1. Introduction

Alternative innovation systems approaches to technology development include national (e.g. Lundvall, 1992; Nelson, 1992; Freeman, 1995), sectoral (Malerba, 2002) and regional systems (Saxenian, 1996). In this paper we use a technological systems framework (Carlsson & Stankiewicz, 1991) to understand technology diffusion in machine tools in India and identify causal factors constraining the process of catching-up.

As compared to production of conventional machine tools, the integration of computer numeric controls (CNC) into machines required producer firms to have very different competencies. The decline of US machine tool industry (Carlsson, 1984; Finegold, Brendley, Lempert, Henry, Cannon et al., 1994; Arnold, 2001; Kalafsky & MacPherson, 2006)) and dramatic rise of machine tool production in East Asia can be attributed to these changes in technology (Amsden, 1977, 1985; Chen, 2009, 2011, 2014; Chuma, 2003; Fransman, 1986; Jacobsson, 1993; Lee, 1996; Lee & Lim, 2001; Tsuji, 2003; Yeh, & Chang, 2003). The remarkable success of East Asian countries provides valuable lessons in catching-up. Rapid
commercialization of CNC technology in 1970s led to Japan emerging as a world leader by 1982 (Fransman, 1986). In Taiwan, machine tool exports increased by more than 30 times between 1970 to 1980 (Amsden, 1985; Chen, 2011). In South Korea, the catching-up process was over a longer duration (Jacobsson, 1993), but by 1990s technology absorption in machine tools reached an advanced stage (Sung & Carlsson, 2003). By contrast, India’s share in world production of machine tools is less than 1 percent and imports account for more than half the consumption of machine tools (Gardner Research, 2016). While CNC technology was introduced in India in late 1970s, the process of technology assimilation has been slow. The innovation system approach used in this paper helps to identify weak links in the technology diffusion process. Policy initiatives that aim to strengthen these weak links will not only help machine tool industry but also contribute to success of Make in India program by giving an impetus to manufacturing sector growth.

The paper is organized as follows. In section 2 we describe the technological systems model and its components. Using the model, we review the experience of East Asian countries to identify distinctive characteristics of technology assimilation in CNC machine tools in these countries. In section 3 we construct the technological system for machine tools in India. Subsections 3.1 and 3.2 describe the evolution of innovation system for conventional and CNC machine tools respectively. Section 4 is a critical discussion of major issues preventing technological catching-up in CNC machine tools in India and implications for Make in India program. In section 5 we conclude with a summary and some policy suggestions.

2. Methodology. The technological systems model

Following Carlsson & Stankiewicz (1991), we define a technological system as a network of agents interacting in a specific economic or industrial area under a particular institutional infrastructure and involved in generation, diffusion and utilization of technology. The technological systems framework has been used to study evolution of CNC machine tools in South Korea (Sung & Carlsson, 2003).

![Figure 1. The Technological System for Machine Tools](source)


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The key elements of the system are given in the schematic diagram in Figure 1; they are structure of industrial organization; technological and knowledge infrastructure and institutional structure.

**Structure of industrial organization**

The main actors in industrial organization are builder firms, user industries, suppliers of parts and components and processes and industry associations. Production of CNC machine tools requires a close interface between producer and user firms to design niche customized machine tools for user firms. The presence of advanced domestic user industries contributes to competitiveness of producer firms in international markets (Fagerberg, 1995; Lee, 1996). An expanding market allows firms to benefit from specialization by concentrating on a specific range of machines (Amsden, 1977, 1985). In production of CNC machine tools, many high value components like CNC controllers, servo motors, ball screws, linear guideways etc. are bought-in by most producer firms worldwide. This feature of the technology changed industry structure as it made small scale production competitive. The ability of reliable supplier firms in providing supporting facilities for supply of parts, components and process technologies is crucial to machine tool firms as they affect cost, quality and durability of machine tools.

The East Asian experience shows a diversity in the role of different actors and institutions. In Japan and South Korea, large conglomerate firms played an important role in machine tool industry whereas in Taiwan small and medium firms played a crucial role. Innovations in user industries in automobile and electronics industries played a critical role in CNC technology absorption in Japan while in South Korea heavy industries and chemicals played a key role. In Taiwan, the presence of a cluster of satellite firms supplying parts and processes played a crucial role in establishing competence of small and medium machine tool firms.

The presence of strong networks plays an important role as such networks enlarge resource base of firms and lends a collective voice to industry concerns (Jacobsson & Bergek, 2006). Continuous interaction in product development through formal and informal networks between producer and user firms and suppliers of parts and processes contributed to learning and innovation (Lee, 1996). Technology assimilation in Taiwanese machine tool firms was nurtured by learning through informal channels in the production cluster (Chen, 2009). Strong intra-firm networks contributed to development and diffusion of technology e.g. information sharing system between design, production and development engineers in Japanese firms (Chuma, 2003). In South Korea and Taiwan, industry associations acted as bridging institutions to foster strong links within the industry and with the government. The role of industry bodies like KOMMA in South Korea was especially instrumental in contributing to growth of machine tool industry.

Strong interconnections were also fostered by a spatial clustering of producer firms and satellite firms supplying parts, accessories and process technologies. Clustering helped in mobilizing resources like capital and entrepreneurship and encouraged intra-cluster informal learning mechanisms by enabling firms to source a wealth of extra-firm knowledge.
locally (Chen, 2009, 2011; Chuma, 2001). The emergence of a subcontracting based production system nurtured by clustering of many small and medium firms in Taichung in central Taiwan contributed to growth of Taiwan’s machine tool industry (Amsden, 1985; Chen, 2011, 2014). Similar network spillovers can be seen in South Korea in Changwon Industrial District where government set up clustering of modern production facilities and technical institutes to promote industrial development (Sung & Carlsson, 2003).

**Technological and knowledge infrastructure**

The generation of flows of technology and knowledge is central to the innovation system. Initial access to CNC technology in East Asian countries was obtained primarily through reverse engineering. But over time firms accumulated R&D capabilities in product development and production engineering (Lee & Lim, 2001). Tacit knowledge gained through interactions with user firms and accumulation of art-based skills through on-the-job experience were important learning mechanisms for machine tool firms. Technological innovation was gained by learning-by-doing as well as learning-by using (Amsden, 1985; Rosenberg, 1982).

Establishment of educational infrastructure like universities and technical institutes and active industry-academia partnership in R&D contributed greatly to generation and diffusion of knowledge flows. Formal learning accompanied by skills acquired cumulatively on the job created a pool of skilled design engineers, assembly workers, machinists etc. that fostered learning and innovation process. Joint effort of public and private sectors contributed to narrowing of technology gap. The Japanese Ministry of International Trade and Development (MITI) contributed immensely to building technological capabilities by facilitating transfer of technological know-how. Strategic alliance between electronics and machine tool makers enabled Japanese firms to master sophisticated technology in CNC controllers, servo motors etc. and firms like Fanuc soon emerged as world leaders in these technologies (Arnold, 2001).

Close links between industry-academia contributed to technology absorption. In Japan a large number of public research centres (kosetsushi) were set up to engage in R&D and help in diffusion of technology to machine tool firms through consultation, training, technology information, etc. (Tsuji, 2003). In Taiwan, state public research institutions like Mechanical Industrial Research Laboratories (MIRL) helped design sophisticated CNC machine tools and provided technology support to small and medium firms in Taichung cluster of central Taiwan (Fransman, 1995). Taiwan Association of Machinery Industry (TAMI) and government collaborated to set up Precision Machinery Research and Development Centre (PMC) in 1993 in Taichung cluster (Chen, 2011). In South Korea, the first CNC lathe was produced in 1977 through collaboration between Korea Institute of Science and Technology (KIST) and machine tool firm Hwacheon. In the early 1980s, Changwon National University and Korea Institute of Machinery and Material (KIMM) were set up in Changwon Industrial District for technology support. KIMM contributed to quality control by testing and evaluating new machines to maintain standards and ensure that CNC machines gain credibility in domestic market (Sung & Carlsson, 2003). Thus, knowledge creation and
diffusion of technology in CNC machine tools in East Asian countries took place through a deliberate and coordinated effort by different actors and institutions.

**Institutional structure**

Institutional structure includes government and its policies like industrial and trade policy, patent laws, labour laws, taxes, subsidies etc. that impact various actors. State’s role is to create an environment that will incentivize firms to engage in innovative activity by reducing perceptions of risk and uncertainty. The state can intervene actively to nurture industry in its ‘macro-entrepreneurial’ role. In East Asian countries the state intervened in many ways to influence evolutionary process in machine tool industry. Machine tool industry was regarded as a strategic industry and building of technological capabilities was taken up as a national program and supported through a range of measures including government protection to the industry from foreign competition, support for technology transfer agreements, subsidized credit, tax incentives, import subsidy, export assistance, fiscal incentives for in-house R&D, etc. (Sung & Carlsson, 2003).

Other examples of nation-specific institutions that contributed to innovative capabilities are the unique role played by conglomerate style firms like "keiretsu" in Japan and "chaebols" in South Korea in mobilizing resources. Rapid expansion in Japanese production of machine tools coincided with expansion and entry of auto industry into export markets. The entry of user firms in automobile industry into machine tool manufacturing is attributed to "keiretsu" structure of Japanese industry (Lee, 1996). In South Korea, entry of "chaebol" affiliates into production of CNC machine tools contributed to building of technological system (Sung & Carlsson, 2003). These nation-specific industrial structures contributed to evolution of CNC technology by making firms less vulnerable to performance pressures. In Taiwan, a subcontracting based cluster of small and medium firms in CNC tools was actively supported by state through financial and technology measures and resulted in large spillovers for the innovation process (Amsden, 1985; Chen, 2011). Other features of the innovation system include role of social networks in the development of entrepreneurship in Taiwan (Chen, 2014) and managerial and organizational structures of the firm like just-in-time production and the system of information sharing practices within firms in Japan (Fransman, 1986).

Finally, it is the cumulative interconnected networks between industrial, technological and institutional structures that will lead to a dynamic innovation system. Successful catching-up in East Asian countries was achieved through a purposeful and coordinated effort by different actors and institutions in the innovation system.

**3. The evolution of a technological system for machine tools in India**

The technological systems framework is now used to understand technology diffusion process in machine tools in India. There are two distinct phases in evolution of machine tool
industry in India. These two phases differ significantly in regard to institutional structure and technology.

3.1. First phase of production of conventional machine tools: 1947 till early 1980s

The first phase from 1947 to early 1980s is when the industry produced conventional machine tools in a regulated environment mainly in the public sector. In this phase, machine tools were regarded as ‘mother machinery’ and public sector played a key role in India’s industrialization after independence. Import substituting strategy of industrialization adopted in the mid-1950s in the second plan provided a protected domestic market for ‘nascent’ industries.

Government emerged as the main actor and played a key role in all three components of technological system for machine tools. The public sector was the main producer of machine tools. It was also an important user industry with railways, defence, ordnance and other public sector units (PSU’s) being main user industries. The PSU, Hindustan Machine Tools (HMT) was set up in 1953 in Bangalore with Swiss collaboration. Rapid industrialization after mid-1950s in the second and third plans led to increasing demand for machine tools. Subsequently the company set up many new units and the last unit to be set up with German collaboration (Siemens) in 1984 was the CNC Systems division. Other PSU’s include Heavy Engineering Corporation (HEC) which was set up in 1966 and Praga tools which was set up with Czech collaboration in 1943 and later became a subsidiary of HMT Ltd.

In 1960s, HMT accounted for more than 55 percent of total value of machine tool production. Over time the company diversified into production of a range of conventional machine tools like lathes, automatcs, grinding machines, drilling machines, Special Purpose Machines (SPMs) etc. to meet demand of user industries. The technology required to manufacture a diverse range of conventional machine tools was acquired through a series of technology agreements with Swiss and German collaborations. Engineers and technical staff received training from foreign collaborators and technology absorption was done in the R&D department of the company through in-house support for design improvements, modifications etc. (HMT, Annual Reports; Mandala, 2007). There were a few large machine tool firms in the private sector that were set up mainly in the 1960s like Mysore Kirloskar, Sandvik Asia Ltd., Widia India Ltd., Bharat Fritz Werner, The Premier Automobiles Ltd. and PMT Machine Tool Automats Ltd. These firms supplemented the production of machine tools in public sector.

After independence, the government set up a number of scientific and technical educational institutions. This helped to create a pool of engineers and scientists that met the skill requirements of machine tool industry. Research institutions like Central Mechanical Engineering Research Institute (CMERI), Mechanical Engineering Research and Development Organizations (MERADOs), Council for Scientific and Industrial Research (CSIR) etc. were set up for technology development. To assist small and medium firms in technology assimilation, the Central Machine Tool Institute (CMTI) was set up in 1960s with Czech collaboration (renamed as Central Manufacturing Technology Institute in 1992).
Government also set up Prototype Development Centres, Tool Room and Testing Centres etc. at various industrial locations for technology diffusion. While there was a significant expansion in educational and research infrastructure, the contribution of these institutions in terms of technology development in manufacturing was limited (Mani, 2002).

Thus, the technological system for conventional machine tools illustrated in Figure 2 assigns a central role to government as the principal actor in all three components of the technological system. Public sector dominated production of conventional machine tools and was an important user of machine tools too. The institutional structure restricted imports and provided domestic producers a protected environment. The technology for production of a wide range of conventional machine tools was acquired through technology agreements with foreign collaborators and over time firms acquired capabilities to gradually assimilate conventional technology. The educational infrastructure supported absorption of technology by meeting industry requirements of qualified engineers and scientists. However, the contribution of public sector research institutes in technology diffusion process in machine tools was limited and linkages between industry and academia were not significant.

3.2. Second phase of adoption and gradual diffusion of CNC technology: 1980 onwards

The second phase corresponds to introduction and gradual diffusion of CNC technology from early 1980s to the present. This phase coincided with reforms that liberalized the industry. Liberalization measures like delicensing of machine tools started in early 1980s.
Major structural reforms in 1991 abolished industrial licensing, removed quantitative restrictions on imports, reduced tariffs on machinery imports and permitted imports of second hand capital goods.

Currently, the machine tool industry has a dual structure with top 25 firms accounting for 70 percent of value of production. There are about 1000 firms in the industry. Many machine tool firms are located in industrial clusters in Bangalore, Pune, Rajkot, Batala and Ludhiana. Imports account for a significantly large share of consumption—around 53 percent, while exports of machine tools are negligible and represent less than 5 percent of total value of production in 2016-17. India produces mainly metal working machine tools. Major items of production are lathes, automats, vertical machining centres and Special Purpose Machines (SPMs) etc. India’s exports comprise mainly lathes, vertical machining centres and cylindrical grinding machines. Imports are mainly high technology items like vertical machining centers, lathes and automats, milling machines, grinding machines, EDMs and gear cutting machines in which domestic industry has yet to acquire capability (IMTMA, Annual Reports).

The technology for CNC machine tools was introduced in India in late 1970s and in 1985 about 65 units of CNC machine tools were produced. This number steadily increased to 1382 units in the year 2000 and further to 19782 units in 2016-17 (IMTMA, Annual Reports). The share of CNC machine tools in value of production of machine tools in the metal working sector went up steadily from 6.6 percent in 1985 to 50.5 percent in the year 2000 and 86 percent in 2016-17 as given in Figure 3. This represents a slow assimilation of technology with a gradual increase in production of CNC machine tools over more than three decades. By contrast, in Japan, Taiwan and South Korea, the process of technology diffusion was much more rapid. In South Korea for example, between 1981 and 1987 share of CNC lathes in total lathes production increased sharply from 10.5 percent to 50.7 percent in this short period (Sung & Carlsson, 2003).

**Figure 3. Percentage share of CNC machine tools in value of production: 1985/86 to 2016/17**

Source: Based on data provided by IMTMA including various annual reports.
Liberalization led to a significant increase in demand for sophisticated quality CNC machine tools from user industries like auto and automotive component makers, durable goods industries etc. But many established firms like HMT in the public sector and Mysore Kirloskar in the private sector lost market share as they were unable to transition from production of conventional to CNC machine tools. Mysore Kirloskar, one of the oldest machine tool firms in India shut down in the year 2000 while HMT has made losses since 1993-94 and needed financial restructuring. However, liberalization had a positive effect on innovation system for CNC machine tools with new actors emerging and interconnections being established. New opportunities incentivized technocrat entrepreneurs to invest in machine tool industry. These include Ace Manufacturing Systems Ltd. (1979), Lokesh Machines Ltd. (1983), Jyoti CNC Automation Pvt. Ltd. (1988), Grind Master Machines Pvt. Ltd. (1984), LMW (1988), ETA Technology Pvt. Ltd. (1991), Parishudh Machines Pvt. Ltd (1995), Macpower CNC Machines Pvt. Ltd. (2003) etc. These new entrants were successful in assimilating CNC technology and could meet demand requirements for niche machine tools from advanced user industries. While formal R&D expenditures of these firms were not significant, they mastered design skills and acquired production skills over time by learning-by-doing through continuous innovation in manufacturing technologies. These firms were able to establish cost advantages in production of specific types of lathes, machining centres etc. and were able to build brand value for their products in the domestic market. The acquisition of ISO quality certifications gave these firms the necessary confidence to explore international export markets too. Technological capabilities in these firms were established through strong producer-user interface, design skills and learning-by-doing (Mandala, 2007).

In the second phase, there was greater dependence of domestic machine tool industry on foreign firms. Firstly, the increase in demand for CNC machine tools led to greater dependence of domestic machine tool manufacturers on foreign firms like Fanuc (Japan), Siemens (Germany) etc. for import of CNC controllers, ball screws and other high precision components which are critical to machine tool production and often represent 40 percent of value of machine tools. Secondly, because of the demand gap that arose due to inability of domestic machine tool firms to catch-up in technology in CNC machine tools, many foreign firms started to export machine tools to India. Global machine tool firms like Mori Seiki, DMG, Mazak etc. set up sales centres in India to import and sell machine tools and provide support services. And finally, imports of low-end machine tools and second hand capital goods increased significantly with imports coming mainly from Taiwan and China. These imports adversely affected smaller machine tool firms in the industry (Mandala, 2004).

The technological system for the second phase is given in Figure 4. The innovation system for CNC machine tools shows many more actors in the industrial organization with many new producer firms that emerged in post liberalization period and new user industries in private sector like auto and automotive parts, consumer durables etc.. Foreign firms also play an important role in meeting demand gap for high technology CNC tools as well as in supply of CNC controllers and other sophisticated parts. Domestic suppliers of parts and components and processes are other actors. The contribution of these ancillary industries and interface with producer firms is a weak link in the innovation system and needs to be strengthened. The Indian Machine Tool Manufacturers’ Association (IMTMA) has acted as an important bridging mechanism in the second phase by facilitating and strengthening
networks between different actors. Technological and knowledge flows have been strengthened by role of IMTMA and CMTI. Training programs run by IMTMA Technology Centre in Bangalore have contributed to skill formation. Technology Centres have also been started in two other regional machine tool clusters in Pune and Gurugram. The Design and Productivity Institutes of the Technology Centre focus on building specific skill sets related to design and other related technologies through a series of training programs and workshops for both machine tool firms as well as user industries. Another initiative is the IIIC (IMTMA Institute Innovation Collaboration) that promotes collaboration with technical institutes to meet industry requirements of R&D skills. Another industry-academia collaboration for development of high quality machine tools is between IMTMA, IIT Madras and Department of Heavy Industry (DHI). Overall, the role of IMTMA in the second phase has been crucial in the evolution of innovation system.

In terms of technological and knowledge infrastructure, government continues to play a key role in providing educational infrastructure. The contribution of CMTI in the second phase is much more substantial with smaller and mid-size machine tool firms being more active in seeking support for technology transfer. The Department of Scientific and Industrial Research (DSIR) has a number of research support schemes that have helped in R&D support to firms in the industry. Thus overall, the radical change in the institutional structure after liberalization from 1980s altered the nature of the innovation system in terms of technology and role of different actors and networks between them.
4. Discussion

A comparison of innovation system for conventional and CNC machine tools reveals distinct differences. Since government was the main actor in the first phase, the functions of the innovation system for conventional machine tools were also performed primarily by it. Government played an important role as a significant producer of machine tools and in directing and coordinating investment decisions. Likewise, it contributed to knowledge development and diffusion through development of educational infrastructure, setting up of research institutes and support to PSUs in acquiring technological know-how from abroad. Machine tools was a priority sector in industrial policy and machine tool firms had an assured domestic market due to protection given to ‘nascent’ industry. Government policy of procurement for railways, defence etc. provided an assured domestic market. The government also facilitated access to export markets through bilateral agreements with traditional trading partners like erstwhile USSR and other East European countries. Thus the state played a key role in creating capacity in production of machine tools in public sector and in mobilization of resources like capital, skilled labour and other complementary assets. The technological system in machine tools served the limited objective of meeting needs of domestic industries by its ability to produce a wide range of conventional machine tools for domestic user industries.

However, there were many shortcomings in evolution of the innovation system. As argued in the literature, the negative effects of ‘infant’ industry protection that extended over a long period resulted in an industrial structure that was inefficient (Jacobsson, 1993). Both public as well as private sector machine tool firms had no pressures to reduce costs in a protected environment. Since end users for public sector machine tool firms were also mainly in public sector the pressure to innovate did not come from these user firms. The technological infrastructure in terms of public research institutes failed to develop strong links with the industry. Institutional constraints in macro environment like shortages in infrastructure development and rent seeking and corruption that emerged during industrialization process also deterred entrepreneurial activity (Nayak, 2016). Thus, overall, the actors in the innovation system and their interconnections did not foster a dynamic innovation system.

The system that emerged in the initial phase provides the backdrop for the second phase. Liberalization opened up the economy in 1991. As profile of user industries changed, domestic producer firms needed to acquire capabilities to design sophisticated niche machine tools to meet demand. With the change in technology and institutional setting, older established firms found it difficult to bridge this technology gap. However, emergence of new progressive firms filled the gap to an extent and over time these firms established competence. Over time, as the scale of output increased these new firms became competitive by making improvements and modifications through production engineering and project execution. In most cases R&D in these firms was on a project-by-project basis. Some of these firms are now established producers of quality CNC machine tools and also export to European countries as well as other emerging markets. Jyoti CNC Automation acquired the French firm Huron Graffenstaden in 2007 giving the firm advantages in technology and access to markets in Europe. The Ace Designer group of firms with its strong
focus on R&D established itself as a producer of superior quality CNC machine tools and became the largest producer of lathes in 1996. Other machine tool firms like ETA Technology, LMW etc. also export niche CNC machine tools to European and other markets (IMTMA, 2008).

In the second phase, many actors were involved in performing different functions in the innovation system. The emerging technocrat firms in private sector played a key entrepreneurial role. While government continued in its role of providing basic educational infrastructure, the IMTMA and CMTI also played a role in knowledge development and diffusion to meet specific requirements of machine tool firms. Market formation in the second phase happened as liberalization led to faster growth of user industries and domestic market expanded. In the second phase, greater coordination between different actors like producer and user firms, supplier firms, foreign firms, government and industry body was required for mobilizing financial resources, skilled labour and other complementary factors like materials, components, processes etc.

While we see many positive developments in the innovation system, successful technology assimilation and diffusion requires the industry to scale up its activities significantly. This requires addressing weak links in the system. A strong positive relation between user investment and innovative performance in producer firms is well known (Fagerberg, 1995). But, in India the emergence and growth of advanced user industries in auto and automotive industry and other durable goods industries in 1990s did not have a stimulating effect on machine tool firms. Firms in the industry have faced constraints in overcoming technology gap to meet requirements of user industries for high-end CNC machine tools. Indian machine tool firms have neither been able to compete with imports from Taiwan and China at the low end nor do they have the capability to produce sophisticated high-end machine tools that are imported from countries like Japan and Germany. A benchmarking study on productivity involving a comparison of Indian firms with Taiwanese and Japanese producers of CNC lathes and machining centers finds substantial differences in productivity with the productivity of Indians firms being less than half that of the minimum level achieved by foreign firms in the sample (Sutton, 2000).

The absence of clustering of small and medium ancillary firms and large firms has also contributed to lack of spillovers in the innovation system. In East Asian countries a clustering of firms led to many positive spillovers to firms through formal and informal mechanisms. Amongst the machine tool clusters, the Bangalore cluster is the most well developed as it has well established producer firms like HMT Ltd., Ace Designer group of firms etc. as well as CMTI and many educational and engineering institutions. In addition, IMTMA has its head office as well as Technology Centre and also its trade fairs and exhibition centre-BIEC (Bangalore International Exhibition Centre). In addition, the Integrated Machine Tool Industrial Park is being set up near Bangalore at Tumkur by IMTMA with support from the Department of Heavy Industry (DHI) and the state government. While there is a greater degree of interconnections between different actors in the Bangalore cluster, such strong networks are yet to emerge in other clusters like Rajkot, Ludhiana, Batala, etc. Development of small ancillary units needs special focus as they face problems in technology assimilation. Smaller firms in particular face shortage of skilled design engineers and machinists and
other resources. Stronger networks between ancillary units, large firms and technical institutions are required for diffusion of technology.

**Make in India and role of machine tools**

The Make in India program is a major national initiative launched in 2014 to make India a manufacturing hub. The aim of this program is to increase the share of manufacturing sector in gross domestic product from 16 percent in 2014 to 25 percent in 2025. The program targets growth in twenty-five sectors of the economy by fostering innovation, enhancing skill development, protecting intellectual property and building best-in-class manufacturing infrastructure ("Make in India", n.d.). While India is one of the fastest growing economies, the performance of the manufacturing sector particularly in comparison with the services sector has been poor. The share of manufacturing sector in GDP has remained at around 15 to 16 percent and employment creation in manufacturing has stagnated (Nayak, 2016). The contribution of industry to GDP in India at 24 percent is much lower than that of East Asian countries like South Korea as well as China where industry accounts for nearly 40 percent of GDP. Industrial growth was achieved in these countries through a proactive and flexible industrial policy, support for technology transfer, positive role played by public technical and research institutions, infrastructure development etc.

In India, on the other hand, the effects of prolonged protectionism led to emergence of an industrial structure with inherent systemic weaknesses. The inability of machine tool manufacturing to enhance technological capabilities has to be seen in terms of the larger picture of manufacturing sector’s poor performance. But with the launch of Make in India initiative, government has taken a number of measures to encourage domestic and foreign direct investment. These include relaxation in regulatory constraints, infrastructure development like industrial corridors and facilitating ease of business and improving governance. The Department of Industrial Policy and Promotion (DIPP) has fast tracked country specific investment proposals through "Japan Plus" and "Korea Plus" etc. In addition DIPP has a number of schemes for technology acquisition as well as specific programs to assist small and medium enterprises. With the focus on manufacturing growth, technological catching-up in CNC machine tools can be achieved by addressing weaknesses in the innovation system through an intervention policy that is well defined in terms of goals. Such a policy has to be part of a larger vision program designed to ensure success of Make in India program.

**5. Conclusions and suggestions**

In this paper the technological systems framework is used to understand the process of diffusion of technology in machine tools in India. In East Asian countries firms responded dynamically to the introduction of CNC technology. Strong and stable links between producer and user firms, clusters and supplier networks as well as industry associations played a key role in establishing formal and informal networks that led to positive spillovers. The establishment of educational and research institutes and fostering of strong industry-academia links helped in the diffusion of technology. Also important were nation-specific
institutions and the role of the government. By contrast, in India, the innovation system for CNC machine tools lacks dynamism. Successful catching-up will require a greater coordinated effort to develop positive spillovers through strong networks between different actors. The weak links in the innovation system are major challenges in the assimilation of domestic technological capabilities for CNC technology in India.

The main conclusions and policy suggestions that emerge from our study are as follows. Firstly, the study illustrates the usefulness of innovation system approach in understanding constraints in technology absorption in machine tools in India. The innovation systems for conventional and CNC machine tools differ greatly. The technological system construct for the two phases shows distinct differences in the role of key actors and institutions and interconnections between them. While the government played a key role in conventional machine tools production; firms in the private sector play a predominant role in case of CNC machine tools. The liberalized institutional environment since the 1980s led to the emergence of progressive firms that have been successful in technology assimilation. The profile of user industries has also changed significantly since liberalization. The industry association-IMTMA now plays a key role in promoting intra-industry links and in fostering networks with government agencies.

Second, the machine tool industry in India is still in the ‘learning’ period. For successful catching-up, machine tool industry in India needs to build technological capabilities to gain critical mass. This requires policy initiatives to eliminate regulatory and infrastructural constraints, strengthen industry-academia links and foster supplier networks and producer-user interface as well as promoting regional cluster dynamics. Such policy measures will also help in growth of manufacturing sector and contribute to success of Make in India program.

Finally the study of the machine tool sector has some general pointers for manufacturing sector. The technological systems framework shows that while the main actors and institutions are present, their roles are constrained by lack of incentives and weak links. Diffusion of technology in CNC machine tools in East Asian countries was achieved through a purposeful and coordinated effort by different actors and institutions. For the innovation system to gain critical mass and dynamism in India, the government needs to act as a facilitator by putting in place mechanisms that will strengthen interconnections between various entities in the innovation system.

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