologies. The unbalanced growths in China's domestic semiconductor industry and low R&D investments support the claim that there are insufficient emphases on technological innovation among Chinese domestic high-tech companies. Then, after arguing that such insufficient emphasis on technological innovation cannot sustain the growth of Chinese high-tech industry, the research has proposed several possible determinants of the performance of technological innovation. Then the research applied statistical analysis based on a sample data collected by the third High Performance Manufacturing project conducted in 10 countries since 2005, to study how these factors influence the performance of innovation. As a result, the regression result supports that long-range plans, the involvement of customers, the continuous development, and the production process have systematic relationships with the long-term performance of technological innovation, while long-range plans, the manufacturing goal of new product and the cycle time have systematic relationships with the short-term performance. This research puts more emphasis on the determinants of long-term technological innovation as they represent the consistent innovation. Finally, the research applies the findings to explain the poor technological innovation in Chinese “Shanzhai” industry and an exceptional company that has made breakthrough with technological innovation. These determinants that influence the long-term performance are obvious in the management strategies of companies making technological developments, but ignored in most companies focusing on simple duplication of foreign products. This research has pointed out that the lack of technological innovation in Chinese high-tech manufacturing industry will ultimately damper the contribution that the manufacturing industry makes to the nation's economic growth. Empirical analysis helps explain the inadequate emphasis on innovation, and the improvements in these perspectives are as important as the increase in the export volume.

Limitations and future research

Although the findings are meaningful and interesting, it is limited in the following ways. First, the samples are selected from three industries. A better evaluation of the performance of technological innovation should include findings in other industries as well. Second, the cross-sectional data of this study cannot make us conduct causal inference. It would be valuable if future studies replicate the results using longitudinal data. Third, the performance of technological innovation is only narrowly measured by the percent of sales represented by product introduced in last five years or last year. Future studies should adopt a more throughout measure of technological innovation. Fourth, the data only contents limited factors from the management perspective. More perspectives can also have influence over the technological innovation, for example government policies, especially in China where government's policies play important roles in the development of technological innovation. Policies after the market-oriented reform have focused on new technologies in selected areas of national priority, such as biotechnology, information technology, space technology, energy technology, new materials, tec. (OECD, 2007) So policies can explain the unbalanced development of technologies in China, which is also an interesting topics for further researches.

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