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The heterogeneity of the machine tool industry in Brazil

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Abstract

The current paper aimed to investigate the reasons for the technological and competitive heterogeneity in the machine tool industry in Brazil. By analyzing the trajectory of the sector, we can highlight three main reasons for such heterogeneity. First, due to the competitive framework that emerged from the Brazilian import substitution industrialization process (ISI), the companies that produce and used such technological artifact gave emphasis to the accumulation of productive capacity rather than to innovative capacity. Second, ISI institutional 'dynamics' configured the machine tool industry international specialization in products with lower technological content. Third, technological and competitive heterogeneity among manufacturers due not only to different innovative efforts among them, but also to the structure of the demand and the level of sophistication and technological efforts by users.

JEL classifications: L16; L64; O14; O33

Keywords: Machine tools; Brazilian economy; Capital goods; Technology

Resumo

O objetivo desse artigo é investigar os motivos da heterogeneidade tecnológica e competitiva do setor de máquinas-ferramenta no Brasil. Através da análise da trajetória do setor, podem-se destacar três razões principais para tal heterogeneidade. Primeiro, a partir do marco competitivo que emergiu do processo brasileiro de industrialização por substituição de importações (PISI), as empresasprodutoras e usuárias de tal artefato tecnológico deram ênfase para acumulação de capacidade produtiva e não de capacidade inovativa. Segundo, a 'dinâmica' institucional do PISI configurou a especialização internacional do setor de máquinas-ferramenta em produtos com menor conteúdo tecnológico. Em terceiro, a heterogeneidade tecnológica e competitiva entre os fabricantes decorre não apenas dos distintos esforços inovativos entre os mesmos, mas também é devida à estrutura da demanda e do grau de sofisticação e esforços tecnológicos dos usuários.

Palavras-chave: Máquinas-Ferramenta; Economia Brasileira; Bens de Capital; Tecnologia

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1. Introduction

The current paper aims to investigate the determining factors of the machine tool industry (MT) technological and competitive heterogeneity in Brazil. From a historical perspective of the ISI process, it seeks to resume some stylized facts in order to characterize them and to argue that the productive and technological dynamism of the MT industry does not depend (and did not historically depend) only on the producer's innovative efforts. They also depend on demand structures and on their sophistication level, which, however, were conditioned by the economy institutional framework within this process. Given that companies and businessmen have a history of learning and they seek to change their productive, technological and organizational routines by implementing innovations—with the support of the institutional environment, science and technology infrastructure (S&T)—it is worth performing an analysis of the ISI regulatory framework and on the incentive environment, in which economic structures were "built" and certain technological and social capabilities were "acquired". Therefore, the study takes the theoretical assumption that growth and development are dynamic processes that occur from the co-evolution of technology, industrial structure and institutions (Nelson, 1998, 2001; Cimoli and Katz, 2002).

The technological and competitive heterogeneity among MT manufacturers has, as its basic causes, the asymmetric innovative efforts among them, the demand structures and the sophistication level as well as the different innovation efforts by users, especially regarding their revealed preference for innovation processes aimed at developing low cost products and not at innovative products to lead and open new markets, thus requiring more specialized and complex MTs. The theoretical basis of such hypothesis lies on the importance given to the intentional producer-user interaction in order to develop new capital goods (Dosi et al., 1993; Lundvall, 1992; Rosenberg, 2006). The technological capabilities of MT users are crucial to MT companies, since their sophistication is critical to the quality of interaction and to the technological development of artifacts. Since users are those who select the innovations within the market, the low innovative efforts and user's limited technological capabilities keep MT manufacturers' heterogeneity and the relative technological gap at an international level. Therefore, the size of the demand, its structure and sophistication level are also important.

Besides the current introduction, this study presents other three sections in order to investigate the technological and competitive heterogeneity of the MT industry in Brazil. Section 2 gives a brief summary of the MT trajectory and its competitive conditions, technological capabilities and expertise of the MT industry up to the 1980s. This section seeks to highlight the productive features and technological efforts that determine manufacturers' development and expertise, including MT production with computerized numerical control (MT/CNC). It also aims at pinpointing the innovative, competitive and institutional environment configured by ISI policies regarding the development and heterogeneity that characterize the capital goods industry and the Brazilian industry. Section 3 presents a summary of the industrial restructuring process and explains the reasons for the technological heterogeneity within the MT industry from its productive specialization, technological dynamics and user's structure and sophistication. Section 4 presents the final considerations.

2. The technological trajectory and learning by the machine tool industry in Brazil

During the ISI period, Brazil had an ambiguous and contradictory policy with respect to the capital goods industry. On one hand, as for the market reserve, the importation of machinery and equipment with similar national product was forbidden. It was done by applying strong non-tariff (National Similar Product Law) and tariff barriers linked to the importation of such goods. On the other hand, such prohibition facilitated the importation of capital goods with no similar national product by applying tax benefits and foreign exchange benefits aimed at the modernization of the industrial park (Erber and Vermulm, 1993; Nassif, 2007). As a result, the industry has focused on producing capital goods with low technological content when compared with the imported ones. Similarly, according to this regulatory framework, on the one side, the entry of foreign companies in several industrial sectors (durable and capital consumer goods) was encouraged and, on the other, there was the induced entry of small and medium-sized companies. Such companies had excessive verticalization and low economies of scale, which was associated with production fragmentation and high diversification within the capital goods industry. It resulted in the spreading of investments and in the horizontal expansion of sectors holding an excessive number of producers. These results would hinder the efficiency and the incorporation of new technologies. However, "these are not criticisms to the strategy itself, but to its conduct because,

in general, the Brazilian import substitution industrialization led to a highly dynamic Brazilian economy for decades" (Carneiro, 2002, p. 312).

Although there is evidence of a machinery and equipment industry in Brazil since the late nineteenth century (Marson, 2012), the ISI acceleration during the 1930s created favorable conditions to the growth of a capital goods Brazilian industry and, especially, to the genesis of a MT industry. Initially, the incentives to MT production were driven by demand and needs from the electro-metal-mechanical sectors regarding repair, maintenance and the manufacturing of products, which require little complexity during production, in the consumer non-durable, consumer durable and capital goods areas (including the new MT industry), as well as by the stagnation of the Brazilian industry productive capacity.[1] The prohibition and the precarious importation possibilities induced the emergence of production bottlenecks that generated the need to technically improve the capital goods production, such as in the case of conventional lathes produced by companies founded by the first-generation of immigrants who have developed their products by copying and adapting foreign technology using reverse engineering (Versiani and Bastos, 1982, p. 14).

With the Target Plan, the automotive and capital goods industries were prior MT users. Industries such as transport, mechanical and electrical equipment presented an annual average growth of 80%, 43% and 38%, respectively, between 1955 and 1959[2] (Serra, 1983). MT units production increased 23% per year over the period, alongside a strong increase in importations. In 1959, the MT industry represented 11.6% of the production and 18.6% of jobs in the capital goods industry.[3]

Foreign companies that settled industries characterized by the use of more advanced technology required high technological level MTs. The MT domestic supply was not able to meet this part of the demand, thus imports played such role. Such fact reinforced the technological gap between MT demand and domestic supply. At the same time, several small and medium-sized mechanical repair and maintenance companies from other sectors were launched, but they were low capital business. MT demands on quality and productivity were fulfilled by the domestic production, despite the prevailing modest technological standards, which explain, at least in part, the fast growth of the sector within the period between 1956 and 1961. "Thus, the domestic supply was almost exclusively limited to the production of less complex universal machines with modest quality according to the international standards, except for those produced by better equipped manufacturers" (Vidossich, 1974, p. 09).

[1] Three reasons help explaining the incentives for the beginning of the activity in Brazil. First, the maintenance of the export sector income (coffee) with the currency devaluation preserved the domestic income and the internal market whereas the increased demand for capital goods coincided with the sharp increase in their import prices, in a period in which the possibilities of imports were the most precarious ones (Furtado, 2000, p. 211). Second, the decree n. 19.739 of 03.07.1931 set to last three years—and that was extended up to March 1937—prohibited the import of machinery for industries with idle capacity (textile, food, shoes, hats) (Fonseca, 2003; Versiani and Bastos, 1982). This determination was instrumental to induce an initial group of MT manufacturers. Thirdly, the steel import difficulties in the period of World War II stimulated the entry of companies and influenced the activity development.

[2] According to the directions given to the industrialization process by these policies, foreign capital was predominant in the so-called dynamic industries, such as in transport equipment, mechanical and electrical equipment. Along with the subsidies, the State demanded high levels of nationalization in the production of inputs, parts and components from the internalized productive activities. It also invested in infrastructure and in longer-term base industries with slower turnover of capital, which created "external economies" to private companies, such as production and distribution of electricity, petroleum extraction and refining, construction of highways and railroads and steel production. National private investments in traditional branches of the consumer non-durable industry, and in some branches of the capital goods industry and the metal-mechanical industry, which expanded from inter-industrial relationships, were combined with the foreign private investments as well as with public investments. According to Tavares (1986, p. 122), "within the new metal-mechanical sectors that emerged in mid-1950s there was [. . .] a vertical articulation, or a complementarity between large monopolistic top of the line companies (foreign ones) and small and medium-sized national companies in the metallurgical and metal-mechanical sectors that modernized and expanded themselves by taking advantage of the demand from large foreign companies. This is not the case of a competitive oligopoly, but of a differentiated oligopoly, which is horizontally and vertically articulated, and gives rise to a star-shaped industrial structure, in which each company has a string of small and medium-sized companies, working as their suppliers and distributors."

[3] In 1919, according to estimates by Bonelli and Façanha (1978), 95% of the Brazilian capital goods industry production was concentrated at transport equipment, whereas in 1939, this industrial genre accounted for approximately 60% of its production and 39% of its employment. In such year, the mechanical genre held 21.5% of the production, and it was concentrated at the MT manufacturing and agricultural machinery subsectors, which corresponded, respectively, to 6.5% and 6.1% of the production and 13.4% and 13.8% of the employment in the capital goods industry in Brazil. From 1919 to 1939, the real growth rate of the domestic production in this industry, with the heroic assumption that relative prices remained constant, was of 12.4% (p. 321). In 1949, the production in the MT and agricultural machinery segments accounted for, respectively, 11.3% and 5.3% of the total, whereas, regarding employment, it reached 17% and 9.2%. In 1961, there were 114 MT producers in Brazil, three of them were subsidiaries of foreign companies, which came with the internalization of their customers in Brazil and started producing more sophisticated MT and gradually nationalized part of the production (Cruz, 1985; Versiani and Bastos, 1982).

According to the literature, despite the strong growth and structural diversification in the Brazilian industry since the Target Plan, especially in sectors related to capital goods and consumer durables, the new industrialization phase demanded an enlargement in the companies' technological efforts, once these "replaced" sectors required more advanced technological knowledge in order to develop innovative capabilities. According to the way this new phase was conducted, the need for external input from incorporated technology decreased, but the importance of transferring non-incorporated technical knowledge, such as technical assistance; of consulting and licensing firms increased (Guimarães and Ford, 1975). According to Erber et al. (1974), the use of licensing represented time and cost savings in opposition to the alternative of spending on R&D. It was a response to an unstable demand of meeting the specifications of user companies, especially of the public ones. Although licensing agreements could lead production to a greater technological qualification, they did not allow the development of technological capabilities on machine or equipment design, the "basic design". This type of capability is results from R&D, from producer-user interaction/cooperation and from the S&T system (science and technology). It happens because physical technologies can be commercialized in the global market, but non-incorporated technology elements cannot be acquired or transferred, as physical products can, not even with their blueprints so, goods must be adapted to local conditions. "Incorporated elements can only be used in their best possible way if they are complemented by several tacit elements that need to be locally developed" (Nelson, 1990 *apud* Lall, 2005, p. 28–29).

With the accelerating inflation from 1958 and the stagnation of the economic growth between 1962 and 1966, the capital goods industry had an annual decrease of 2.7% in Brazil. The gradual use of the idle capacity derived from the increased production of consumer durables from 1967, along with investments from the public sector, stimulated investment increases, as well as reactivated capital goods and intermediate goods demands. As for the MT sector performance in the period from 1962 to 1967, there was wide oscillation in production and importations.[4] Exportations, which were incipient in 1961, reached 26% of the total MT production and 13% of the production value in 1970. From 1966, the industrial policy and the maintenance of market reserve that allowed the importation of parts and components and that gave incentives to exportation were key items to attract foreign companies. Twenty three (23) out of approximately 86 companies comprising the sector in 1975 were owned by foreign capital, 19 of them were German, 4 Italian, 1 was Japanese and 1 American[5] (Tauile, 1985, p. 685).

The automotive, auto parts and capital goods industries were the largest MT users during the "Economic Miracle" period. The demand for unsophisticated machines was met by the domestic production. The importations, whether of parts and/or components, continued to supply the noblest market segments. Along with domestic supply diversification, the variety of types and models produced by a "multitude of manufacturers that produce identical or very similar machines, both in technique and quality" underwent reductions (Vidossich, 1974, p. 49). As for the MT "technological diversity" in the Brazilian economy—such as the percentage of different produced and used MTs in the country compared to the diversity comprising the international supply—the author emphasizes the role imported MTs[6] to meet technology demands from the national industry as well as the existing technological gap in the MT national industrial park in 1971

> even when referred to the development level of industries that use them. [. . .] in the universe of types and models which comprise the machine tools world supply, only a portion of it is required by the national metal-mechanics

[4] In the 1960s, the MT sector concentrated and centered itself with the increase in the average size of firms and the participation of foreign subsidiaries (Tauile, 1985). In 1960, there were 90 companies in the MT sector, eight of which employed more than 100 people and accounted for 55.4% of the employed staff, and the two largest ones (Romi and Nardini) accounted together for 33.4% of the total employed staff. The mean number of jobs per company increased from 53.1 in 1961 to 109.0 in 1971. In this year, there were 18 companies with more than 100 employees, whereas the total of jobs in the sector increased from 4780 in 1961 to 6646 in 1971 (Cruz, 1985, p. 72).

[5] Among the main reasons for the interest of foreign companies in setting up subsidiaries and/or associates in Brazil, Magalhães (Tauile, 1985, p. 686) highlights: (i) possibilities offered by the Brazilian market as well as by the markets from other LAFTA countries; (ii) political stability; (iii) lower wages; (iv) need of expanding foreign companies; and (v) government incentives.

[6] From 1971 to 1974, there was a growing share of imported serial capital goods, either as parts or as spare parts, or as final goods. According to the estimates by Mazzucchelli (Tironi, 1979, p. 31)—which is actually an overestimate, because part of the assumption that all MT can be taken as serial goods—in a survey about the imports of capital goods accumulated from 1971 to 1974, corresponding to 73% of total imports, 83% were imports of "serial" MT. This growth in the serial MT imports "reflects the general type of growth and diversification of the productive structure, and more specifically, the sharp capacity expansion of the major international companies" (Tironi, 1979, p. 31–32), which were the main importers of such equipment, and the largest importers of parts and spare parts. "In this sense, it can be stated that the industry has internalized the offer of a high range of capital goods, but produced them incomplete, depending on the import of parts and spare parts generally produced in series" (p. 32).

> industry; however, not even this portion was met by the domestic manufacturers [. . .]. Imports have played great role in allowing the machine tool using sectors incorporating the technology domestic manufacturers were not able to provide[7] (Vidossich, 1974, p. 59–60).

Thus, two technological gaps coexisted among the incorporated technology sophistication levels concerning national/foreign supply and domestic MT demands (MT international market, domestic supply, domestic demand, domestic companies and foreign subsidiaries supply). The first gap was between the technology internally used in the country and the latest global innovations (MT/NC/CNC). The second was the technological gap corresponding to the disparity between domestic demands and domestic technology supply. There was a long time lag between the changes in structure demands and the MT supplying of technological capability because "users and producers interact in Brazil within a market that is internationalized by means of imports, local production held by subsidiaries from foreign companies and even by means of international production standards adopted by local users" (Tauile, 1985, p. 683). In the mid-1970s, the sector consisted of three distinct types of producers: (i) small and medium-sized companies, which less sophisticated production was destined to less dynamic sectors of the economy; (ii) medium and large-sized national companies that produced a great variety of sophisticated machines destined to more dynamic sectors; (iii) foreign companies that, given their characteristics and linkages, targeted their production on leading sectors (Magalhães, 1976, p. 17 *apud* Tauile, 1985, p. 686).

The growth of the MT sector in the 'Economic Miracle' period was extended by the II PND (National Development Plan) investments—given the specific inter-industrial relationships within the sector—which led to productivity gains and to increase in the value of exported products. During this period, the MT companies got government funding for expanding their productive capacity (Cruz, 1985).

In the early 1980s, Brazil had a well-diversified and sophisticated capital goods industry but, in international term, it was uncompetitive due to the companies' excessive verticalization and to the insufficient scales of production in some sectors. The serial capital goods production sectors (such as trucks and tractors, for example) were the most competitive ones. The MT subsector also stood out as competitive, at least with respect to companies with a history of productive and technological learning, which sought to extend their knowledge in order to follow the radical change in the industry's technological trajectory, i.e., machine tools with computer numerical control (MT/CNC).[8] In the early 1980s, the industry was still geared to the domestic market, but it had reached an export coefficient of 17.4% (Cruz, 1993, p. 31) by targeting the Latin American market, particularly Mexico, Argentina, Peru, Uruguay and Chile (Araújo et al., 1992, p. 93), and this expansion comprised conventional MT and price was key to competition factor to it.

The national companies within this sector had a long history of technological learning: firstly, since the mid-1930s founders, generally immigrants, developed design and manufacturing capabilities by copying and adapting technologies by means of reverse engineering. At that time, small conventional MTs were produced. In the 1940s, these MTs started being produced in industrial scale. Secondly, in the 1960s, companies began hiring engineers, and in the 1970s, those that had the leading technological strategies established their formal and systematized R&D departments as well as institutionalized their innovative activities. However, as in the Brazilian industry, the sector

[7] The sample from five MT producing companies studied by Cruz (1985), among which Romi, Nardini and Traub companies stood out, allowed stating that, by the end of the 1970s, the industry grew and showed greater technological expertise and capacity. The author highlights that "the specialization of companies regarding types of products was enhanced with the installation of multinational companies that targeted the most sophisticated market segments in which they mainly competed with Romi and Nardini." (p. 73). Cruz (1985, p. 73–74) observes, regarding the installation of these two companies' new plants, that the industry began with two relatively large companies within an underdeveloped technological environment that, in the absence of suppliers etc., increased the vertical integration degree. However, the organization in multiplants allowed performing the production processes specialization and seeking greater economies of scale. Moreover, Cruz affirms the quite innovative technological behavior and the great technological sophistication of these companies (Romi, Nardini and Traub). Despite the apparent contradiction between the findings by Vidossich and Cruz, both authors are correct, because they highlight different facets of the industry. "Despite the sector evolution identified by Cruz, the gap was still large between the national machinery technical levels when compared with the ones produced in more developed countries" (Erber and Vermulm, 1993, p. 172).

[8] Some national companies with greater technological capacity started producing MT with numerical control in the 1970s. In 1972, Indústrias Romi SA produced the first one by adapting it from a conventional machine. According to Laplane and Ferreira (1985, p. 116), in 1979, "three national companies (Romi, Nardini and Italbrás) and four foreign ones (Wotan, Index, Heller and Traub) produced MT/NC". By using data from Sobracon, Laplane (Erber and Vermulm, 1993, p. 176) states that, up to 1979, 100 MT/NC were produced and other 274 were imported. These data are similar to those presented by : in 1980, the stock of MT with numerical control in the Brazilian manufacturing industry, especially in the capital goods sector, was of 550 machines, of which approximately 23% were produced in Brazil.

was characterized by great technological and competitive heterogeneity. Few companies in the industry had developed innovative capacity. The growth and technological learning trajectory of the national leading companies, which were working with scale economies in the serial MT sector, and the emergence of foreign companies, with high technical standard, made it possible to significantly reduce the production technological gap in the 1970s. The accumulation of technological capability happened by continuous and incremental product development in these domestic leading companies, whereas the technological strategy for the development of more complex MT was getting overseas licensing. Notably, the expertise assimilated by companies in the sector primarily came from learning-by-doing and learning-by-using processes.

From 1981 to 1983, the decline in public and private investments affected the industry as a whole, as well as the capital goods sector, mainly the MT sector. At this point in time, the industrial policy instruments were put in service of the priority macro goals in order to save currencies. Besides, imports control lost its aim of promoting industrialization. Foreign companies also reversed their expansion strategies in Brazil. The internal crisis met the economic crisis in Latin America, which affected countries that traditionally imported Brazilian MTs. Nevertheless, it was possible to solve the crisis by expanding MT/CNC production by meeting users' modernization needs in the capital goods, auto parts and automotive sectors. In fact, it is known that the leading companies seeking to enter the sector's new technological trajectory by means of licensing increased their investments in R&D in relation to the net revenue. Actually, only one MT manufacturer spent, in 1982, about 80% of the sector's technological spending (Ferraz, 1987, p. 439).

It was also in the 1980s that the Special Secretariat for Informatics (SEI—Secretaria Especial de Informática), according to the National Informatics Policy, sought to induce the development of technological capabilities in companies producing microelectronic-based industrial automation equipment in Brazil by getting technology overseas licensing. The use of licensing was the "natural" solution in face of the technological trajectory shift within the MT sector. It radically changed with the advent of CNC, because "the new paradigm represented a discontinuity in terms of product design and process—a knowledge local companies did not have and which did not exist in other institutions within the country" (Erber and Vermulm, 1993, p. 246). However, market reserve for computer goods showed contradictory effects. On one hand, it stimulated the accumulation of technological capabilities. On the other, it pressed the domestic production costs and, somehow, led to delays in the companies' technological capacity to fast develop microelectronics and automation at global level.[9]

One of the most controversial aspects of the computer policy within SEI industrial automation area is the "potential competitiveness of locally produced products, given the reduced market size in the face of minimum production scales that characterize major producers from developed countries"[10] (Laplane and Ferreira, 1985, p. 112). The price of the national MT/CNC was considered high when compared with that from international competitors, due to low-production scales and to the high price of the CNC unit. "Comparing the prices of the Brazilian products with their foreign counterparts, the differential dropped 1.94 times in 1983 and kept on dropping to 1.63 in 1987. The CNC manufactured in Brazil, with national design, has lower differential price (approximately 1.46 times drop in 1987) than that manufactured under license (2.72 times drop in 1987) [. . .] due to the introduction of new models" (Erber and Vermulm, 1993, p. 193). Another limiting factor to the external competitiveness was the technological gap of the

[9] The possibilities of companies to produce and eventually introduce product enhancements concerned a given technological generation, "but these resources may not be sufficient to enable the development of new generations of products, without resorting again to the transfer of technology from abroad. A similar situation happens in other segments protected by the Market Reserve established by the National Informatics Policy, as in the case of the Brazilian computer industry" (Laplane and Ferreira, 1985, p. 135).

[10] There seems to be consensus on the idea that the current market does not hold four manufacturers (ROMI, DIATUR, DIGICON and MAXITEC + 2 in 1983: MCS Engineering and Zselicks). The future of the companies will fundamentally depend on the rapid expansion of the market in the context of a possible resumption of growth. The sales increase will also depend on the possibility that the manufacturers can reduce their products' prices. In this case, there is a perverse effect between the market size and prices, since Brazilian companies work with reduced scales of production. The result is that the price of the products is higher than the international one. The SINUMERIK-3 system from Siemens, which had in 1982 a Fob price of $ 5000, was sold for $ 15,000 by MAXITEC. The diversification of production lines by producing other automation equipment such as programmable logic controllers (PLC) has been used by companies as a strategy to use the idle capacity and increase their revenue (Laplane and Ferreira, 1985, p. 121). Romi was the only MT manufacturer that had its project approved for manufacturing CNC from technology acquired from the American company Allen Bradley concerning the manufacturing of Mach-3 system for lathes, milling machines and for general use up to 8 axes. The licensing predicted the progressive training in the areas of quality control, software for NC and, finally, electronic hardware (p. 120). Foreign companies have developed such technologies by accessing the knowledge of their matrices, and focused on the production of machining centers and special machines.

sector's process due to low use of both design and manufacturing automation. Even when there was such equipment and routines, few companies used them in an integrated way, such as in CAD (computer-aided design) and CAM (computer-aided manufacturing). Competitive weaknesses in the supply chain also limited competitiveness. In 1989, as indicated by the Integrated Sectorial Program for ABIMAQ-SINDIMAQ elaborated to the Machine Tool Industry, the main factors limiting the external competitiveness of the national MT industry was the cost of electronic and mechanical components that were approximately three times more expensive than that of the imported ones (Erber and Vermulm, 1993, p. 194). The supplier networks in the sector showed little development their products had quality issues and they faced delivery delays. The largest companies' vertical integration softened these problems, but it undermined the level of expertise due to excessive production diversification and dispersion of technological efforts.

The SEI policy within the industrial automation field had limited goals and resources. In some OECD countries, the manufacturing automation policy covered a larger scope due to the rapid and widespread diffusion of electronic automation equipment. It was another instrument used to increase competitiveness in the selected sector. The industrial automation policy had a more restricted feature in the Brazilian case; it was limited in scope and aimed at the technological qualification of companies[11] (Laplane and Ferreira, 1985, p. 137). The MT/CNC improvement protected the MT industry from the recession in the developed countries; however, it widened the technological gap between developed and under-development countries, which remained relatively backward with respect to the application of microelectronics technology in manufacturing.

Araújo et al. (1992) highlights that the progressive targeting of the Brazilian MT exports in the late 1980s towards developed countries such as USA, Germany, Italy and Canada shows that the industry made a significant competitive effort. The growth of the intra-industry trade, the diversification of exports lists and the increase in the exports price reflected "an increase in the technological content of the exported product, and the strengthening of the foreign competition power." (p. 93). At the end of the decade the MT production was consolidated by a more advanced technological level if compared with that of countries such as India, Mexico and Argentina (Cruz, 1993, p. 04). Specialization among MT sector producers in the early 1990s was practically the same as that from the mid-1970s: foreign companies produced highly sophisticated products, such as special MT (e.g., presses). The machining centers and the serial medium sophistication MT/CNC sector competed with national and foreign companies, whereas small and medium-sized national companies offered less sophisticated products to less dynamic sectors.

The interdependence between macro and microeconomic forces, which was expressed in the co-evolution of the institutional structure of the industry and technology changes, guaranteed a high rate of economic growth since the ISI and had set up sectorial incentive regimes characterized by high productive investment opportunities. However, it encouraged vicious sectorial technological regimes as well as informal and passive technological learning efforts that, when active and formal, were restricted to few sectors and companies. Given the acceleration in the industrialization process, the use of foreign licensing and the importation of capital goods enabled enhancing the productive and manufacturing capabilities by means of technological efforts and informal and passive learning processes—the most innovative processes to replace imports. However, these processes were not sufficient for the accumulation of capabilities which were fundamental to the widespread development of innovation products (and process) to the international market. Moreover, even the ISI leading companies sought to be major leaders in order to meet the domestic market demands. The accumulation of innovative capabilities and the technical progress materialization in new products and processes (services, etc.) to the international market resulted from R&D learning processes and efforts to adapt foreign technology based on intense and stable producer-user interactions and cooperation processes set with institutions such as universities that produce and reproduce theoretical and practical knowledge. According to Ferraz (1987), these tech-

[11] Since 1981, the production of MT/CNC exceeded the import of these machines. In 1985, it came to represent about 80% of the units (470) sold in the country. In 1985, it is estimated that 1600 MT/CNC operated in Brazil; more than 50% of them were produced in the Country. "Despite the growth of the established MT/NC industrial parks, their dissemination was incipient" (Laplane and Ferreira, 1985, p. 116). Although it is quite modest and of low pace, the MT NC/CNC diffusion pattern presented analogous movement to that occurred in advanced economies. Due to higher cost, its use was initially restricted to large companies, and, in Brazil, mostly to foreign companies, which, in 1982, accounted for 65% of the installed machines, since they had free access to the knowledge and technology from the matrices. With the resumption of economic growth between 1984 and 1988 from the exporter drive and the apparent success of Cruzado currency, the demand for MT resumed as well as the expansion of the MT/CNC production. In 1988, about 80% of the demand was met by the local production, thus representing approximately 35% of the global sales. In 1989, the domestic production of about 1000 MT/CNC accounted for 44% of the industry sales. At the end of the decade, about 6000 MT/CNC had been installed in Brazil.

nological efforts were restricted to a few sectors, even when they were intentional. The efforts were restricted to a few companies within these sectors, thus they generated a framework of great technological and competitive heterogeneity in the Brazilian industry.

The expansion of the concentrated MT/CNC production and its use brought more technological and competitive heterogeneity to the sector. The Brazilian economy and public finances crises in the 1980s have constrained the formation of a mass market and the development of the Brazilian innovation system. The emergence of microelectronic-based technologies and the low demand for such technologies by the mechanical industries in Brazil helped enlarging the technological heterogeneity among MT manufacturers—to the extent that the market was small and unsophisticated. In addition to the crisis, few companies have managed to step into the new technological trajectory. The economic openness process would enhance the competitive challenges in face of technological and productive efforts required to face the evolving determinations of the sector's technological and competitive trajectory at international levels. Competitiveness was achieved by means of price and technology competition, increase in the production scale, specialized economies and systemic conditions for competitive equality with importations, such as: marketing conditions, financing, taxation, interest rates, exchange rates and industrial policy.

3. Machine-tools sector restructuring from 1990 to 2000: specialization and innovative dynamics

The trade openness experienced by the country since late 1980s found an accommodated industry without stimuli for product innovation and differentiation. Moreover, the paradox was an industry with strong presence of foreign capital, but extremely closed, with little international insertion, and which, by facing the crisis, reversed its expansion strategies in Brazil. The structural reforms of the 1990s consisted of trade and financial openness to increase the economy external integration. The largest real and potential contestability in the Brazilian economy and industry lowered the level and dispersion of protective tariffs, changed the patent legislation, property rights and sought for foreign direct investments. According to the new model, competition would be the central mechanism to stimulate the incorporation of new technologies able to sustain a virtuous circle of increasing productivity and real wages (Carneiro, 2002).

The new model would be a radical alternative to the developmentalism responsible for the limited competition derived from excessive protectionism and state regulations that ensured high profit margins despite the low productivity (Franco, 1998). Inflation stabilization due to Plano Real ('Real Plan'): a monetary, fiscal and exchange rate reform which complemented the frame by trying to gear the economy towards virtuous macroeconomic balance and growth. According to the official rhetoric, the new incentive regime aimed to move the Brazilian economy from an uncertain environment, which was closely regulated by the State, to a more predictable and competitive environment, less State orientated based on new fundamentals of economy—exchange and interest rates, real wages, relative prices—to induce the improvement in business expectations and "animal spirits".

On one hand, the trade liberalization and inflationary stabilization to import raw materials, components, products and high-tech capital goods had positive implications on price stabilization, productivity gains, the reduction in operating and financial costs, i.e., led to gains in the domestic production competitiveness. On the other hand, liberalization and stability weakened productive and technological linkages, decreased spending rates on R&D and demobilized engineering teams which were previously involved with this activity.

The investments done by the companies aimed at reducing costs with the cheapening of highly technologically sophisticated imported capital goods,[12] thus seeking rationalization. The industrial restructuring process, mainly in leading companies, was geared to organizational rationalization and modernization. It led to job reduction, quality

[12] Since the early 1990s with PICE (Industrial and Foreign Trade Policy), and also later, between 1995 and 2002 (Barros and Goldenstein, 1997), the economic policy was guided taking into account the importance of importing capital goods. In both periods, the governments shared the view that although these imports were expensive in the short term, in terms of an international current account, thus increasing the need for compensatory entries in the capital account, they constituted a strategic element to increase the Brazilian economy productivity. According to Chudnovsky and Erber (1999, p. 584), these would be the "necessary and sufficient condition to, in the long term, expand exports, reduce the current transactions deficit and, simultaneously, promote the economy growth". One can also say that there was a continuity of this policy between 2003 and 2010, because it also continued with the "ex-tariff" regime for the imports of capital goods. The "ex-tariff" regime reverses the balance of power that existed between buyers and suppliers in the similarity regime, because the machines can be imported with zero rate if the buyer informs that there are no similar national products.

improvement, costs reduction and increased productivity by modernized plants. Productive restructuring main features were: de-verticalization, specialization and flexibilization, all based on conservative business strategies such as the abandonment of high technology product lines in favor of more standardized ones, reduced levels of vertical integration consubstantiated in the replacement of the local production of parts, spare parts and components by imported ones, i.e.: a reversed substitution import process, a phenomenon known as "downgrading". In parallel, processes were reorganized and adjusted. There were plant layout changes, reduction in hierarchies and in organizational levels, as well as new sectoral and intra-sectoral specialization strategies to achieve productive gains, allocative efficiency, and greater external integration within the Brazilian industry. It resulted in reduced inter-sectoral relations in the Brazilian economy and disrupted in a growth pattern based on the densification of departmental relationships. Companies also neglected oriented efforts to develop new products, R&Ds and brandings. The structural changes led to the modernization of productive capability in the largest companies and of the economic structure, but they did not lead to increase in innovation capability at the micro-level or in the economy as a whole (Carneiro, 2002; Miranda, 1996).

As for the institutional changes in the MT industry, the trade reform and the openness process in the first half of the 1990s eliminated non-tariff restrictions (National Similar Product Law) and sought to reduce tariffs and their dispersion in the importation of capital goods. In practice, according to the ex-tariff regime, machines could be imported with zero tariff rates if the capital goods buyers reported that there were no national similar products. In 1990, the rate of conventional MT was of 40%, and of MT/CNC, 65%. In 1996, the rate applicable to all kinds of machines was of 17%, but it increased to 20% in 1997, due to the Asian crisis. In 2001, the rate was reduced to 14%, due to the convergence process established among MERCOSUR countries (Chudnovsky and Erber, 1999, p. 589). The automotive regime which was used as sector policy also had implications in the MT sector, because the automotive complex constitutes the main MT market, especially among more complex products, according to a technological point of view (p. 593). The regime reduced MT tariffs (2%), and at the same time, it forced automakers and component manufacturers to keep the ratio between local purchases and capital goods imports, mainly MT.

Among the expected effects of the opening, there was the fact that it would allow the importation of parts, spare parts, electronic and mechanical components, which would enable enhancing the quality and performance of MT/CNC as well as the decrease in their production costs and prices. However, "The tariff levels applied to important MT components such as bearings, engines and CNC units are equal to or higher than those applied to the final product, thereby lowering the effective protection given to the MT production" [. . .] "Differences between national and international taxes reduce competitiveness of local machines against their foreign competitors" [. . .] "The highest financing cost for national MT purchasing favors the imports" (p. 590). Accordingly, the openness exposed the sector to a systemically set competition. In the early 1990s, "the economic crisis has reduced the availability of funding, increased interest rates, increased tax burdens and the exchange rates suffered great instability with overvaluation trends" (Erber and Vermulm, 1993, p. 198). These systemic conditions remained in the 1990s and 2000s and held a lower or higher degree of intensity due to times of exchange rate depreciation, such as the period between 1999 and 2003, and/or improved marketing conditions due to the decline in the Finame Leasing interest rate in 2005 and the increased demand between 2003 and 2008. However, throughout the period, real interest rates of funds borrowed in Brazil were much higher than the external ones, mostly due to the overvaluation of real effective exchange rates.

Structural reforms and a bad planned economic openness process developed a highly selective environment and, along with changes in the technological paradigm, enabled a productive restructuring process that led to market concentration and to the consolidation of national and foreign MT manufacturers who had greater technological and financial capabilities as well as production plants favorable for increasing economies of scale.

Increasing productivity, reducing costs, and the expansion of the complexity and value of the offered products (best price/performance ratio) was more pronounced in leading companies[13] because of the adoption of organizational

[13] The "process transformations tended to be more radically introduced in companies leading the sector, many of which had ISO 9000 certification. Among the leaders, the subsidiaries were connected to their headquarters through electronic means, including the development of machine designs, whereas the national leading company that produced serial machines concentrated its production on a smaller number of lines, thus managing to save resources by making its machines in an international scale (Chudnovsky and Erber, 1999, p. 599). The national leader, Romi, sold, on average, about 1300 CNC lathes per year between 1995 and 1997, which have accounted for more than twice the minimum international scale. Between 1990 and 1994, there was the trend of increasing from 10% to 24% the participation of the MT/CNC produced by the MT industry, whereas their production value increased from 45% to 54%. Nardini, a company founded in 1908 and now part of the DebMaq Brazil LTDA group, which disputed

changes associated with headcount reduction to rationalize production; changes in production processes targeting reduced costs; quality and productivity programs, and new routines linked to procedures, controls and best management practices; reduction of administrative levels and the centralization of project activities; the increasing importance of microelectronic automation in manufacturing and designing processes just in timing processes; production cells; and the increased acquisition of parts and components.

The MT industry trajectory, in the last three decades, has sought the technological concentration and consolidation of leading, foreign and domestic companies, which have acquired R&D capabilities and which have constantly invested in innovation. The available information indicates that the leading companies fulfill most of the domestic market demands and almost all exportation ones. These companies believed that the combination of investment in R&D, licensing and the development of their own technologies showed to be a consistent technological strategy for the long-term growth. That would be the competitive strategy of companies categorized as "leaders" by Erber and Vermulm (1993) and Vermulm (1996). However, there are still differences among the market sectors supplied by foreign companies and leading national companies. MT foreign manufacturers focus on producing multi-station machines and machining centers for multinational corporations, whereas local companies produce CNC lathes as well as turning and machining centers for local companies.

Small manufacturers of serial goods were the most affected by the trade liberalization. Their production scale would not economically face production diversification. There were also the manufacturers of medium complexity level goods produced in batches, which price/performance mix would not be competitive against the imports. Other companies have left the industry or became suppliers, representatives, etc., due to various reasons: low economic growth and insufficient investment in the 1990s; late adoption of the electronic paradigm; high productive diversification and/or because they had low production scales and financial issues. These companies presented lower accumulated R&D capabilities and some of them sought to achieve process innovations and organizational changes aimed at reducing costs. However, these innovations and changes were unfortunately insufficient against the imports competition and the new competition regime. Erber and Vermulm (1993) and Vermulm (1996) characterized the competitive strategies set by these companies as "subservient" and/or "passive survival."

Several small domestic companies operate in a third group of conventional deformation MT manufacturers. This group was apparently less affected by the economic liberalization and by the radical change in the technological trajectory of the sector, probably because the technological transformation in this sector was weak, and because their products were targeted to undemanding market niches, in which the competition with imports was not intensely felt.

Therefore, companies with deep knowledge and great financial strength excelled for productivity gains and competitiveness through specialization, larger production scale and sales volume. In general, these companies underwent a specialization process, and concentrated their production in lower number of MT families with better quality, higher technological content and lower prices, thus complementing imports and/or licensing goods. Specialization and exports fulfilled the complementary relationship by means of the international trade of products such as presses, machining centers and CNC lathes.[14]

with Romi the leadership in the production of conventional lathes and CNC, ran into difficulties for a number of reasons. Nardini's exports had been very affected by the crisis and downturn of the Mexican market in the early 1980s. The company also took too much time to adopt the electronic paradigm. Problems in the domestic market up to 1997 had aggravated the company's situation, whereas its exports targeted the USA. Between 1995 and 1996, about half of its exports corresponded to MT/CNC.

[14] All MT positions or groups of products (based on the MT codes and classification according to the Harmonized System of the Mercosur Common Nomenclature (MCN) at 4 digits) showed net imports between the annual averages from the early 1989s/1990s up to 2005/2006. In this period, there were substantial changes in the Brazilian MT exports structure. In 1989/1990, about two-thirds of the exports consisted of lathes, most of them conventional. From 1992/1993, deformation MT exports increased, compared with the biennium 1989/1990, from about 13%, in 1989–1990, to about 50% MT in the following average biennia. There was also the increase in exports of machining centers when they came to represent on average US$ 48,921 million between 2003 and 2004, approximately 35% of total exports. The CNC lathes exports surpassed the exports of conventional lathes in 1994. In 1995/1996, these products represented about 68% of the category and, between 2002 and 2006, about 83%. Brazilian exports (average of the years 2002–2006) were allocated to Europe (44.7%), mainly to Germany (25.9%), country of origin of the companies that had more branches in Brazil. The United States accounted for 19%, Latin America, 18% (mainly Mexico, 10.5%, and Argentina, 3.7%), whereas the exports to China accounted for 9.9%. Exports to Germany were concentrated in machining centers, CNC lathes and other deformation MT. As for the United States, they were concentrated in CNC lathes, presses and rectifying MT, and machining centers. The MT imports structure also underwent changes, homologous to changes in the structure of exports, but it is possible to notice that imports were always less concentrated than

The best performance of companies that have invested in the accumulation of technological capabilities according to the mechanical paradigm and made significant efforts towards the development and production of numerical control and MT/CNC production enabled them not only to enter, but also to remain in the new technological trajectory. The best competitive performance of companies that made technological efforts and learning in R&D, before and after liberalization, corroborates the hypothesis by the Neo-Schumpeterian theory which states that the cumulative knowledge accomplished through their learning, research, development and innovation processes gives them dynamic capabilities to face an evolving technological regime.

The new competitive regime resulting from the economic openness also favored MT users because, given the diversity of machines within the world market and the better flow of information among price/quality/performance and possibilities of imports, there is an increased degree of freedom for choosing the equipment. The economic openness and the restructuring of companies seeking for production efficiency led to the convergence of product prices, but the domestic technological gap in the sector is still noticeable at an international level. The technological gap tended to persist after the opening. The technological and competitive heterogeneity in the MT sector also tended to increase. The technological gap remained after the economic openness and the technological and competitive heterogeneity in the MT sector increased.

This competitive heterogeneity has as its underlying cause the technological heterogeneity regarding the different technological learning and the innovative efforts undertaken between both the MT manufacturers and users. Sophisticated domestic buyers of capital goods may have strong influence on innovation patterns, given their important role in the development, testing and modification of such goods, which enables information flows, tacit knowledge and skills. Therefore, according to Smith (1776), only the size of the demand is important, however, we believe that its structure and level of sophistication are also relevant. As the demand structure and users' technological capabilities are crucial to the MT companies, the MT manufactures' market structure and technological performance are endogenously generated by three groups of fundamental determinants: the sources and nature of technological opportunities; the nature of user's requirements, the actual and potential markets; and the companies' ability of appropriating the profits from private investments in R&D (Dosi et al., 1993, p. 106).

Information from PINTEC (Table 1) about the rate and types of innovation in the manufacturing industry and in selected sectors that possibly represent the highest proportion of MT demanding sectors reveal that the companies undertake more process than product innovation, and they prefer to have incorporated technology in machinery and equipment rather than investing in R&D activities. The preference for process innovation aimed at reducing costs and increasing productive efficiency, by associating it with the acquisition of capital goods and with the productive plant upgrading. The reduced effort by the Brazilian industry regarding R&D results in companies' partial knowledge on their own production processes and in their limited innovative capabilities to improve and adapt technology to their needs and to demand trends. Furthermore, the spending on manufacturing industry innovative activities in 2005 was of approximately 2.8% in net sales revenue (NSR): R&D was 0.66% of the NSR, acquisition of machinery and equipment amounted up to 1.3%, and other expenses in innovative activities represented 0.8% of the NSR. The distribution of expenditures with innovation within the manufacturing industry in 2005 ranged 23.5% in R&D, 48% in machinery and equipment and, regarding other expenditures, they ranged 28.5% and were especially spent with industrial design of machinery and equipment. Likewise, in 2005, of the entire manufacturing industry, approximately 27% of the companies conducted process innovation, and little less than 20% of them made product innovation. Innovative companies in metal products manufacturing, machinery manufacturing, electrical equipment and materials sectors and in the manufacture and assembly of automotive vehicles, etc. also performed more process innovation than product innovation and they spent proportionally more on purchasing machinery and equipment than in R&D, with no exception. An expansion in the manufacturing and assembly of automobiles, trucks and parts sector and in its three subsectors reveals that spending on R&D and the acquisition of machinery and equipment, were, respectively, in 2005: 33.2% and 34.5% for the manufacture of automobiles, vans, trucks, etc.; 19.1% and 32.1% for the manufacture of cabins, bodies and reconditioning of engines; and 15.7% and 68.4% for the manufacture of parts and accessories for

exports, thus reflecting, among other features, the development degree of the national supply. Although the imports of all product groups showed an increase in value, those that stood out within the total ratio were presses, machining centers (which doubled their importance between 1989/1990 and 2005/2006), CNC lathes and rectifying and burnishing MT. Brazilian imports (average of the years 2002–2006) come mainly from developed countries, notably Germany (24.6%), Japan (16.5%), Italy (14.5%), USA (9.0%), Switzerland (7.9%) and Spain (4.3%).

Table 1
Rate and types of innovation in the manufacturing industry and selected MT users sectors—2005 (% of the companies from the sectors).

Industrial sectors	Companies that have implemented innovations in							Total of companies
	Innovative companies	Product	New product to the company	New product to the national market	Process	New process to the company	New process to the national market	
Manufacturing industry	33.6	19.8	16.9	3.3	27.0	25.6	1.7	89,205
Manufacture of metal products	31.1	17.5	15.0	2.7	25.5	24.4	1.2	8773
Manufacture of machinery and equipment	39.3	29.8	21.4	9.0	23.3	20.9	2.6	5799
Manufacture of office machinery and computer equipment	69.2	64.5	530	14.7	44.9	40.8	4.6	211
Manufacture of electric machinery, equipment and material	45.7	29.8	21.7	10.4	31.3	27.6	4.0	1892
Manufacture of electronic material and communication equipment and appliances	56.9	44.2	27.3	18.2	37.6	34.1	4.2	644
Manufacture of medical equipment, precision instruments, industrial automation equipment and clocks	68.0	54.4	43.6	12.0	38.6	34.2	4.4	921
Manufacture and assembly of motor vehicles, trailers and bodies	37.0	19.4	15.1	5.1	31.7	28.9	3.8	2214
Manufacture of other transport equipment	34.8	26.1	19.5	7.6	22.9	17.6	5.7	589
Total of MT innovative users	7978	5292	4078	1364	5656	5189	525	20,893
Innovative companies (% of the total)	38.3	25.4	19.5	6.5	27.1	24.9	2.5	100.0

Source: IBGE/PINTEC, 2005.
Note: PINTEC covers companies with ten or more employees.

vehicles. Therefore, the innovative manufacturers of machinery and equipment (the sector of capital goods)—which together with the abovementioned sectors are supposedly MT users, about 83%—performed more product innovations than process innovations; but, in 2005, they also concentrated greater innovative activity in the acquisition of machinery and equipment (43.6%) than in R&D (13.3%).

Therefore, the structure of the MT demand in Brazil is mostly composed of sectors characterized as medium-high technological intensity, mainly in regards to the electro-metal-mechanical complex. It can be inferred that a proportion of innovative companies from the following industries demand more sophisticated MTs: automotive, aeronautical, manufacturers of medical equipment and precision instruments; and other 'specialized suppliers' which are leaders in the capital goods sector (which invest in R&D and differentiate products), and leading manufacturers of consumer durables, whether mechanical, electrical and transport equipment. Accordingly, the mechanical, transport equipment and electrical equipment complexes account for about 42% of the companies that innovate and produce differentiated products, about 390 companies employed 270,000 people in 2000.[15] According to the competitive strategy, companies that innovate and differentiate products are understood as those that perform product innovations in the market and get premium price above 30%, in their exports. Therefore, they generate more value and cover the most dynamic sector because they tend to capture a larger share of the income generated by the industry when comparing them with other exporters of the same product.[16] Another 17% of the companies in these sectors are classified as specialized in standardized products. There are about 1540 companies employing 280,000 people. It is understood as specialized in standardized products manufacturers those companies which competitive strategy requires focus on cost reduction and companies that tend to be updated in terms of operational characteristics such as manufacturing, production management, conformation quality management and logistics – all imperatives for sustaining relatively lower costs –, but on average, they are outdated in terms of other competition tools such as R&D, marketing and brand management, if compared with the previous category. Eight per cent (8%) of companies that do not differentiate products and that have lower productivity were from the analyzed sectors and comprised a total of 1170 companies that employed approximately 92,000 people, 38% of the companies from such complex and 15% of the employed staff. Companies that do not differentiate products and that have lower productivity encompass the typically non-exporting ones, which are smaller and may even innovate, but that are less efficient in different senses. Companies that are capable of capturing spaces in less dynamic markets through low prices and other possible advantages.

It can be inferred that companies' innovating and differentiating products import MT with high technological content and/or interact with foreign manufacturers through special MT orders, whereas those that are specialized in standardized products—most part of the users—use medium sophistication MTs. Therefore, most of the production, export and domestic consumption of MT correspond to intermediate technological content. It is a productive specialization that reflects the demand structures and the requirements of local/national users that mostly ask for products from the technology and price mix. As the economies of scale are very important to serial production, the internal and external markets are complementary and specialization is endogenous, according to Dosi et al. (1993) and Malerba (2002). However, there is a large gap between technological efforts and competitive strategies among companies in the electro-metal-mechanical complex sector. It is similar in the Brazilian manufacturing industry as a whole. Such gap is marked by a large sectoral and intra-sectoral heterogeneity. Companies that do not differentiate products and that have lower productivity demands and low sophistication MT—a fact that helps explaining the reasons for the low technological efforts in R&D by companies with imitative and dependent strategies, or "subservient" strategies and/or "passive survival" strategies (Erber and Vermulm, 1993)—also focus on process innovation and on the acquisition of new MTs in order to possibly compete via price. Since users also spend more on innovative activities related to the absorption of embedded knowledge aimed at process innovation, we come across a little virtuous circle for systemic innovation.

Therefore, the innovative dynamics analysis shows that the MT supply and demand are fragmented and the innovative efforts and technological capabilities to perform innovation both between manufacturers and users are heterogeneous. It can be inferred that the leading companies that cooperate and invest in R&D and the foreign companies seek-

[15] Calculations of the number of workers performed from Table 1, pages 262 and 263 by Kupfer and Rocha (2005).

[16] On the categorization of companies into three groups, from the empirical point of view, by taking into account their competitive strategies and their patterns of technological efforts, see the work by De Negri et al. (2005, p. 07–08).

ing knowledge from their matrices are more aggressive in their innovative strategies and they are also the most competitive ones in the industry, because they have the capacity to improve and adapt technology according to the resources available and to the internal and external target markets. Thus, in the "imitating" companies, innovation processes take place by copying products and technologies from other companies without conducting routine R&D activity. Indeed, these companies do not develop skills and abilities to closely follow the technological dynamics of the sector.

4. Final considerations

Technical progress is an evolving, changing and idiosyncratic phenomenon, and its materialization occurs in the form of new products, processes, services and new forms of industrial organization. Although productive capacity is essential for technical progress realization, it is only achieved through R&D and from licensing and cooperation between producer-user and suppliers, with the science and technology systems (S&T) from different technological learning processes. Some sectorial technological regimes emerge or are configured from the interaction between the macro and microeconomic spheres expressed in the co-evolution of institutional, economic and technological policies and changes. Such regimes can be virtuous or vicious depending on the companies' technological efforts, the characteristics of competitors, suppliers and customers, the type and cumulativity of knowledge, the appropriability conditions of the profits from innovations, the size, structure and sophistication of the demand and on the institutional setting of the national innovation system.

The technological discontinuity imposed by the new paradigm represented an ultimate change for both product development and the way of organizing the artifact production process. The change of technological paradigm involved an evolutionary process configured in specific experiences and skills to solve specific problems regarding the search and innovation for new knowledge and information technology applications. The gradual development of MT/CNC changed the production methods, which now allow associating automation, accuracy, integration and flexibility of production systems, and in which economies of scope are important sources for the economies of scale. The paradigm shift led to a change in the trajectory and technological regime of the industry by increasing opportunities for investment in new technologies. At the same time, the basic knowledge of the industry has evolved into greater coding, complexity and integration with scientific knowledge, thus reinvigorating the companies' technological capabilities accumulated with more systemic and complex knowledge basis. Therefore, the sectoral competition pattern has radically changed due to the need for growth in production scales, increased investments in R&D, the increasing importance of automation and microelectronics integration in the manufacturing and design processes, and to the intensification of relations between suppliers and users.

From the user's perspective, the analysis suggests that the different innovative efforts among the companies in the MT sector find their counterpart in the structure of the demand and in the user's innovative efforts. Therefore, there is a fragmentation in the dynamics of innovation and production at sectoral level. There is also the reproduction of an innovative system that finds its match in the fragmentation of the demand and in the user's sophistication level. Accordingly, the technological and competitive heterogeneity among MT manufacturers has as its basic causes not only on the different innovative efforts among them, but also on the low efforts by MT demanders, especially regarding their revealed preference for process innovation aimed at low costs and not at product innovations that would aim at leadership and at the opening of new markets, fact that would require more specialized and complex MT. Since, at last resort, users select the innovations in the market, low innovative efforts to build their technological capabilities keep, at an international level, the heterogeneity and relative technological gap among MT manufacturers in Brazil, even those who remain competitive in the market in which they operate. Additionally, the institutional dynamics of the ISI period helped defining and propagating the structural heterogeneity that characterizes the sector, the industry and the Brazilian economy.

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