New Economic Policies and the Diffusion of Machine Tools in Latin America

LUDOVICO ALCORTA
Maastricht School of Management, Maastricht, The Netherlands

Summary. — This paper argues that both old and new economic regimes in Latin America only partially ensured the successful diffusion of machine tools in the region. Import-substitution policies focused on suppliers, with resulting advances in domestic imitative, adaptive and innovating capabilities, but at high cost for users in expensive and technically inferior machine tools. The New Economic Model (NEM) focus on the user has provided wider availability and lower price of technologies, with resulting increases in productivity and efficiency, but domestic suppliers cannot establish themselves nor make the technologically crucial jump into the electronics era. The paper suggests an approach focusing on the joint upgrading of users and suppliers, and proposes policy initiatives aimed at addressing market failure and “systemic” issues.

1. INTRODUCTION

Machine tools are at the heart of any country’s technological capabilities. They embody the country’s accumulation of the most advanced scientific and engineering knowledge of mechanics, nowadays increasingly used in the context of rapidly emerging findings in the field of electronics, and its capacity to develop complex mathematical models and software programs. The technological complexity of machine tools implies at the same time a deep understanding of the full range of manufacturing activities, including simple human motions and their replacement by machine functions, basic and advanced operating processes, and how to design, research and develop sophisticated products (Chudnovsky & Nagao, 1983). Technological advances in machine tools usually have the highest possible impact on the productivity of economic systems because of their potential to spread to all sectors (Rosenberg, 1982).

The adequate diffusion of machine tools, or computer-numerically-controlled (CNC) machine tools as they are known today, is therefore, a major factor in improving the productivity and reducing the costs of the activities that use them. Whether domestically manufactured or imported, successful industrializing countries have always ensured the availability of necessary machine tools. Yet, at the same time, the specificity of many production processes and the widespread externalities arising out of domestic manufacturing of machine tools calls for their local production. Therefore, society needs to maintain a balance between users that require appropriate, advanced, efficient and cheap machine tools and producers that want to create and capture arising externalities, a process that normally takes significant time and learning.

During the 1960s and 1970s several Latin American countries attempted to develop a local machine tool industry as part of their import-substitution industrialization strategy and restricted importing foreign technologies. Subsidiaries of foreign machine tool manufacturers as well as domestic producers of machine tools working under license established production facilities throughout the region. Although progress was achieved, particularly in the mechanical engineering dimension of machine tool manufacturing, producers could not keep up with the rapid advances in electronics, resulting in substandard or expensive machine tools and dissatisfied users. Following policy changes toward domestic machine tool manufacturing, much of the industry closed and, with a few exceptions, local machine tool demand is today mainly sourced from abroad.

The purpose of this paper is to examine the diffusion of machine tools in some Latin American countries and to discuss whether the
The New Economic Model (NEM) has allowed society to benefit from improved technologies and therefore higher productivity and to reap the gains from knowledge externalities. It will proceed as follows. The next section will provide a conceptual discussion of the diffusion process. Section 3 analyzes the diffusion of machine tools during import-substitution. Section 4 examines changes in public policy relevant to the diffusion of machine tools, mainly in the areas of trade, industry, finance and technology. Section 5 analyzes machine tool diffusion since the new policies were introduced. Some policy suggestions are made in Section 6.

2. THE DIFFUSION OF NEW TECHNOLOGY

The literature on economics of innovation and technical change usually distinguishes between invention, innovation, diffusion and adoption. Invention refers to the generation of new ideas and artifacts while innovation alludes to the first commercial use or application of inventions. Diffusion, in turn, is defined as the spread of innovations, products or processes, throughout an economy while adoption concerns the incorporation of those new products and processes into individual firms (Diederen, 1993; Metcalfe, 1988; Rogers, 1995; Thirtle & Ruttan, 1987). Adoption focuses, therefore, on the decisions of individual firms to incorporate technology while diffusion is an “aggregate” phenomenon centered on how innovations and new technologies are transmitted across an economy and through time.

In essence, diffusion is a process involving choices, simultaneous interactions and outcomes between suppliers and users which, in turn, are influenced by technological, economic, institutional and individual considerations (Karshenas & Stoneman, 1995; Stoneman, 1995). Despite the multiple factors at play and its apparent chaotic nature, the process would seem to have an internal logic and regularity, i.e., where there are established relationships and feedback between decisions by suppliers and users, although the extent of the impact of each decision cannot be determined a priori (Diederen, 1993). Indeed, while specific relationships and feed-backs are determined either by random or causal interactions, the accumulation of effects will normally result in a sigmoid or S-type diffusion curve whereby the number of firms using a technology and the intensity of its use increase over time. When causal relationships are at play, diffusion can also be seen as a learning process where developments by a supplier or the adoption by a user lead to cumulative experiences that are continuously fed back into the process for the benefit of other suppliers and users.

Stoneman and Diederen (1994) argue that for society there is a welfare optimal diffusion path, on which the rate of adoption maximizes the present value of the intertemporal stream of social costs and benefits. By the same token it can be argued that, at any moment in time, welfare optimal diffusion is achieved at the point where the marginal social benefit to be gained from the use of a technology is equal to the marginal social cost of producing that technology. Yet, welfare optimal diffusion is unattainable because technology markets cannot operate perfectly. Market failure arises for three reasons. First, due to information asymmetries and deficiencies, costless knowledge is created during diffusion. Second, particularly at the beginning of the process, both sellers and users are few and the supplying industry is concentrated, affecting the incentives to innovate and adopt new technologies. Third, a firm’s adoption of a technology may result in positive or negative externalities through its impact on the adoption decision and profitability of other enterprises. Stoneman and Diederen (1994) add that diffusion goes beyond a market-mediated process and involves a number of additional issues and decisions. These include the adaptation of the new technology to individual firms’ requirements and of the firms’ organization to the new technology, undertaking research and development (R&D) in order to engage in adoption, the competition from related technologies and firms’ capacity to learn.

While optimality is unattainable or at best can be considered as a possible benchmark, diffusion can clearly vary in intensity. At one end of the spectrum, diffusion can be characterized by a virtuous process of knowledge accumulation both in users and producers that feeds into productivity increases and cost and price reductions and then back into incremental changes in the initial innovation, further increasing productivity and reducing costs and prices. As diffusion proceeds, specific user demands become more stringent forcing producers to improve even more upon their innovations and resulting in further improve-
ments in price, performance, quality and reliability of the innovation (Freeman & Soete, 1997). At the other end, there is a vicious process of little or no knowledge creation, few linkages and interactions and poor productivity increases and cost reductions. Diffusion can, therefore, be “shallow” or “deep” depending on its effect on society. In between, there is a range of possibilities with varying degrees of societal impact: only some producers raise their innovativeness and capture externalities and or only a few users benefit from rising productivity.

Carlsson and Jacobsson (1994) suggest that ensuring successful technological diffusion requires a range of systemic factors. First is the institutional infrastructure, including academic and technology supporting institutions, which provide adequate manpower, research and scientific and experimental knowledge. Second is a combination of networking elements including “bridging institutions” which are capable of scanning, monitoring, adapting and experimenting with technology. Also necessary are close user–supplier linkages, which allow the development of problem-identifying and problem-solving capabilities that are crucial in the diffusion of advanced technologies. Third is a critical mass of users and producers that can create the minimum density of relationships required to generate knowledge. Fourth is economic and technical competence in terms of price, capacity to generate businesses and performance parameters. Carlsson and Jacobsson (1994) argue that it is the role of government policy to help develop these factors and hence ensure maximum social benefit is obtained.

3. DIFFUSION OF CNC MACHINE TOOLS DURING IMPORT-SUBSTITUTION IN LATIN AMERICA

(a) The diffusion process: local supply

Local production of machine tools started in Argentina and Brazil around the 1930s and in the rest of the region between the mid-1950s and late 1960s. In its origins the industry aimed at maintenance departments and machining services (De La Cruz, 1989, UNIDO, 1990a; Castaño, Katz & Navajas, 1986; Unger, 1994; Vermulm, 1994). During 1950–60 machine tool manufacturing expanded significantly, propped by the demand of the emerging vehicle industry. Foreign subsidiaries began entering the machine tool markets of the largest economies, often following automobile assemblers, while local producers attempted to upgrade their products through licensing. In Argentina, by the mid-1950s there were 150 manufacturers of machine tools producing around 10,000 units, of which 20% were lathes and 40% were universal drills (Castaño et al., 1986). In Brazil, in 1961, there were around 300 machine tool manufacturers producing 15,517 conventional machine tools of which, the highest level during the 1960s, 82% were of the metal-cutting type (Vermulm, 1994). In Mexico, in 1966 there were around 30 manufacturers of conventional machine tools and a few others producing specialised equipment (UNIDO, 1990b).

In the 1970s the diffusion of machine tools throughout the region accelerated. By 1971, Brazil was producing around 15,312 conventional machine tools while by 1979 this number had increased to 72,627 (Vermulm, 1994). By 1973 Argentina was already producing 22,500 conventional machine tools while the average production for the 1970s was around 16,000 units (Chudnovsky, Lópe & Porta, 1992). Smaller countries in Latin America also expanded machine tool output. In 1968, Peru did not produce machine tools but by 1975 output had already reached US$1.5 millions, mostly as a result of a licensing agreement from a Rumanian manufacturer, while during 1970–80 employment in Colombia’s machine tool industry increased by more than 50% (Berrios & Sagasti, 1990; Fundación Científica de Tecnológica, 1990; UNIDO, 1990a). Adverse macroeconomic conditions, including falling demand and foreign exchange limitations, meant that during the early 1980s machine tool output fell drastically and factories had to close down throughout the region (Table 1).

Despite growing availability of local machine tools during the import-substitution era, users faced a number of problems. The prices of the machine tools were exceedingly high as compared to equivalent models produced by developed countries’ or Taiwanese and South Korean competitors. UNIDO (1990c) compares the prices of the numerical-controls available in machines tools in the early 1980s and finds differentials of 1.6–1.9 times depending on the year. UNIDO also finds that locally designed products tend to narrow the price gap while licensed products actually increase it.

According to Chudnovsky et al. (1992) and UNIDO (1990c) the reasons for the high prices
of domestically manufactured machine tools include, the lack of scale economies and production specialization. Even though machine tools, especially of the conventional type, have traditionally been manufactured in firms with few workers, these firms are normally focused on a few components or a narrow set of products, allowing them to produce in large numbers. Indeed, the international machine tool industry was highly fragmented with large numbers of specialized subcontractors and final products, which allowed the industry to reduce down-times and increase capacity utilization and thus efficiency. Such specialization was not present in Latin America but rather firms undertook the production of as wide a range of products and components as possible. A second, and related, factor is the high costs of components. Local components were expensive due to their conditions of production while imports of foreign components were normally in small orders increasing transport costs and preventing from volume discounts. They also had to pay import duties, which could be as high as 30% depending on the country. Third, there was little competition among suppliers, arising from import restrictions and market segmentation between foreign subsidiaries and domestic producers.

Yet, expensive as local machine tools were, their manufacturing allowed firms partially to advance along complex technical learning processes. Nowhere is this better illustrated than in the cases of Turri SA, an Argentinean manufacturer of lathes studied by Castro et al. (1986), and of Oerlikon Italiana SA, a Mexican machine tool producer studied by UNIDO (1990b). In terms of product development the firms moved from merely copying foreign designs to higher degrees of local design and eventually to an own-design, numerically-controlled lathe. Initially, as most machine tool companies in Latin America, Turri SA and Oerlikon Italiana SA licensed foreign designs but these were often simplified to cope with local circumstances, so licenses were eventually abandoned. A machine tool had a significant degree of local content as most components were built in-house. In terms of process development there were significant changes in the machines used in the production process, which also had to be adapted to the specifications of the new product designs. In addition, it was necessary to train and specialize the personnel in specific activities previously unknown to them as well as to increase drastically the ratio of technical and engineering personnel. New functions and departments had to be established including technical assistance, planning and quality control. Learning processes involving different stages of knowledge creation, including imitation; product, process and organizational adaptation; and, eventually, own design and engineering were common among Latin American producers up to the early eighties (Chudnovsky & Nagao, 1983; UNCTAD, 1985a).

(b) The diffusion process: imports of machine tools

It is commonly believed that during the import substitution era there was hardly any access to foreign machine tools, but this was not the case. A significant amount of imports

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<tr>
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<td>4</td>
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<td>Mexico</td>
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Source: Own elaboration on the basis of American Machinist data.
complemented local production although governments restricted the timeliness and extent of competition of foreign products through a combination of tariff barriers and import licensing mechanisms. Table 2 shows the worldwide level of consumption of machine tools. Latin American local consumption has been, on average, double local production (Table 1), which suggests that foreign machine tools were also locally available.

Indeed, national data confirm this. In 1971 Brazil was importing 4,058 machine tools while by 1978 this figure had increased to 10,162 or 30% of the total apparent consumption in units. By value, however, imports accounted for 49% of total apparent consumption in 1978, as imported machine tools were far more sophisticated than locally produced ones (Vermulm, 1994). The share of imports by value in total apparent consumption fell, however, more than proportionately during the early 1980s as companies responded to shrinking demand by cutting down on investments on most expensive equipment and purchasing only machine tools that were strictly necessary. By 1985, the share of imports in total apparent consumption in Brazil had fallen to 10%. In Argentina in 1974 imports were 7,763 units accounting for around 34% of total apparent consumption while 10 years later the equivalent figures were 1,765 and 59% (Chudnovsky et al., 1992). In Mexico and Peru, during the 1970s and early 1980s imports accounted for around 90% of total demand (Berríos & Sagasti, 1990; Mercado, 1990; Unger, 1994).

While imported machine tools were locally available, actually getting them was neither cheap nor easy. To begin with, they were subject to tariffs. Argentinean tariffs averaged 80% during the 1960s, falling to around 40% in the early 1970s and 25% in the late 1970s (Chudnovsky et al., 1992). Brazilian tariffs, although also falling during the 1970s, stood at over 55% for most of the 1980s (Suzigan & Villela, 1997). Mexican tariffs by contrast were only 10% during the 1950s but increased consistently during the early 1980s until an average of 50% for imports of machine tools similar to those that were manufactured in Mexico (James, 1991; Lorentzen, 1984).

More important than price was availability. Although imported machine tools would eventually be available, actually getting them was always fraught with problems. Machine tool imports were normally subjected to an import license. Although licensing requirements varied across countries and time, they normally involved justification of the purchase, proof of lack of local production and a certificate of availability of foreign exchange. The process was cumbersome, subject to delays and often needed the approval of local manufacturers, who were afraid of foreign competition, particularly from cheap machine tools coming from the Far East. In fact, only large, well-organized companies, normally government or multinationals firms, had access to foreign equipment but not always at the required moment. Even large firms, however, often had to compromise on technical features, as information was not fully available due to the small number of foreign machine tool representatives, or had to settle for technically inferior local machines due to timing. Small firms’ access to advanced machine tools was extremely limited.

### Table 2. World metal-cutting machine tool consumption, 1973–96 (US$, millions)*

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<td>24,971</td>
<td>20,180</td>
<td>42,422</td>
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<td>Developed countries</td>
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<td>16,111</td>
<td>12,736</td>
<td>30,271</td>
<td>25,053</td>
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<td>Western Europe</td>
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<td>7,539</td>
<td>4,961</td>
<td>17,025</td>
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<td>North America</td>
<td>1,581</td>
<td>5,867</td>
<td>4,285</td>
<td>5,537</td>
<td>8,515</td>
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<td>Far East</td>
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<td>2,705</td>
<td>3,490</td>
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<td>Eastern Europe and Russia</td>
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<td>6,271</td>
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<td>Asia</td>
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<td>Latin America</td>
<td>256</td>
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<td>344</td>
<td>795</td>
<td>1,359</td>
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<td>Brazil</td>
<td>117</td>
<td>419</td>
<td>152</td>
<td>482</td>
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<td>Argentina</td>
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<td>118</td>
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<td>Mexico</td>
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<td>Africa</td>
<td>44</td>
<td>230</td>
<td>81</td>
<td>132</td>
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*Source: Own elaboration on the basis of American Machinist data.
(c) The intensity of the diffusion process

It is evident that the import-substitution period allowed a measure of development of engineering technological and innovative capabilities in machine tools throughout Latin America. The diffusion of local and imported machine tool production also seems to have benefited users. Indeed, although there are no aggregate figures from specific users, industry figures suggest that, as machine tools’ use spread throughout the region, labor productivity increased (Katz, 1997). Between 1970–90 labor productivity in transport equipment and electrical machinery, two major machine tools user sectors, grew respectively by 1.8% and 4.3% pa in Argentina, by 0.3% and 2.2% pa in Brazil, by 2.4% and 2.9% pa in Colombia, and by 3.9% and 4.1% pa in Mexico.

While diffusion during import-substitution was certainly not shallow, machine tools’ high prices and their limited availability in terms of opportunity, variety and quality suggests that the process did not achieve the necessary depth to generate a virtuous circle of growing knowledge and cumulative productivity increases. Furthermore, labor productivity improvements are much more humble if compared, for instance, with changes in labor productivity in the United States. During 1970–90, the Argentina/US ratio of labor productivity in transport equipment improved from 0.32 to 0.33, while the equivalent Colombian and Mexican ratios improved from 0.23 to 0.34 and from 0.27 to 0.49, respectively. But the Brazilian, Chilean and Peruvian equivalent ratios fell from 0.3 to 0.25, from 0.13 to 0.12 and from 0.34 to 0.29 respectively (Katz, 1997).

A number of factors seem to have militated against the successful diffusion of machine tools during import-substitution in Latin America. First, information did not seem to flow freely. Licensing of foreign products was normally restricted to older generations of technology while the most advanced knowledge was not disclosed by the licensor. Even in cases of relocation of production by foreign machine tool producers into Latin America, there was a clear division of labor between headquarters and subsidiaries, where the latter focused on the least advanced segment of the product range. Partially this was a way of protecting property rights but it seems also to have been the result of the financial restrictions imposed on licensing payments (Alcorta & Peres, 1998).

Information did not flow either, due to the limited number and operations of foreign representatives as local markets were found uninteresting. Selecting a machine tool implies trading off desired technical characteristics against cost, but the technical choices became restricted in a context where local producers specialized in less sophisticated machine tools and there were few foreign representatives. The protected nature of the economy also meant that users did not look hard for alternative sources of information (Katz, 1987). Finally, and perhaps more importantly, there was little communication and information exchange within and between firms. There are numerous cases of firms repeating the same errors over and over again despite having already identified the source of the problem and solving it (see case studies in Castaño et al., 1986). Experiences were not systematized and documented and key personnel did not remain in companies or in the industry for long. Firms were not used to collaboration in the development of new technologies either, and when they did, it was with great trepidation and distrust (Alcorta, Plonski & Rimoli, 1998).

Second, in most countries there was no critical mass. As noted, the broad product-mix approach and high vertical integration of most domestic manufacturers of machine tools was a way of compensating for the insufficiency of specialist companies. User-producer linkages were close only in the case of multinational car manufacturers and machine tool suppliers from their original countries but these had been built long before locating in Latin America. A few mechanical engineering knowledge clusters emerged in regions such as Sao Jose do Campo, in Brazil, but by and large firms attempted to be self-sufficient, kept their experiences with advanced technologies to themselves and established arms-length relationships with suppliers. As a result external economies were not widespread. Indeed, the upgrading of small firms, arising from the demands by large firms for supplier improvement and from “demonstration” and “bandwagon” effects which result in accumulated profitability and accompany successful diffusion processes, was absent in Latin America during import-substitution.

Third, users and producers did not achieve full economic and technical competence. The high local price of machine tools forced users either to seek larger markets abroad to compensate for the high fixed costs of the machine tools or to postpone the investment...
until higher demand was available locally. Given the limited size of several domestic markets and the fact that few firms turned to exports, the likely result was postponement or, as Katz (1987) argues, output-stretching efforts. Hence, the old age of the machine tool stock: in the mid-1980s 65% was older than 10 years and 40% older than 20 years in Bolivia, while 51% was older than 10 years in Mexico (UNIDO, 1990a,b). Technically, local machines were less efficient, had fewer technical features and could achieve lower technical standards, whereas obtaining the required imported machine tool took considerable time. In the meantime the international price-performance frontier for machine tools was rapidly moving forward.

Fourth, the academic and institutional infrastructure was weak. Although there is no evidence specifically related to mechanical engineering and machine tool production, studies on co-operation between universities and businesses suggest that there was little interest to support businesses among the academic community. Universities did not depend financially on the business sector but on the state, while academics’ careers rested on publications and peer evaluation, not on services rendered to industry (Plonski, 1993). As for other institutional support, the evidence also suggests that most government industrial institutes did not have deep knowledge of technological advances in their field and were not even aware of public domain technological information (Machado, 1993). Mexico’s mechanical engineering research institute had only eight engineers by 1982 (James, 1991). Research programs were determined on the basis of what the government or individual researchers wanted and there was little consultation with the private sector. Private industry associations for their part were mainly concerned with lobbying.

4. THE NEW ECONOMIC POLICY REGIME

Despite the importance of successful diffusion for economic development, Latin American countries have not had policies specifically aimed at ensuring the rapid spread of knowledge and new technologies. There has been a range of science and technology policies and institutions but their focus has been on creating local technological capabilities. Hence, the diffusion of new technologies has not only been shaped by science and technology policies but also, if not mainly, by commercial, industrial and financial policies.  

While new economic policies have been implemented in all sectors, it is in the trade sphere where changes seem to have been more radical. As far as machine tools are concerned, two major changes occurred: tariff reductions and freedom to import (Erber & Vermulm, 1997; Fontanals, 1996; Suzigan & Villela, 1997). Machine tool tariffs have gradually been reduced and additional surcharges eliminated in most countries in Latin America. In Argentina, Bolivia, Mexico and Peru tariffs currently stand at around 10–15% while in Brazil they are around 17%. In Brazil, however, tariffs of 0% apply to noncompetitive imports and MERCOSUR trade and of 10% to machine tool imports for the automobile industry. Tariff reductions are continuing and it is expected that within the next three years most countries in the region will have rates lower than 14%. Tariff reductions have also reached inputs and components for machine tools and the trend is to set them at the same level as final products, thus reducing effective protection for local producers. Import freedom has consisted of eliminating all nontariff barriers and exchange controls and differentials to foreign machine tools imports and, unlike before, it is now easy to claim that there are no equivalent products manufactured in the region. In addition, second-hand machine tool imports are allowed in most countries although mechanisms to fight unfair trading practices have also been put in place.

Another area where there have been some changes is financial policy (ECLAC, 1989; Erber & Vermulm, 1997; Chudnovsky et al., 1992; Unger, 1994). In the 1970s and early 1980s there were a number of official credit facilities for both export and local use of domestically manufactured machine tools in countries such as Argentina, Brazil, Colombia, Mexico and Peru. Finance is crucial for machine tool users due to the high investments required to purchase them and the long recovery period. Except for Brazil, however, in most other countries these facilities have been eliminated. In Brazil, FINAME, a subsidiary of the National Development Bank, has been providing credit for domestic capital goods purchases since 1965. Initially FINAME was a response to the competition of foreign machine tool companies that provided financing for their machine tools as a matter of course. Over
the years FINAME has adapted its financial conditions, extending the period of the loan and financing exports, making Brazilian machine tools extremely competitive locally and abroad. Since the early 1990s, however, the lending conditions have got more stringent and the interest rates are far higher than in the international market (Erber & Vermulm, 1997).

During import substitution, a key aim of industrial policy was the development of a thriving local machine tools industry. Four main mechanisms were used: state-owned machine tool companies, fiscal incentives to the industry, enlarged market through integration agreements and export subsidies. Countries such as Mexico and Peru established state-owned machine tool firms as it was believed the private sector did not have the entrepreneurial and technical skills to deal with complex technologies (Chudnovsky & Nagao, 1983; Mercado, 1990; UNCTAD, 1985a; Unger, 1984; UNIDO, 1990b). By contrast, in Argentina and Brazil, tax rebates to local producers and export subsidies of up to 25% of the value of machine tools were granted (Chudnovsky & Nagao, 1983; Jacobsson, 1982). Andean Pact countries, including Bolivia, Colombia, Ecuador, Peru and Venezuela, allocated the production of different machine tools and their parts among them (UNIDO, 1991).

In the new economic regime, local machine tool production is no longer a priority. State-owned machine tool companies have been closed down or privatized and taxes no longer discriminate in favor of local machine tool producers. Complex regional division of labor agreements were scrapped although revamped versions of enlarging market mechanisms, such as the Andean Community of Nations and MERCOSUR, remain or have been created. Export subsidies are under review and are being brought in line with international trading agreements. The only vestige of industrial policy is Brazil's automotive regime imposing restrictions on imports of vehicles via quotas and special tariffs, providing fiscal incentives to local investment and exports, and reducing the tariffs on machine tools, while at the same time forcing vehicle assemblers and component manufacturers to maintain a ratio between local purchases and imports of machine tools.

Changes have also taken place in technology policy. In the past Latin America had an elaborate set of technological policies (Alcorta & Peres, 1998). In the area of machine tools these included controlling technology transfer through limiting restrictive conditions on foreign licenses, having weak or weakly enforced intellectual property regimes, establishing government research and technology centers and developing key new "generic" technologies, such as electronics, by several means, including forcing machine tool manufacturers to use locally produced controls.

As with industrial policy, all selective technological mechanisms have been eliminated and priorities are now set by the market on the basis of comparative advantage or profitability. Controls and regulations on technology transfer have been eliminated, including provisions that discriminate in favor of local firms (Braga, 1993). Intellectual property protection laws have been strengthened by expanding the scope of patents to previously excluded products and increasing their duration and by introducing tougher penalties (Braga, 1993). Government research institutions are required to obtain a significant portion of their funding from the private sector while overall there is more emphasis on increasing productivity and efficiency than on innovating (Alcorta & Peres, 1998). The Brazilian Program of Quality and Productivity (PBQP) was started in 1990, aimed at supporting industrial modernization. Activities include the development and diffusion of new managerial methods and new ways of organizing human resources, increasing the awareness and mobilizing firms toward better quality and productivity, and the improvement of the articulation between government, university and industry. The only selective and innovation-oriented mechanism in the region is now found in Brazil, where machine tool manufacturers can get extra funding and lower interest rates from FINAME should they have an ISO 9001/2 and/or invest in research and development.

5. DIFFUSION OF MACHINE TOOLS IN THE POST IMPORT-SUBSTITUTION ERA

(a) Local production of machine tools

A major casualty of the new policy regime has been local machine tool production. In countries like Peru and Colombia there is no longer any production left, except for simple component manufacturing and repair of old machines (De la Cruz, 1989; UNIDO, 1990a). Former manufacturers, which were able to survive policy changes, are today merely...
representing foreign brands. In Mexico, only five metal-cutting machine tool enterprises survived (Unger, 1994). Except for one specialized machine tool company working to order, however, none of the others is able to produce CNC machine tools but concentrate on conventional machine tools which are sold to training schools, local workshops and factories for repair jobs or exported to Central America.

In Argentina and Brazil, although without disappearing completely the industry has gone through a major transformation (Erber & Vermulm, 1997, Fontanals, 1996). By 1994 there were only 37 firms manufacturing machine tools in Argentina, of which only 10 had a CNC model. In Brazil there was around 100 metal-cutting machine tool manufacturing firms, of which around 30 produced at least one CNC model. Yet, the ratio of value of production of CNC machine tools relative to conventional ones has increased to over 40% in Argentina and to an estimated 57% in Brazil, so further industry concentration and closures among conventional machine tool producers should be expected. In Argentina already five major companies account for 75% of the machine tool market.

In terms of technological progress and structural characteristics of the industry, there are some changes (Erber & Vermulm, 1997; Fontanals, 1996). To begin with, the product range has become more specialized. Regarding CNC machine tools, the focus of local producers is on lathes and drilling machines while that of foreign subsidiaries is on custom-built transfer lines and machining centers. Locally manufactured CNC lathes, however, are still “simplified” versions of machine tools produced elsewhere, while transfer lines and machining centers are at the bottom end in complexity. Indeed, the source of product technology continues to be the adaptation of foreign licenses in the case of the former and the technology provided by headquarters in the case of the latter. Second, productive efficiency has increased. Leading firms have rationalized the production process, reduced administrative layers, decentralised design, introduced just-in-time techniques and hold ISO 9000 certificates. Scale of output among leading producers is also around half or two-thirds of the most efficient plants worldwide. Third, exports have a larger role in industry sales. Brazilian exports of CNC machine tools have grown and the main markets are the US and Germany. Argentinean exports by contrast are more focused in Brazil and other Latin American markets.

At the same time, there are a number of characteristics that have not changed. Although the gap seems to be narrowing, prices of Brazilian and Argentinean CNC machine tools would seem to continue to be higher than in the international market. In 1997, a Brazilian produced simple two-axis CNC lathe costs around US$40,000 while a three-axis CNC lathe with attachments would cost around US$80,000 (Erber & Vermulm, 1997). The average unit price in 1994 of UK CNC lathes was US$70,000, of Indian lathes US$61,000, of South Korean lathes US$59,000 and of Taiwanese lathes US$53,000 (Alcorta, 1998). Prices have fallen since. The prices of Argentinean CNC lathes too are far higher than those of their Taiwanese and Chinese competitors (Fontanals, 1996). Besides, a significant portion of Brazilian exports is intrafirm trade of foreign machine tool subsidiaries so it is difficult to be precise about the international competitiveness of Brazilian CNC machine tool exports.

There has not been much progress in the technical standards of the equipment either. As during import-substitution, the “role” in the “international division of labor” continues to be that of producing low-tech machine tools. Indeed, Brazilian and Argentinean manufacturers of CNC machine tools would not seem to have been able to make the jump to the electronics era. All Argentinean CNC machine tools are delivered with foreign controls, while Brazilian CNC machine tools exported have Japanese controls and only those sold in the domestic market have a locally built control. Often exports only involve the mechanical part of the machine, leaving the purchaser to couple the control unit (Erber & Vermulm, 1997).

The high degrees of vertical integration of the past also seem to continue. Most mechanical components of machine tools in Argentina and Brazil are produced in-house and the largest Brazilian firms also have foundries attached to their facilities (Fontanals, 1996). There are few independent suppliers of parts and components and those that are available are seen as unreliable, expensive and of poor quality. Many manufacturers operate with high degrees of unused capacity and are forced to integrate vertically to amortize their investment.
(b) Machine tool imports

If there is anything that characterizes diffusion of machine tools in Latin America under the NEM, it is imports. Except for Argentina and Brazil, all CNC machine tools and most transfer lines are supplied from abroad. Most of the conventional machine tools are also supplied from abroad but their share in total imports is falling anyway (Tables 3 and 4). In Argentina, during 1990–94 machine tool imports grew four-fold to US$82 millions and accounted for 86% of total apparent consumption (Fontanals, 1996). In Brazil, imports reached 50% of total apparent consumption in 1996 although the auto industry rules should bring this level down to around 30% in the future (Erber & Vermulm, 1997).

In addition to changes in trade policy, five factors seem to have underpinned the diffusion of imported machine tools: prices, technology, finance, service and the auto industry regime (Erber & Vermulm, 1997; Fontanals, 1996; Unger, 1994). Low prices have been coming from the growing number of South Korean, Taiwanese and Chinese CNC and conventional lathes and machining centres imported into the region. Albeit technically inferior to their European, Japanese or American counterparts, these machines are cheaper than equivalent local versions even after transport costs and tariffs have been added (Fontanals, 1996).

Most advanced users, for their part, have obtained their equipment mainly from German, Italian and Japanese suppliers. Machine tools supplied from these countries tend to be among

| Table 3. World imports of metal-cutting machine toolsa (US$ millions)b |
|---|---|---|---|---|---|---|
| Africa | 165.0 | 208.7 | 159.7 | 113.0 | 100.0 | 98.6 |
| North America | 1678.5 | 1530.3 | 1336.7 | 1213.4 | 1407.1 | 1879.3 |
| Latin America | 380.8 | 363.8 | 415.6 | 463.5 | 399.2 | 396.9 |
| Brazil | 108.2 | 139.0 | 139.9 | 85.8 | 75.0 | 109.5 |
| Mexico | 156.5 | 126.3 | 127.3 | 222.4 | 145.1 | 141.0 |
| Developed Asia | 333.4 | 423.9 | 412.6 | 319.5 | 205.6 | 252.8 |
| Developing Asia | 1573.1 | 1755.3 | 1954.7 | 2152.3 | 2380.0 | 2658.5 |
| Europe | 4939.8 | 6649.7 | 4958.3 | 3951.2 | 2446.9 | 2913.6 |
| Oceania | 117.8 | 100.5 | 75.6 | 66.8 | 82.8 | 118.0 |
| Developed economies | 5927.8 | 7053.3 | 6119.2 | 5154.1 | 3864.2 | 4778.2 |
| Developing economies | 2094.2 | 2324.3 | 2476.9 | 2705.2 | 2818.7 | 3128.3 |
| Economies in transition | 1166.5 | 1654.6 | 717.0 | 420.5 | 298.6 | 411.1 |
| World | 9188.4 | 11032.2 | 9313.2 | 8279.7 | 6981.6 | 8317.7 |

a Some small discrepancies in the data from the original source.
b Source: United Nations COMTRADE statistics.

| Table 4. World Imports of CNC metal-cutting machine toolsa (US$, millions)b |
|---|---|---|---|---|---|---|
| Africa | 0.4 | 3.4 | 4.5 | 37.2 | 28.1 | 24.2 |
| North America | 1312.2 | 1219.3 | 1063.2 | 1077.8 | 1192.9 | 1601.2 |
| Latin America | 94.7 | 160.1 | 181.5 | 271.2 | 194.6 | 207.8 |
| Brazil | 57.0 | 87.3 | 94.4 | 65.1 | 53.0 | 64.5 |
| Mexico | 37.4 | 64.0 | 66.1 | 156.4 | 95.1 | 85.8 |
| Developed Asia | 73.3 | 110.5 | 131.1 | 87.1 | 62.2 | 48.3 |
| Developing Asia | 314.9 | 434.1 | 539.2 | 757.7 | 1109.4 | 1294.2 |
| Europe | 3308.1 | 4014.8 | 3187.3 | 2541.9 | 1403.1 | 1792.3 |
| Oceania | 50.1 | 44.5 | 35.9 | 34.8 | 42.8 | 72.4 |
| Developed economies | 3984.2 | 4792.2 | 4046.6 | 3431.8 | 2522.9 | 3223.9 |
| Developing economies | 451.5 | 645.9 | 725.3 | 1055.2 | 1318.3 | 1520.9 |
| Economies in transition | 678.9 | 457.5 | 272.1 | 189.8 | 126.4 | 227.7 |
| World | 5114.7 | 5895.6 | 5043.8 | 4676.8 | 3967.5 | 4971.9 |

a Some small discrepancies in the data from the original source.
b Source: United Nations COMTRADE statistics.
the more sophisticated technically, are not available locally and are demanded by auto manufacturers and capital good producers, including machine tool manufacturers themselves. In the case of Brazil, for instance, the relationship of cost/weight ratios between imports and exports were 2.4 in the case of CNC lathes and 7.6 in the case of drilling machines. In Mexico and Brazil, often these imports were related to demands from German, Italian or Japanese vehicle assemblers and component manufacturers.

The enticing financing conditions offered by foreign manufacturers have also contributed to the surge in imports. Imports of machine tools can be financed at 6–8% in US$ per year, grace periods of up to two years and repayment periods of up to five years. By contrast, in Brazil for instance, FINAME finance only recently covers the full cost of the machine tools and involved during 1995–96 an average 13% real interest rate and a maximum of one year grace period. FINAME finance accounts today for less than 10% of total machine tool exports and less than 20% of total machine tool output.

The increasing attractiveness of the Latin American market has also brought a flurry of representatives of foreign machine tools and importing joint ventures. Chinese and Taiwanese machine tools are sold by local representatives handling a range of brands from those countries. Large European and Japanese makes are represented by brand in Argentina, Brazil and Mexico but in other countries a single representative handles a number of brands from several countries. A couple of Brazilian manufacturers have entered import-export partnerships whereby the foreign partner handles their sales abroad while they handle the local distribution in Brazil, an arrangement that works well in the presence of a complementary product range.

Finally, an important pull factor for machine tools, particularly in Brazil, Argentina and Mexico, has been the growth of the vehicle industry and, more generally, of aggregate demand during most of the 1990s.

(c) Is diffusion getting any deeper?

The impact of the growing number and diversity of mainly CNC machine tools on the efficiency of users has been impressive. In Argentina the average age of the stock of machine tools, which stood at around 8.5 years in the second half of the 1980s, fell to 6 years by 1996, a level only comparable to that of the early 1970s (Katz, 1998). More importantly, labor productivity in transport equipment and electric machinery increased by 15.5% and 11.6%, respectively in Argentina during 1990–96; by 11.8% and 14.6%, respectively in Brazil; by 12.4% and 1.1%, respectively in Colombia; and, by 4.6% and 4.3%, respectively in Mexico (Katz, 1997). Moreover, between 1990 and 1996 the Argentinean/US ratio of labour productivity in transport equipment improved to 0.64, in Brazil it increased to 0.39 and in Colombia to 0.48 (Katz, 1997). Only in Mexico it remained at the same level as in 1990. According to Erber and Vermulm (1997), Brazilian machine tool producers’ productivity has also improved: during 1990–96 the number of hours worked increased by 20% and salaries by 15% while sales increased by 80%.

Other evidence would also seem to confirm that adopters of CNC machine tools and of related organizational changes have benefited from higher productivity. A study of Brazilian CNC machine tool users found labor productivity improvements of 16–18% among capital good manufacturers, of 72–156% among car component producers and of 28–42% among companies providing machining services (Carvalho, 1998). Similar studies in Mexico and Venezuela showed improvements in labor productivity of 40–116%, 60–125% and 275% and of 75–111%, 219–810% and 112–204%, respectively, among users in the same three industries (Dominguez & Brown, 1998; Alonso, Tamayo & Cartaya, 1998).

No doubt the new policy regime has favored users. There is choice of machine tools in terms of price and quality and better links to the international markets via exports and imports and through the institutions and information that supports trade. The official emphasis on markets, productivity and efficiency has also helped to improve performance. Yet, diffusion is not only about users but also about producers and perhaps even more, about the cumulative effects and improvements that emerge during their interaction.

As far as information flows are concerned, some of the old habits die hard. In the multinational sector, information seems to be flowing between users and machine tools manufacturers from the same origin. Given that many of these relationships involve custom built machines, interactions and information exchange need to be extensive and related to circumstantial specifics. But most of these relationships are the
result of headquarters’ histories, experiences and decisions. Hardly any local firm is involved in this type of activity, but rather there is a clear separation between foreign machine tool producers focused on transfer lines and machining centres producing for multinational corporations and local companies producing conventional and CNC lathes for local firms (Erber & Vermulm, 1997). Given the intense competition by multinational users, particularly in the vehicle industry, the emerging “islands of information” relate little between themselves.

Local machine tool manufacturers do not seem to generate or communicate much information and knowledge either. While improvements in operating efficiency were clearly necessary in order to be viable, processing and making sense of the growing amount of information being generated means that some research and development capability beyond imitation and adaptation is also necessary. Yet, the new set of skills and scientific information and knowledge required to comprehend and fully exploit the electronics dimension of machine tools does not seem to be emerging in the majority of firms. Indeed, the inability to advance somewhat in the microelectronics field suggests that previously acquired imitation and adaptation skills are also being undermined. Even in user firms some capacity to understand the implications of new technologies is required. Carvalho (1998), for instance, found that a number of small Brazilian firms were facing financial difficulties because they invested in CNC machine tools without actually being fully aware of their productive potential. In one of these cases, the local manufacturer who provided the equipment, which was financed, has yet to be seen. It is difficult to see dynamic interactions emerging under such arm’s-length conditions.

Information flows are also limited in another respect. Foreign licensors are no longer interested in selling their designs, or only the oldest ones, to local producers but prefer to sell the units themselves. Indeed, many expiring licenses have not been renewed but the licensor has established local representative offices instead. Or representatives have taken over the previous licensor, closed down its manufacturing facilities and used only the marketing channels. Collaborations with foreign producers are often emerging in the area of marketing, not of technology (Alcorta et al., 1998).

Self-sufficiency approaches continue to be rampant among local machine tool producers. The NEM has had little effect on improving the standards of the supplier industry and indeed, if anything, reinforces them through the speed with which the measures were introduced. While the technical and economic differences between large local manufacturers of machine tools and several small potential suppliers is substantial, not only theory but also the international experience shows that the way to deal with such conditions is not less but more information and training (Hoffman & Kaplinsky, 1988). Local manufacturers, however, continue to mistrust suppliers and are reluctant to outsource parts and components and upgrade them.

The problem of critical mass has also worsened. Today there are 50 or fewer metal-cutting CNC machine tool producers throughout Latin America, and these are heavily concentrated in Brazil. If components and conventional machine tool firms are added, the figure more than doubles but the conventional segment of the industry has little future as CNC machine tools dominate. According to Erber and Vermulm (1997) and Fontanals (1996), local CNC machine tool manufacturers can be classified into two categories: leaders and followers. Leaders have a research and development capacity, early on incorporated electronics into their products, export their machine tools and some have developed their own CNC controls. Followers are smaller, have little research and development capabilities, produce under licenses and have been hardest hit by import competition. Several followers have closed down or are facing insurmountable problems and many others are turning into component production or machining services. Because most followers are family firms, they are generally against merging, casting even more doubt about their potential. Hence, the industry that has emerged includes the local facilities of foreign manufacturers, a handful of local leaders and what will remain of the restructuring of followers.

Users are far more abundant and include the automobile industry, the emerging aircraft industry in Brazil and the capital and durable goods industry throughout, including machine tools and, particularly in Mexico, producers of equipment for the glass industry (Fontanals, 1996; Unger, 1994). Foreign suppliers are catering to the most sophisticated users, such as the automobile industry, often directly from abroad. Local suppliers cater to the capital and durable goods industries, larger in number but
lower in technical demands and shrinking in size. The aircraft and glass equipment industries are turning to foreign suppliers to satisfy their increasingly technically complex and varied demands. Thus, the “operative mass” of users and producers would seem to amount to a few “leaders” and a decreasing number of unsophisticated users.

Related to critical mass is the issue of technical and economic competence. As users become more complex, the nature of their demand changes. From individual machine tools they go on asking for combinations of them, including both CNC lathes and machining centers, and eventually system solutions such as Flexible Manufacturing Systems (FMS), which combine machining centers or lathes with handling and transporting devices, or other custom built specialized or flexible combination of machine tools. Yet, none of the local manufacturers has the capability of providing such solutions, not even the most able of the leaders.

Firms are also struggling to find new markets. In terms of price/performance economics, Latin American producers are being squeezed out from the bottom by Taiwanese and Chinese competitors and from the top by European and Japanese counterparts. Latin American CNC machine tools are either too expensive or too simple. Brazilian firms are devising clever ruses to enter foreign markets and provide the after-sales service so important to users, such as the two-way marketing agreements mentioned above. But there are very few local firms that can engage in these partnerships and some of the foreign partners, after learning about the domestic market, prefer to go-it-alone, often buying off their initial partners.

Turning to the academic and institutional environment only some of the new policy efforts seem to have been successful in advancing the diffusion process. Attempts at university-business co-operation such as transfer offices, university companies and joint programs and projects, while having been well received by the “starved of funds” academic community, have only had a qualified acceptance by business. Firms continue to have a different perception of what needs to be provided by universities in terms of technological advance (Velho, Velho & Davyt, 1997). Hence, most programs have had limited success. The policy of bringing government research institutes closer to the market by forcing them to raise private funding seems to have backfired (Machado, 1993). Organizations that have successfully moved toward self-financing have done so at the expense of eliminating necessary long-term research and development projects. Less successful ones are struggling to make ends meet and are shedding personnel, normally the most capable which can find alternative employment, and to sell equipment. Those remaining in the middle have a low ratio of permanent to temporary professional staff and very high turnover of professional staff, which does not allow research and organizational continuity. Market orientation has also meant the elimination of wage, recruitment, promotion and training policies leading to professional frustration and low moral.

6. CONCLUSION

Achieving a successful diffusion process involves a balance between suppliers obtaining the resources and time to incorporate technical change and users obtaining the embodied and disembodied knowledge at the price and moment that will make them more competitive and profitable. During import-substitution the policy regime focused almost exclusively on suppliers. Advances were made in terms of generating domestic imitative, adaptive and innovating capabilities. But such gains were made at too high costs from the user point of view: they had to bear expensive and technically inferior machine tools often at the wrong moment. The new policy regime has reversed the previous focus. The emphasis today is totally on the user. The results have been wider availability and lower priced technologies and, in turn, a sharp increase in productivity and efficiency. Producers cannot, however, establish themselves nor make the technologically crucial jump into the electronics era. Both policy regimes would seem to have missed the essential point of diffusion: both users and producers have to be jointly upgraded, obviously as quickly as the international market allows it.

It is now time to learn from experience and redress the balance. Given the current ideological stance of many governments in the region, diffusion policies aimed at correcting market failure could fall well within their limits. Following Stoneman and Diederen (1994), three sets of polices would seem to be relevant. First, information provision policies. These include demonstration projects and advertising
campaigns, publicly funded technology information and monitoring centers, subsidizing consultancy activities, encouragement of science and technology parks, establishment of joint public–private research laboratories where the government acts as a risk carrier and setting standards. Some of these mechanisms have already been tried in the region but often they have been mechanical copies of what is done elsewhere with little adaptation to local circumstances (Velho et al., 1997). Second, competition policies are necessary to reduce prices and improve quality, although they should not always focus on increasing the numbers of competitors as this is not necessarily conducive to successful diffusion. Third, appropriating externalities policies. Policies in this field comprise support for early developers and adopters of new technologies and government procurement.

For those governments that may be less tied to ideological considerations, some additional “systemic” policies could be considered. It must be noted that these polices are complementary to market failure mechanisms and a clear border between both often cannot be drawn. Following Carlsson and Jacobsson (1994) three sets of policies could be considered: cluster development, improving economic competence and institutional development. Cluster development involves creating a common vision and purpose and increasing the connectivity of firms around a specific technology. Improving economic competence implies providing clarity as to the overall direction of the economy and giving the necessary confidence and guidance for firms to invest long term. Institutional development means updating the educational and training support to the requirements of technological change.

NOTES

1. There is no sharp distinction between diffusion and innovation as what is diffused is not a single innovation but a sequence of generations or improvements of the original technology (Carlsson & Jacobsson, 1994).

2. Machine tools are defined as power-driven machines, not portable by hand while in operation, which work metal by cutting, forming, physico-chemical processing or a combination of these techniques (AMT, 1993). Machine tools can be classified by function, metal cutting or metal forming; means of control, conventional (operator) or computer-numerically-controlled (CNC); or use, general purpose (variety of operations, shapes and sizes) or special purpose (single operation). Metal-cutting machine tools, the focus of this paper, shape or surface work-pieces by removing metal, and include lathes which perform turning and boring operations, drills, grinders and milling machines. They also include specialized machines as transfer machines. They account for around 80% of total machine tools in use.

3. One important implication of the adaptation of machine tools to relatively simple use was that the most sophisticated users had to import required machine tools or settle for locally available equipment.

4. Imports of numerically-controlled machine tools in Argentina during the 1970s amounted to 102 units, there was no local production (UNCTAD, 1985b). During 1980–83 consumption of numerically-controlled machine tools increased to 131 of which 103 were imported.

5. Not all users, however, faced the same prices for imported machine tools, as there were a number of exemptions and tariff reductions arising from policies to promote specific sectors.

6. Latin America’s departure from import-substitution industrialisation took place against the growing worldwide diffusion of CNC machine tools. CNC machine tools can adjust to varying circumstances and instructions, can integrate several mechanical functions and are much faster and precise than the conventional machine tools they replace (Alcorta, 1998). Although CNC machine tools had been available since around 1975, it was only in the mid-1980s that they started to diffuse widely and a succession of improvements and innovations followed. By 1994 more than two-thirds of world production was CNC machine tools.

7. Cost/weight ratios refer to the price per kilo or ton of machine tools. The larger the ratio the more advanced a machine is supposed to be.

8. There is a fundamental danger in copying and adapting alone, as it may only lead to a process of degrading product quality and, through price competition, to stiffening the innovation potential (UNCTAD, 1985a).
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