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Learning through informal local and global linkages: The case of Taiwan's machine tool industry

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ABSTRACT

Most existing studies of successful late industrialization, which draw on findings from high-technology industries, emphasize the need to invest in formal channels of technology acquisition to allow latecomers to catch up. This line of reasoning neglects the fact that in some industries, including low- and medium-technology (LMT) sectors, much knowledge can be acquired by informal means. Through the study of Taiwan's machine tool (MT) industry, this article demonstrates the significance of informal learning activities in LMT industries and the possibility for latecomer clusters to climb the technological ladder through exploiting various local and global informal knowledge linkages.

1. Introduction

The fast growth of some East Asian newly industrializing countries (NICs), such as South Korea, Singapore and Taiwan, has been touted as the most successful catching-up model for late-industrializing economies (World Bank, 1993). The phenomenal growth of high-tech industries in these countries, for example electronics and information technology (IT), has attracted a great deal of attention from academic researchers and policy makers who try to derive theoretical and policy implications for promoting economic development in the late industrializing countries (e.g. Amsden, 1989; Hobday, 1995; McKendrick et al., 2000; Mathews and Cho, 2000; Amsden and Chu, 2003). The findings from the successful experience of high-tech industries in these countries have not only seemed to dominate our understanding of the recent development of East Asian NICs, but have also led to the emergence of policy suggestions that emphasize an alleged need to invest in formal means of technology acquisition – for example, contractual cooperation with foreign technology suppliers or performing R&D with state support – to drive the technological upgrading of late industrializing economies.

However, many scholars have contended that generalizing from such high-tech centered theoretical models and policies has serious limitations. For instance, as noted by Hobday (1995), in the electronics industry the division of production tasks across national boundaries is technologically feasible and advantageous to multinational corporations (MNCs) in industrialized countries. In addition, it is a manufacturing-driven, high-throughput industry where labor costs play a crucial part in competitive advantages (p. 187). Therefore, its experiences might not apply to industries with different characteristics.[1] The dominant science-based policy discourse has also been criticized for neglecting the significance of other dimensions of learning that are taking place in some non-high-tech industries in which technology building may be based largely on craftsmanship, apprenticeship, learning by doing, work routines, informal networks, employee training and experiential knowledge, etc. (Amin and Cohendet, 2004, p. 140; Malerba, 2005; von Tunzelmann and Acha, 2005).

In the same vein of thought, this paper argues that the existing high-tech industry-centered development models emphasizing formal learning channels should not be generalized to all other industrial sectors in NICs. For one thing, these models are insufficient to account for the catching-up of low- and medium-technology (LMT) industries in some NICs that do not share the characteristics of the electronics or IT industries as illustrated by Hobday. Furthermore, as opposed to the predominant view that stresses that the industrialization of Asian NICs has been stimulated by MNC-led or state-led formal learning mechanisms, I argue that the technological advance of a latecomer LMT industry may

[1] For instance, Hobday (1995) stresses that the lessons and experiences of electronics industry could be shared by the fast-growing consumer goods manufacturing industries like bicycles, apparel, footwear and sewing machines in these East Asian NICs, but may not apply to complex systems sectors, such as energy, aerospace, large-scale capital goods, etc.

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actually be nurtured by informal learning mechanisms established and exploited by local firms.

By using Taiwan's machine tool (MT) industry as a case in point, this article deals with issues related to the technological capability building and learning of LMT industries, especially in the context of late industrialization. Based on more than 60 in-depth interviews with decision-makers in MT firms, their suppliers, and related public and private agencies in Taiwan conducted in 2005 and 2006, I empirically investigate the strategies and resources used by Taiwanese MT firms to build their technological capabilities. On this basis, the article enhances our understanding of the factors contributing to, and the underlying mechanisms and institutional environment behind, the successful development of a particular LMT industry in an NIC.

I begin by discussing the limitation of the existing literature in explaining the successful technological upgrading of Taiwan's MT industry. The second section introduces some distinctive features of innovation and learning in the machinery industry in general, and the MT industry in particular, that influence decisions and affect the learning strategies of latecomer Taiwanese MT makers. The third section then discusses the various external knowledge channels utilized by Taiwanese MT firms for sourcing advanced technology, and how the learning mechanisms embedded in these channels contribute to their technological advance. In the final section, I conclude the research findings and discuss their policy implications.

2. Limitations of existing explanations of the catching-up of Taiwan's MT industry

Although the MT industry has not been studied in the same depth as the electronics industry in recent years, Taiwan was the world's fourth largest MT exporter and sixth largest MT producer in 2006 (Gardner Publications, 2007). Unlike other leading MT manufacturing countries such as Japan, Germany, the US and Italy, with more than a hundred years of history in machinery building, the MT industry in Taiwan did not begin until the late 1940s when Taiwan was still predominately an agricultural society with weak industrial capabilities. According to the earliest available data, in 1969, the total production of machine tools in Taiwan was only US$ 9 million (Liu and Brookfield, 2000). By 2006, however, that figure amounted to US$ 3.7 billion (Gardner Publications, 2007), a more than 400-fold increase.

The key to the fast growth of Taiwan's MT industry has been the existence of a well-articulated subcontracting-based production system composed of numerous small- and medium-sized MT manufacturers and specialized suppliers clustered in central Taiwan that have contributed to the flexibility and adaptability of the MT industry (Amsden, 1985; Brookfield, 2000; Liu and Brookfield, 2000).[2] This experience mirrors the studies carried out since the 1980s on local enterprise clusters in certain areas of the world harboring and nurturing many SMEs (small- and medium-sized enterprises) that were able to enter global markets competitively (Brusco, 1982; Saxenian, 1994; Porter, 2000; Guerrieri et al., 2001). An ability to obtain collective production efficiency (Schmitz, 1995) as well as interactive learning advantages (Maskell and Malmberg, 1999) through industrial clustering, however, is just part of the story that explains the success of Taiwan's MT industry. Like other latecomer clusters, many of those technologies that Taiwanese MT firms required to sustain their competitiveness as well as to catch up were mostly developed by their counterparts in industrialized countries rather than generated locally within the cluster. To better comprehend the development of Taiwan's MT industry, we also need to determine the mechanisms through which crucial extra-local knowledge is found and assimilated by Taiwanese MT firms.

In the studies of the successful catching-up of East Asian NICs, the existing literature stresses the knowledge inflows into these countries through the MNC-led or state-led learning mechanisms. In the former case, the argument goes that it is the foreign MNCs who have assisted in channeling technological resources to their latecomer partners through contractual arrangements in the forms of direct investments, joint ventures, licensing, OEM (original equipment manufacture) or ODM (own-design manufacture) partnerships, etc. (Gereffi and Korzeniewicz, 1994; Hobday, 1995; Lall, 1996; Ernst, 2002; Schmitz, 2004). On the other hand, the proponents of the state-led model, especially those who draw conclusions from the experiences of electronics sector, emphasize the critical role of latecomer governments in facilitating the acquisition of foreign technology through such means as establishing public research institutes or funding R&D activities (Kim, 1997; Amsden and Chu, 2003; Mazzoleni and Nelson, 2007).

The importance of external knowledge in precipitating the development and further upgrading of late industrializing countries seems to have become received wisdom. However, little evidence can be found to support the thesis that formal mechanisms of technology acquisition among latecomers, or learning stimulated and mediated by either foreign MNCs or the state, have much power to account for the upgrading trajectory of the Taiwanese MT industry, in which those widely cited MNC-led and state-led formal learning mechanisms have been only weakly present. In this paper, I argue that the existing literature not only fails to recognize the heterogeneity of the technology building process of different latecomer sectors, but also neglects the fact that in some industries, such as machine tools, much knowledge has been acquired and accumulated by informal means. Furthermore, in the case of Taiwan's MT industry, I contend that it is the informal learning mechanisms established by local firms, not the formal ones led by the MNCs or the state, that nurture the sustained upgrading capability of the industry.

Before laying out findings and explanations, we need to understand some features of technological learning in the machinery industry, or the MT industry in particular, which have a direct impact on the particular technology acquisition strategies and learning behavior of Taiwanese MT manufacturers.

3. Distinctive features of innovation and learning in the MT industry

3.1. Innovations in the machinery industry

Innovation differs considerably across sectors (Pavitt, 1984; Malerba, 2005; von Tunzelmann and Acha, 2005). In the so-called knowledge-intensive, or high-tech, industries like electronics, IT or biotechnology, knowledge inputs are often derived from reviews of existing research, and knowledge generation is often radical in nature and based on the application of widely shared and understood scientific principles and methods through formal R&D activities. Innovations in the machinery industry, however, are often based on the application or novel combination of obtainable knowledge with low levels of R&D (Dosi, 1988; Malerba, 2005; von Tunzelmann and Acha, 2005). They are largely incremental and often arise from the machinery firms' persistent efforts to satisfy requests from customers (Lissoni, 2001).

[2] In Taiwan, more than 60% of the MT manufacturers are agglomerated in central Taiwan, including Taichung, Nanto and Changhwa (MIRL, 1999, p. 3–107).

The most recent and widely recognized technological innovation in the machinery industry is perhaps the wide adoption of computer numerically controlled (CNC) technology since the 1970s (Mazzoleni, 1999), which made machinery more flexible and easier to use through the utilization of programming devices. In the MT industry, the radical technological breakthrough in electronic innovations, however, did not bring about radical changes in industrial structure. Instead, MT firms adapted well to the new technology by using external suppliers for control systems and for the technical assistance needed to incorporate micro-electronic components into their machines (Lissoni, 2001). In Taiwan's case, most local MT makers managed to adjust successfully to numerical control technology with the assistance of Japanese NC suppliers in the 1980s (Fransman, 1986).

With the emergence of CNC technology, the application of electronics has become a critical aspect in the development of advanced machine tools. But the core competencies of MT firms still rest firmly in the mechanical field, as the design principles of and technologies embodied in the most advanced machinery still remain largely mechanical (Lissoni, 2001). Although the improvement of knowledge in electronics demands more science-based learning, i.e. obtained largely in the classroom or R&D laboratory, the accumulation of mechanical competences that tend to be more art-based still need to be acquired through on-the-job practices (Amsden, 1985) in the forms of learning by manufacturing (doing) or by using (Rosenberg, 1976).

3.2. Learning by imitation

In addition to learning by doing and using, imitation is a widely used way of learning in the MT industry. In fact, even Japan's MT industry – one of the current global leaders – began by copying foreign machine tools and gradually absorbed advanced technology as well as developing its capabilities to introduce product innovation based on imported models (Tsuji, 2003). Imitation is often regarded as the demonstration of a lack of creativity and talent, as well as not being innovative. Japan's success, however, has made people re-evaluate the meaning of imitation in industrial development. Not only is imitation often the first step towards learning to become innovative (Bolton, 1993; Hobday, 1995; Kim, 1997), but firms endeavoring to imitate also require capacities similar to those needed for new product innovation (Nelson and Winter, 1982). Moreover, successful imitation rarely occurs in a vacuum (Bolton, 1993). This capacity calls not only for engineering skills to take an imported machine and produce a simplified and cheaper version of it, but also for a reasonable level of design capability to introduce quality improvements without raising the price (Chudnovsky et al., 1983).

In the case of Taiwan, the original source of design for most MT firms has also come mainly from imitating foreign products through reverse-engineering, in which MT firms scrutinize and analyze all of the technical details and specifications of the target products, such as structures, layouts, parts, components, and materials. Through their involvement in analysis and reproduction, MT firms were gradually able to accumulate technical competence and experience in manufacturing. Later, they tried to make incremental changes to the imitated product, such as incorporating new functions or using different parts or materials, to adapt to local manufacturing conditions (such as the availability of local supplies) or to meet customer requirements (e.g. lower-cost products or easy maintenance and repair). To remodel the machines successfully, they not only had to reconfigure the mechanical elements, but also needed to devise ways to tackle problems resulting from the design changes. In the process of constant redesigning and problem-identifying and -solving, the indigenous technological capabilities of Taiwanese MT firms have been further strengthened.

3.3. The role of experienced engineers

Manufacturing experience may have little to do with quality improvement in some industries like electronics, but it is a critical source of learning and competence in the machinery sector (Amsden, 1985). Much mechanical technology remains tacit or non-codified in a written form. It is largely developed and cultivated through shop-floor and practical experiences, and embodied mostly in the engineers directly involved in the everyday manufacturing activities (Malerba, 2005). Experienced engineers are therefore at the core of an MT firm's skill formation.

Experienced engineers play a critical role in enhancing the innovative performance of MT firms. As mentioned earlier, innovation in machine tools, especially in the mechanical portion, relies heavily on recombination and incremental changes. In this context, given their higher absorptive capacity, experienced engineers are likely to be able to handle such tasks faster and more efficiently than inexperienced ones. With prior experience and accumulated knowledge, they are more effective in assimilating the technologies and screening design ideas or components applicable to the new projects from the existing knowledge pool (Chudnovsky et al., 1983), as well as more skillful in identifying and solving emerging problems, greatly helping their firms to reduce the amount of trial-and-error in developing new machines. Their experience and skills are also of critical importance to MT firms' imitation projects. In Taiwan, for instance, many MT managers who are also senior machinists claimed in my interviews that their prior hands-on experience in various reverse-engineering and machine development projects allowed them to derive design ideas and analyze the critical technical details of a machine from just a brief period of observation and inspection inside its sheet metal.

After presenting some distinctive features of innovation and technical learning in the MT industry, the next section discusses in detail how these features influence the technological capability building processes of Taiwanese MT firms that are manifested in two spatial dimensions, namely within and outside the MT cluster.

4. Learning through informal local linkages

There has been a large body of literature documenting the advantage of industrial clusters in inducing knowledge dissemination and interactive learning (Bell and Albu, 1999; Maskell and Malmberg, 1999; Cooke, 2001; Bathelt et al., 2004). In industrial clusters, firms can easily stay alert to external changes by acquiring information on business opportunities, innovation, and incremental improvement in products or processes that are circulated rapidly and incessantly amongst them (Chen, 2002). There are many channels through which such information spreads. In some industrial clusters, such as Silicon Valley's IT cluster, there is considerable movement of personnel from one firm to another, and there are informal communication networks among engineers working at different firms, as well as professional meetings at which information is exchanged (Saxenian, 1994). In other clusters, suppliers, subcontractors, traders, and customers can be the most important agents (Beerepoot, 2005). In Taiwan's MT cluster, three knowledge linkages established by MT firms in their local production networks, i.e. with users, suppliers and public research institutes, are especially conducive to technology acquisition.

4.1. Working with local users

The role of user-producer interaction in the technological development (or innovation) process has been analyzed by several

authors (Lundvall, 1988; Fagerberg, 1995; Gertler, 1995). In the development of the MT industry, scholars especially emphasize the important role of technologically sophisticated domestic users, such as the automotive and automation industries (Carlsson, 1984, 1995; Lee, 1998). With the assistance of these advanced users who possess significant problem-identifying and -solving capabilities in the user-producer interaction process, MT builders improve their technological competence (Carlsson, 1995). Therefore, it is easy to observe that countries such as Germany, Japan, the US, Italy, or even the latecomer Korea, which currently lead in the global MT industry, also have strong domestic automotive industries or automation sectors, not to mention that these industries are often the largest buyers of machine tools. Yet in the case of Taiwan, since domestic automobile companies use mainly imported equipment[3] and most MT firms' domestic clients are small machinery workshops with weak technical competence, local MT firms do not seem to expect much in the way of advanced technology inflows through these channels.

4.1.1. Local users as innovation stimulators and machine testers

The role of these relatively technologically backward domestic users, however, should not be neglected in the upgrading of Taiwan's MT industry. As the vice president of a major Taiwanese MT firm points out:

> We consider domestic clients as our trainers. Compared to our foreign clients, Taiwanese clients are more demanding in terms of the price and function. Unlike most foreign users who would use each of their machine tools in a single processing activity, Taiwanese users would use just one machine tool to perform multiple machining tasks, say, from part processing to die processing. Their requests have created great challenges for our machining design capability. (Author's interview, 28 April 2005)

To accommodate the requirements of their domestic users, Taiwanese MT makers are spurred to devise ways of improving the functionality of their machines while managing to keep them in an affordable price range for their local clients, who are mostly small machinery workshops with limited capital. For this reason, the current strength of Taiwanese MT firms in the global market, especially in the segments of low- to medium-end and multi-purpose machine tools, is considered to be largely stimulated by their domestic users.

When developing new machines, Taiwanese MT firms also rely on their trusted local users to assist them in machine testing. The workers of their user firms would be more experienced in operating machine tools than the MT firms' own engineers and therefore could more effectively detect the flaws of new machines. At the same time, in these local users' metalworking shops, the functionality and reliability of a new machine could be tested in situations that cannot be simulated in MT firms' in-house testing. As these Taiwanese local metal working shops are known for operating their machines in harsh conditions, such as working around the clock and using machines to perform various processing procedures, MT firms can expect their new models to receive the strictest testing in their users' workshops, helping to optimize the final products.

4.1.2. Local users as technology agents

Although unable to provide advanced knowledge directly themselves, the domestic clients of Taiwanese MT firms are nonetheless among the most critical agents of foreign technologies. In the past, when undertaking to imitate foreign products, Taiwanese MT firms might have first imported the machines of interest from foreign makers and then dismantled them for detailed inspection. Today, however, they rarely deploy such strategies, given the high cost of importing these high quality machines as well as the increasing difficulty of purchasing them, as foreign MT makers have become aware of their Taiwanese counterparts' hidden intent in purchasing their products. In this context, the relational networks of Taiwanese MT firms with domestic users give them an alternative and more economical way to access advanced technological know-how.

To get instant feedback on machine use, an important input for improving products, MT firms need to send out their staff regularly to visit local users. Since some of these local MT users might have purchased foreign advanced machine tools for sophisticated processing, their knowledge and experience of using imported products is useful for product improvement by MT firms. Moreover, this offers Taiwanese MT makers a chance to have an 'inside look' at these machines by taking advantage of their relationships with the machine owners. According to a R&D department director of one of Taiwan's top 10 MT firms:

> Upon learning that our local suppliers or clients have imported a machine tool that might be of technological interest to our firm, we will ask their permission to see that machine. With our long-term business and personal relationships, some of them might even be willing to allow our engineers to dissemble that machine for thorough scrutiny when it is off-duty. (Author's interview, November 2, 2005)

In addition to opportunities for physical inspection, machine owners may provide the instruction manuals that contain detailed specifications and guides to operation and trouble-shooting. These manuals also serve as a complementary knowledge source, helping engineers employed by Taiwanese MT firms to extract and comprehend the know-how embodied in the imported machines.

4.2. Know-how diffusion and sharing facilitated by the suppliers

Taiwanese MT firms are competing against each other with similar products on the international market. In contrast to the existence of intense vertical interaction between MT makers and their customers, horizontal interaction among domestic MT firms has been sparse. Their cut-throat competition in the market has made it hard for them to work together. Except in rare cases in which domestic firms selling different products might help each other out by supplying complementary products for marketing, cooperation between MT makers, especially in terms of technology or product development, has been almost non-existent. Nevertheless, mutual learning by domestic MT makers in the cluster has been surprisingly vigorous.

Scholars have argued that industrial clustering facilitates learning, as agglomerated firms can easily acquire information about their rivals either through informal interactions of their employees (Saxenian, 1994; Dahl and Pedersen, 2004) or by being exposed to the 'local buzz' (Storper and Venables, 2002; Bathelt et al., 2004). Indeed, such a mechanism is still at work in Taiwan's MT cluster. MT firm managers whom I interviewed kept stressing that in the cluster they can easily obtain updated business information concerning their local competitors—data, for example, on which firms are doing well (or badly) in selling which products in which mar-

[3] Taiwan's domestic automobile firms are mainly joint ventures with leading foreign automobile giants like Ford, Toyota, Nissan, etc. They have been using imported manufacturing equipment, as advised by their foreign partners, since their establishment. Given that there seems to be no urge for them to consider import-substitution and that there are risks in changing manufacturing equipment, Taiwanese automobile makers have continued to use a substantial proportion of imported machine tools in their plants.

kets, or on which firms have introduced new products or acquired new technologies. This information is critical in influencing their decision-making regarding business operations and product development. However, to learn from their competitors, knowing what they are making is not sufficient. MT firms are more interested in learning how their competitors make it, i.e. the detailed nature and operation of the new products or technologies developed by their domestic competitors. But such know-how is often treated as a firm's business secrets and would not be circulated freely 'in the air' as suggested in the industrial cluster literature. To acquire this knowledge, firms need to make deliberate efforts. In such a case, Taiwanese MT firms manage to acquire their domestic counterparts' confidential know-how with the help of their suppliers in the production networks.

Suppliers are active facilitators circulating information and know-how among firms in Taiwan's MT cluster. These suppliers provide services for multiple local MT firms and may very well possess specific information or know-how concerning their respective clients. They therefore serve as a great source for firms wishing to dig out their local rivals' unrevealed information. For instance, Taiwanese MT makers sometimes adopt aggressive learning strategies to 'steal' their competitors' know-how. These include private inspections of competitors' products, be they whole machines or the internal components, through the assistance of local suppliers. They would ask suppliers to let them inspect the machine tools that the suppliers just purchased from other domestic MT firms. Sometimes, even without being asked, suppliers actively give their client MT firms the chance to check the components of their competitors' new products. If a supplier, for instance, is subcontracted by one MT firm to manufacture or process a part or a component that he knows might be of great interest to his other client MT firm, he may privately inform the second firm and invite its engineers to come over and take a look, as well as offering complementary technical information, such as technical drawings and know-how related to the manufacture of that product. Through such knowledge sharing (or leaking) mechanisms, even in the absence of direct interaction, technological learning amongst local MT makers may be achieved indirectly.

4.3. Using public research institutes

In the late 1970s, the Taiwanese government sponsored the establishment of the Mechanical Industrial Research Laboratories (MIRL) in its renowned Industrial Technology Research Institute (ITRI) as a vehicle to drive the development of Taiwan's machinery industry in general, and the MT industry in particular, through channeling foreign technology. Nevertheless, in the development process of Taiwan's MT industry, MIRL's role as a technology gatekeeper has not been as successful as was hoped. Local MT firms have seriously criticized not only the technological incompetence of MIRL, but also the so-called leading technologies it owned as having little application or commercialization value. In the eyes of local MT machinists, the products developed by MIRL's young and ill-experienced engineers were often immature and of little value. They were immature in the sense that these MIRL prototype machines might look good in terms of specifications but had low reliability. They were also of little value because of low manufacturability, i.e. the machine designs were either too complicated or required high-grade supplies that could not be sourced locally.

Unlike its poor performance as a gatekeeper, MIRL's role as a technical supporter seems to have been more successful. In 1995, MIRL relocated its MT division from its headquarters in Hsinchu to Taichung, the center of Taiwan's MT cluster, in order to gain proximity to its service target. Since then MIRL has been more integrated in the localized learning networks within Taiwan's MT industry.[4] Today, when local firms have encountered problems in absorbing imported technology and therefore have not been able to adopt and apply it effectively, some of them may consult MIRL for possible solutions or commission it to do related research to solve their problems. Additionally, once they have generated a machine design concept, they can use MIRL as their design house by subcontracting it to produce detailed technical drawings, or even to be in charge of all the machine design activities. While the overall contributions of MIRL to the upgrading of Taiwan's MT industry is still debatable, there appears to be no disagreement among my interviewees that MIRL's provision of complementary R&D services does allow firms to respond more efficiently to the fast-changing technological and competitive environment.

However, in common with subcontracting to local suppliers in the cluster, firms also run the risk of leaking their technological secrets to other local firms through their work with MIRL. Sometimes confidential information shared by MIRL and its private partners is informally released, intentionally or unintentionally, by the former's engineers to their acquaintances in other local firms. Furthermore, some MIRL's engineers are actually moonlighting for local MT makers and might also release technical secrets to their part-time employers.

This section has concentrated on how Taiwanese MT firms exploit the learning channels embedded in their local production and relational networks to enhance their technological capability. Thanks to the institutional environment, the cluster nurtures various informal intra-cluster learning mechanisms, allowing the firms to source extra-firm knowledge locally and to perform indirect interactive learning with one another, contributing to a sustained advance in their technological competence. The next section will investigate how they secure extra-local knowledge, an effort often claimed to be particularly needed by latecomers for their long-term survival and growth.

5. Learning through informal global linkages

There is a consensus that latecomer industrial clusters especially need non-local knowledge to precipitate further upgrading and higher levels of competitiveness (Bell and Albu, 1999; Guerrieri et al., 2001). In the literature, the extra-cluster knowledge channels – usually cited as critical to the success of latecomer industries – are those established by leading foreign firms or buyers. They incorporate latecomer manufacturers into contractual arrangements, such as foreign direct investment, licensing, joint ventures, OEM or ODM, subcontracting, etc. (Gereffi and Korzeniewicz, 1994; Hobday, 1995; Lall, 1996; Ernst, 2002; Schmitz, 2004). In the case of Taiwan's MT industry, however, there are institutional barriers between foreign technology suppliers and local MT firms resulting from (1) the existing and potential competition between both parties in the market, (2) the latter's limited resources to induce the former to initiate knowledge transfer, and (3) the latter's intention of pursuing business autonomy.[5] As a result, the knowledge inflows through formal linkages with foreign technology sources have rarely materialized. Endowed with limited capacity or opportunities to be involved in formal transnational contractual arrangements, Taiwanese MT

[4] See Chapter 5 in Chen (2007) for a detailed discussion of the process about MIRL's integration into Taiwan's MT industry.

[5] To enable transnational production and technological collaborative arrangements, Taiwanese firms are often required by their foreign contractual partners to compromise their manufacturing profit, or to surrender some marketing or product development rights. This is unacceptable to some entrepreneurs from mechanical industries who wish to preserve the autonomy of their businesses.

firms have to tap foreign scientific and technical competences through alternative channels, which are often informal in nature. Three cases demonstrate how they exploit foreign sources of knowledge via various informal external linkages embedded in their global sales networks. The first is through actively attending international trade shows to acquire market and technological know-how. The second is by using their foreign dealers as agents or suppliers of advanced knowledge. In the third case, firms aggressively undertake learning when being invited to join contractual collaborative relationships with foreign firms.

5.1. International trade shows

International trade shows have been identified as an efficient marketing instrument for Taiwanese MT firms (TAMI, 2005). They provide low-cost access to new markets that would otherwise be unapproachable. By attending international trade shows, MT firms can gain access to a large number of current and prospective global customers in a short span of time. Nevertheless, international trade shows serve more than just marketing functions for Taiwanese MT firms. They also provide a platform on which the learning activities of Taiwanese MT firms are practiced and some of their extra-cluster knowledge linkages are built.

During trade shows, MT manufacturers derive ideas for new products and technologies from analyzing their competitors' products, gathering data on specifications, prices, related technological and marketing information, etc. This information is of critical value to them in making future products and marketing plans. Besides gathering publicly available information, Taiwanese MT firms make more aggressive efforts to learn from their technologically advanced competitors. These sorts of learning activities, however, do not actually happen during the exhibition period of an international trade show, but prior to its opening.

When attending an international trade show, experienced engineers from Taiwanese firms arrive at the exhibition location a few days before the event. This is the time when show participants set up their booths and assemble the machines they are going to exhibit. The responsibilities of these engineers are to stop by the booths of their target firms and seek an opportunity to watch the assembly processes of the machines. When a chance arises they start collecting technical details about the machines, ranging from things such as machine structures, to assembly methods, installed parts, and components. Thanks to their accumulated skills and experience in reverse engineering, these Taiwanese engineers extract technical intelligence quite efficiently and later apply it to their own firms' existing or developing products.

International trade shows are also an important venue to which firms come to search for partners around the world that exhibit interesting products and capabilities (Maskell et al., 2006). For Taiwanese MT firms, their collaborative relationships with overseas partners in sales, marketing, production or product development are often established during the shows. In the case of recruiting dealers to help them market their products in distant markets, in addition to posting advertisements at their booths and inviting interested individuals or firms to apply, they actively approach major leading foreign distributors to inquire about the possibility of establishing a partnership. Other forms of international collaborative arrangements, such as OEM/ODM or subcontracting, sometimes also stem from interactions at the trade shows. Foreign MT makers might approach Taiwanese firms to initiate manufacturing partnerships after seeing the latter's products exhibited at the shows.

In sum, the international trade shows serve at least two principal functions for Taiwanese MT firms in terms of knowledge acquisition and learning. First, they provide short-term knowledge sources that allow Taiwanese MT firms to obtain the latest technological information about their competitors, suppliers and customers. At the same time, Taiwanese engineers also use the opportunity to acquire frontier technologies by observing the operations of the products and technologies of leading global firms and exchanging ideas directly with their engineers.[6] Second, international trade shows are also the occasions on which Taiwanese MT firms establish external linkages with foreign technology suppliers, especially MT dealers and subcontracting partners. In next sections, the learning of Taiwanese MT firms from these two knowledge sources will be discussed.

5.2. Foreign dealers

With their limited resources and capacity to build and maintain their own global distribution networks, more than 90 per cent of Taiwanese MT firms have to rely on local dealers (agents or distributors) to sell their products in distant markets (MIRL, 1995, 1999). To reduce the costs of post-sales services requested by their worldwide users, they may also require their foreign dealers to be equipped with a certain level of technical competence to perform on-site technical services on their behalf. By providing not only marketing information, but also product and technological knowledge, these foreign dealers facilitate the technological advance of their MT suppliers in Taiwan.

The opinions of foreign dealers greatly influence the decisions of Taiwanese MT firms regarding the direction of upgrading. Many of these dealers sell not only Taiwan-made machine tools but also a variety of machine tools from makers around the world. Given their knowledge of the technological characteristics and marketability of different machines, they serve as important consultants for Taiwanese MT firms in product improvement and development. In the words of the vice president of one of Taiwan's major CNC lathe manufacturers:

> Our European dealer also sells Japanese products ... He provides us with ideas for new products derived from the latest and most popular Japanese machine tools. For some of his customers, Japanese machine tools are too expensive and complicated. Thanks to his advice and information, we developed a simplified machine tool covering the most commonly-used functions of Japanese machine tools but with much friendlier prices. (Author's interview, 15 July 2005)

Yet knowing what to improve and develop is one thing, but knowing how to achieve it is another. Taiwanese MT manufacturers may often lack sufficient technological capability to accomplish a proposed project. In such a situation, their foreign dealers can be of great help. Some of the overseas sales partners of Taiwanese MT firms, especially those in advanced countries, are run by former machinists, or by people who were actually MT makers before shifting their business focus to sales. They may even still be manufacturing their own machine tools while selling products imported from other MT firms to complement their own range. The skills and knowledge of machinery technology of these dealers may actually be greater than that of their Taiwanese partners, and they are therefore regarded by the latter as valuable technology suppliers. According to the founder of a leading Taiwanese MT firm:

> I do appreciate what our German dealer did for us. This dealer's sales performance actually is the poorest among our foreign

[6] Maskell et al. (2006) even view trade shows as 'temporary clusters', as the knowledge-exchanging mechanism within international trade shows is similar to what happens in permanent clusters.

> dealers. Its owner, however, taught us the most in terms of technological know-how . . .. He restlessly inspected the shortcomings of our machines and offered us possible solutions from modifying machine designs to improving manufacturing processes . . . Because of his help, we are the first Taiwanese MT firm introducing the full-closure sheet-metal concept into machine designs. (Author's interview, 26 August 2005)

At other times when its engineers and local partners could not successfully resolve problems with its machines, this firm also benefited from advice from its other foreign dealers. This founder goes on to describe how,

> We once experienced great difficulty in figuring out what went wrong in our newly developed machine that could not perform according to its designed accuracy. Thanks to a 70-year-old machinist from our Spanish dealer, who inspected the problematic machine and suggested some fabulous ideas for machine design modification, those chronic problems troubling our engineers were solved.

For Taiwanese MT firms, their foreign dealers, especially those in advanced MT-building countries, play a crucial role in their upgrading endeavors. In addition to relying on foreign dealers to penetrate distant markets, Taiwanese MT firms strategically use them as gatekeepers who help them screen available technologies and products as sources of improvement. Moreover, because they are able to source technical know-how and assistance from capable dealers, Taiwanese firms develop greater competence in the course of pursuing technology advance.

5.3. Transnational strategic alliances

The manufacturing advantages in the cluster sometimes offer Taiwanese MT firms opportunities to build cooperative relationships with leading foreign firms that approach them with initiatives for strategic alliances in the form of technological licensing, OEM/ODM, marketing, etc. Regardless of their short-term and unstable nature, the transnational strategic alliances can prove to be effective instruments of technology acquisition for Taiwanese firms, as is illustrated in the following two cases.

5.3.1. Licensing

Negotiating directly with the technology owners to transfer the needed technical know-how through license agreements is one way for latecomers to acquire advanced technology as well as to build up endogenous capabilities in a short period of time. Such strategies have been employed by MT industries in countries like Japan (in its early development), Korea and China, where MT firms used licensing as a key strategy to acquire all the elements of design and production know-how related to their target products or technologies with the support of their parent conglomerates or their governments (Jacobsson, 1986; Lee, 1998; Sung and Carlsson, 2003). In Taiwan's case, however, licensing has rarely been a feasible option for local MT firms in need of advanced technology. In fact, the lack of licensing actually has been studied by some scholars as a distinctive feature in Taiwan's MT industry since its early development (Amsden, 1985; Fransman, 1986). Most Taiwanese MT SMEs do not have sufficient resources to engage in licensing. Due to their smaller production and sales, it is also hard for them to negotiate favorable deals with technology owners.

Nevertheless, some Taiwanese MT firms have been involved in licensing arrangements with foreign firms. But, surprisingly, such investment decisions seem to have come largely involuntarily. The success of Taiwan-made machine tools based on copying products from countries like Germany, Italy, Japan, and the US has threatened the business of some of these advanced MT makers in world markets. To avoid lengthy and costly international lawsuits, foreign firms that have suffered from aggressive imitation may choose a direct approach to Taiwanese MT makers who they believe are the copycats. Such confrontations may end up in strategic alliances between the two rivals through signing formal licensing agreements or becoming production or business partners. A Taiwanese firm specialized in grinding machines, for example, was invited to be the OEM and marketing partner of an Italian MT firm that once faced severe competition from Taiwan-made products which imitated this Italian firm's popular model. When approached by the Italian firm, this Taiwanese grinding machine manufacturer needed only to pay as little as US$ 1 million to get a technical licensing agreement. Based on the agreement, the Taiwanese firm not only could expect additional technical assistance from its Italian counterpart, but also was allowed the full use of the imported technology in its products sold in Asia. At the same time, it also became the Italian firm's OEM partner, supplying it with products for sale in the European market. Under this arrangement, the Taiwanese manufacturer actually benefited the most, according to its general manager, not from the technologies transferred from its Italian partner per se, since it had acquired most of the know-how before their partnership was initiated, but from the establishment of potential learning and marketing channels through the OEM partnership. (Author's interview, 31 May 2005).

5.3.2. OEM/ODM arrangements

To take advantage of the manufacturing strength of Taiwan's MT industry and harness the severe competition with Taiwanese MT makers in the market, some advanced global MT firms have come to Taiwan to seek local OEM/ODM partners. Considering the roughly 20–30 per cent profit margins on their own brand name products sold on the market, OEM/ODM orders, however, are not particularly appealing to many Taiwanese MT makers in terms of revenue. Rather than seeing them as imperative for survival as most firms do in Taiwan's other export-oriented industries, my informants in MT firms explicitly stressed that they consider OEM/ODM arrangements merely as a strategy to learn from technologically advanced foreign firms, since through such involvement they might expect to receive advanced technological, as well as managerial, know-how inflows.

To Taiwanese MT firms, however, the learning activities in the OEM/ODM arrangements are often limited to the acquisition of know-how in manufacturing. To advance their indigenous technological capabilities, Taiwanese MT makers are more eager to learn the 'know-why', i.e. the related design principles of higher quality machine tools, which their OEM/ODM partners often decide not to divulge and are thus hard to acquire simply through following the latter's instructions in the manufacturing processes. Unless it is addressed in their cooperation agreements, such important design information is often kept confidential and would not be released to Taiwanese OEM/ODM manufacturers. Even in a situation like this, some keen Taiwanese learners still have found ways to get what they want by accessing the fellow engineers at their client firms. In the experience of one Taiwanese firm:

> There was an engineer, aged between 50 and 60 in [a US MT firm], who helped check our design drawings, and did critical modifications, and most importantly, taught us everything we should or wanted to know in the design and manufacturing of the machines. (Author's interview, 14 December 2005)

Even in some cases in which their OEM/ODM clients had taken certain precautions against releasing technological information, the Taiwanese engineers did not give up. The vice president of

another leading MT manufacturer points out:

> Our Japanese client would only show us the blueprints and ask us to manufacture accordingly. Its managers were so cautious about not revealing irrelevant technological know-how to us during the cooperation. However, we would look for an opportunity to approach its engineers at the plant. They would answer all my questions upon learning we were their manufacturing partners. Such a strategy was also applied to our German client. (Author's interview, 19 October 2005)

By being involved in OEM/ODM arrangements with leading foreign firms, Taiwanese MT firms are able to secure required technologies and to bridge the gap between themselves and the frontier. However, their aggressive learning strategies have raised their foreign partners' concern about nurturing new competitors, resulting in a scarcity of transnational contractual collaborative initiatives in Taiwan's MT industry. Moreover, given that foreign firms often try to preserve their economic as well as technological dominance and therefore refuse to adjust the arrangements according to the requests of their Taiwanese partners, even when such contractual arrangements materialize, the marginal gains in terms of the finance or technology that Taiwanese MT firms obtain from their foreign partners have been decreasing. Therefore, such trans-national contractual cooperation between MT firms is often easily terminated as intra- or extra-firm technological and market conditions change.

6. Conclusion

Central to the industrial upgrading and catching-up of Taiwan and other East Asian latecomers during the postwar period have been the learning, acquisition, adoption, application, and re-innovation of technologies first developed in economically advanced countries (Amsden, 1989; Mowery and Oxley, 1995; Poon et al., 2006). As opposed to the popular view that the industrial upgrading of latecomers was fostered through formal learning channels such as MNC-led or state-led mechanisms, in the case of Taiwan's MT industry the evidence suggests that it is the proliferation of informal learning mechanisms established and exploited by local firms that mainly precipitates the learning dynamics in the industry.

Just as technological capacity building in machine tools is in general characterized by incremental learning on the shop-floor, in Taiwan local MT firms gradually accumulated their technological competence through constant learning by manufacturing and imitation, both of which have been facilitated by industrial clustering. The production advantages in the cluster enable Taiwanese MT makers to ramp up sales quickly in the world market, which brings them abundant opportunities to practice learning by manufacturing. The institutional environment of the cluster also nurtures various intra-cluster informal learning mechanisms, allowing the firms to source extra-firm knowledge locally. In the vertical dimension, MT firms are able to benefit from knowledge inputs and feedback from their local production and relational partners. In the horizontal dimension, thanks also to their local production partners who provide them with secret channels to access their rivals' products and technologies, Taiwanese MT firms are able to perform indirect interactive learning with one another. And because of the existence of such local knowledge sharing mechanisms, one firm's improved competence is diffused to and learned by others, leading to a synchronized improvement of all clustered firms.

Nevertheless, the most important pieces of knowledge needed by Taiwanese latecomer firms for technological upgrading are rarely generated locally, but instead imported from abroad. In the case of Taiwan's MT industry, creating formal channels for technology inflows has always been difficult, due to either the limited capacity of local MT SMEs to initiate technological transfer from foreign knowledge suppliers, or the difficulties both parties face in negotiating acceptable collaborative arrangements because of their existing or potential economic and technological conflicts in the market. To overcome such hurdles, Taiwanese firms have had to make deliberate and active efforts to acquire foreign advanced technology through alternative channels, which are often informal in nature. As demonstrated in this article, they sought to secure extra-local knowledge by accessing machines and engineers and technicians of their technologically advanced foreign counterparts, in which much of MT know-how and know-why is embodied. By utilizing various extra-cluster informal learning mechanisms, such as learning at international trade shows, from foreign dealers as well as from foreign contractual partners, the smaller Taiwanese MT manufacturers have managed to catch up steadily with the frontier.

The example of technology acquisition of Taiwan's MT industry demonstrates not only the significance of informal learning in LMT industries, but also the possibility for a latecomer cluster to climb the technology ladder through exploiting various informal learning mechanisms. Even so, I do not suggest that such informal learning by itself is sufficient to support the sustained development of firms in this industry. Nor do I downplay the importance of formal learning channels, such as R&D. On the contrary, I argue that, to keep stimulating further technological advance, Taiwanese MT firms should recognize that informal learning cannot be a full substitute for formal learning. Instead, the two are complementary. More specifically, to continue to exploit foreign sources of knowledge through informal channels, Taiwanese MT firms especially need to enhance their absorptive capacity by increasing R&D investments (Cohen and Levinthal, 1990), given the fact that MT technology is beginning to incorporate more and more codified and science-based knowledge in such fields as electronics, information and communications technology, software, and materials science.

To improve its R&D capabilities, the Taiwanese MT industry not only needs the efforts of local firms. The state can also play a crucial role. While providing local SMEs with R&D resources would be useful, the state should also take into account the existence of informal learning mechanisms utilized by local firms when designing policy measures to promote their technological progress. As the localized learning mechanisms in the cluster seem able to take care of themselves, the state could focus on facilitating the establishment of global knowledge channels by MT firms. Acknowledging that the formation of transnational formal learning linkages is often subject to control by foreign technology suppliers (Humphrey and Schmitz, 2002), in order to break the technological ceiling established by the forerunners, it is particularly crucial for latecomer Taiwanese MT firms to build and explore alternative foreign informal learning channels. For the state, one way of achieving this goal would be to assist local manufacturers to broaden their access to various sources of extra-local advanced knowledge. In addition to providing market and technological information, promoting collective marketing efforts by local firms in foreign markets – for example, by establishing joint marketing institutions – could help Taiwanese firms to gain direct access to sophisticated foreign MT users from whom they can secure crucial knowledge. Improving the global exposure of the international trade shows that Taiwan hosts, and supporting the attendance of local firms at similar venues held elsewhere, would also enable Taiwanese firms to build better connections with technologically sophisticated foreign MT firms, suppliers, users, etc. Furthermore, the state can create programs to improve the foreign language and managerial skills of local MT manufacturers for effective exploration and governance of global knowledge resources. In fostering further upgrading of Taiwan's MT industry, all of these pol-

icy suggestions are just as important as the traditional R&D subsidy programs.

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