Entrepreneurship, technological changes, and the formation of a subcontracting production system: the case of Taiwan's machine tool industry

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Abstract: The advantages of subcontracting production nurtured by industrial clustering have been broadly documented. Using Taiwan's machine tool industry as the study case, this paper contributes to this realm of literature through examining factors influencing and the process underlying the formation of subcontracting production systems in late-industrialising contexts. By combining perspectives on entrepreneurship and technological regime, this paper considers the formation of subcontracting networks to be the outcomes of entrepreneurs' optimising decisions and behaviours. It also explores how the entrepreneurial activities involved in building such networks are influenced by the socio-institutional, and more importantly, the technological environments within which the entrepreneurs are embedded.

Keywords: technological regimes; machine tool industry; subcontracting; production systems; industrial clusters; entrepreneurship; Taiwan.

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1 Introduction

The advantages of industrial clustering have been broadly documented (e.g., Marshall, 1920; Krugman, 1991; Porter, 2000), with studies noting that the most prominent inter-organisational feature of industrial clusters is the prevalence of networked production, i.e., subcontracting arrangements, stemming from manufacturers' dependence on other local firms for the production of components and semi-finished goods (Markusen, 1996; Guerrieri et al., 2001). In examining the economic progress of late-industrialising countries, industrial clusters particularly have been chosen by many

scholars as a point of inquiry because the subcontract-based production systems nurtured by clustering could be effective instruments to help these countries characterised by the dominance of small-scale industries to gain collective efficiency in production and learning, and overcome growth constraints (Schmitz, 1995; Schmitz and Nadvi, 1999; Chen, 2009). However, issues concerning how such spatialised subcontracting networks emerged in these latecomers have rarely been addressed. This paper aims to fill this gap. More specifically, by using Taiwan's machine tool (MT) industry as the empirical case, this paper will study the factors influencing and the processes underlying the formation of subcontracting production systems in late-industrialising contexts.[1]

As the world's 4th largest MT exporter and 6th largest MT producer in 2011 (Gardner Publications, 2012), Taiwan has attracted scholars to study how this latecomer in the global MT industry has successfully advanced to its current competitive position. The literature emphasises that the main element behind the growth of Taiwan's MT industry has been the existence of a well-articulated subcontracting production system composed of numerous small and medium-sized MT manufacturers and suppliers agglomerated in the central Taiwan region, including Taichung, Nantou and Changhwa (Liu, 1999; Brookfield, 2008).[2] In this region, MT makers can literally outsource each step of the production process to capable local subcontractors, allowing these firms to maintain low overheads while achieving high flexibility in both internal and external operations. At the same time, they are able to take advantage of their suppliers' respective specialisations to improve manufacturing quality and efficiency (Chen, 2009, 2011). Furthermore, industrial clustering has also enabled these manufacturers to respond to changing competitive conditions by experimenting with numerous forms of production organisation (Liu and Brookfield, 2000; Chen, 2011). Recognising the significance of spatialised subcontracting production systems raises the question how such systems emerged in Taiwan's MT industry in the first place.

The literature on technological regime (Dosi, 1982; Nelson and Winter, 1982; Pavitt, 1984) suggests that, given the nature of MT production, adopting subcontracting practices seems to be imperative for MT makers (Pack, 1981; Chudnovsky et al., 1983; Fransman, 1986b). The MT production process is characterised by the sequential organisation of discrete manufacturing operations, from the manufacture of individual parts and components to their final assembly into machinery. Because the minimum optimal scale of production varies for the different processes involved, it is difficult for vertically integrated firms to maintain an adequate rate of capacity utilisation at all stages. MT industry operations have therefore given rise to an extensive division of labour between numerous small- and medium-scale 'job shops' specialising in the manufacture of parts and components or in particular processes (e.g., casting, forging, heat and surface treatment, testing facilities, specialised machining facilities and larger-scale final machinery assemblers) [Chudnovsky et al. (1983), p.14].

Yet, the development of subcontracting networks in the MT industry is not a natural process. Studies carried out in the 1970s and 1980s particularly pointed out that subcontracting in the production of capital goods, including machine tools, in late-industrialising countries was particularly weak (Watanabe, 1983; James, 1991). With a low degree of specialisation and a high degree of vertical integration, MT firms in developing countries, small or large, kept nearly all production activity internally. In addition to the influence of the market (Amsden, 1977), it is contended that this shortcoming was a result of the inability of actors in these latecomers' capital goods industries to fulfil two principal requisites to benefit from subcontracting. First, the parent

firms needed to be able to coordinate multiple sources of supplies. Second, the subcontractors had to be efficient and reliable [Pack, (1981), p.232]. However, if this is the case, one might wonder how Taiwan's MT industry managed to escape the traps encountered by its other late-industrialising counterparts to develop its currently renowned localised subcontracting networks.

While technological determinism seems unable to provide satisfactory explanations, this paper adopts the perspective of entrepreneurship to understand the development of subcontracting networks in Taiwan's MT industry. As Carton et al. (1998, p.1) explained, "entrepreneurship is the pursuit of a discontinuous opportunity involving the creation of an organisation (or sub-organisation) with the expectation of value creation to the participants". In studying the evolutionary processes of industrial clusters, Feldman and Francis (2006) further emphasise the special role played by entrepreneurs. According to them, cluster formation could be realised as "a process predicated on the actions of entrepreneurs and their symbiotic relationships with their local environments" (p.115). Following this vein of thought, this paper considers the formation of subcontracting networks to be the outcomes of entrepreneurs' optimising decisions and behaviours. Nevertheless, noting that such entrepreneur-centred studies are often criticised for ignoring analysis of the technological environment that might affect the entrepreneurial activities of specific industries (Baark, 1994; Kenney and von Burg, 1999; Marsili, 2002), this paper attempts to combine the perspectives of entrepreneurship and technological regime to account for the formation of the subcontracting networks in Taiwan's MT industry. In addition to investigating various entry modes of MT entrepreneurs in nurturing the subcontracting arrangements, this paper also discusses how the potential for entrepreneurial ventures is influenced by Taiwan's socio-institutional environment and, more importantly, by the changing technological conditions in the global MT industry.

To illustrate the above-mentioned viewpoints and findings, the rest of the paper is organised as follows: Section 2 reviews literature that discusses the influence of technological change on entrepreneurial opportunities and behaviours, along with studies on Taiwan's entrepreneurial environment. Section 3 investigates how the development of computer numerically controlled (CNC) technology, one of the major innovations in the history of the MT industry, in the 1970s affected the evolution of the world's MT industry and, in particular, the upgrading of MT makers in late-industrialising countries. Section 4 introduces the development of Taiwan's MT industry, addressing the emergence process of local MT subcontracting arrangements and its relation to CNC technology. Section 5 then explores the sources of entrepreneurial entry and the entrepreneurial activities involved in the formation of Taiwan's MT subcontracting production systems. The final section concludes.

2 Technological changes and entrepreneurship

This section discusses two sets of relevant literature. First, I review literature that studies the relationship between technological changes and entrepreneurship. As Taiwan is widely considered an entrepreneurial island that nurtures many entrepreneurs venturing into new businesses or organisations, in the second part of this section, I examine literature that studies the institutional and structural environments underlying Taiwan's strong entrepreneurship.

2.1 Technological changes and opportunities for entrepreneurship

Innovations and technological change have been posited as the critical drivers of economic development (Schumpeter, 1934; Nelson and Winter, 1982; Rosenberg, 1982), with entrepreneurs acting as agents possessing unusual ability to perceive and exploit business opportunities created from these innovations and changes (Olsson and Frey, 2002; Eckhardt and Shane, 2003; Feldman and Francis, 2006). Nevertheless, scholars also suggest that, because the opportunities and trajectories of innovation and technological change differ among various industrial sectors, entrepreneurial opportunities and activities are conditioned by the technological regimes of industries within which the entrepreneurs are embedded (Winter, 1984; Malerba and Orsenigo, 1997; Kenney and von Burg, 1999). In the words of Marsili (2002, p.217),

> "[T]echnology is important in constraining the nature of market competition. Innovation allows new firms to enter the market and compete with varying degrees of success with established firms, but these opportunities for entrepreneurship and growth are structured by the nature of the technology that prevails in different sets of industrial activities."

The literature on technological regime (Dosi, 1982; Nelson and Winter, 1982; Pavitt, 1984; Winter, 1984) further indicates that a firm's rate of innovation is influenced by the technological (and industrial) environment, including the opportunity conditions, appropriability conditions, degree of cumulativeness and knowledge base, facing the firm, resulting in two patterns of entrepreneurial activity [Guerrieri and Pietrobelli, (2006), p.16]. For instance, in conditions characterised by medium-low opportunity, low appropriability and low cumulativeness, the entry of new firms is easier, and these new firms play a major role in injecting their respective industries with innovative ideas, such as new methods of organisation, production or distribution. On the other hand, in conditions characterised by high opportunity, appropriability and cumulativeness, higher entry barriers for entrepreneurs and small firms may exist because incumbent firms have accumulated a relatively larger stock of knowledge [Guerrieri and Pietrobelli, (2006), p.17].

However, such patterns of entrepreneurial opportunities and activities might change as the technological regimes of various industrial sectors constantly evolve (Nelson and Winter, 1982; Malerba and Orsenigo, 1997). Moreover, sometimes the development of certain technologies, either within or outside the industry, would exert pervasive effects throughout the economy, bringing new possibilities for entrepreneurial activities. A good example is the advances in information technology (IT) that have had a profound influence on changes to the technological paradigm of many industrial sectors since the 1970s. Thanks to the introduction of IT, many manufacturing industries that had been largely technologically stagnant throughout the world were reinvigorated (Freeman and Perez, 1988; Malerba and Orsenigo, 1997). The application of IT allowed entrepreneurs to introduce new products, production methods and organisations in various industries. In the meantime, many new small firms were also given the chance to break through entry barriers established by larger incumbents, because the new technological paradigm based on IT has made possible large reductions in economies of scale and has given an advantage to smaller firms (Nelson and Winter, 1982; Dosi et al., 1988; Varaldo and Ferrucci, 1996).

Although the nature of technological regimes and the changes which occur within them are crucial factors that contribute to or constraint the creation of opportunities for entrepreneurs to innovatively enter into an industry, one should note that the effective exploration and exploitation of technological opportunities is also determined by how these opportunities interact with the institutional environments in which the entrepreneurial activities take place (Kenney and von Burg, 1999; Marsili, 2002; Shane and Venkataraman, 2003; Holmen et al., 2007). More specifically, it is also essential to learn why some places nurture greater entrepreneurship that not only stimulates but also supports entrepreneurial activities in response to the opportunities brought by technological changes. As entrepreneurship is an inherently local phenomenon (Feldman and Francis, 2006), in the next part I turn to literature explaining the characteristics of and the social, institutional and spatial factors that foster the entrepreneurship in the particular case of Taiwan.

2.2 Social, institutional and spatial factors underlying Taiwanese entrepreneurship

Taiwan's economic development is considered to be entrepreneur-driven (Shieh, 1992; Hayashida, 1994; Hamilton, 1997; Ding and Abetti, 2003; Wu and Huang, 2003), and a number of studies have explored the sources of entrepreneurship in this island. While Confucianism has already been identified as having a general and primary influence on the entrepreneurial culture of Chinese society (Redding, 1990; Orru et al., 1997), here I focus on literature that discusses the social, institutional and spatial factors determining the Taiwan-style entrepreneurship.

2.2.1 Taiwan's networked society

In studying Taiwanese entrepreneurship, some scholars point out that Taiwan's society, as a complex network of social relationships, has provided a fertile ground for new start-ups and small- and medium-sized enterprises (SMEs) (Shieh, 1992; Hayashida, 1994; Hamilton, 1997; Luo, 1997; Numazaki, 1997). It is argued that these dense local human relationships creates extensive networks which allow Taiwanese entrepreneurs to obtain the critical resources, such as capital, information, complementary supplies and services, and labour required to initiate and succeed in their businesses. In addition, within such an environment, Taiwanese entrepreneurs have been found to develop several characteristics:

1 independence, making them conducive to frequent 'spin-offs,' which break up old combinations of factors of production and create new ones

2 risk taking and money making, enabling them to open up new markets in both developing and developed world

3 partnership, enabling them to combine different types of capital and managerial resources through the flexible utilisation of Guanxi, i.e., the social networks, and create partnerships in their ventures.

Moreover, as a result of their entrepreneurial activities, these Taiwanese entrepreneurs have helped reallocate resources from dying industries to burgeoning ones, open up new markets and secure new resource suppliers, and format localised complex subcontracting networks [Numazaki, (1997), pp.443–455].

2.2.2 The Taiwanese state

The state has played a well-recognised role in fostering entrepreneurship in Taiwan (Wade, 1990; Orru et al., 1997; Wu and Huang, 2003; Yan et al., 2011). In addition to maintaining a stable macro-economy and implementing market-friendly policies, the Taiwanese state has devised specific policies to channel resources, in terms of capital and technology, into Taiwanese entrepreneurs' ventures. For example, as early as in 1974, the Taiwanese Government established the SME Credit Guarantee Fund to guarantee loans for entrepreneurs' SMEs. In 1991, the state further set up a Small and Medium Business Development Fund of approximately NT$12 billion (US$ 358.6 million) accessible to local entrepreneurs. By 1998, more than 100 thousand Taiwanese SMEs had received loans through such funds, and the amount guaranteed was about NT$ 1,885.8 billion (US$ 58.9 billion) (Wu and Huang, 2003).

Aside from providing financing, the Taiwanese Government helped build institutions to improve the upgrading of SMEs' technological capabilities. As start-ups are constrained by the complexity of the knowledge base required to develop and commercialise new or improved products and production processes (Marsili, 2002), the Taiwanese Government used public research institutes (PRIs), such as the renowned Industrial Technology Research Institute (ITRI), as major vehicles to channel necessary technologies into local SMEs and other entrepreneurial activities (Hong, 2003). In the processes, these PRIs obtained advanced technologies, either through their own R&D or through public-private research consortia, and then diffused these technologies to the private sector. As a result, Taiwanese SMEs, often characterised by limited indigenous technological and R&D capacity, were empowered to expand their entrepreneurial ventures into those market segments with higher profits and more complex technology (Amsden and Chu, 2003; Hsu et al., 2003).

2.2.3 Industrial clustering

The existence of a positive correlation between entrepreneurship and industrial clustering has become a common wisdom (Porter, 2000; Johannisson et al., 2002; Lechner and Dowling, 2003; Asheim et al., 2006). Owing to the presence of agglomeration economies, industrial clustering not only breeds greater entrepreneurship but also contributes to a higher start-up survival rate (Delgado et al., 2010; Spencer et al., 2010). Clustered industries are also found to demonstrate high levels of specialisation and decentralisation, giving small firms flexibility while allowing them to benefit from external economies of scale and scope (Schmitz, 1995; Scott, 2002; Brookfield, 2008). In Taiwan's case, many successful industries, such as IT (Kuo and Wang, 2001), footwear (Hsing, 1999), bicycles (Chen, 2002), saxophones (Yan et al., 2011) and MTs (Liu, 1999; Brookfield, 2008; Chen, 2009) are all characterised by spatial clustering in which the entrepreneurial SMEs engage aggressively in subcontracting for production, contributing to the sustained vitality of these industries.

While the majority of the existing literature focuses on the influence of clusters on entrepreneurship, studies on how entrepreneurs stimulate the development of a cluster and its distinct subcontracting-based production organisations are largely absent (Feldman and Francis, 2006). Some scholars have therefore attempted to bring entrepreneurship back into the analyses of cluster formation (Boschma and Lambooy, 1999). Varaldo and Ferrucci (1996), for instance, argue that cluster firms are based on an organisational model centred on entrepreneurship. In a more comprehensive account, Feldman and Francis (2006) suggest that it is the entrepreneurs who "spark cluster formation" (p.116). On the one hand, entrepreneurs "may act collectively to shape their local environments by building institutions that further the interests of their emerging industry and, in this way, form innovative industrial clusters" (p.116). On the other hand, "the cluster and its characteristics emerge over time from the individual activities of various entrepreneurs and the organisations and institutions that evolve to support them" (p.115).

After reviewing literature that informs the theoretical and empirical contexts in which this study is situated, the following sections use Taiwan's MT industry as a case for discussing the environments and entrepreneurial activities influencing the formation processes of subcontracting production networks.

3 The emergence of CNC technology and its influences on the evolution of the world's MT industry

The origins of the MT industry can be traced back to the late 18th century, when British developed a new boring machine to create a cylinder of sufficient roundness for use in Watt's steam engine (Row, 1916). Since then, many types of MTs, including lathes, gear-cutting machines, planers and shapers, have been developed. Starting from the 1840s, American machine builders took the lead in innovation, introducing MTs capable of mass-producing supplies for the manufacture of firearms, sewing machines, bicycles, etc. From the beginning of the 20th century, the automobile industry supplanted the bicycle industry as the key driver of MT development. The introduction of Ford's moving assembly line in 1913 further stimulated the demand for special-purpose and high-precision MTs. During the Second World War, the aircraft industry exerted a dominating influence on innovation in the MT industry, leading to the emergence of numerical control (NC) MTs in the US in 1948 (Rosenberg, 1963; Carlsson, 1984; Kumar, 2003).

3.1 Japan's advancement in CNC MTs

Although the introduction of NC MTs by the US represented the most radical innovation in the history of the MT industry, the high cost, complexity and unreliability of NC controllers significantly restricted their broad diffusion (Carlsson, 1984). Given ample funding from the US Department of Defense, American NC manufacturers were not motivated to commercialise the technology (Arnold, 2001). However, Japan's MT makers spotted the market opportunity presented by NC MTs, actively licensing the technology from the USA (Fransman, 1986a). Fanuc, a subsidiary of GE in the USA, and Fujitsu in Japan, collaborated with Makino, a Japanese MT manufacturer, to develop an NC milling machine in 1958, three years after the first commercial NC MT was introduced in the USA (Tsuji, 2003). In 1975, Fanuc took advantage of advances in

micro-computer technology to develop the world's first CNC controllers, significantly improving NC MT reliability, while significantly reducing programming complexity and prices, and initiating the automation of a range of functions, from tool changing and diagnostics to material handling. All of these changes increased the potential for the commercialisation of this technology (Jacobsson, 1985).

With the support of the Japanese Government as well as cooperation between Japanese MT builders and CNC controller suppliers, Japan's MT industry soon succeeded in mass-producing a series of standardised and lower-cost CNC MTs, targeting initially domestic, and then the USA, small job shops that needed inexpensive, simple and flexible MTs with short lead times (Wieandt, 1994). From the second half of the 1970s, CNC MTs, particularly CNC lathes, experienced a growth phase and began to be produced in hitherto unheard-of volumes (Jacobsson, 1985).[3] Furthermore, this phenomenal growth in worldwide demand for CNC MTs allowed the Japanese MT industry to not only achieve economies of scale in production but also improve its technological capabilities through specialisation, reinforcing its global competitiveness. By 1982, for the first time Japan surpassed the USA to become the largest MT producer in the world (Fransman, 1986a).

3.2 The rise of the rest in the world's MT industry

Along with the growing popularity of CNC MTs, other latecomers in the MT industry in some Asian newly industrialising countries (NICs), such as Korea and Taiwan, gained momentum by seizing the global market for conventional MT, exploiting a vacuum left by the shift of Japanese and European manufacturers from the production of conventional MTs to NC machines (Sonobe et al., 2003). Moreover, with their continuing development, MT builders in Korea and Taiwan gradually accumulated technological competence and joined the production of CNC MTs, spurring another wave of rapid growth in their MT industries (Jacobsson, 1985; Fransman, 1986a; Sung and Carlsson, 2003).

For the latecomers in the world's MT industry, the emergence of CNC MTs not only brought market opportunities in conventional MTs, it more importantly provided them with a shortcut for product upgrading. It is commonly recognised that NIC makers of conventional MTs could not achieve machine accuracy comparable to that of similar products from the leading manufacturers. While the technological gap in terms of machine design might have been the fundamental reason, the existence of such quality differences also had a lot to do with the weaker in-house manufacturing capabilities of these latecomer MT firms, resulting from the lack of sophisticated equipment or skilled labour, as well as the inferior capacity of their local suppliers. However, the probing system capacity and adaptive behaviour embodied in CNC MTs provided NIC MT builders with the means to alleviate these problems. For example, the inaccuracy of machine performance caused by the poorer quality of installed parts or inadequate design and assembly methods could be rectified through adjusting the CNC controller's compensating parameters (Arnold, 2001). In this regard, for NIC MT manufacturers, the chronic mechanical problems in their MT production were therefore partially resolved through short-term electronic means brought by the CNC technology.

The development of modularisation of MTs offered another upgrading advantage to NIC MT firms. To achieve mass production, the Japanese MT industry also innovated the modularisation of CNC MT design that led to the emergence of a number of specialised

MT component suppliers, especially in Japan and Germany (Alexander, 1990). Because these modular components are the key to determining the end-performance of CNC MTs, latecomer MT firms were able to improve their own product quality by upgrading some critical components in their machines. In the case of Taiwan's MT industry, for instance, in its early development of CNC MTs, the value-adding and quality improvements of CNC products were mostly achieved through the use of imported components, especially CNC control units, rather than through the advancement of indigenous technological capabilities (TAMI, 2005).

To expand their markets, the module suppliers actively diffused the CNC technology to latecomers and assisted them in building competence in producing CNC MTs (Fransman, 1986a; Sung and Carlsson, 2003). Along with the maturation of CNC technology in the late 1980s, manufacturing of CNC MTs was no longer limited to a handful of dominant players in the industrialised countries, with Taiwan, Korea and some other NICs overcoming the barriers to enter the market for such advanced machines. Starting with the production of simple CNC MTs, these newcomers gradually penetrated into the market for mid–range MTs predominated by Japanese and European MT builders (Tsai, 1992; Sung and Carlsson, 2003; TAMI, 2005).

4 The development of Taiwan's MT industry

Whereas other leading MT manufacturing countries such as Japan, Germany, the USA and Italy each have more than a hundred years of history in machinery building, Taiwan's MT industry did not begin until the late 1940s when Taiwan was still an agricultural-based society with weak industrial capacity. In this section I will review the development history of Taiwan's MT industry. In addition to the evolution of this industry, the emergence process of local subcontracting arrangements and its relation to the CNC technology will be addressed.

4.1 The late 1940s–1960s: infancy

The development of Taiwan's MT industry started in the 1940s when Taiwanese mechanics, who had learned their machining skills from working in sugar mills, military plants, or local machinery firms during the Japanese colonial period, established their own metalworking shops to capitalise on the emerging domestic demand from civilian industries, such as the woodworking, textile and agriculture industries, after the Japanese retreated (TAMI, 2005). While their business activities mainly involved the provision of repairing services, spare parts or small and simple machines to domestic industries, a handful of local mechanics also started producing MTs. Among these ventures, most notable was the founding of the Yang Iron Works by a former mechanic of a sugar mill, Ru-Ming Yang, in Taichung in 1943. By providing repair services for broken machinery, Yang accumulated knowledge and experience related to the repair and manufacture of machinery and expanded his business to include MT production in the 1960s, making Yang Iron not only the seedbed for domestic MT machinists, but also a prominent pioneer of Taiwan's MT manufacturing (TAMI, 2005). In the 1950s and 1960s, increasing domestic demand, along with new international demand due to the Vietnam War, induced a group of mechanical entrepreneurs to join in the manufacture of MTs. Many of Taiwan's current major MT firms, including Far East (1949), Victor (1954),

Yeong Chin (1954) and Dah Lih (1960), for example, all originated from metalworking shops and began MT production during this period.

4.2 The 1970s: fast, export-driven growth

The strong demand for MTs from Southeast Asian markets in the late 1960s and 1970s continued to attract mechanical entrepreneurs to MT making (Sonobe et al., 2003). Although the production of conventional MTs still accounted for the majority of activities in Taiwan's MT industry, some local firms leveraged their accumulated skills and financial capacity to begin to develop more technologically advanced MTs, namely NC MTs. In the instance of Yang Iron, by copying a Japanese-made NC lathe, this firm introduced Taiwan's first NC lathe in 1974. Other firms, such as Dah Hsin and Tatung, also developed NC products through technology transfer from their Japanese partners. Since then, these firms started producing small batches of NC MTs for domestic and international markets (TAMI, 2005).

4.3 The 1980s: progression toward CNC and the emergence of subcontracting networks

As European and Japanese MT makers shifted their focus towards the CNC MTs in the late 1970s, Taiwanese MT firms acquired greater business opportunities in the conventional MT market, inducing more local mechanical entrepreneurs to transition into MT making (Sonobe et al., 2003). At a time when the production of MTs in Taiwan was predominately integrated, the new entrants sought to adopt subcontracting practices through the supplier networks nurtured by Taiwan's sewing machine industry which, beginning in the 1960s, had helped cultivate a number of domestic metalworking shops in central Taiwan that were capable of taking subcontracting orders for machine parts manufacturing or processing from other machinery-related industries, including the MT industry. In this context, for MT entrepreneurs who did not intend to or could not afford to invest all manufacturing equipment in the plants as their predecessors, subcontracting became a feasible and economical option.

Another crucial factor influencing the emergence of a subcontracting production system in Taiwan's MT industry was the development of CNC technology. With technical assistance from Japanese CNC controller suppliers, some Taiwanese MT firms started introducing commercialised CNC MTs to the market (Fransman, 1986a; Tsai, 1992). The successful production and sales of these higher value-added products allowed local leading MT firms like Victor and Yeong Chin to reach annual sales of over NT$ 1 billion (US$ 30 million) by the second half of the 1980s.[4] In the meantime, the benefits from developing CNC MTs spread beyond the leading integrated MT firms. Thanks to the introduction of CNC technology, it became possible to subcontract higher-end MT manufacturing without necessarily compromising the quality of final products.[5] As a result, local MT builders who relied on subcontracting were able to market CNC MTs of comparable quality to those of the leading firms.

The phenomenal success of Leadwell (2001) serves as the best example. By fully employing subcontracting in the production of standardised CNC MTs, Leadwell, a small start-up with a capital of NT$ 8 million (US$ 0.22 million) in 1980, devised a mass production system for standardised NC machines, especially machining centres. By aggressively using specialised subcontractors for most of its manufacturing activities

Leadwell itself focus on designing, assembly and marketing. Coupled with world's sharp-rising demands for machining centres, Leadwell's ingenuity paid off with huge business success. In less than ten years, it outpaced the then domestic leaders to become Taiwan's largest MT firm with a turnover of NT$ 2 billion (US$ 76 million) in 1989 (Leadwell, 2001). Later, not only were the smaller-sized Taiwanese MT builders mushroomed in Leadwell's wake, but existing integrated firms were also inspired to adopt subcontracting arrangements for greater production flexibility. The quest for CNC MTs resulted in a remarkable increase in the production value of Taiwan's MTs, amounting to NT$ 26.1 billion (US$ 1.04 billion) in 1992 (MIRL, 1999).

4.4 The 1990s: the development of indigenous supplying capacity

Despite the continued success of Taiwan-made CNC MTs in the world market, local profits were limited by firms' heavy reliance on imported bought-in components, such as CNC controllers, ballscrews, etc., especially from Japan. Taiwan's MT industry set out to address this issue by fostering indigenous manufacturing capacity for secured and lower-cost supplies of critical components. Supported by the government's 'Development of Critical Components and Products Act' in 1992 which aimed to promote the domestic production of imported critical components, Taiwan's MT industry started to actively develop critical components for MTs.

With the close cooperation between domestic manufacturers and the PRIs, especially ITRI's Mechanical Industrial Research Laboratory (MIRL), the endeavour of Taiwan's MT industry yielded fruitful outcomes. Not only were some Taiwanese MT firms able to improve their internal technological capabilities for producing these critical components, but specialised critical component suppliers also began to appear in local production systems (Chen, 2012). While some higher-end components, such as CNC controllers, servo motors and bearings still had to be imported from overseas, Taiwanese MT firms and their suppliers successfully nurtured indigenous competency in the production of other components for CNC MTs, including spindles, rotary tables and automatic tool changing (ATC) systems. Being able to source these components locally rather than from distant foreign suppliers greatly improved the production efficiency of Taiwanese MT makers.

4.5 Beyond 2000: Sustained stable growth and upgrading

Starting as a latecomer in the MT industry, Taiwan has evolved to become one of the world's major MT producers and exporters. By 2011, Taiwan accounted for about 9% of the global MT trade (Gardner Publications, 2012). In addition, the successful worldwide sales of Taiwan's MT industry have been accompanied by gradual technological upgrading, with CNC MTs now comprising more than 60% of total production, as opposed to only 4% in 1981 (MOEA, 2011).

Currently, Taiwan's MT industry competes with MT builders in both industrialised and industrialising countries. In low-end MTs, Taiwanese MT firms have maintained their competitive advantage against rivals from other NICs, such as Korea and China, through offering higher quality products and faster delivery at competitive prices. Meanwhile, they have upgraded their capacity to compete with European, American, Japanese and Korean MT firms in the middle- and higher-end MT market. At this level, Taiwan-made MTs might not be able to compete on specifications or quality, but are

promoted by a higher price/performance ratio than that of similar products from global leaders. In the global market, for instance, Taiwanese MT makers claim that their products are capable of delivering 70–80% of the performance of comparable Japan-made products at a price discount of 30% or more.[6]

5 Entrepreneurship in the formation of Taiwan's MT production networks

The previous sections discusses how the emergence of CNC technology provided opportunities for Taiwan's MT industry to penetrate into the higher-valued market of CNC MTs and, more importantly, to engage in subcontracting arrangements. However, the significant role played by entrepreneurs in making such a decentralised production system possible should not be neglected (Feldman and Francis, 2006). In this regard, this section examines the involvement of key entrepreneurs in Taiwan's MT industry, including:

1 MT firms

2 parts and processing technology suppliers

3 specialised accessory and component suppliers in building the local subcontracting production system.

5.1 MT firms

Taiwanese MT firms can be categorised as those founded before and after the late 1970s when the production of MTs started to flourish in Taiwan. As will be demonstrated in the following discussions, the two groups also display two distinct modes of production. While the first group of MT firms places a greater emphasis on integrated manufacturing, the second group is more outsourcing-oriented.

5.1.1 Traditional major MT firms

These firms are Taiwan's first generation of MT manufacturers founded before the 1970s, such as Victor, Yeong Chin and Dah Lih. Being able to stand up to the tough global competition despite their humble origins, some of them have evolved into Taiwan's largest and leading MT firms. In comparison to other local MT makers, the size of these firms is relatively large,[7] for they were founded during a time when the manufacture of MTs was vertically integrated, and they have since accumulated relatively sufficient equipment and manpower. Although they have stressed more on internal manufacturing, since the 1980s these traditional firms have sought to leverage local subcontracting networks to gain flexibility (Liu, 1999; Brookfield, 2000).

As subcontracting gradually became the popular mode of production in Taiwan's MT industry, these traditional firms further enhanced the utilisation efficiency of their internal equipment. For example, to improve the quality of casting for its products, Victor established a subsidiary precision foundry in 1992. Instead of manufacturing all the casting parts needed by Victor, this foundry strategically focused on manufacturing only critical casting parts (e.g., MT beds) for its parent firm, and exhausted the rest of its

capacity on manufacturing higher value-added parts for outside clients. Victor then relies on its local suppliers for other non-critical casting parts.[8] A similar strategy is employed by Dah Lih, which invested in heavy equipment for the internal manufacture of sophisticated parts, while subcontracting out low-end ones.[9] Through such an arrangement, these traditional MT firms managed to upgrade their critical supplies with minimal capital investment and to reduce the associated risks by putting their invested equipment into more economic utilisation.

5.1.2 Outsourcing-oriented MT firms

The majority of Taiwan's current MT firms were established after the late 1970s (TAMI, 2005). Unlike the above-mentioned traditional firms that perform more integrated manufacturing, these latecomers depend mainly on subcontracting for the manufacture of their products. Besides, with the development of local specialised production networks, the manufacture of MTs in Taiwan has ceased to be capital- and technology-intensive, allowing entrepreneurs with limited financial or technological capabilities to become MT makers. Based on the backgrounds of their founders, these outsourcing-oriented MT firms can be categorised into the following three types.

5.1.2.1 Non-machinist-founded MT firms

Leadwell and Fair Friend represent the first type of outsourcing-oriented MT firms, whose founders' specialties are in marketing or international trade, rather than in machining. Actually, these two firms emerged from the bankruptcy of a major Taiwanese MT firm, Lien Fong. Leadwell was founded in 1980 by Paul Chang, Lien Fong's former marketing manager, while Fair Friend's founder, Chih-Yang Chu, was an importer and agent for Japanese machinery products before acquiring Lien Fong in 1979 and renaming it Fair Friend. By recruiting experienced machinists and workers to oversee subcontracting and be in charge of MT design and assembly, these firms source most of their supplies externally (Liu, 1999). Their strength lies in their quick market response, with the founders leveraging their backgrounds and rich business networks to access more up-to-date market information, giving them an advantage over other domestic machinist-run MT firms. Through utilising the manufacturing capacity of local subcontractors, these firms are able to achieve competitiveness in speed-to-market and speed-to-volume. As mentioned in Section 4.4, Leadwell was the first to promote subcontracting arrangements in the manufacture of CNC MTs, leading not only to its own phenomenal success but also to the subsequent development of subcontracting production networks in Taiwan's MT industry. Although Fair Friend's early development was not as well-known as Leadwell's, its full adoption of subcontracting arrangements has positioned it among Taiwan's top 10 MT firms since the early 1990s (MIRL, 1999)

5.1.2.2 Machinist-founded MT firms

The second type of MT firms are those founded by machinists who had worked in other MT firms as ranking managers or senior engineers and have strong backgrounds in the design and manufacture of MTs. Equipped with limited capital equipment, these firms focus on machinery design, assembly or testing, which are critical manufacturing steps influencing the functionality and performance of MTs, while subcontracting all other

activities to suppliers. Among the machinist-founded outsourcing-oriented MT firms, Quaser is one of the most successful cases. Established by the former general manager of Leadwell, Edward Shar, Quaser started up with a capitalisation of NT$ 36 million (US$ 1.3 million) in 1991 and has become one of Taiwan's top 20 MT makers, with turnover of NT$ 1.6 billion (US$ 50 million) in 2005. Thanks to the strength of Quaser's technical team, composed of Shar and his former subordinates, the firm is particularly noted for the high quality and performance of its products, comparable to those of local traditional firms. Shar personally has over 20 years of experience in developing MT, and is a widely-respected machinist in Taiwan's MT industry. His reputation and past experience has given him an edge in recruiting skilful machinists to create a solid technological base for his start-up. Moreover, Shar was one of the original initiators of Taiwan's MT subcontracting production system,[10] and his long-standing relationships with many local suppliers has allowed Quaser greater knowledge and leverage in governing local supplier networks. With the capability to combine internal technological and external manufacturing competencies, even a small, new firm like Quaser or other machinist-founded firms can manage to manufacture market-competitive quality MTs.

5.1.2.3 Sales-founded MT firms

The mature supplier networks in central Taiwan have made possible the appearance of the third type of MT manufacturers who do not directly control any productive capacity themselves. MTs from such firms, often called Gongbangi (Taiwanese for 'public-managed MTs'), are simply manufactured through assembling off-the-shelf standardised parts and components without necessarily performing any fine-tuning. According to our investigation, many of these Gongbangi manufacturers were ex-sales representatives of MT firms or trade firms. As sales representatives, they were required to interact closely with customers, paying frequent visits to obtain feedback or provide post-sales service for their products, enabling them to build good relationships with customers. After accumulating a sufficient number of clients and acquiring local knowledge about the production of Gongbangi, some of these salespersons might launch their own manufacturing start-ups. As the Gongbangi perfectly meet the demand of price-sensitive users for low-end CNC MTs, they were especially popular in domestic small metalworking shops. Moreover, in recent years, a great number of Taiwan-made Gongbangi have been sold to developing countries, such as China and other East Asian countries, where there is greater demand for low-price CNC MTs.

5.2 Parts and processing technology suppliers

The suppliers discussed here are metalworking shops that supply products, such as gears, sheet metal and other hardware parts according to client specifications or that undertake processing services, such as the milling, grinding, foundry or heat treatment of given components. Like many subcontractors in other Taiwanese industries, most supplying firms in the MT industry were founded by former employees of MT firm, and, more importantly, their start-ups were actually supported by their ex-employers. Shieh (1992) argue that this is a common practice among Taiwanese SMEs, because the parent firms can hence avoid the expense of retirement pensions mandated by Taiwan's labour laws. In the case of Taiwan's MT industry, MT makers have additional strategic motives. For instance, when planning to outsource manufacturing activities, an MT firm might

consider encouraging its own internal specialists to spin off as a supplier. The MT firms' support to their employees' ventures may range from providing loans of money and machinery, placing consistent orders, to referring them to other prospective clients. Through such means, on the one hand, local mechanical entrepreneurs could fulfil their dreams of being their own bosses. On the other hand, for MT firms, being able to work with trusted and familiar suppliers would greatly minimise the risks and costs associated with subcontracting arrangements (Chen, 2011).

5.3 Specialised accessory and component suppliers

While most local metalworking shops mainly supply parts or processing services that do not involve much sophisticated technology but rather require the craft-based skills of mechanics or metalworkers, some critical MT accessories and components, such as spindles, ATCs, rotary tables, CNC controllers and ballscrews, demand greater knowledge in not only machinery but also in electronics and material science. These technologies are far beyond the capabilities of local metalworking shops or sometimes even Taiwanese MT firms themselves, so such specialised supplies might need to be manufactured internally by MT makers or imported from abroad (IEK, 2002). Nevertheless, through the joint efforts of local firms and the PRIs, indigenous capacity to supply these sophisticated elements has been developed (Chen, 2012), which also led to the emergence of specialised accessory and component suppliers in Taiwan's MT industry.

5.3.1 Specialised accessory suppliers

In the 1990s, sharply rising demand in the export market prompted some Taiwanese MT firms with internal over-capacity to consider further outsourcing the manufacture of some accessories. At a time when such subcontractors had yet to exist in the cluster, local MT firms might persuade their employees to set up their own businesses to exploit such prospective business opportunities. With the encouragement and expected support from their parent firms, some mechanics were willing to take the risk to become entrepreneurs. Spintech, currently one of Taiwan's major spindle suppliers, serves as a good example. Tony Wang, Spintech's president, initially managed the spindle manufacturing section of Quaser. As he describes the process:

> "Encouraged by Quaser's president Shar, two colleagues of mine and I collected NT$1.5 million by ourselves and established Spintech in 1995. In the beginning, we only received orders from Quaser for assembling spindles. Two years later, a few local MT firms started subcontracting some of their spindle assembly to us. After our assembly business was stabilized, we began to introduce our own spindles to local clients. The first product was a standardized spindle designed for the best-selling machine tools at that time. Fortunately, this product earned great success in the domestic market. Inspired by such success, we introduced more of our own products and have become a specialized spindle supplier." (Author's interview, 11 October 2005)

To reduce their dependence on imported and often high-priced accessories, Taiwanese MT firms have also brought in external partners. For instance, recognising that the technological knowledge embodied in the production of cams was applicable to the development of ATCs, in the late 1980s Yang Iron collaborated with Te Shih, a specialised cam manufacturer, to develop ATCs for CNC MTs. With Yang Iron's

technical assistance, in 1991 Te Shih introduced the first Taiwan-made ATC. This ATC was able to deliver performance comparable to imported products, but at a 30% cost savings.[11] As a result, Te shih's ATCs were adopted by many local MT manufacturers, and have increased its domestic market share gradually.

Another entry point for specialised accessory suppliers in Taiwan's MT industry comes from the PRIs, specifically MIRL. Having participated in the R&D of specialised accessories since the early 1990s, MIRL has helped many of its collaborating MT firms enhance their internal technologies in these realms. Furthermore, with the emergence of domestic and foreign markets for specialised accessories, several MIRL researchers involved in these projects later left to start up their own businesses. For instance, Taiwan's domestic specialised MT accessory firms, such as Deta, Royal and Neo that produce tool storage systems, high-speed spindles and rotary tables, were all founded by former MIRL researchers.

5.3.2 Key component suppliers

In Taiwan's MT industry, some MT key components, like CNC controllers, ballscrews, and linear guideways, that are critical to the functionality of CNC MTs, share a great proportion of production cost, and, more importantly, often need to be imported from foreign suppliers (IEK, 2002). The manufacture of these components is more capital- and technology- intensive and has been dominated by a handful of leading global firms, mostly in Japan and Germany. These high technological and marketing thresholds, however, have not stopped actors in Taiwan's MT industry from trying to build up domestic competencies. A case in point is the successful development of ballscrews.[12]

Taiwan began producing ballscrews in the early 1980s. In 1981, Finest Ballscrew was established as a public-private joint venture between Lien Fong and two domestic public banks: Bank of Communication and China Development Trust. After receiving technology transferred from the UK through licensing, Finest introduced its ballscrew products to local MT manufacturers in 1983. Unfortunately, being influenced by Lien Fong's financial crisis and the dumping of Japanese ballscrews, Finest was out of business in 1989, and was subsequently acquired by Eric Y.T. Chuo, a former ranking manager of Bank of Communication. Chuo renamed the new firm Hiwin afterward.

According to Chou,[13] due to the low acceptance of its products in domestic market, Hiwin was forced to promote its products to foreign MT makers in countries like India and the USA where no single ballscrew manufacturer had established a commanding lead. In 1993, Hiwin acquired a bankrupt German ballscrew maker, Holzer, which helped Hiwin fill its technological gap in ballscrew manufacturing, and to access the European market. Simultaneously, Hiwin undertook outward investments in other countries, such as the US and Japan, to enhance its marketing capacity in foreign markets. Thanks to its success abroad, Hiwin was then able to convince Taiwanese MT makers to adopt its products, thereby increasing its domestic market share.

Other entrants into ballscrew manufacturing in the 1990s, such as PMI and ABBA, also contributed greatly to the subsequent development of Taiwan-made ballscrews. By 2001 more than 75% of the ballscrews installed in Taiwan's MT products were provided by domestic suppliers, led by Hiwin (IEK, 2002). Moreover, through exploiting its foreign and domestic technological and production networks [Chen, (2007), pp.223–226], Hiwin now has become the world's leading manufacturer of linear-motion components, including ballscrews, linear guideways and linear motors, the critical components for

machine tools, and had reached an annual turnover of NT$ 82 billion (US$ 259 million) in 2010 (Hiwin, 2011).

6 Concluding remarks

One of the crucial elements underlying the global competitiveness of many Taiwan's industries has been the presence of localised subcontracting production systems. While the advantages of decentralised production for industries and firms have already been repeatedly emphasised in the literature, the current paper contributes to this realm of study through discussing the emergence and formation of subcontracting networks in the specific case of Taiwan's MT industry.

By combining the perspectives of entrepreneurship and technological regime, this paper argues that, on the one hand, Taiwan's industrial system and institutions were favourable to the creation of new firms and SMEs, as was the strong motivation of Taiwanese mechanical entrepreneurs to start up their own businesses and 'be their own bosses' (Shieh, 1992; Hamilton, 1997). In addition, the local environment is particularly supportive of new ventures aiming to develop specialised competence in each phase of manufacture, as is exemplified by the active formal and informal assistance from critical actors, such as the MT firms and the state (e.g., through PRIs), to the establishments of specialised suppliers in the cluster. These factors have jointly fostered the development of subcontracting networks in Taiwan's MT industry.

On the other hand, the essence and development of subcontracting networks indeed lies in the entry of new firms. The process of nurturing new ventures, however, is correlated with the emergence of technological opportunities which can be exploited and commercialised by small firms (Kenney and von Burg, 1999). In the case of Taiwan's MT industry, the emergence and application of CNC technology in the 1970s provided a window of opportunity for Taiwanese MT entrepreneurs to advance their manufacturing capabilities and, more importantly, to overcome their inability in benefiting from the advantages of subcontracting. In this context, many MT entrepreneurs were encouraged to capitalise on their specialised skills and innovative ideas through establishing start-ups, engaging in either the manufacture of MT products or the provision of processing services and supplies, leading to the development of the comprehensive subcontracting production system in Taiwan's MT industry.

While this paper focuses on the processes and dynamics within the early formation of subcontracting networks in an industry of a late-industrialising country, the evolution of such networked production systems along with the changing conditions of technology and market has yet to be properly explored. In the case of the MT industry, for instance, the recently improved information and communication technologies (ICTs) and transportation infrastructures that facilitate interactions and cooperation between distantiated actors have enable Taiwanese MT firms to upgrade their technological capabilities and products through trans-local learning (Chen, 2009). In fact, these advances in ICT and transportation have further opened the possibility of de-localising the MT subcontracting networks (Boschma and Frenken, 2010). For Taiwanese MT firms, sourcing manufacturing inputs from foreign suppliers has now become feasible and economical. Suppliers, especially accessory and component firms, would also be able to market their products to MT makers worldwide. One might expect such developments to weaken the once-strong interdependence between MT firms and their local suppliers

within the cluster's subcontracting networks. If this is the case, it would be worth further investigating how the technological and business opportunities brought about by advancements in ICT and transportation would influence entrepreneurial behaviours and, consequently, the production organisations of a spatialised industry. Such a study might provide deeper insight regarding the evolutionary processes of a cluster's production systems.

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Notes

1 In addition to archival data and relevant studies concerning the development of Taiwan's MT industry, the main source of information for this paper comes from the author's more than 70 in-depth interviews with key actors involved in the local MT production networks. These interviews were conducted in 2005, 2006, 2008 and 2009, and the interviewees included Taiwan MT manufacturers and their suppliers, and officials and researchers in Taiwan's MT-related institutions, such as government agencies, research institutes and industry associations. The interviews typically lasted from one to three hours, and were fully recorded and transcribed.

2 The central Taiwan region is estimated to host more than 60% of Taiwan's MT manufacturers and their suppliers (MOEA, 2007).

3 The world's production of CNC lathes grew from US$ 445 million in 1975 to US$ 1,639 million in 1981. As for Japan, its production of CNC lathes even grew more than 10 times from US$ 66 million to 730 million in this period (Jacobsson, 1985).

4 Author's interview with Bert M.H. Huang, President of Victor, 14 November 2005.

5 As discussed in Section 3.2, in the manufacture of CNC machine tools, machine part quality requirements are not as strict as for conventional machine tools. In this case, even if some of the installed parts sourced from external suppliers are poorer in quality, the performance and precision of CNC machine tools might not be affected, since the issues resulting from inferior parts might, to some extent, be solved through adjusting the programmes of CNC controllers. Therefore, MT firms can still manage to produce higher quality CNC machine tools through subcontracting.

6 Information provided by the MT firms during the author's interviews.

7 While more than 98% of Taiwanese MT firms have fewer than 50 employees, these traditional major firms may employ anywhere between 300 to 900 workers (MOEA, 2005).

8 Author's interview with Bert M.H. Huang, the President of Victor, 14 November 2005.

9 Author's interview with David Chuang, the General Manager of Dah Lih, 3 October 2005.

10 While Leadwell's ex-President, Paul Chang, was often regarded as the originator of subcontracting manufacturing in Taiwan's MT industry, Shar, as Leadwell's ex-general manager, also played a crucial role in making such arrangements possible by cultivating the manufacturing capacity of local subcontractors.

11 Author's interview with Yi-Chien Lee, the President of Te Shih, 31 August 2005.

12 The other notable case is the development of CNC controllers. Although not as commercially successful as ballscrews, domestic suppliers of CNC controllers, particularly PC-based controllers, have emerged in Taiwan's MT industry since the late 1990s [see Brookfield (2000) and Chen (2007) for discussions on the development of CNC controllers in Taiwan).

13 Author's interview with Eric Y.T. Chuo, the CEO of Hiwin, 9 November 2005.