

Chapter 3

Industrial Organization of the Latecomer's Technological Upgrading: Experiences of China's Machine Tool Industry

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1 Literature Review

The process of technological innovation is multi-faceted. Firstly, from the perspective of input, it is featured as persistent and large scale of research and development (R&D) investment, and increasing intensity of R&D. Secondly, from the perspective of output, it is with the characteristics of more new products, higher quality or lower price. And, lastly, from the perspective of industrial organization (IO), it demonstrates itself as increasingly specialized in technological innovation activities and optimization of the coordination mechanism between different specialized innovative activities. This present paper tries to understand technological innovation from the last angle, and defines the IO of technological innovation as the distribution of and the coordination mechanism between the technological resources and activities. "Good" industrial organization should not only promote the deepening specialization of knowledge production, but also enable to enhance effective coordination of the specialization.

According to Pavitt, specialization of knowledge creation covers three intertwined aspects. First, intra-firm specialization, where specialized R&D unit within the firm as the core component; second, inter-firms specialization, mainly in the form of the production networks usually characterized with a large number of small and medium enterprises (SMEs); third, the division of labor between the production of public and private knowledge, universities and other public research institutes that are in responsible to the production and supply of public knowledge (Pavitt, 2004). Since technological process is a complicated interaction process between diversified knowledge, such that there is another feature of IO of technological upgrading, namely the coordination between the specialized agents in the innovation system. In line with specialization, the coordination of technological upgrades has three correlated aspects as well. First, the coordination between the activities of different specialized R&D units and also with those of other functional departments, such as manufacturing and marketing; second, the coordination of inter-firm's innovation, where complementary knowledge between enterprises is in presence; and, third, the coordination of the knowledge creation between enterprises

and public research institutions. If putting the production of public knowledge aside, there are two basic types of IO of technological update, i.e., intra-firm specialization and coordination, and inter-firm division of labor in innovation and coordination. The former is grounded on integrated firms, and the later is based on the innovation networks. Here arises an important issue in the field of technological innovation and industrial development, i.e., which one of these two types of IO is much more favorable for the long-term technological progress.

Some authors argue that large integrated enterprises (LIEs) are advantageous in technological progress. As Chandler pointed out, the advantages of LIEs in technological innovation are as follows. Firstly, due to the economies to scale in production, LIEs are more willing to carry out process innovation through large scale of investment. Secondly, for the sake of maintaining market share and building up barriers to entry, LIEs facilitate product innovation by a large amount of investments in human capital and R&D. Thirdly, they push forward commercialization of new technologies through integrated investments in marketing and management (Chandler *et al.*, 1997). Lazonick argues that LIEs are capable of incorporating both the strategic flexibility and economies to scale, meanwhile, their control of key inputs grants investment in technological innovation (Lazonick, 1991). Mowery figures out that large scale investment in R&D is highly uncertain and heterogeneous, so large enterprises have unparalleled advantages than other forms of organizations in contracting R&D and coordinating scientific and technological (S&T) resources (Mowery, 1995). In the context of ‘technological catch-up’, Kim argues some advantages of large firms in technological innovation. In his explanation, LIEs are better in implementing the industrial policies that carrying the national strategy, comparing to the innovation networks of SMEs. The government can provide incentives to, and make constraints on the innovative activities of large enterprises, which serve as the innovators, and support exports and international market competitiveness-oriented policies. So large firms can be shaped to be the most crucial engine of industrial and national technological learning and innovations (Kim, 1997).

Some other authors insist that effective (formal and informal) transaction mechanisms of enterprise innovation networks are the more important IO groundwork to safeguard technological progress. Koschatzky and others argues that technological innovation is a systematic learning process with high uncertainty and risk. Informal information exchange and formal R&D cooperation in networks can help enterprises acquire complementary knowledge needed for innovation much sooner, and networks are the decisive element for innovation and economic development (Koschatzky *etc.*, 2001). Sturgeon’s study shows that, due to the sophisticating product designing and manufacturing, a single firm is facing more and more difficulties to carry out the R&D of new products solely. Moreover, as the standardizing of modulization and component interface, accompanied with outsourcing the component designing and

manufacturing, the ‘specialized production networks’ formed through market transactions become the dominant form of IO (Sturgeon, 2002).

As for the machine tool industry, the majority of the empirical studies on the leapfrogging of the Japanese machine tool industry over American’ emphasize the importance of Japanese technological innovation network. For instance, some authors stress the significant role of the strategic alliance of machine tool firms, suppliers of excellent Computerized Numerical Control (CNC) systems and equipments, and producers of precision components in the success of Japanese machine tool industry (Finegold *et al.*, 1994; Mazzoleni, 1999). Lee’s study shows that the active cooperative innovations between producers and consumers are the main sources of the successful catch-up in capital goods industry of Japan and Korea, as the latecomer countries (Lee, 1998).

In our point of view, LIEs and innovation networks, as the two basic forms of IO, are not completely against each other. From the view of transaction that fulfills coordination, technological innovation of LIEs is coordinated through the internal authority based transaction, while technological innovation of the firms in networks is coordinated by market transactions. In the light of transaction cost economics, there is substitution between these two forms of IO. One technological innovation can be carried out through the form of either the integrated organization or network. Hence, one cannot simply justify which one is much more important while ignoring specific ‘transaction conditions’. The right question should be asked is, under certain specified ‘transaction conditions’, which form is the more efficient for technological progress than the other? We propose that due to the effects of transaction settings, country-specificity of technological innovation and stage-specificity of industrial development, and thus the path-dependence, the optimal form of IO turns out to be context specific and evolutionary. Observations from the real world also illustrate that there are persistent and significant country-level divergences in the forms of IO of the same industry.

For both the two existing strands of studies on the optimal IO, no matter LIEs or networks, there is a common weakness: they all inquire which form is more efficient than the other under the presupposition that large firms or networks (enterprises) have enough incentives to innovate. In our study, however, the question we are interested in is for the LIEs or network, which one is more sensitive to the incentives for innovation in the surrounding context than the other. IO does not only affect the ‘structure’ of innovation itself, but also the incentives for innovation. Because of serious failures in technology market and relatively higher incompleteness in innovation systems in latecomer countries, the question who is the appropriate agent of first mover innovator is especially important.

To sum, the key topic of this paper is the locus of incentive and source of technological upgrading in China. More specifically, how do the country-specific

social and economic factors and the basis of industrial development affect the forms of IO of technological progress? And what's the relationship between IO and long-term innovative performance? On the methodological ground, we follow Porter and Lazonick, and analyze the industrial and national competitiveness from the perspective of the strategy and structure of a firm (Shenyang Machine Tool (Group) Co., Ltd, hereafter, SMTCL¹), and reveal the economic-social embeddedness of the IO of technological progress, and its industrial specificity with a comparative study. This rest of this paper is organized as follows. After the question forming and literature review, Section II highlights the IO's uniqueness in China's machine tool industry through a comparative analysis. Section III discusses the distributional structure of the incentives for innovation in this sector. Section IV deals with the organizational features of the specialization and coordination in China's machine tool industry. Section V concludes with some policy implications.

2 The Similarities and Differences of Main Machine Tool Manufacturing Countries in the IO of Technological Upgrading

Different from other manufacturing industries, e.g. automobile and IT, one obvious feature of machine tool industry is that there is still no globally vertical disintegration in value-chain— cross-border vertical disintegration and division of labor in R&D, manufacturing and marketing, which happens in a way of either cross-border investment, or outsourcing. Until now, its R&D and manufacturing are still largely integrated within a country (or region), even in a firm. This feature makes the growth and technological updating of machine tool industry affected by the industrial technological paradigm itself on the one hand, and the country's specifically economic and legal settings on the other. Therefore, the IO of technological updating of a country's machine tool industry is based on the generality of technological paradigm, and has significant country specificity as well.

According to the existing studies on the sectoral innovation system, the technological paradigm of machine tool industry should be a type of 'specialized supplier'. On the one hand, the firms' products are highly custom-specialized and insignificant in scale economies. On the other hand, technological upgrading is

¹ In May 2009, the Research Unit of Innovation and Development, Institute of Industrial Economics, Chinese Academy of Social Sciences, made a four-day field investigation to SMTCL, Shenyang, Liaoning Province. The investigation arrived at a thirty-five-hour-long sound recording of the interviews to the CEO, directors of Central Research Institute, Internal Manufacturing Techno-Department, two techno-subdivisions, department of human resource management, department of finance, department of marketing and also other departments and business units, and core R&D personnel, technologists and skilled workers, effectively answered 111-question composed questionnaire, and near one thousand B-3 paper internal publications.

mainly through incremental improvements with the interaction process of producers and customers, and the economies to scale of formal R&D is also not remarkable. Hence, IO in this technological paradigm is featured as a large amount of SMEs (Pavitt, 1984; Malerba, 1992, 1996). The networks of enterprises and customers, and inter-firm networks are the basis of sectoral innovation. The form of IO dominated by networks has the characteristics that the S&T inputs and outputs are scattered to the knots in the networks. Alternatively, for the form of IO that dominated by LIEs, few large enterprises have concentrative control over S&T resources and R&D process, and they are also the most prominent contributors of innovative output in this innovation system.

Take a glance from the overall level. There is a shared characteristic among each country's IO of technological learning and innovation in machine tool industry—notable networks of innovation.² Although the ways of transactions within the innovation network in each country are undergoing evolution, the dominant feature of innovation networks remains constantly. The innovation networks in the traditional machine tool industry are regional clusters, and inter-firm technological learning has the characteristic of informal information exchange. In recent years, the dominant IO of machine tool industry in some main countries is still SMEs networks, but we can witness remarkable changes in technological learning: technological learning and innovation in networks are increasingly dependent on the strategic cooperation between enterprises and public research institutions. Although informal knowledge flows keep on playing an important role, formal cooperation based on explicit contracts and procedures shows its growingly magnificence. Meanwhile, the scope of learning and innovation of the network are being broadened. Besides the traditional product innovation, process and organizational innovations for production and service solutions are gaining importance.

On the other part of this story, since each country's social and economic elements are distinct to others, machine tool industries in a different countries have certain country-specificities in IO and technological learning.

Japanese machine tool industry has advantage in massive and low-cost production, meanwhile mainly supplies higher reliability and flexibility CNC machine tools. It is configured partly by some strong internationally competitive medium-size enterprises (in terms of the number of employees), and partly a large number of small firms with specialized technological advantages. The main locus of innovation in Japanese machine tool industry lies in firms, rather than public research institution. For both Japanese large enterprise and SMEs, they all have strong in-house R&D and capability, and set the intimate corporation with clients as an important organizational

² Comments on the IO of machine tool industry in Japan, Germany, US and Italy in this section are largely leaning on Wengel & Shapira (2005) and Ulrich (2000).

form of innovation. Since overseas market share accounts for a considerable part, the development of Japanese machine tool firms has a strong strategic inclination of internationalization. Collaborative development of components and parts with overseas suppliers is an important business when forming their overseas cooperation.

The IO of German machine tool industry is portrayed as SMEs, such that innovation has an obvious characteristic of network. Associations in the fields of machinery or engineering play very active roles in promoting inter-firm collaborations. For the collaborative innovation in the supply chain, according to the statistics of ISI manufacturing innovation survey of 1999, 52% machine tool firms out of the sample did cooperative innovation with clients, 45% with suppliers, 46% with foreign clients, and 33% with foreign suppliers. Normally, machine tool manufacturers shoulder the systemic responsibility for clients, and the parts and components suppliers are responsible for machine tool manufacturers, so the overall inter-firm relationship on the supply chain is long-term cooperation, trustworthy and limited competition. In addition, German S&T policies are effective in strengthening up- and down-streams and inter-industrial technological collaborations.

In Italy, the IO of the machine tool industry is mainly in the form of small firms. According to a 1998 statistics, for 450 firms in this business, the average number of employees was merely 70. Their strategy is dominated for clients. Accordingly, although they are small sized, but highly integrated. Most of them function in designing, assembling, testing, and even software developing. Innovation networks in Italy are industrial clusters. In some industrial-cluster zones, few lowly integrated large enterprises play a decisive role in technological learning and innovation of the network that roots on market transactions. But in some other zones, some non-firm organizations, such as universities, technical schools and guilds, are more active in facilitating technological upgrading.

In the USA, machine tool industry is composed by SMEs— about 90% firms hire less than 100 employees. Since 1980s, Japanese has outperformed American machine tool industry. Some explanations are: lacking of coordination on technical standardization; short of large enterprises who make persistent and large scale investments in R&D; no facilities and platforms for small firms to cooperate; short term transaction relationship between manufacturers, suppliers and clients. Those factors cumbered the USA to leverage its advantages in scientific research (actually, this advantage lasted till 1990s and even now) to overall industrial competitiveness through firm-level technological development. In Japan, comparatively, supports from government, intimate inter-firm cooperation and information sharing empower the Japanese machine tool industry with technological dynamics, and eventually occupies international market with their advantages in the liability and excellent cost performance of products.

As the acceleration of the global manufacturing industries transfer to China, and also China's push-forward in industrialization and urbanization, since mid-1990s, its capital goods industries, including machine tool industry, has been undergoing prosperous development. In 2008, the output of China's machine tool industry has reach 13.965 billion US dollars, ranked third globally, only behind Japan (15.847 billion US dollars) and Germany (15.657 billion US dollars). Generally speaking, China's machine tool industry is also featured as a great number of scattered SMEs. In 2007, two sub-industries of machine tool industry— metal cutting and metal forming, had 586 and 444 firms whose annual sale incomes were over 0.74 million US dollars (about 5 million Yuan)³, and their average employees were 329 and 176 respectively. The distribution of the firm's size shows an obvious discrete layering. In metal processing machine tool industry, there was only two firms— Dalian Machine Tool Group Corporation (DMTG) and SMTCL— whose output value was over 1.5 billion US dollars, accounts 20.5% of the total output value of this industry. According to a report of 2009 by the US Gardner Company, the year of 2008's sales revenue of SMTCL, China's largest machine tool enterprise, has reached 1.63 billion US dollars that ranked 7th in the world, almost 60% of the world's largest machine tool manufacturer (Trumpt of Germany), 2.77 billion US dollars. China's 2nd and 11th largest manufacturer of the world, DMTG's annual sales revenue was 1.42 billion US dollars. However, China's 3rd largest machine tool manufacturer, Beijing First Machine Tool Factory's sales revenue was merely 0.36 billion US dollars. There were only 10 firms' product values higher than 0.15 billion US dollars (1 billion Yuan), accounted merely 35% of the whole industry. Compare with other strategic industries that related to national economic security, China's machine tool industry shows a stronger inclination of private running and more intensive competition. Until 2007, over 90% of the firms in this industry were non-state controlled. Among them, private, collective held and joint venture with Hong Kong, Macau or Taiwan was 71.3%, 7.8% and 5.9% respectively. Multinational companies (MNCs) account a little share in this industry of China, only 7.7%. The share of state-owned machine tool manufacturers was 7.3%.

Generally speaking, market concentration of China's machine tool industry is not so high. Nevertheless, it is highly concentrated as we observe from the distribution of S&T resources. LIEs play a dominant role in controlling S&T resources and outputs. That means, in terms of overall productive resource and market share, IO of China's machine tool industry is decentralized. But observing the distribution of S&T resources, IO of technological innovation of China's machine tool industry is highly concentrated. A peculiarity of the development of China's machine tool industry is: at

³ Since the official statistical sampling is constrained to medium and large scale firms, so the actually number of China's machine tool firms may be far higher than those figures.

the early stage of industrial growth, the distribution of S&T resources and innovation capacity between agents is highly uneven. A large amount of S&T resource is concentrated in a few large SOEs have strong ability of engineering and R&D. Since 1990s, a great number of private enterprises plugged into this industry, they only commanding limited technological resources. For this reason, national key S&T inputs, such as national key laboratories and '863 Projects', run to larger enterprises. Since non-state-owned machine tool enterprises are small-sized, they cannot afford higher competitive salaries as their larger state-owned counterparts who can gather most of the crux technological talents.

LIEs are also the major suppliers of S&T outputs. In 2007, SMTCL succeed in 74 newly developed products, 9 out of them were internationally advanced, 2 filled blanks nationally, and the rest were international or national top. It has 6 sets of 5-axis and 10 sets of planer CNC machine tools, and 7 lathing-mining centers. Most of China's high-end machine tools are firstly created in SMTCL, DMTG and other few large SOEs. And, an overwhelming rate of SMEs engages in technological imitation (mainly through hiring few technicians from larger SOEs).

Table: International Comparisons of IO of Technological Innovation in Machine Tool Industry

Country	Characteristics of Agents	Intra-firm Features	Features of Network
China	Large firms carry out innovation; no obvious innovation networks	The 'Leaders' Projects' of Highest managers (normally General Directors); Emerging cross-function cooperation	Short-term, explicit contracts
Japan	Both large enterprises and SMEs are active agents of innovation, distinct innovation networks; Government and public institutes are important in coordinating innovation; Firms cultivate their own employees' technological capacity	The role of managers is relatively weak; active and informal-procedure-based cross function collaborations	Long-term, implicit relation contracts; Network cooperation usually is exclusive.
Germany	Both large and SMEs are important agents of innovation, distinct innovation networks; Government and public institutes are important in coordinating innovation; Firms rely largely on public education and training institutes to increase employees' technological skills.	The role of managers is relatively weak; Active and informal-procedure-based cross function collaborations	Long-term, implicit relation contracts; network cooperation is usually non-exclusive.
USA	Public institutes are the main sources of innovation; No distinct innovation networks	Less and usually formal-procedure- based cross-function collaborations	Short-term, explicit contracts
Italy	SMEs are main innovative agents; Distinct innovation networks	Low level specialization within SMEs; Less cross function collaborations	Horizontal network (industrial cluster); Geographical approximation and public institutes play an important role in facilitating learning and innovation

3 IO and the Latecomers' Technological Upgrading: Incentive

Technological innovation is a sort of economic adventure of high investment and high risk. In LDCs, since market incompleteness, ineffective protection on intellectual property (IP), and strict low price requirements of consumers, incentives for enterprises' technological innovation are weak. In this case, it is especially important for latecomer's technological upgrading that economic agents are more earlier and sensitive to perceive the market and non-market incentives for innovation and then make R&D investment. We think that the features of economic incentives formed by market and nonmarket opportunities, and the varieties of economic agents make difference to the innovation performance⁴.

Expansion of market opportunity offers rather favorable conditions for the innovation of China's machine tool industry. In 2001, total demand for Chinese machine tools was 4.74 billion US dollars, and China became the world's largest consuming country since 2002. In the year of 2008, its demand has increased to 19.45 billion US dollars, with an average year-on-year growth rate of 22% over 7 years. In 2008, the world's 2nd and 3rd largest consuming countries were Germany and Italy, whose consumption was 9.95 and 8.55 billion US dollars, respectively. But these two countries' total consumption was less than that of China. Rapid expansion provides necessary incentives for R&D investment. But the most crucial external market opportunity that encourages firms' innovation comes from the mismatch between the imported machine tools and China's local demand. There are two reasons account for the scarcity of MNCs' investment in China's machine tool industry: this industry's technological paradigm and its special national status. For machine tool industry,

⁴ The innovation incentive problem from the perspective of industrial organization is largely overlooked by the existing studies on technological innovation. Few studies touch this question indirectly. For example, Huang and Khanna argue that when comparing to Indian economy, there exists a serious problem with China's long-term economic development—industries leaders are large SOEs, rather than private ones. "China and India have pursued radically different development strategies. India is not outperforming China overall, but it is doing better in certain key areas. That success may enable it to catch up with and perhaps even overtake China. That is because China's export-led manufacturing boom is largely a creation of FDI, which effectively serves as a substitute for domestic entrepreneurship. During the last 20 years, the Chinese economy has taken off, but few local firms have followed, leaving the country's private sector with no world-class companies to rival the big multinationals." (Huang & Khanna, 2003). We can see in their study, there is a latent assumption that large SOEs are necessarily weak in innovation. Although Lazonick doesn't agree on state-owned property is beneficial for innovation, at least he believes that property right doesn't matter. "The form of ownership is not the critical issue for understanding the type of strategic control that supports innovative enterprise. Critical are the abilities and incentives of those managers who exercise strategic control" (Lazonick, 2004). For him, if there exist appropriate regulations that give reasonable incentives for firms, SOEs could be innovative firms as well. Our paper's study doesn't support the point made by Huang and Khanna, but partially supports Lazonick's conclusion. In our view, appropriate incentive is not a sufficient condition for SOEs' long-term innovation investment. Entrepreneurs' individual aspiration and motivation are important elements that affect SOEs' innovation investment. Those subjective factors, combined with appropriate incentives are sufficient conditions for SOEs' long-term innovation investment.

coordination and interaction between R&D and manufacturing are the particular technological paradigm. This exogenous technological characteristic makes cross-boarder separation of R&D and manufacturing detrimental to the overall technological capacity, so R&D and manufacturing in each country are generally value-chain integrated. In addition, machine tool industry is trouble of national security related to aeronautics and astronautics, military equipment supplies, so the major machine tool manufacturing countries impose strict prohibition on foreign investment on domestic enterprises. Therefore, foreign machine tool enterprises have rather limited access to Chinese market in the form of direct investment. To 2007, the foreign holding machine tool firms were 7.7% in numbers and 8.7% in market share. Under this setting, foreign machine tool can enter Chinese market only through exports.

Chinese machine tool enterprises have cost advantages in low-end market, which compels foreign machine tool firms only to occupy, with exports, China's high-end market. Before 2008, foreign products account as high as 85% market share of medium & high end CNC machine tools. Tremendous potential market and high profit in higher end market, and intensive competition between local firms drive some Chinese firms, which have comparative technological advantages, to upgrade their technological capacity and explore higher end market. After 2000, Chinese indigenous firms' market share keeps on increasing: grew from less than 40% in 2000 to 56% in 2007. Among others, CNC machine tools grew faster. The output of CNC metal cutting machines increased from 14,000 in 2000 to 122,000 in 2008. As shown by the data of SMTCL, in 2008, the outputs of medium & high end machine tools was only 5% of its total outputs, but contributed its 45% sales revenue.

The "multi-level market" may raise Chinese machine tool firms' inclination to investment, but cannot lend explanations to the question: why limited few large enterprises, rather than most of the firms, in the form of networks, are more willing to invest in R&D of product and explore new market? For us, in China, larger machine tool enterprises have stronger motivation and incentive to innovate for the following three reasons.

First of all, 'selective' industrial policy empowers large enterprises with higher motivation for innovation. Until now, a basic idea of China's industrial policy sticks to promoting certain dominant enterprises to be 'bigger and stronger'⁵. Government channels resources of capital, technology and talents into large enterprises through fiscal, taxation, financial, human capital, land and other policies. Generally,

⁵ Government set large SOEs, rather than the entire network as the carrier of industrial policy, not only because of their easier rent seeking, there are some other reasonable economic factors, such as network, as a carrier of industrial policy, has higher coordination cost than firms. Furthermore, government controls patronage of high-rank managers of SOEs, this helps government to implement industrial policy through its administrative commands.

government distributes S&T resources mainly following certain criteria, such as “owning formal R&D department”, “owning well-equipped laboratory” and “owning important technological innovations in the past”. Large firms often have advantages in those items, so they are more accessible to governmental S&T resources. On the one hand, governmental S&T resources encourage larger firms’ complementary R&D investment. On the other hand, those resources also provide large firms the incentives to acquire further public resources by demonstrating high technological capability.

Secondly, economy to scale and scope economy intensify LIEs’ incentive to innovate. SMTCL was merged from three big machine tool factories in a way of asset restructuring by local government in 1995.⁶ Ever since the founding, SMTCL is highly diversified and integrated. In 2004, SMTCL acquired German Schiess Gmbh⁷ and restructured Yunnan Machine Tool Factory, and held Kunming Machine Tool Factory in 2006. A series of restructuring and M&A further extend its business scale and scope. In 2007, its products were over 20,000 units (sets) and ranked No.1 of the world. In 2008, its total assets have reached 2.4 billion US dollars and hired 18,000 employees. SMTCL’s business cover general-purpose machine tools, CNC machine tools, large manufacturing equipments (for aeronautics & astronautics, automobile, ship-building and railway industries), assemble line sets and core functional components (CNC system, sw and five-axis head). Due to the advantage in scale formed by institutional and policy factors, SMTCL can appropriate from R&D by mass production. But for a mass of Chinese small machine tool and specialized components manufacturers (such as of spindle, electronic machinery, CNC controller and integrated circuit chip, etc.), the story is different. They are slow movers in technological upgrading and insufficient to meet China’s high end market demand, which depend rather heavily on technology transfer.

Thirdly, scarcity of entrepreneurship in developing countries means that only a few firms have aspiration for the high risky innovation. Comparing with developed countries, LDCs are not only lacking of capital and technology, but also more in short of entrepreneurship. The technological learning of China’s SMEs in machine tool industry is mainly technological imitation, so they have a strong tendency of market opportunism. Oppositely, some large state-owned enterprises (SOEs) employ elite techno-entrepreneurs that have abundant expertise knowledge of this industry. Those entrepreneurs are not only able to sensitively identify the market opportunity from the mismatch between foreign enterprises’ supply and domestic demand, but also armed with a strong ‘spirit’ of technological innovation. They are bearing strong aspiration to

⁶ They are Shenyang First Machine Tool Factory, China-Czech Friendship Factory and Shenyang Third Machine Tool Factory.

⁷ Schiess Gmbh is a world famous machine tool manufacturer with over 140 years of history, located in Asherleben City of Sachsen-Anhalt State, Germany. Its manufacturing technology stands for the world’s top level, and enjoys a worldly famous reputation.

outpace foreign competitors and shake off technological dependency on overseas enterprises, by means of employing the firms' self-accumulated innovations. Those entrepreneurs' individual abilities and aspirations are the most primary driver and basis for large enterprises' technological innovation (Winter, 2000). With respect to China's SOEs, since the 'absence of ownership', their corporate governance is strongly 'insider controlling'. In this case, comparative advantages of entrepreneurs' individual capabilities and beliefs are decisive to form a long-term intra-firm financial commitment to innovation and S&T resources allocation.

Take SMTCL as an example. SMTCL's present Chairman Guan Xiyou graduated from Department of Mechanical Engineering, Tongji University, one of the most distinguished institutes with Engineering in China, and holds bachelor degree in mechanical manufacturing. He joined Branch of Borer Machine of then China-Czech Friendship Factory—one of the three founding factories of now SMTCL—as a senior technologist in 1988. Technological background and industrial experience make him has a strong sense of innovation. Besides, SMTCL takes historical tasks of the country's important break-through projects in machine tool industry since its founding. Many China's machine tools were initially born here: the first normal machine tool, first radical drilling machine, horizontal boring machine, and first automatic lather. So this firm has a historical tradition of pursuing technological break-through. The concentration of innovative entrepreneurship and organizational culture in few LIEs, rather than broad distribution in the whole industry, determines that the power of innovation lies in few firms, rather than in network. Furthermore, after reforming and restructuring, those entrepreneurs' private benefits are more directly linked to the firms' benefits. When the number of SOEs is small, the principal agent cost between the government and large integrated SOEs can be further reduced.

4 IO and the Latecomer's Technological Upgrading: Specialization and Coordination

4.1 Specialized R&D Structure

When external protection of IP is weak and the inter-firm knowledge transaction cost is high, LIEs can efficiently arrange specialized R&D and coordination. Since China's machine tool industry developed uneven, S&T resources and technological capability are extremely asymmetric between large SOEs and SMEs, which grew up till after China's 'reform and opening up'. Actually, it is difficult to forge technological complementarity between SMEs and SOEs, which however is a necessary condition for network forming.

SMTCL' early R&D has three characteristics. First, low-level specialization of R&D, there was no independent department for new products developing and

improving. Second, informal R&D procedure, the initial R&D was largely relied on few technological talents' enthusiasm and capability. Third, R&D functioned mainly for government projects, rather than forward-looking R&D for market and specified R&D for customers. As competition in international and national machine tool market became more and more furious, and the firm continuously penetrates high-end market and extending product line, wider technology portfolio was in need, and R&D became more and more sophisticated. All of these require the enterprise to make larger investment and organize increasingly complicated R&D. Expanding R&D coverage and increasing complexity provide economic rationales for R&D specialization.

At present, the R&D system of SMTCL is a four-layer structure. The highest decision-making organization is the Committee of Technology on the group level, and the R&D executive organizations are Central Research Institute on the group level, techno-subdivisions in the affiliated firms and business units, and the Internal Manufacturing Techno-Department on the group level. The Central Research Institute and techno-subdivisions are in charge of product R&D. This R&D system is seasoned with the firm's product strategy, "produce one generation, trial-produce one generation and reposit one generation".

The Committee of Technology includes its internal R&D staffs, external academicians, experts, and scholars of related technological issues. The Committee acts as a decision-making and consulting organization for R&D strategy, and makes decisions on key R&D projects collectively. The function of the Committee covers identifying key prospective R&D and break-through directions, checking on the proposals submitted by projects. The Committee is totally independent from the administrative hierarchy, which promises the continuity of R&D investment.

For the executive internal R&D system, the first tier is Central Research Institute. It focuses on developing prospective (mainly over 3 years) products, and research on basic, generic and core technologies. The products developed by the Institute are set for high-end market, with the emphasis on the sophisticated CNC machine tools that meet the demand of national key industries. The Institute also acts as a platform to cooperate with the public scientific research institutes in collaborative research and promoting generic and fundamental technological upgrading. The function of techno-subdivision is to carry out client-oriented R&D. According to their clients' needs, the different techno-subdivision operates commercial development, customized design and persistent improvement of their product portfolio, in order to push further the specialized capability for product engineering. SMTCL also founded an Internal Manufacturing Techno-Department, which is an inward looking department that responsible for improvement in process, such as upgrading production procedure, manufacturing technological improvement, ameliorating product quality and cutting production costs, *etc.*

Based on specialization, SMTCL also designed coordination mechanisms to facilitate knowledge flowing and sharing in each direction. It constructed a three-layer synergic innovation system between R&D units. The first mode is total innovation process participation. Central Research Institute assumes prospective product design and development; its R&D staffs have to engage in the following engineering and manufacturing process. By detecting problems with designs during production process, they are able to perfect their designs. The second mode is cross-department staff transfer. Some R&D staffs transfer directly to the business units and strengthen their designs and developments of the new products. The third mode is horizontal coordination mechanism. The Committee of Technology checks on key R&D projects to avoid overlapping of R&D projects, and the coordination of branches and businesses is also realized through joint R&D projects.

4.2 Provision of the Experimental market

In innovation system, “experimental consumer” is an important factor that safeguards the survival of new technology and stimulates ongoing improvement (Malerba, *etc*, 2007). The significances of experimental consumer lie in (1) providing the emerging market for the new technology; (2) giving constructive feedbacks of technological information to supplier⁸. For the machine tool industry, which is relatively technologically matured from an international perspective, the experimental consumers are strategic assets for innovation with particular scarcity in developing countries. When market couldn’t supply experimental consumers, LIEs firstly apply immature technologies to downstream divisions within firms, who actually serve as ‘experimental consumers’ for the new technologies.

Innovation of the CNC system is a typical case of this sort. On 1st August 2009, SMTCL declared that they had realized industrialization of the world’s first-class Feiyang CNC system. That indicates China has owned the most advanced core CNC technology of world. In 2006, SMTCL introduced the initial technology from Fidia, an Italian firm which is a worldly excellent in CNC system designing and manufacturing, and spent three years to assimilate, adapt and re-innovate. By applying to self-produced CNC machine tools, SMTCL collaborates with clients to tackle the problems with product and then further improve them. For example, during R&D process, Feiyang CNC system has being continuously operated on 10 sets of CNC vertical machining centers of the auto components production lines of Shenyang Hangtian Xinguang Group. By persistent internal trials and improvements, SMTCL finally had certain core technologies of CNC in hand, including Real-Time

⁸ The difference between “experimental consumer” of internal firm and external market is the later delivers information of product and technology by price system (vote by price) and market organizations (e.g., spontaneous forums), *etc*. However, the former operates through non-price system and non-market organizations (e.g., firms’ internal meetings and informal conversations).

Controlling, Servo-Control Computing and Numerical Bus Technology, and successfully developed FOM for machining centers and FOT for CMC machine tools. This paves way for further building its own CNC soft- and hard- platform.

4.3 Organizer of the network

SMTCL is also a crucial ‘organizer’ of the innovation network. Here by ‘organizer’ we mean a similar function like ‘entrepreneurship’ in Austrian economic tradition. Firstly, in collaborative innovation, SMTCL usually pays a fix returns to its partners (typically for the cooperation’s with universities), and bears the primary risks and residual claimant of R&D return by itself. Secondly, controls the dominant power of R&D and the direction of technological breakthrough of the innovation network.

SMTCL normally collaborates with universities by its Central Research Institute on machine tool technologies. In Shanghai, it develops generic and key technologies of numerical, and research and optimization of the techniques of typical parts of automobile with Tongji University. In Beijing, it cooperates with Beijing Aeronautics & Astronautics University on the R&D in typical parts for aeronautics & astronautics. In addition, SMTCL built partnerships with other universities (e.g., Tsinghua University, North-East University, Jilin University, Ruhr-Universitae Bochum and Technische Universitaet Berlin) and scientific research institutes (e.g., CAS Shenyang Institute of Computing, Shenyang Mechanical and Electrical Research and Design Institute), sponsors their researches, such as specialized machine tool development, key functioning components design, and CNC systems optimization. In this sort of partnerships with research institutes, SMTCL functions as ‘entrepreneur’ *per se*: financially support those institutes’ research that could lower the R&D risks, and SMTCL extracts ex-post ‘residual claimant’ of the risky innovation.

Theoretically, since they are short of internal S&T resources and friability to risks, SMEs are more likely to conduct collaborative R&D with others. But the experience of China’s machine tool industry shows that since SMEs are lacking technological capability, hitherto, LIE is the agent who speeds up the firm’s open innovation. In 2009, with the support from Ministry of S&T of China, a strategic technological innovations ally of high speed and precision CNC machine tool was founded. This ally is initiated by SMTCL, the Chair membership, which is aimed to enhance sustainable R&D capability in this field. This ally covers 13 top enterprises and universities of China⁹. It mainly relies on national key laboratories, national centers of engineering technology and the technological center of SMTCL. By building mechanisms of S&T resources and products sharing and technology transferring,

⁹ In this ally, there are, e.g., Chongqing Machine Tool (Group) Co., Ltd, Tsinghua University, Kunming Machine Tool Co., Ltd. of SMTCL, Hangzhou Machine Tool (Group) Co., and Nantong S&T Co., Ltd.

drawing industrial technological standards and criteria, setting a principle of protecting IP, this ally is going to integrate the decentralized S&T resources.

4.4 Acceleration of the Cross-border Technological Learning

As Chinese indigenous machine tool enterprises gaining technological capabilities, the traditional technological learning, through decoding and acquiring technological knowledge by reverse engineering became increasingly less effective. In particular, high-end CNC machine tool is highly systemic, reverse engineering cannot uncover technological knowledge that related to ‘integral architecture’, so enterprises have to speed up technological learning and assimilating through inter-organizational technological learning. Since 2000, the trend of accelerating technological learning through overseas M&A of large SOEs, such as SMTCL and DMTG, is getting more and more obvious. Those large SOEs have financial advantages, so after M&A, they can make use of the intra-firm ‘transactions’ and ‘management process’ to facilitate knowledge decoding, and accelerate the transmission and assimilation of the tacit knowledge embodied in the technological leader’s organizational process. In 2004, SMTCL took over the famous German machine tool firm, the Schiess GmbH, in a financial distress then. After restructuring the Schiess, SMTCL strengthens technological learning by staff training project. After 2006, SMTCL began to dispatch its staffs to Germany and work with Schiess R&D staffs on collaborative new product development. Turning and milling machining centers, their jointly designed and produced in Shenyang, has being sold in European market. SMTCL, as a technological latecomer, overseas M&A greatly facilitates its technological learning pace in medium-high and high ends markets.

4.5 The Boundary of LIEs as the Engine of Technological Innovation

As we have shown, on the demand side, LIEs substitute experimental consumers in the market with their internal demand. On the supply side, LIEs substitute market technological transactions with a multi-layer R&D system. Hence, the nature of the LIEs dominated IO of technological innovation is that LIEs have a relatively efficient ‘internal innovation system’—including internal specializations and their coordinations—to replace the still underdeveloped and immature sectoral innovation system in LDCs. Machine tool industry is a technology and skill intensive one, far from simply production of assembly. So large SOEs have competitiveness due to their rich accumulated technological capacity. Listing in stock market can further curtain their institutional costs, and thus reinforces the state-owned machine tool enterprises’ competitiveness. Nevertheless, LIEs are still constrained to a boundary in organizing innovation.

Firstly, LIEs’ tight control of S&T resources could easily lead to monopoly. However, monopoly is incompatible with the dynamic nature of technological

innovation, which based on market process. There are three interlinked dynamic processes in technological innovation: forming of the technological and organizational diversity, technological duplication and technological selection (Nelson, 1995; Metcalfe, 1998). Technological diversity that based on network is not only favorable for the statically matching of many R&D inputs, but also increase the rate of radical innovations dynamically (Fritsch, 2001). For a single firm, its technological selection could be path-dependent: a firm always abandons those “capability-destroying” and “capability irrelevant” technologies. Therefore, few LIEs’ monopoly of the S&T resources and technological standards go against the formulation of technological diversity. Furthermore, LIEs significantly affect government’s industrial policies, so it might undermine the market’s selection process of the ‘survival of the fittest’.

Secondly, decision-making on technology of state-owned LIEs has a strong political tendency. In LDCs, LIEs are not a purely the outcome of market competition, and S&T resources concentrate in LIEs is always done by governmental intervention. So those firms are inclined to taking the governmental, rather than market competition and consumers’ demand, into their consideration when selecting R&D projects. On the investment side, the firms’ influence cost (e.g., vanity projects) and ‘soft budget’ are rather prominent.

Last, in the long run, SOEs’ innovation is discontinuous. There are some strict conditions for SOEs to carry out sustainable innovation. (1) The firm must own necessary foundation and resources for innovation; (2) the institutional arrangements by the government must be flexible enough to provide its entrepreneur with necessary economic incentives. (3) The entrepreneur holds a strong preference and aspiration for innovation. However, China’s SOEs’ high-rank managers are normally administratively appointed by the government, which distorts the continuity of the entrepreneurs’ operation and eventually the firms’ strategies of business and innovation. When innovation has not yet been the firms’ necessity for market competition and the firms’ internal cultural claim, turnovers of the top managers of SOEs always hit their innovation fatally.

5 Conclusions and Policy Implications

The evolution of IO of technological innovation is affected by a country’s specialized economic and social factors, technological basis of industry and technological paradigms, so efficient IO of technological innovation is dynamically changing. Thus, we have to keep in mind that machine tool industries in different countries share similarities on the one hand, but there are also significant differences on the other hand. No such an IO is absolutely efficient, but efficient in the specialized

environment in which it formulated. For any form of IO, its efficiency works only if it meets some certain conditions.

Our study on China's machine tool industry tells the following story. As the S&T resources for long-term industrial development is relatively limited, poor legal protection on IP, non-existent long-term inter-firm trust, and insufficient inter-firm complementarities in technologies and capabilities, specialized R&D and coordination carried by LIEs became the dominant IO of technological innovation in China's machine tool industry. This type of IO is relatively faster and sensitive to detect the market and non-market incentives for innovation, and more efficiently in mobilizing various S&T resources of the whole sector, thus promotes specialization and coordination of R&D. That means, under particular circumstance, Chinese LIEs satisfy the three types organizational criteria proposed by Lazonick: strategic control, financial commitment and integration (Lazonick, 2004).

One caveat applies here. Due to the differences in technological paradigms of different sectors, part of this paper's conclusions cannot be simply applied to other industries (e.g., bio-pharmacy industry). But for machinery industry, this paper's conclusions have wide applications.

Specialization and coordination mechanism of technological innovation are dynamically evolving, we need to see that each IO is 'historically efficient'. In a long run perspective, network-based, technological resources and capabilities relatively decentralized, and diversified IO would be beneficial for the upgrading of machine tool industry. However, the formulation of network is constrained by a society's legal (e.g., IP protection law) and economic environment. So as a result of 'collective action', comparing to the formulation of integrated IO, evolution of network and its efficiency growth (market transaction) are much more tardy and difficult. Thus the key points of the policies should gradually turn to cultivate the formulation and amelioration of technological innovation network. In particular, in order to guarantee diversity, competitiveness and dynamics of sectoral innovation system, it needs to enhance technological capability of SMEs of machine tools, in both their parts and the whole equipments.

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