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INDUSTRY**

Ruy de Quadros Carvalho

Federal Government of Brazil

**Secretariat of Strategic Affairs of the
Presidency of the Republic**
Minister Roberto Mangabeira Unger



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TEXTO PARA DISCUSSÃO Nº 378

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Ruy de Quadros Carvalho

JULHO DE 1995

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COPING WITH CHANGE IN THE ECONOMY: NEW TECHNOLOGIES, ORGANISATIONAL INNOVATION AND ECONOMIES OF SCALE AND SCOPE IN THE BRAZILIAN ENGINEERING INDUSTRY*

Ruy de Quadros Carvalho**

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I. INTRODUCTION

This paper is concerned with the implications of the diffusion of new technologies, particularly microelectronics-based automation, and of organisational innovations, for scale and scope in the Brazilian engineering industry. The objective is to examine prospects for the location of industrial production in developing countries.

In the attempt to cope with major problems faced by the Brazilian economy in the past fifteen years, Brazilian industry has been undergoing a process of restructuring. Continuous economic crisis and the exhaustion of import substitution industrialisation have induced substantial policy changes in Brazil. With the help of export promotion instruments, exporting industries gradually increased their importance for economic growth. Moreover, the 1990s inaugurated a policy of trade liberalisation, which has brought tough competition from imports to the internal market. Industrial firms have been rushing to adapt to greater international economic integration. Restructuring is the word in Brazilian business circles. Firm restructuring has been based on the diffusion of information technologies and on the adoption of modern concepts and forms of organisation.

There is a considerable literature on the Brazilian experience with new forms of industrial automation and new management practices. Although it shows an ample range of research interests, this literature¹ has not addressed scale and scope issues. Yet, much of the recent productivity gains reaped by Brazilian industrial firms is associated with cost reductions and economies of scope yielded by the adoption of new technologies. Moreover, the impact of new technologies on scale and scope is object of dispute in the international literature. The debate raises points of immediate interest for newly industrialising countries, since they affect prospects for industrial location.

In short, the discussion is on whether and to what extent the diffusion of new technologies is changing the central role attributed by industrial organisation theory to economies of scale. Authors like Ayres (1991), Auty (1992), Hoffman (1989), Jaikumar (1986) and Kaplinsky (1990) sustain that new technologies lead to de-scaling, that is, to falls in optimal scales of output. New technologies reduce product scales, by decreasing minimum batch sizes, simultaneously increasing production flexibility. This change, associated with reduction in the cost of equipment and to greater divisibility of investment — which are presented as central features of new technologies — would be enabling smaller firms and plants to incorporate advanced automation technologies and to become as efficient as large plants. For developing economies, this wave of technical change would bring an enhancement of the prospects for industrial location, since scale

¹ Some of the recent works are: Fleury (1995), Humphrey (1994), Fleury and Humphrey (1993), Quadros Carvalho (1993), Silva (1992), Githahy e Rabelo (1991) and Posthuma (1991).

barriers would be reduced and entry of small-scale production would increase. However, critics like Alcorta (1994) and Mody *et al.* (1992) suggest that the de-scaling argument mixes up reduction in the physical size of equipment and plants with reduction in economic size. They further suggest that, by being more efficient and able to operate longer hours, new technologies may lead to increase in plant capacities and in total plant output. Moreover, they contest the argument that new industrial automation equipment costs less and entail decreasing fixed costs.

In order to test these arguments and to explore the potential benefits of the new technologies for developing countries, we carried out an investigation of the experience of Brazilian engineering industry with new technologies, focusing on the implications for scale and scope. This sector of Brazilian industry has substantially suffered the effects of economic instability and of the recent reduction in protectionism, and is a pioneer in the adoption of new technologies. The empirical investigation relied on case studies of ten firms. They belong to the segments of car component producers and of manufacturers of pumps and valves. The main criteria for the choice of firms was the degree of adoption of new technologies — we aimed at firms with a considerable level of adoption — and the diversification of the sample in terms of the origin of capital ownership and size. Case studies comprised the realisation of several visits to firms and interviews with managements and industrial engineers, from March to July 1994. A semi-structured questionnaire was utilised, to facilitate the organisation of quantitative information by firms. Firms' internal documents and published reports were also important sources.

The findings and conclusions of the research are presented in the following sections. The paper is organised into four parts. Section II provides the economic context in which sample firms have been operating. The focus is on the process of economic adjustment and on the diffusion of new technologies in the Brazilian engineering industry. Section III examines the features of recent technical change in the sample firms. Firstly, the product and production strategies adopted by these firms, in order to adapt to the changing economic environment and to become more competitive, are examined. Firms' reasons for adoption of new technologies are presented. Secondly, the pattern of adoption is described and analysed. Particular emphasis is given to the connections between the introduction of new production technologies and organisational change. Section IV addresses scale and scope issues. An effort is made to situate the actual changes in scale and scope within firms' competitive strategies and objectives. The section starts by examining changes in setting up and machining times, variation in batch sizes and diversification in product ranges. It is shown that, in fact, sample firms have been operating to reduced *product scales*. These firms have benefitted from scope economies associated with the adoption of new technologies. They are now producing a greater variety of products, to smaller batches, but in a more efficient way. However, our case studies

suggest that scope economies are not displacing scale economies. Section IV reveals that plant capacities increased, in most sample firms. *Plant scaling-up* was primarily due to efficiency gains resulting from the introduction of new technologies and new organisational methods. More importantly, our evidence shows that increased output scales are crucial for cost reduction in the sample firms. This is so because technical change implied a significant increase in the burden of capital costs and overhead costs on firm total costs. In short, the recent experience of the Brazilian engineering industry suggests rising optimal scales. In the final section (Section V), an attempt is made to draw conclusions and policy implications from the case studies.

II. ECONOMIC AND TECHNICAL CHANGE IN THE BRAZILIAN ENGINEERING INDUSTRY: 1980/1993

This section examines the economic and technological adjustment which the Brazilian engineering industry has undergone since the early eighties. The main purpose is to set the context for the better understanding of the case studies on firm adoption of new technologies, which follow in the next sections. The focus is on the process of technical change in the segments of the engineering industry to which our sample firms belong. Particular attention is given to the diffusion of new automation technologies in the engineering industry. The section starts with an account of the major macroeconomic and policy developments occurred in Brazil in the past fourteen years, which have affected the evolution of the engineering industry and the diffusion of new technologies.

II.1 Economic Crisis, Adjustment and Policy Change: the Impact on Firm Restructuring

The period considered in our firm case studies (1985/1994) was one of major changes both in the pattern of growth and technical change in Brazilian manufacturing industry, and in the aim and style of economic policy.

Industrialisation was the driving force of stable economic growth in Brazil, until the 1980s. Since the end of World War II, the average annual growth rate of Brazilian manufacturing industry was above 8 per cent. The main objective of the import substitution (IS) policy which supported and stimulated industrialisation was the building up of production capacity to serve the highly protected and cartelised internal market.

This trajectory was interrupted in 1981. The structural weakness of Brazilian industrialisation — particularly technological fragility² and the slow down in productivity growth — interacted with a

² On the technological fragility in Brazilian manufacturing, see Quadros Carvalho (1992).

deteriorating macroeconomic situation, revealing that the IS model had exhausted its potential. These limitations became more evident in face of the worldwide acceleration of technical change and the increasing importance of international competitiveness as a strategic policy objective in industrialised countries.

In contrast with the previous decades, Brazilian industry suffered three successive recessions, in 1981/83, 1987/88 and 1990/92. The balance of the decade was industrial stagnation. Given recession in the internal market, the industry started to put greater emphasis on exports, initially as an outlet to occupy idle capacity. However, as government extended export promotion policies and some industrial segments succeeded in international markets, Brazilian manufacturing industry assumed the leading position in the country's export trade. From an average of 28 per cent in the seventies, the share of manufactured goods in Brazilian total export increased to 53 per cent in the eighties.

Researchers are divided as to whether the Brazilian export drive of manufactured goods is a steady tendency or just a short-lived consequence of internal market retraction. Yet, in some segments of manufacturing industry which are based on the intensive use of either labour, or energy, or natural resources, and are characterised by low to medium level of technological complexity, exports have shown a stable tendency to growth (irrespective of the local demand). Thus industries producing goods such as steel, pulp and paper, car components, heavy commercial vehicles, heavy electrical machinery and leather shoes stand out today as important Brazilian exporters.

Even though the rate of investment in Brazilian economy presented substantial decline in the 1980s,³ private industrial firms — and particularly the leading exporting firms — began a systematic effort for technological and organisational modernisation. Firm restructuring was based on a mix of selective adoption of electronic industrial equipment, the updating of products and the adoption of so-called organisational innovations or new management techniques.⁴ The major aim, at the level of the firm, was the enhancement of quality standards and the achievement of greater production flexibility. Since this technological upgrading was rather concentrated on a limited number of firms, the result was the increase in the level of technological heterogeneity in Brazilian manufacturing industry.

³ From an average of 23 per cent of GNP in the 1970s, the investment rate fell to 16 per cent in the late 1980s.

⁴ We are referring to new principles and techniques for firm organisation, particularly those related to production and work organisation, such as Just-in-time and Total Quality Control. Their common feature is the superseding of the most rigid principles of Scientific Management, regarding specialisation and the division of labour.

In the 1990s, the Brazilian economy has been marked by a radical shift in economic policy, towards a more liberal model. Privatisation, market de-regulation, the pursuit of fiscal discipline, the reduction in the role of the state in providing economic infra-structure and the opening of the economy are the new elements of economic policy which have most affected the manufacturing industry. Trade liberalisation and the gradual reduction in import tariffs have been adopted in order to substantially increase competitive pressure on the internal market. They also signaled government's concern with promoting greater integration of Brazil into the world economy. International competitiveness became the priority of trade and industrial policy.

At firm level, the greater impact of the new economic and policy environment has been the enormous increase in competition in the internal market. As the case studies in this paper attest, the actual or potential competition from imports have led industrial firms to substantial revisions in their marketing, investment and production policies, in order to reduce cost and prices and to further enhance quality. One important consequence has been the intensification in the process of firm restructuring referred to above. Moreover, the movement of firm change has been enlarged, encompassing not only exporting firms, but also companies which primarily serve the internal market.

The process comprising the recent policy and economic change and firm restructuring, in Brazil, has been vaguely called (and promoted as) "economic modernisation" by policy-makers and the media. Economic "modernisation" has generated a lot of interest and excitement in business circles. There are important results which justify such an excitement. After seven years of stagnation, labour productivity in the Brazilian manufacturing industry increased approximately 30 per cent from 1992 to 1994 (Bernardes and Lemos 1995). Still, if the process of change has gathered momentum, it is not short of problems. So far, the new industrial policy has almost exclusively emphasised trade liberalisation, de-regulation and the promotion of competition. Even though the original design of the new industrial policy envisaged the adoption of programmes promoting industrial technological capabilities, little has been done in this respect. The consequences of leaving industrial investment entirely under the imperative of market forces are not difficult to observe. One of them, as contended in this paper, is the deepening of the technological and managerial gap between Brazilian large and small firms.

II.2 Recent Evolution of the Brazilian Engineering Industry (with emphasis on the metal-mechanic industry)

Brazilian economic growth in the 1970s was primarily driven by expansion in the engineering, chemical and metallurgy industries. Within the engineering industries, the automotive and the (mechanic) capital goods sectors were the most dynamic. They were also the most affected by economic crisis in the 1980s, as shown in Table 1, below, in which the "mechanic industry" comprises capital goods producers and the "transport material industry" comprises the motor vehicle industry (including the car component industry).⁵ The steep output fall in the "mechanic industry" (as from 1981) reflects the drop in the investment rate. A new recovery started from 1993, as seen in Table 1, but with distinctive impacts in different sectors.

TABLE 1
Industrial Output in Brazilian Manufacturing Industry (1980/1993)

Year	(1980=100)				
	Manufacturing Industry	Metallurgy	Mechanic Industry	Electric and Telecoms	Transport Material
1980	100.0	100.0	100.0	100.0	100.0
1981	89.6	83.0	80.3	84.6	77.1
1982	89.5	80.0	66.5	87.0	74.9
1983	84.2	77.9	57.6	77.4	69.9
1984	89.4	88.6	68.4	78.9	73.1
1985	96.9	95.1	75.5	93.9	81.6
1986	107.8	106.5	92.1	115.1	91.9
1987	108.9	106.9	95.8	112.6	82.5
1988	105.1	103.4	87.5	107.6	90.0
1989	108.2	108.6	91.9	113.7	87.5
1990	97.9	94.9	76.5	107.4	73.6
1991	95.6	89.5	68.6	100.3	73.4
1992	91.7	88.9	62.0	87.6	71.8
1993	99.0	95.7	72.7	100.6	85.9

Source: IBGE.

The following sub-sections present the different implications of the 1980s/1990s crisis and economic adjustment for the segments of the metalworking industry which are most relevant in the sample composition of this research. Our case studies are based on firms which are either producers of car components or capital goods (pumps and valves), or suppliers of machining services to these industrial segments (thus depending on their economic performance).

II.2.1 Capital goods

⁵ The classification utilized in Table 1 is adopted by IBGE (Instituto Brasileiro de Geografia e Estatística), the Brazilian federal agency in charge of the economic census and industrial surveys (Brazilian Institute of Geography e Statistic).

Within the "mechanic industry", the capital goods segment was the most affected by the retraction in the Brazilian domestic market in the 1980s. Table 2, below, reveals the steady tendency to decrease in capital goods sales since 1980, with a short period of partial recovery (1985/1988). Employment followed the same tendency. By the end of 1993, the volume of employment in the capital goods segment was just above half the volume of 1980.

TABLE 2
Output, Exports, Imports and Employment in the Brazilian
Mechanic Capital Goods Industry (1980/1993)

(US\$ Billions)					
Year	Output		Export	Import	Employment
	Value	1980=100			1980=100
1980	24.89	100.00	1.76	2.75	100.00
1981	22.19	89.15	1.81	3.20	96.84
1982	18.19	73.08	1.30	2.06	84.55
1983	14.90	59.86	1.24	1.25	68.36
1984	15.63	62.80	1.54	1.06	66.87
1985	18.40	73.93	1.74	1.17	78.29
1986	21.04	84.53	1.55	1.51	91.50
1987	21.59	86.74	1.77	2.02	96.40
1988	20.96	84.21	2.34	2.55	94.23
1989	20.10	80.76	2.44	1.99	91.94
1990	18.34	73.68	2.18	2.60	86.60
1991	15.19	61.03	2.08	2.47	69.73
1992	13.69	55.00	2.23	2.38	61.10
1993	13.42	53.92	2.55	2.45	55.02

Source: Abimaq/Sindimaq.

It is known that the diffusion of new technologies, and particularly of computerised numerically-controlled machine-tools (CNC machines) accelerated in the 1980s, in most industrialized economies (including the NICs). Although the diffusion of these new technologies was (and still is) limited in Brazilian industry, the capital goods sector is one of the major users. This is even more underlined in the case of leading, domestic machine-tool producers, which have adopted the new technology more intensively (both in their manufacturing processes and as new products).

Together with the adoption of new production technologies, the leading capital goods producers started, in the mid 1980s, the introduction of new management practices (inspired in Japanese management techniques). The dissemination of organisational innovations has been recently intensified, following trade liberalization. Technical change and the growth in capital goods imports suggest that employment in this sector may fall further, even in case of an economic sustainable recovery in Brazil.

The segment of machine-tool producers requires some attention. In contrast with the international tendency towards specialisation, the machine-tool industry in Brazil developed high level of verticalisation and a structure of production to supply large variety of products at low scale. This was the result of the combination of trade barriers, government requirements of product nationalisation and the insufficient development of cost effective, good quality local suppliers of parts.

The Brazilian machine-tool industry can be classified into three groups of firms, which cater for distinct segments of the internal market. The first group comprises multinational producers (like Traub and Index) and the largest national machine-tool maker (Romi). This group supplies machine-tools (universal or customised) with high technological content and was responsible for the introduction of CNC in Brazil. An intermediary group is formed by large and medium-sized local firms, which supply conventional machine-tools and simple CNC machine-tools. A third group comprises a bunch of medium-sized firms which produce cheap and simple conventional machines, for less demanding customers (Vermulm, 1994).

The economic crisis, the tendencies of technical change and the opening of Brazilian economy have brought substantial changes in the machine-tool industry. The successive and close recessions eroded the internal market in the past fifteen years. The output in 1993 was less than 60 per cent the 1980 figure. Unlike other industrial segments, the export outlet was not an available option for most local producers, given their technological limitations. In fact, Brazilian exports of machine-tools fell from the level of 70 to 80 US\$ million in the early eighties to US\$ 24 million in 1989. With tougher competition from imports, some firms left the industry, while others merged into larger firms. Import liberalisation is inducing firms to specialise, de-verticalise production and lower local content. There seems to be no room in the market for the intermediary group. The incorporation of microelectronics is requiring higher technological capabilities, larger investment in R & D and engineering activities and larger scales of production. The tendency is towards polarisation between large producers of CNC machine-tools and producers of conventional machines for the lower end of the market. As the enhancement of the network of local suppliers is much needed, some of the smaller machine-tool makers are

opting for becoming specialised suppliers of parts to the larger producers.

II.2.2 Car components

In contrast to the capital goods segment, the Brazilian car components sector grew significantly in the past 20 years. In 1975, this industry accounted for 2.9% of the industrial GDP, whereas by 1991 this share had increased to 7.2%. It is important to add that such a growth occurred in spite of the crisis which affected the whole automobile industry during the 1980s.

Since the 1950s, auto parts producers have been developing in parallel to car assemblers in Brazil. Brazilian vehicles presented an increasing nationalization rate, from 50 per cent of the average value of a car, in 1958, to 96 per cent in the late 1960s. Such a share of national components have been reduced since the early 1990s due to trade liberalization.

The 1970s were marked by the beginning of government policies aiming at promoting local exports. They were an important support to open opportunities for Brazilian auto parts producers, at a time when the world automobile industry entered the process of globalization. Transactions in the international market have been very important to upgrade local producers' technology and products.

The previous access to international markets was decisive for the industry to circumvent the 1980s crisis. In the early 1980s, recession in the car industry led to a steep reduction of the car component producers' domestic market. After a period of sales decline (Table 3), the car parts sector resumed the route of growth by increasing its exports to a greater variety of countries. In 1993, car parts exports had increased by almost four times the 1980 level (Table 3). As a result of such diversification, the car component industry changed its market structure: in 1992, the share of sales to domestic car assemblers was less than 60 per cent, in contrast to 71 per cent in 1980.

TABLE 3
Sales and Exports in the Brazilian Car Component Industry (1980/1993)

Year	Total Sales		Exports	
	Value	1978=100	Value	1978=100
1980	6,287	100	732	100
1981	4,361	69.36	825	112.70
1982	4,986	79.30	658	89.89
1983	3,454	54.93	799	109.15
1984	4,272	67.94	1,264	172.67

1985	4,917	78.20	1,396	190.71
1986	6,469	102.89	1,401	191.39
1987	7,276	115.73	1,679	229.37
1988	8,689	138.20	2,081	284.28
1989	10,581	168.29	2,119	289.48
1990	10,816	172.03	2,126	290.43
1991	8,453	134.45	2,047	279.64
1992	8,428	134.05	2,312	315.84
1993	9,900	157.46	2,750	375.78

Source: Sindipeças.

At the moment, an approximate number of 750 firms compose the car component industry, producing more than 10,000 items. The vast majority of these firms are small and medium sized, and controlled by local entrepreneurs. Only 5 per cent of them employ more than 1,000 workers, whereas half of them employ less than 200 employees.

However, the large car component producers are technological leaders in the industry and account for most exports. Only fifteen auto-part producers account for 75 per cent of Brazilian exports of car components. Out of these, 10 firms are European and American MNCs. Brazil is among the top exporters from newly industrialising economies, but exports are very concentrated in few product lines (engines, engine and gearboxes parts and motorradios). The largest external market has been for years the USA (between 40 and 50 per cent of Brazilian car part exports). However, exports to the Argentinian, Mexican and German markets have grown faster in the past three years.

The car component industry employed 176 thousand direct workers, in 1993 (Table 4), as compared to 214 thousand in 1980. Until 1986, employment has followed output fluctuation. However, as the process of firm restructuring based on rationalization, introduction of new technologies and new organisational practices, has been intensified, it has led to substantial employment reduction. Labour productivity, as measured by the sales/employment ratio, almost doubled between 1980 and 1993.

TABLE 4

Employment and Labour Productivity in the
Brazilian Car Component Industry (1980/1993)

Year	Employment	1980=100	Productivity ^a	1980=100
1980	214,300	100	29,33	100
1981	151,000	70.46	28,88	98.46
1982	167,300	78.06	29.85	101.77
1983	161,500	75.36	21.45	73.13

1984	184,600	86.14	23.21	79.13
1985	203,200	94.82	24.22	82.57
1986	229,700	107.18	28.12	95.87
1987	218,100	101.77	33.37	113.77
1988	224,300	104.66	38.79	132.25
1989	237,900	111.01	44.45	151.55
1990	217,400	101.44	49.84	169.92
1991	193,600	90.34	43.57	148.55
1992	170,700	79.65	49.28	168.01
1993	176,000	82.12	56,25	191.78

Source: Sindipeças.

^a Sales (US\$ million) per 1,000 employees.

The restructuring process was also based on firm concentration. A great number of merges and acquisitions occurred, in addition to the leaving of the more fragile firms, contributing to the reduction in the number of firms from a level of 2,000, in 1989, to the present level of 750.

In the 1980s, the restructuring process affected mostly exporting firms, since firms catering only for the domestic market were still protected. At that time, keeping external markets induced firms to upgrade product design, product quality and production processes. However, after trade liberalization, the restructuring process has deepened (Posthuma 1994).

Brazilian car component producers have adopted a two-folded restructuring strategy. On the one hand, there has been a limited and selective incorporation of electronically controlled machines (CADs and MFCNs), which is concentrated in the areas of the production process in which quality and precision requirements are greater. On the other hand, and combined with the first strategy, there has been an intensive (in comparison with investment in new machines) adoption of new organisational practices. The latter has brought significant improvement, not only in productivity, but also in quality. Techniques such as Statistical Process Control, Kanban control and Manufacturing Cells have been disseminated in most leading firms, even though it is necessary to add that the extension and quality of utilization vary considerably from one firm to another.

Together with the changes mentioned above, it has been noticed the dissemination of polyvalent (multitask) work in the car component industry, which is in line with employment decrease in the past three years [Posthuma (1994)]. A further tendency, which is still in its initial stage, is

de-verticalization and the expansion of car parts producers' sourcing parts, components and machining services from other firms.

Finally, it is necessary to stress that the process of restructuring in the car component industry is not evenly disseminated. On the contrary, it has helped to improve the most dynamic areas and firms, while others, less competitive, have become more fragile after trade liberalization.

II.3 The Diffusion of New Technologies in Brazilian Manufacturing Industry

In the light of the economic changes discussed above, the final part of this section provides a general account of the diffusion of microelectronics-based automation in Brazilian industry. The focus is on the new technologies which are more relevant for the engineering industry.

The diffusion of new production technologies in Brazilian manufacturing has been a steady tendency, although the pace of diffusion is slow as compared to OECD countries and to some of the Asian NICs. The adoption of CNC machine-tools, robots, CADs and other specialised, electronically-controlled machinery, in the engineering industry, has been primarily motivated by the pursuit of product quality enhancement, in order to serve export markets. Various factors contribute to the current low level of diffusion. However, if one should be single out, this is macroeconomic instability and its effect on the decline of the investment rate. Slow diffusion of new technologies in Brazilian industry reflects, above all, the retraction of the internal market for capital goods (as seen in section II.2.1).

Unfortunately, there is lack of reliable, updated, aggregate data on the diffusion of new technologies in Brazil. Table 5, below, presents the stock of universal, microelectronics-based machinery. Except for robots, these figures underestimate the current stock, because first they are based on a survey which does not cover the entire population of user firms and, second, they do not comprise imports since 1988.

TABLE 5

**Stock of Microelectronics-based Equipment
In Brazilian Manufacturing Industry — 1992 (Number of Units)**

CNC Machine-Tools ^a	Robots ^b	CAD/CAE ^a
7,141	345	1,664

Source: Sobracon (1992).

^a The number of CNC machine-tools and CADs does not include imports since 1988.

^b Estimated by Asea-Brown-Boveri do Brasil, as for 1994.

The figures in Table 5 reveal that, as regards CNC machine-tools and CADs (computer-aided design equipment), the stock has reached a considerable level. Brazilian manufacturing firms are increasingly relying on programmable automation. In the engineering industry, as attested in our case studies, medium and large firms are intensifying purchase of CNCs, in their procurement of new machine-tools. This tendency seems to be irreversible. According to the SOBRACON survey [SOBRACON (1992)], 49 per cent of the users of industrial automation (including other equipment in addition to those considered in Table 5) are in the engineering industry. The same survey suggests that 45 per cent of industrial users are large firms, whereas medium-sized firms represent 20 per cent.

However, when compared to data from advanced industrialised countries and from some of the East Asian NICs, it becomes clear that programmable automation techniques have been adopted to a much less extent in Brazil. Quadros Carvalho (1993) showed that this gap is systematic, in terms of both stock of equipment and density of diffusion. In 1985, the density of diffusion⁶ in the OECD countries varied within the range of 10,505 to 28,619 for CNC machine-tools, 1,188 to 22,011 for robots and 1,385 to 9,047 for CADs, whereas, in Brazil, in 1987, the density figures were, respectively, 2,100 (CNC), 60 (Robots) and 431 (CAD). The Korean figures, for 1985, were, respectively 5,176, 2,100 and 1,437.

Data on the evolution of diffusion suggest that this gap is likely to have widened. Since 1989, the worsening of the economic crisis in Brazil has accounted for a steep fall in the rate of diffusion of programmable automation. Annual sales of industrial equipment for the automation of manufacture (CNCs, CAD, Robots and Programmable Logic Controllers) dropped from a peak of US\$ 400 million in 1989 to approximately US\$ 220 million in 1992 (SOBRACON 1992, p.15). This tendency is confirmed by the figures on the local production of CNC machine-tools, which accounted for the largest

⁶ For the purpose of this comparison, the definition of density of diffusion was drawn from Edquist and Jacobsson (1988) and is the stock (number of units) of equipment per million employees in the engineering industry. A different definition is adopted in section 3 of this paper, regarding the diffusion of new technologies in sample firms.

part of supply in the 1980s. After a peak of 1,052 units in 1989, local production fell to an annual average of 500 units in the 1990s.

However, quantitative data do not tell all. It is important to look at the quality of diffusion. The literature on the Brazilian experience suggests that the engineering industry has been incorporating the new technologies in a *selective way*, combining old and new techniques, at plant level. The adoption has been mainly determined by the need to improve product quality to attend requirements of export markets.

For the Brazilian exporting industries, the toughening of competition gave rise to a demand for programmable automation techniques necessary in order to match international requisites of quality, precision and homogeneity [Fleury (1988), Quadros Carvalho and Schmitz (1989)]. Yet, the attainment of such standards has not generally required, so far, the adoption of full plant automation.

Prado, reporting on the case of the Brazilian auto-components industry, presented the following picture regarding the adoption of CNC machine-tools: "The adoption of microelectronics-based equipment has been mainly determined by quality reasons and is occurring at critical points of the productive process, in which the existing machines do not attain the required standards." [Prado (1989, p.34)]. Similar conclusions were drawn in the studies by Fleury (1988) and Posthuma (1991), regarding the car component industry and by Quadros Carvalho and Schmitz (1989), with respect to the terminal car industry.

This particular pattern of adoption in Brazil is partly related to relative factor prices, that is, cheap labour and expensive capital unit costs. As regards labour, it is important to mention that not only low (direct and indirect) wages, but also the great labour flexibility prevailing in Brazil are responsible for low unit cost (Quadros Carvalho 1993). Labour cost matters particularly in decisions regarding the adoption of robots (Edquist and Jacobsson 1988, p.156). On the side of capital, not only the cost of equipment, but also rocketing interest rates, contribute to the financial burden of investment.

Still, factor price does not seem to be the major influence on investment in new technologies. As suggested above, quality and performance requirements are above factor price in the process of decision-making regarding the purchasing of new equipment. What Brazilian authors have pointed to as the most significant cause for low diffusion is Brazilian economic instability, which generates a conservative investment behaviour in firms [Prado (1989), Coutinho and Ferraz (1994), Quadros Carvalho (1993)]. Only after trade

liberalisation, as the case studies in this paper suggest, the adoption of new technologies and of new organisational practices has been primarily driven by the search of cost reduction.

III. TECHNICAL CHANGE IN THE BRAZILIAN ENGINEERING INDUSTRY: THE CASE STUDY EVIDENCE

This section looks at the process of technical change in the sample firms. It focuses on the adoption of new technologies and on the diffusion of new management methods. First, some basic features of the sample firms — regarding their product orientation, size, market position and capital ownership — are summarised in Table 6, below. In order to cover the identity of firms, but at the same time to facilitate the reader's memorising of individual situations, we opted for giving firms the name of their products. The sample firms belong to two distinct segments of the Brazilian engineering industry: producers of auto parts to supply the car terminal industry and manufacturers of pumps and valves, who are part of the wider capital goods segment. However, given their distinct position in the chain of suppliers of the car industry, the group of producers of car components can be further divided into the group of proper car parts manufacturers and the group comprising their suppliers of machining services. Except for the small suppliers of machining services, the sample firms stand out as major competitors in their respective market segments and groups in Brazil. Furthermore, some of the car components firms of the sample export a large part of their output. Thus, it seems appropriate to characterise the sample firms, except for the machining services suppliers, as leading firms in the Brazilian engineering industry. The sample was balanced to include a number of local firms and another number of multinational subsidiaries, as well as to include large, medium and small firms.

TABLE 6
Basic Features of the Sample Firms

OIL-HYDRO: Established in 1964 and controlled by Brazilian owners. Main products comprise hydraulic fittings, valves, hose fittings, control valves and gear pumps. Leader in the Brazilian market of oil hydraulic fittings and valves. Exports are insignificant. Located in the town of Jundiaí, state of São Paulo. Medium to large size: 596 employees in 1993.
WATER-HYDRO: Established in 1953. Subsidiary of German multinational company. Main products are hydraulic, centrifugal pumps. One of the major suppliers of hydraulic pumps for industrial use in the country. Exports mainly to the parent company. Located in Jundiaí. Medium size: 361 employees.
TRANSMISSIONS: Established in 1953. Mechanical transmission division of North American group. Major producer of mechanical transmissions for light and medium trucks in the country. Exports to USA and Europe. One of the largest plants in the world dedicated exclusively to mechanical transmissions. 2,466 employees. Located in Valinhos, state of São Paulo.
AIR-BRAKES: Established in 1979. Subsidiary of North American multinational company. Produces air-brake systems for commercial vehicles. Main customers are Mercedes Benz, Volvo, Scania and Volkswagen. Exports to Germany, Austria and UK. Located in Campinas, state of São Paulo. Medium size: 343 employees.
PISTON-RINGS: Established in 1951 and controlled by Brazilian family. One of the largest manufacturers of car parts in Brazil. The business unit included in the sample is leader in the Brazilian market for piston rings. Exports 50 per cent of output to the US, Germany, Italy, UK and other countries. Located in Santo André, state of São Paulo. 3,085 employees.
DIESEL-ENGINES: Established in 1953. Subsidiary and diesel engine division of German company. One of the major suppliers for light and medium trucks. Main clients include Autolatina, Fiat Allis and Valmet. Exports to Mercosul countries. Located in São Paulo. Large size: 1,400 employees.
MEDIUM-SERVICES-A: Established in 1966. Controlled by Brazilian owners. Major supplier of machining services to manufacturers of auto parts and electro-electronic appliances in the Campinas region. Main clients include AIR-BRAKES and TRANSMISSIONS. No exports. Located in Campinas. Medium size: 186 employees.
MEDIUM-SERVICES-B: Established in 1956 and controlled by Brazilian family. Large supplier of machining services to car parts producers. Main clients are R. Bosch, Weber and Caterpillar. Exports to Germany, Switzerland and USA. Located in Campinas. Medium to large size: 580 employees.
SMALL-SERVICES-A: Established in 1972. Controlled by Brazilian family. Small supplier of machining services to car parts manufacturers. Main clients are AIR-BRAKES and other brake producers. Located in Campinas. Small size: 35 employees.
SMALL-SERVICES-B: Established in 1986. Controlled by Brazilian owner. Small supplier of components for car steering systems and other components.

Main clients include TRANSMISSIONS. Located in Campinas. Small size: 50 employees.

Source: Interviews and firm reports.

III.1 Product and Production Strategies in the Sample Firms: Reasons for Adoption of New Technologies

The restructuring strategies adopted from the mid eighties by the firms investigated in this research were marked by the particular effects of macroeconomic problems on their market segments. Indeed, our case studies show that firms' responses to economic instability and to a shrinking and more competitive internal market were clearly influenced by the particular constraints faced by their industrial segment.

Following the general fall in investment and decrease in the local demand for capital goods, the market for pumps and valves declined and competition became harder with import liberalisation. Table 2 shows that the sales of OIL-HYDRO and WATER-HYDRO in 1993 were still below the 1985 level, in spite of the general industrial recovery in that year. This point was most stressed by these firms in their reasoning about the adoption of a strategy oriented towards product diversification, greater customisation and quality improvement.

TABLE 7
Sales, Employment, Productivity and Exports in Selected Brazilian Engineering Firms (1985 x 1993)

Firms	Oil Hydro	Water Hydro	Trans missions	Air Brakes	Piston Rings	Diesel Engines	Medium Services A	Medium Services B	Small Services A	Small Services B
Sales (US\$ million)										
1985	29.18	35	97	13.36	80		9.13		0.60	
1993	30.81	30	184.37	30.13	172	170	9.5	12	0.84	0.60
Employment										
1985	667	487	3,312	361	2,465		254		32	
1993	596	361	2,466	343	3,085	1,400	186	511	35	52
Productivity ^a										
1985	43.75	71.87	29.29	37.01	32.45		35.94		18.75	
1993	51.69	83.10	74.76	87.84	55.75	121.43	51.08	23.48	24.00	11.54
Exports (US\$ million)										
1985	0.60	-								
1993	0.99	1.64	44.8	6	45	30		1.5		

Source: Interviews and firm reports.

^a US\$ thousands per employee.

To OIL-HYDRO, this change consisted of an increase in the variety of products manufactured, from a range of 150 (in 1982) to more than 350 types (in the early 1990s). Such a diversification was accompanied by substantial "complexification": many of the new product lines correspond to more complex, higher value-added hydraulic devices. Moreover, the new strategy involved the shift from a rigid, catalogue-based product mix to a more flexible, customer-oriented supply of products and services. OIL-HYDRO spends an average of 2 per cent of sales annually in product development and has accumulated some capability in design of quick couplings, control valves and gear pumps. Thus the firm had the technical basis to add manufacturing according to clients' specification to its traditional supply of standard parts. Moreover, OIL-HYDRO's aim is to integrate its sales and engineering departments into the client's process of detail engineering. In the management's view, this would represent the transition to a service-like type of industrial production.

WATER-HYDRO has gone farther in the direction of customisation of serial hydraulic equipment. Its German parent group is a world leader in water hydraulics and centrifugal pumps. The Brazilian affiliate has acquired significant experience in product adaptation and development and the prospect is for the Brazilian engineering division to become the central engineering unit for WATER-HYDRO Americas. Its outlay on product development in 1993 was 5 per cent of sales. At least 40 per cent of the firm's sales are based on special pumps manufactured to customer specification, but a large part of the standard pumps are supplied in dimensions also determined by clients. Crisis and hardening competition has led this firm to look even more carefully to the service side of its business, intensifying the integration of its technical areas (including sales) into clients' engineering activities. Managements in both firms considered that the adoption of new technologies, particularly of CAD systems and of CNC-based machining, was crucial to implement this new marketing strategy. In addition to integrating product development to manufacturing, only the new automation technologies could provide the required flexibility for frequent product change.

In addition to product diversification and customisation, the firms producing hydraulic parts and equipment stressed the attainment of high quality standard as the major factors determining competitiveness in this market. Therefore, they initiated in 1986/87 the upgrading of their quality procedures; at the time of the visits, both firms were changing project, production and quality control routines in order to obtain the ISO 9,000 certificate. However, the emphasis on product and quality does not imply that price competition is no issue in this market. Particularly after import tariff reduction, both firms felt the pressure of cheaper imports on profit

margins and took action to reduce costs. One such action, which was still in course at the time of visits, was the introduction of computerised production control systems, in order to enhance cost control.

In contrast to the group of producers of hydraulic devices, car component manufacturers have been facing much tougher price competition. The diversification of their sales to export markets during the 1980s required the auto parts firms of our sample an effort to modernise and diversify their products and to improve quality to attain international standards. While they could benefit from the protection of the internal market, these firms were partially compensated for lower, competitive international prices, by practicing higher prices and margins in their internal sales. However, import liberalisation and the intensification in global sourcing by local car assemblers have led car component manufacturers to face, in the local market, the hardening of price competition which marks the current situation in the global market (Posthuma 1994).

Most firms in this group of the sample, namely TRANSMISSIONS, PISTON-RINGS and DIESEL-ENGINES, have been involved with product innovation. Their spending in product development varied from 3 per cent to 7 per cent of their annual sales in 1993. Since the mid 1980s, these efforts have been mainly related to materials research and product design, in connection with product performance and product diversification. Although the manufacturing of car components in Brazil can be considered the typical mass production of standard parts, it has followed the general car industry tendency towards diversification within large volumes. Thus TRANSMISSIONS and PISTON-RINGS launched more new products in the last eight years than they did in the previous period since their establishment in the 1950s. AIR-BRAKES, the fourth car component firm in our sample, presented a similar trajectory of greater product variety. However, in contrast to TRANSMISSIONS and DIESEL-ENGINES, this multinational subsidiary does not participate in product development activities, which are entirely located in the European affiliates. Since the late 1980s, as car assemblers intensified global sourcing, auto parts manufacturers have been required to increase their integration into assembler product development activities, in order to enlarge their responsibility in the basic design of new parts.

This initiative towards product upgrading and diversification required change in production and design methods. The four auto parts firms in the sample initiated their experience with new technologies, particularly with CNC machine tools, in the early eighties and increased the rate of adoption in the period 1986/1988. Initially, the new technology was selectively

incorporated mainly due to quality/product-related reasons. As in the case of hydraulic devices, the use of CNC-based machining for certain operations in car components manufacture is tied to product design innovation. Moreover, product homogeneity is also favoured by the use of microelectronics-controlled equipment. As car component firms realised that the market tendency (and assemblers' demands) was towards greater variety of smaller batches in volume production, CNC machine tools and machining centres became the major technological option in the companies' investment programmes. The adoption of these new technologies helped firms to attain the flexibility required by more frequent product changes, because they enabled reduction in the size of economic batches and of lead times.

The same reasons (the attainment of quality and flexibility) were at the root of TRANSMISSIONS's and PISTON-RINGS's decision to start the implementation of JIT-TQC programmes in 1985/86. Since then, these firms have extensively shifted from functional production layouts to production cells organised according to groups of parts of similar shape, in which the responsibility for the attainment of quality was partially delegated to production workers. At DIESEL-ENGINES and AIR-BRAKES, a more systemic adoption of JIT/TQC methods came only with the 1991 recession and import liberalisation, even though these firms had also taken action before to upgrade their quality control procedures.

The new economic policy climate in the early nineties induced the car component firms to increase and to deepen the process of organisational change. This time, their primary goal was the attainment of cost efficiency. The four firms embarked in a route which they named as *downsizing*, comprising many different actions aiming at cost reduction, such as the reduction of management layers, the outsourcing of production, maintenance and administrative jobs and the intensification of work at the production cells. In this respect, the case of AIR-BRAKES stands out. Combining *downsizing* and the adoption of systemic JIT/TQC methods, this firm underwent an organisational "revolution", in a short period of time (from 1991 to 1994).

Finally, let us consider the strategies of the machining services firms. To this group, a very tough price competition is the central feature in the market they service. This is mainly to do with car component firms' struggle for cost effectiveness. TRANSMISSIONS and AIR-BRAKES are among the major clients supplied by our sample machining service firms. In the search for cost effective production, the auto part producers substantially increased the outsourcing of machining jobs, while putting pressure for price reduction onto the suppliers of such services. Such a pressure often assumed the form

of the threatening of (or effective realisation of) importation by the client. The medium sized service firms fear the competition from Chinese and Taiwanese competitors. The machining service firms are in turmoil and face a major challenge. As one interviewee has put it, "we have a lot more service, but our margin is nihil". However, as compared to the other sample firms, they have much less the necessary financial and technical resources to change and overcome their problems.

Having no product line of their own, the machining service firms do not carry out product development activities, nor do they participate in their clients' product design. The situation common to the four service firms is that they work from detailed product drawings supplied by the customers. Still, the manager of MEDIUM-SERVICES-B stressed that an upgrading of the product engineering area was in course, since the technical relationship with clients tended to become more sophisticated.

Market evolution and performance in the service firms closely followed the change in the car component industry. After the sudden drop in sales provoked by the 1981/82 recession, the growth in Brazilian auto parts exports was responsible for a correspondent increase in machining services, which reached the peak in 1986/87. The adoption of new production technologies by the service firms began at that time. It was restricted to the incorporation of CNC machine-tools. The introduction of more reliable quality control procedures also dates from that period. The adoption of microelectronics-based machining was suggested, if not required by auto-part manufacturers. The attainment of precision in certain operations, as well as product homogeneity demanded a gradual diffusion of the new technology. In the case of MEDIUM-SERVICES-A and B, the change in clients' orders also contributed to motivate the continuing adoption of CNCs. Although part design did not change often, the orders were more and more becoming smaller in volume, short-noticed and frequent. Therefore, reduction in lead times and increase in plant flexibility were necessary. This was less so for SMALL-SERVICES-A and B, because these firms have always worked to attend rather small batch orders. In 1990, when some clients started to require Just-in-time deliveries, the machining service firms were already flexible enough to adapt.

The cost reduction urgency of the 1990s accelerated the process of restructuring in the service firms. Auto part producers began to require new management practices of suppliers, such as the organising of production in cells and the adoption of quality control methods based on statistics. Yet, the introduction of new production concepts is still incipient in these firms.

III.2 New Technologies in the Sample Firms

The first part of section 3 intended to present a brief account of how the sample firms have responded to changes in the Brazilian economy and economic policy, focusing on their product and production policies. This sets the context for this subsection, which looks at the adoption of new production technologies. Situating firms' technological choices within their product and market context contributes to the understanding of the rate and pattern of adoption. However, a short review of the basic steps of the production process in the sample firms is useful before the discussion on diffusion.

III.2.1 The production process in the engineering firms

As regards basic phases of the production process, the engineering firms of the sample can be clustered into two groups. In the group comprising producers of hydraulic devices and of car components, firms carry out internally most phases of the manufacture of their respective products. In short, the production process consists of the machining of metal castings and forged pieces in order to obtain parts of various shapes which are assembled into the final product (fittings, valves, pumps, transmissions, brakes, engines, etc.). The group of suppliers of machining services is different in that firms are mostly restricted to machining operations of small parts.

A complete description of each firm's production processes is beyond the reach (and length) of this paper, as it would require a look at each plant (if not each product line) separately. Yet, a rough but useful simplification allows us to suggest that the production process in the firms of the first group involves up to six stages. Most firms do not carry out all stages in-house.

Stage one refers to metal casting and forging and is internally executed by WATER-HYDRO and PISTON-RINGS (casting) and by TRANSMISSIONS (forge). The other firms have their metallic raw material (including steel bars) supplied by external steel mills, forges and casting firms. Castings and forged parts are basically made of steel, iron or aluminium. The latter is used to a lesser extent. Even in the case of the three firms mentioned above, the production of castings and forged parts would perhaps be better classified as a separate production process, for these operations are carried out in separate plants, and

constitute independent business units, which also supply external customers.

The second stage, machining, is the core of the production process. Here, components of the final product are separately machined. The variety of machining operations found in the whole set of sample firms is enormous. These machining operations can be clustered into four types: a) major machining operations of small to medium parts, involving turning, milling, drilling and boring; lathes and milling machines are most used in these operations; b) machining operations of medium to large and heavy parts, carried out in machining centres or in transfer-lines which are capable of multiple operations; c) auxiliary operations, generally consisting of additional drilling or boring in manually operated machines; and d) deburring and grinding operations, which are carried out in order to improve the first cutting operation and to attain the required measurement tolerance.

Except for PISTON-RINGS, which only deals with relatively small parts and does not need machining centres in its operations, all pumps and valves producers and auto parts makers go through these various types of machining operations. As their products are made of many distinct parts with different shapes, these components are generally processed in parallel, each shape going through a particular route of machines. As these components also vary in terms of the level of complexity of the shape, the range of the average number of operations per part is wide, if the whole set of firms' components is considered. They vary from an average of five machining operations per part (OIL-HYDRO, WATER-HYDRO and AIR-BRAKES) to fifteen operations (PISTON-RINGS). In the case of producers of major auto parts (TRANSMISSIONS and DIESEL-ENGINES) the average is ten operations per part.

The next stage (three) consists of providing cohesion and durability-related qualities to the machined parts. In all firms, this involves heating to high temperatures. PISTON-RINGS, TRANSMISSIONS and DIESEL-ENGINES have their own heating facilities, while the other firms subcontract this service. This stage may also comprise a chemical treatment aimed at strengthening the anti-oxidation properties of parts. Not all parts go through this process. Most firms subcontract this operation, except for PISTON-RINGS and TRANSMISSIONS whose facilities encompass chemical treatment.

Stage four is assembly. The complexity of this stage varies from firm to firm and from product to product. In most cases, this stage is organised around fixed assembly lines, with products moving on tables and being passed on by workers, with the help of pulleys to move heavy pieces. The assembly of standard valves and pumps (hydro or oil) is relatively simple and the number of assembly posts goes from two to eight. However, the assembly of customised hydraulic pumps is more complicated and requires knowledge of mechanics. Thus it is organised in assembly teams and not in lines. The assembly of major car components (TRANSMISSIONS and DIESEL-ENGINES) involves a much larger number of parts and posts (up to 30 posts, in the case of engines), and the principles of organisation here are closer to those of car assembly.

Testing and quality control is the fifth stage. Although most firms of the sample have adopted TQC procedures, involving production workers with quality production and control, the final quality control stage is necessary. In the case of more complex products (gear pumps, hydraulic pumps, transmissions and diesel engines) each product goes through performance testing, involving electronic monitoring. Simpler products still pass through visual inspection (piston-rings, for instance) and sample testing. The last and sixth stage corresponds to packaging. In the firms which deliver just-in-time (AIR-BRAKES and PISTON-RINGS), products are packed in boxes which follow directly to the customers' assembly lines.

To conclude this section, it is necessary to mention the production process in machining services. These firms are only involved in stage two (machining) and in the final stages of the process (quality control and packaging). In the case of the small service suppliers, the client firm often provides raw material to be processed. Generally speaking, machining operations are simpler in these shops. The average number of operations per part is below five and these operations do not require integrated machining (machining centres or transfer-lines). The medium sized service firms carry out their own quality control inspection and are also involved with just-in-time deliveries.

III.2.2 The diffusion of new technologies and new concepts of production in sample firms

In the group of manufacturers of hydraulic devices, the diffusion of new technologies (particularly of CNC machine-

tools) started in the mid eighties and has kept a steady pace since then. Before the adoption of new technologies, production layouts were organised along functional lines, with conventional machines clustered by type of machine (type of machining operation) and size. The typical layout included one area for conventional automatic lathes (single and multi-spindle) and another for conventional transfer machines, which were followed by the area for drilling, boring and milling machines, which, in turn, was followed by a fourth area for grinding machines. Batches of products in-process of different shapes went this sequential order until assembly.

OIL-HYDRO and WATER-HYDRO present by far the highest density of diffusion of CNC machine-tools in the sample, if we take the percentage of parts which are machined in CNC machines as an indicator of density. As shown in Table 8, below, at the time of visits, this share was 75 per cent at OIL-HYDRO and 60 per cent at WATER-HYDRO.⁷ This table also reveals that OIL-HYDRO has the second largest stock of CNC machines (59 machine-tools and 7 machining centres) in the sample. This firm started to experiment with new technology in 1983/84, with the purchase of two INDEX CNC lathes. The results were considered so promising that, since then, OIL-HYDRO has sustained a permanent programme for the adoption of CNC machines. While the largest purchases of new machines were made between 1985 and 1988, the last acquisition occurred in 1991. At that time, CNC machine-tools and machining centres had replaced one hundred conventional machines.

TABLE 8
Diffusion of Microelectronics-Based Automation in Selected Brazilian Engineering Firms (1994)

Firms	Stock of NT		Density of Diffusion ^d (%)	Adoption of IT in design and production management ^e		
	CNC-MT ^a	CNC-Machining Centres		CAD Systems (seats)	CAM Systems	Computerised Production Control
Oil-Hydro	59	7	75	3	x	-
Water-Hydro	8 ^b	-	60	3	x	x
Transmissions	103	9 ^c	20	11	x	x
Air-Brakes	10	2	30	3	-	-
Piston-Rings	19	-	10	8	x	-
Diesel-Engines	nd	nd	10	25	x	x
Medium-ServicesA	33	-	20	-	x	-
Medium-ServicesB	25	-	15	-	x	-

⁷ These numbers are not precise, but estimates made by firms' industrial directors and engineers. Our observation during plant visits confirmed that the density of utilisation of new technologies in machining operations is substantially higher at hydraulic device plants than at car component plants.

Small-ServicesA	4	-	30	-	-	-
Small-ServicesB	6	-	nd	-	-	-

Source: Interviews and firm documents.

^a Number of CNC machine-tools adopted in the plant.

^b One of these machines is served by a laser micrometer.

^c Four CNC machining centres are integrated into a Flexible Manufacturing System.

^d The density of diffusion is the percentage of output due to CNC machining.

^e In these columns (x) refers to the occurrence of adoption, whereas (-) means no adoption.

At WATER-HYDRO, adoption was intensified only after 1990. Management considered import liberalisation as a major incentive to adoption, since CNC machine prices were halved after tariff reduction. In 1993, this firm imported two sophisticated Mazak CNC lathes, equipped with one Mitutoyo electronically-controlled, laser micrometer. Given the versatility and precision of these machines, this move was considered by management as a qualitative jump in the machining capability of the firm.

As regards the utilisation of information technology in project and management areas, the acceleration of diffusion has also occurred in the 1990s. The information system which WATER-HYDRO was implementing at the time of interviews is one of the most integrated among sample firms. The subsystem for design and engineering was upgraded with the introduction of an Intergraph CAD system, with three seats. This system is integrated to a Digicon/Smartcam system for CNC programming, which was introduced with the first CNC machines. The most comprehensive move towards informatization, however, is the adoption of SIMEX, a network system, based on a Hewlett Packard (HP) supermicro computer supporting one hundred terminals, which will be spread around the factory (each plant supervisor will work on his own terminal) and offices. The SIMEX software is designed to integrate production planning and programming, production control in real time (utilising bar codes on products), cost control, sales and inventories. This system will allow WATER-HYDRO to obtain a much finer control of production costs and times, a weak area in most Brazilian firms, as will be seen ahead in this paper.

In this respect, OIL-HYDRO is behind, but following in the same direction. In addition to the utilisation of integrated CAD/CAM systems, the firm has started the introduction of direct numerical controls (DNC) in most of the CNC machines, in order to integrate them to the project/programming systems. This is seen as an important step to improve cost control.

In both pumps and valves firms, the evolution of adoption of new production and design technologies was simultaneously accompanied by and integrated to the process of organisational innovation. At WATER-HYDRO, change to cellular plant layout was simultaneous to the adoption of the first CNC machines, in 1985/86. At that time, the major aim of both innovations was to reduce lead time, to gain flexibility and quality, and to expand capacity within the plant. Later, the firm widened the scope of production workers' tasks, including the delegation of greater responsibility over quality, even though keeping a conventional, atomised job classification. A reduction in the size of inventories was also obtained, although management does not see the firm as matching internal JIT standard. As to quality-related actions, WATER-HYDRO is seen as a pioneer, due to its early supplying to Petrobrás (which is known for tough quality requirements made on suppliers). The firm has been a Petrobrás Quality-assured supplier since 1984. Moreover, it was undergoing an audit to qualify for an ISO-9,000 certificate at the time of our visits. Next, WATER-HYDRO plans to introduce a programme based on the concept of Total Quality Maintenance.

OIL-HYDRO also presents high standard in quality procedures, having developed a quality tradition in the market. The firm developed its own, formalised quality audit system in 1978. It is now adapting this system aiming at the ISO-9,000 qualification. In 1989/1990, with the technical support of a renowned management consultancy/training institute, the firm started a process of comprehensive organisational change. This included the shift to cellular organisation, change in production job titles and an increase in the average wages (the bottom machine operator wage was levelled with the top). An involvement campaign was started, aimed at obtaining workers' good will towards change and innovation. After two years, the experiment was considered problematic and reverted. Instead of physical production cells, OIL-HYDRO adopted the concept of *featuring cells*, which consisted of returning to the functional layout and adopting a concept of production programming that takes into account the best machines to be followed by a batch, in order to reduce lead time. In spite of these problems, and of the fact that none of the hydraulic devices sample firms went much far in changing crucial areas such as the management of human resources, their experience went beyond the narrow, localised use of a few techniques. As far as the organisational changes discussed above were related to

common objectives (increasing flexibility, reducing lead times and improving quality), their systemic nature can easily be attested.⁸

In the group of car part firms, the adoption of new technologies has also kept a steady pace since the mid eighties, even though the density of diffusion indicates a more selective utilisation, when compared to the previous group. Before new technologies, plant layouts were mostly organised in functional lines, following the criteria of grouping types of machines/operations. However, at the huge plants of TRANSMISSIONS and PISTON-RINGS, a division by major product line (for instance, car transmissions, truck transmissions, powershift, and so on) preceded the functional division. Moreover, the machining of the heavier parts of transmissions and engines was made in very large transfer lines which constituted separate areas. In all cases, the vast majority of machining operations were carried out in rigid, conventional, automated machine-tools.

Table 8 above shows that car part firms present lower density of diffusion of CNC machine-tools than firms in the pumps and valves business. The share of output machined with new technologies varied between 10 and 30 per cent within the group of auto part firms, at the time of our inquiry. TRANSMISSIONS has the largest stock of CNC machines in the sample, even though its density of diffusion is just 20 per cent. This is due to the fact that this firm has the highest stock of conventional machines as well (approximately 1,200 machines in operation). This company is the only in the sample (and one of few in Brazil) which adopted a Flexible Manufacturing System (FMS), comprising four Grob machining centres, one head changer and a system for automatic transfer and feeding. The FMS carries out the machining of the bodies of the most recent product launched by the firm. TRANSMISSIONS's experience with CNC machines started in 1980 and adoption was intensified in 1986/87, at the time when the firm introduced cellular layout. Since then, investment in new machines has been exclusively oriented to the new technologies. Management stressed that import tariff reduction, and the correspondent fall in CNC machine prices, contributed to accelerate diffusion. With TRANSMISSIONS's average investment of three to four per cent of annual sales (US\$ five million) in new

⁸ For a reference on systemic organisational and technological changes opposed to the adoption of single, isolated techniques see Fleury (1988).

machines, the firm is now able to purchase at least double the number of CNC machines it used to procure before.

A similar story, regarding investment in new machines, was told at AIR-BRAKES and DIESEL-ENGINES, even though the former started the adoption of new technologies in 1982, whereas the latter only started in 1987. DIESEL-ENGINES is now building an entirely new production line for the machining of a more compact and more efficient engine (to be launched in 1995), in which 95 per cent of production will run in CNC machines.

The case of PISTON-RINGS is substantially different, because this firm only started to adopt CNC machines in 1986, one year after the beginning of change from the functional production layout to the concept of production cells. This firm presents the lowest rate of density and one of the smaller stocks of CNC machines in the sample. Yet, it is the only firm to incorporate automated handling/feeding devices, which are dedicated to serving CNC machine-tools. Management argued that the process of production of piston rings demands special machines, given the need for machining very large batches of small parts of a peculiar shape, and that the application of new technologies to these machines has not developed much worldwide. PISTON-RINGS manufactures in-house most of the machines utilised in production. Nevertheless, the manager of the Ring Processes and Methods Division stressed that "after the introduction of cellular organisation and of the JIT philosophy, and with the fall in CNC prices, the choice and adoption of CNC equipment became imperative". The introduction of CNCs in the machines built at PISTON-RINGS allowed automating the control of product homogeneity and of the attainment of precision tolerances in the machining of rings. With conventional technology, this control demanded a lot of attention and time from workers. The new technology "freed" workers to assume other tasks in cell, contributing to increase productivity. Given the high share of labour in the cost composition of piston rings, labour productivity is a central concern for management. This is why 80 per cent of all planned investment in new machines in 1994 is to be realised in the making of CNC machines.

In fact, this and other connections between new organisational practices and a greater urgency in the adoption of new production technologies seems to be one of the most interesting findings in this research. The car

component producers included in our sample are among the most advanced Brazilian firms in terms of the comprehensiveness and depth of the organisational innovations they developed and adopted in the past ten years. Firms like PISTON-RINGS and TRANSMISSIONS are show-cases of organisational change and have inspired and served as parameters to other companies within and outside the industry. A thorough account of their achievements in this field would be beyond the objectives of this paper. What we want to emphasise in this study is the simultaneity and the links between these organisational innovations and the diffusion of information technologies. The experience of AIR-BRAKES is another case in point. The full organisational "revolution" undergone by this firm has been already mentioned. Change at AIR-BRAKES involved from full adoption of production cells and minifactories, in connection with new cost control procedures, to implementation of a new, flatter and more integrated job classification aimed at motivating workers to participate in Kaizen groups, and to Just-in-Time delivering to its major clients. In the interviews, AIR-BRAKES management emphasised that the new organisational format and practices increased the exigency for new technologies. For instance, some of the old equipment became bottlenecks for the balancing of cells (due to the high set up and machining times of conventional equipment). The acquisition of two OKUMA CNC lathes in the last two years was aimed at overcoming such problems.

A similar tendency could be found in the adoption and integration of information systems. While most car part firms adopted CAD/CAE systems in the eighties in order to match the required flexibility of constant product change, they were substantially investing in the extension and upgrading of information network systems, at the time of our visits. The main goal is to increase computerised control of production at the shopfloor (in real time), and to integrate such control to design and inventory areas. As the industrial director of TRANSMISSIONS has put it: "A good information system is a concern which is high in our agenda. Information is a basic tool for competitiveness today. It is critical to reduce lead time in new product development. It is essential for an agile cost control and to keep cell teams informed. We want to bring to and display at the shopfloor as much information as we can." The pressure for cost reduction has contributed to increase the importance of the utilisation of computer networks in production control. Plant management at TRANSMISSIONS keeps the cells informed by displaying

control graphs referring to cells' own performance in terms of productivity, quality goals, absenteeism and work accidents. Management revealed that the firm is investing US\$ 2.4 million this year in an ORACLE network system, which is designed to integrate engineering, production and general management areas. The network design comprises three HP Risc computers which provide support to eleven CAD seats (using a Computervision software) and to 150 PCs (which will serve different areas at offices and shopfloor). Similar strategies were detected at PISTON-RINGS and AIR-BRAKES.

Last, let us examine diffusion in the group of machining service firms. Here the pace of diffusion is more irregular compared to the other groups, due to the fact that firms' investment programmes are more affected by economic up and downturns. As in the case of car component firms, the pattern of diffusion is selective, as indicated by the relatively low density of adoption showed in Table 8 (from 15 to 30 per cent of output). However, the area in which service firms seemed to be lagging behind most, is the adoption of organisational innovation. Even in the medium service firms, which produce quite a large variety of parts, the conventional (functional) layout, based on the grouping of similar machines/operations, was kept in most areas of plants.

Between the two medium sized service firms, MEDIUM-SERVICES A presents the largest stock of CNC machine-tools and the highest rate of density (Table 8). However, this apparent advance in equipment modernisation is not unproblematic. This firm introduced the first CNC machine-tool in 1986, and after a short period of try it accepted ROMI's offer of a special payment scheme and purchased a lot of 13 machines. At the time of our interviews, management complained that the capacity of CNC machining services in the firm was well above demand. In fact, even though MEDIUM-SERVICES A's sales in 1993/94 were at the level of its historical peak, we could observe that CNC machine-tools were substantially idle. This suggests that the firm hastily purchased more CNC machines than it really needed in the near future. A similar problem occurred at SMALL-SERVICES B, with two aggravating factors. Here, the idle capacity of CNC machines was higher and the financial burden of the investment in new equipment was driving the firm to disaster. In contrast to these cases, MEDIUM-SERVICES B and SMALL-SERVICES A presented a more balanced and

adequate process of adoption. These findings raise the issue of the lack of knowledge and information in small and medium local firms, for the adequate planning for the adoption of new technologies. This point is discussed later in this paper.

Given the limitations of their project capabilities and the lack of technical resources, the utilisation of information systems in these firms is also limited. The medium sized service firms rely on DIGICON equipment for the generation of CNC softwares. However, no plans for a more extensive utilisation of information systems or networks were found. As compared to the other groups, the diffusion of organisational innovation in the machining service firms is incipient and far from systemic. Similarly to the adoption of new technologies, the introduction of new management practices in these firms owes much to clients' pressure and demands. Car component firms have been requiring that service firms adopt certain quality procedures and cellular organisation. Although one can observe that the upgrading of quality procedures has really progressed, it is also clear that improvisation is still the dominant managerial model and that systemic organisational change is beyond the reach of these firms.

Our interviewees complained about their lack of managerial and financial resources to meet clients' demands and about the lack of effective support received from them. The manager of MEDIUM-SERVICES-A criticised the short run, price-oriented approach of his larger clients (car component producers) : "They are not developing true partnership; at the slightest price variation, they shift to another supplier." Still, MEDIUM-SERVICES-B is following another route to attain cost effectiveness and price competition in an industry which is labour intensive. This firm is changing employment practices in order to reduce the cost of labour. Firstly, it replaced a large share of male workers with female workers, who are paid 20 to 30 per cent less for the same job (50 per cent of production workers were women at the time of the interview). Secondly, the firm hired ex-employees as outworkers to carry out simpler machining jobs. This form of informal labour is cheaper, since the firm does not have to assume the burden of social security and other social taxes. This situation (outwork) also raises the hypothesis that a fourth tier in the car industry chain may be developing fast.

Before moving ahead, it seems useful to draw some conclusions from the findings presented in this section. They refer to the pattern of diffusion and to the prospects of adoption of new technologies in the Brazilian engineering industry. A contribution of this study is to show evidence of the existence of *organic links between the diffusion of new technologies and of new management practices*. At least in the leading firms of the Brazilian engineering industry, the experiences with microelectronics-based automation, with the re-shaping of organisations in line with JIT/TQC methods, and with the more recent speeding-up in the adoption of information systems, can be better understood as inter-related parts of a continuing process of change, rather than as separated experiences.

The evolution of these experiences and the particular balance of techniques and organisational forms adopted, varies according to each firm's possibilities and capabilities, and is influenced by macroeconomic and sectoral factors. Thus, the fact that the diffusion of new production technologies is extensive in the capital goods firms and more selective in the car component firms is related to their market insertion and to the product strategy they have chosen to follow. However, a look at firms' planned and realised investment in new machines suggests that the diffusion of new production technologies is likely to accelerate in both sectors, if Brazilian economy resumes sustained growth. Moreover, our evidence shows that the continuing increase in competition severity is contributing to the stepping-up of the diffusion of information technologies, at least in the leading firms. These points are further discussed in the concluding section of this paper.

III.2.3 Selecting and adopting new technologies: procedures and problems

As regards sources of information and procedures for adoption of new industrial automation technologies, there is a clear gap between the group of machining services firms and the rest of the sample, which is in line with the technical gap between these firms. The selection of machines in the car part firms and in the producers of hydraulic devices is based on information which is permanently monitored by firms' industrial engineers. This is done through the follow up of the literature, constant visits to international and national fairs and in contact with machine suppliers. At the MNC subsidiaries, the technical process of searching and selecting machines is entirely

carried out by the local team of engineers. In terms of the decision-making process, the interviews suggested that MNC subsidiaries have a more accurate and formalised process of cost/benefit analysis (cases of WATER-HYDRO, AIR-BRAKES and TRANSMISSIONS) than local companies (OIL-HYDRO). At least in two of the MNC subsidiaries, the final decision requires the agreement of the parent company.

Local engineer teams are also the major actors in the gathering and processing of information about organisational change, even at MNC affiliates. For instance, TRANSMISSIONS is considered a pioneer in Brazil in the introduction of management innovations. This firm has a long established relationship with the engineering departments of the University of Campinas and the University of São Carlos; these departments help the firm to train technical personnel in new management practices. Other firms have also searched outside support in specialised institutes, as the local IMAM Institute and the North American Just-in-Time Institute.

In the less capable, machining service group, firms have less resources to monitor technical information and, thus, are more dependent on machine suppliers. Moreover, the process of selection and decision-making is empirical and not at all formalised. As seen before in this paper, this limitation has led two of the four service firms of the sample to overestimate their demand for new technologies. This technical limitation is probably behind the fact that the service firms' list of problems related to the utilisation of new technologies is much larger than that suggested by the other, better organised firms. The major problems raised by the former comprise 1- lack of trained and skilled workers to deal with CNC machines and new concepts of production; 2- higher maintenance costs of new technologies and 3- delays in deliveries of imported reposition parts, particularly in the case of electronic parts. In contrast, the latter problem was the only one emphasised by firms belonging to the auto parts group and to the hydraulic devices group. In fact, problems with human resources have been comparatively less felt by these firms, because they have invested in training and education. This point is examined again in the next section.

IV. THE IMPACT OF NEW TECHNOLOGIES ON SCALE AND SCOPE

This section examines the implications of the process of technical change examined above for scale and scope in the sample firms. It will be seen

that scope economies reaped by firms adopting new technologies have been important for their product flexibility and variability strategies. Following adoption, sample firms changed to producing a greater range of diversified products, to smaller scales. However, falling product scales did not imply falling plant scales. On the contrary, the evidence presented in this section shows that plant capacities increased, in most sample firms, due to efficiency gains resulting from the introduction of new technologies and new organisational methods. More importantly, our evidence reveals that increased output scales have been crucial for cost reduction in the sample firms, because technical change implied a significant rise in the share of capital costs and overhead costs on total costs.

IV.1 Changes in Product Scale and Scope

The literature has emphasised the contribution of new technologies to produce economies of scope. New technologies' programmability and flexibility are associated to reduced set-up and machining times, greater accuracy and reduced scrap and re-work. The result is that firms are able to economically manufacture larger variety of products or parts to smaller batch sizes. In this subsection, our case studies provide further evidence on these points.

IV.1.1 Changes in setting up times and machining cycles

The reduction of setting up times and of machining cycle times was one of the major goals of sample firms which adopted microelectronics-based automation. Gains in both aspects were crucial to the attainment of product and process flexibility, due to their implications for reducing batch sizes and lead times and increasing product variety. Moreover, both aspects, together with the increase in inventories turnover, were the most emphasised in cost/benefit analyses of new technologies.

In order to better understand the implications of new technologies for scale and scope at the level of product, our survey collected a number of examples based on the comparison of setting up and machining times involved in the manufacture of single parts in the sample firms, before and after the introduction of CNC machine-tools or machining centres. The comparison refers to parts which were produced with conventional machines and are now manufactured with CNC machines. The results of these comparisons confirm the enormous potential gains associated with new technologies, as indicated in Table 9 below.

TABLE 9
Gains in Setting up and Machining Cycle Times in Single Parts
(Selected Engineering Firms — Brazil — 1985 x 1994)

Firm	Piece	Batch	Setup	Machine	Ratio Setup/ Machin.Cycle ^c	
		Size	Gain(%) ^a	Gain(%) ^b	Before	After
OilHydro	PumpBody	30	75	80	2	2.3
WaterHydro	PumpAxle	100	82	71	9	5.5
AirBrakes	ValveBody	300	75	20	17	5.5
SmallServicesA	ValveLid	350	50	40	23	21
PistonRings	Ring	5,000	20	33	14	16
MediumServicesA	Joint	18,000	80	-	-	-

Source: Interviews.

^a Percentage reduction in setting up time in the manufacture of the art, after the introduction of new technology.

^b Percentage reduction in machine cycle time, after the introduction of new technology

^c Ratio setting up time/machine cycle time, before and after new technology.

In the cases of pieces produced to smaller batches (up to 100 pieces), machining with the old technology involved several different operations, carried out in separate machines. At WATER-HYDRO, for instance, the machining of hydraulic pump axles used to involve seven distinct machines and five workers, who carried out cutting, pre-machining, turning, milling and finishing operations. Each operation required a separate setting-up, comprising machine adjusting, tool changing, loading and unloading and fixing the piece to the machine tool. Some aspects of the set up of conventional machines were particularly time consuming, as, for example, tool changing and fixing workpieces to drilling machines. The cumulative setting up time for smaller batches amounted up to 340 minutes (the WATER-HIDRO case), in the examples collected. In the manufacture of large batches, we collected cases showing up to 1.000 minutes cumulative setting up time. Tool changing and machining adjusting, in these cases, were the most time consuming set up activities.

With the adoption of CNC machining, the setting up and machining times involved in our examples were substantially reduced, as seen in Table 9. The previously separated operations are now grouped together in one CNC machine, thus the number of different set ups is smaller. At WATER-HYDRO, the machining of pump axles now involves only 3

machines and two workers. The core machining operations are carried out at the Mazak CNC lathe. The level of machining precision enabled by the combination of the new machine with the laser micrometer, dispensed with the finishing operation. Moreover, set up activities are simpler and easier with new technology. There is little time involved in machine adjustment and tool change was considerable simplified. To this latter aspect, the organisation of production in cells has also brought an important contribution. As a result, the setting up times in the examples related to smaller batches amounted to up 60 minutes (case of WATER- HYDRO), after the introduction of new technologies. In the examples referring to parts produced to large batches, the maximum cumulative setting up time found among our examples, after CNC machining was adopted, was 600 minutes (the PISTON-RINGS case).

Another important aspect of the new technologies which has contributed to plant efficiency and to the reduction in lead times is the increase in machining speeds. In the examples of sample firms considered above, gains in machining cycle times were up to 80 per cent. The issue of improvement in plant efficiency resulting from gains in setting up and machining time will be resumed in the section on plant scale.

IV.1.2 Reduction in batch sizes

Most sample firms reported significant reductions in batch sizes, following the adoption of new technologies and of cellular layouts. Table 10, below, compares batch size distributions before and after technical change, in the firms which gave us detailed information on this topic.

In addition to the cases presented in the table above, other firms presented data referring to changes in the average batch size. TRANSMISSIONS reported a 75 per cent reduction in the average batch size, while PISTON-RINGS mentioned an equivalent reduction of 35 per cent. SMALL-SERVICES-A and MEDIUM-SERVICES-B also reported reduction in clients' orders with consequent reduction in batch sizes.

TABLE 10
Distribution of Machining Batch Sizes in Selected Brazilian Engineering Firms (1985 x 1994)

Firm	Number of items	Before (1985) (%)	After (1994) (%)
OilHydro	1-50	13	52
	51-100	29	14
	101-500	29	20
	501-	29	14
WaterHydro	1-5	40	43
	6-20	30	40
	21-100	20	15
	101-300	10	2
AirBrakes	1-100	5	10
	101-200	10	25
	201-500	15	50
	501-1000	50	10
	1001-5000	20	5
MediumServicesA	1-100	0	4
	101-200	0	8
	201-300	0	8
	301-1000	5	30
	1001-5000	80	30
	5001-	15	20

Source: Interviews.

Until the mid eighties, most sample firms used to work with large inventories of raw materials, parts and finished products. Most firms reported that no criteria of optimal or minimum batch sizes were adopted. Instead, they used to machine the necessary to accumulate for several months of sales. AIR-BRAKES and MEDIUM-SERVICE-A were exceptions. In the former, the 'rule of thumb' was to produce at least three months sales. In the latter, the minimum batch was eight days production for a 10 hours set up.

With the adoption of new technologies and *a substantial reduction in the size of orders*, this policy was completely changed. Most firms reported that the central rule is to keep inventories as low as possible (from 15 days to 30 days sales are considered as the minimum safe inventory). At OIL-HYDRO, the need to improve cash flow was mentioned as a crucial pressure in favour of this rule. Other firms reported substantial increase in inventory turnovers. At TRANSMISSIONS, the operating inventory turnover grew from 5.9, in 1989, to 11, in 1994, which was made possible with

reduced batch sizes and lead times. However, even with new technologies firms have not introduced criteria for optimal or minimum batch sizes. The most common 'rule of thumb' found was to produce the necessary to attend the new order plus the amount required to complete the minimum inventory. In this sense, one can say that batch sizes are primarily determined by demand evolution, rather than by calculation on economic batch quantities. In fact, at OIL-HYDRO, we were informed that the firm sometimes produced very small batches just to attend clients, irrespective of the costs involved. The policy was to attempt to pass on these costs to prices. Other firms confirmed the difficulties of establishing economic parameters to define optimal batches, difficulties which were related to both the lack of information on set-up costs and the large fluctuation of interest rates.

The latter aspects seem to be the manifestation of a more general fragility found by this study regarding cost control schemes in the sample firms. This point is further discussed in section IV.2.

IV.1.3 Increment in product variety

As seen in section 3 above, the introduction of microelectronics-based equipment was crucial for sample firms to increase product variety within their main area of specialisation. This move contributed to improve firm's capacity to meet clients' demands either for more customised equipment or for the development of new components for clients' new products. The increment of product variety in sample firms, between 1985 and 1994, is presented below.

In the case of producers of hydraulic devices, the adoption of CNC machines combined with CAD/CAM systems allowed the manufacture of pumps, valves and connections tailored to customers' technical requirements. As suggested by OIL-HYDRO's industrial director, the new technologies "permitted a radical change in our business philosophy". Not only the firm introduced three more complex, new product families of valves and gear pumps, but it also began to adapt its catalogue products to clients' drawings. At the time of the interviews, this firm was able to manufacture ten times the number of different product dimensions it used to manufacture before. At WATER-HYDRO, two new products were introduced. Yet, the most important aspect stressed by management was the newly gained flexibility to attend

clients' dimension specifications. The firm's customer oriented marketing policy and the flexibility and quality resulting from the new production techniques also facilitated the increase in sales of special pumps.

TABLE 11
Increase in Product Variety in Selected Brazilian Engineering Firms (1985 x 1994)

Firm	Number of Different Product Families		Number of different Products		Number of Different Parts Machined	
	1985	1994	1985	1994	1985	1994
OilHydro	7	10	150	352	4,411	41,892
WaterHydro	3	4	18	22	-	-
AirBrakes	29	6	245	350	520	650
Transmissions	-	-	7	15	800	1,500
PistonRings	453	624	4,000	6,000	36 ^a	47 ^a
MediumServices-A	-	-	-	-	900	1,500

Source: Interviews.

^a The figure refers to number of basic shapes.

In the car component firms, greater product variety has been important in order to develop new clients and to satisfy the increasing product diversification of the current clients. At AIR-BRAKES, the reduction in number of product families is to do with a recent re-definition in the concept of product family. PISTON-RINGS is the case presenting greater diversification of products, among car part firms. According to management, this significant increase in the number of products (50 per cent) is directly related to the diversification of PISTON-RINGS international clients.

As to the service firms, it is worth to add that other firms reported an increase in the variability of parts machined, in addition to MEDIUM-SERVICES-A. MEDIUM-SERVICES-B reported a 40 per cent increase in the number of component sizes machined, whereas SMALL-SERVICES-A stressed the greater diversity in different items subcontracted by autopart clients.

Finally, the interviews confirmed that the use of new technologies may be a necessary condition for the introduction of new product designs. Managements at AIR-BRAKES and WATER-HYDRO emphasised that *some of the parts designed for new products simply could not be economically manufactured with old technology.*

IV.2 Plant Scales, Firm Scales and Costs

The section on product scale and scope has shown that the incorporation of new technologies, in association with organisational change, is allowing sample firms to benefit from economies of scope. They are producing greater variety of products, to reduced product scales (smaller batches), but in a more efficient manner. Our question now is to inquire whether these economies of scope are displacing economies of scale. In order to answer this question, first we need to examine what happened to plant scales in the innovating firms.

IV.2.1 Increase in plant scales

In the sample firms where the pertinent information was accessible, we estimate that plant scales increased with the adoption of new technologies. In fact, appraising plant scales in the sample firms has not been simple and straightforward a task, since most firms were operating with idle capacity at the time of research. Most firms usually keep output records, but no capacity records. Except for PISTON-RINGS, in which the data on plant capacity increase has been published in firm's reports, plant capacities in the other firms needed to be estimated.

At PISTON-RINGS, capacity has been systematically expanded, from a level of 100,000,000 rings per year, in 1986, to 118,000,000, in 1993. The 1993 report says that a 30 per cent increase in the production of cylinder liners at the São Bernardo plant was obtained, only in that year. This was due mainly to the shift of the plant layout to production cells, but the adoption of new technologies also contributed to the achievement. Except for 1990 and 1991, this firm has operated close to full capacity in the past ten years.

The other sample firms presented a tendency for fluctuation in output in the same period. In 1993, a year of recovering sales for the industry, the output at OIL-HIDRO, WATER-HYDRO, TRANSMISSIONS, DIESEL-ENGINES and MEDIUM-SERVICES-A was still below the 1985 level. These firms

presented substantial idle capacity in 1993. Thus, the projection of changes in plant capacities had to take into account output levels, firms' estimates of idle capacity and the number of shifts run in both years involved in our comparison. Table 12, below, presents the estimate of plant capacities in the firms here referred.

TABLE 12
Estimates of Plant Capacity in Selected Brazilian Engineering Firms (1985 x 1993)

Firm	Oil Hydro	Water Hydro	Transmissions	Diesel Engines	Medium Serv.A
1985 capacity	711 ton/shift ^a	500 pump/shift ^b	393 units/shift ^c	30,000 units/shift ^d	525 ton/shift ^a
1993 capacity	777 ton/shift	750 pump/shift	465 units/shift	37,500 units/shift	730 ton/shift
Capacity growth	9.2%	50%	18%	25%	39%
1985 output	1,423 tons	14,400 pumps	242,550 units	54,000 units	1,025 tons
1993 output	1,013 tons	12,000 pumps	222,950 units	50,000 units	950 tons
Number of shifts					
1985	2	2	3	2	2
1993	1.4	1.6	2	2	1.3
1993 idle capacity ^e	47%	50%	30%	33%	53%

Source: Interviews

^a Capacity in tons per year per shift.

^b Capacity in number of pumps per month per shift.

^c Capacity in daily units of transmissions per shift; Transmissions data refer to 1986 instead of 1985.

^d Capacity in number of engines per year per shift.

^e Idle capacity was calculated considering the plant running in three shifts,⁹ except for the case of Diesel Engines (2shifts). The night shift capacity amounts to 80 per cent of daily shifts, in average.

Table 12 shows that the increment in production capacity was substantial at WATER-HYDRO and MEDIUM-SERVICES-A (50 per cent and 39 per cent, respectively). In the assessment of the engineer in charge of the implementation of new production methods at Water Hydro, a 70 per cent of the increase in plant capacity was due to the introduction of CNC machines, whilst the shift to cell organisation accounted for the rest.

⁹ Although night shifts are associated to higher labour costs and lower productivity, they are not an unusual practice in the Brazilian engineering industry, in periods of growth.

An intermediate capacity expansion was found at TRANSMISSIONS (18 per cent) and DIESEL-ENGINES (25 per cent). However, further plant capacity increase is expected in the next year at DIESEL-ENGINES, as a result of the implementation of the new engine production line, almost entirely based on CNC machines. In 1986, total plant capacity will grow to 50,000 engines per year per shift, a 33 per cent expansion from the current level. TRANSMISSIONS is also considering investment in a new line of transmissions designed for small cars, which will entail further capacity growth.

At OIL-HYDRO, the capacity in terms of tons of raw material machined did not expand so much. However, as this firm changed to manufacturing more complex and more varied parts, the number of machining operations per ton increased. This is reflected in the rise of the value of sales per ton of product, from US\$ 20.5 in 1985 to US\$ 30.4 in 1993. In short, this firm is adding approximately 50 per cent more value per ton of output. As OIL-HYDRO has benefited from scope economies and productivity gains yielded by the new CNC machines, the increase in the number of machining operations per part did not imply a larger utilisation of capacity. The ratio output/number of paid working hours, which was close to 1kg. per hour in 1985, has presented little variation since then. The conclusion is that, if the machining utilisation per ton of output is considered, the increment in capacity at OIL-HYDRO, was well above 9 per cent.

Another important point to be examined is the high idle capacity presented by these firms. At WATER-HYDRO this was an intended result of the process of technical change. The firm believes that export sales will increase in the near future and that it must be ready to hold its market share when the Brazilian economy returns to sustained growth. Moreover, although aiming at capacity expansion, the firm was not willing to increase the area of the plant. A similar situation was found at TRANSMISSIONS and DIESEL-ENGINES. At OIL-HYDRO the expansion of capacity was more an unintended result than the produce of design. Still, it was welcomed, since the firm believes that sales have been low due to the crisis in the capital goods sector and that its potential demand is considerably higher than the actual one. In contrast, the case of MEDIUM-SERVICES-A seems to suggest that this firm was not expecting such a large capacity increase and that CNC machining capacity is now too above the projected demand. This is one more reason to believe that this firm overestimated

its need for and its purchase of new equipment, as seen before in this paper.

Finally, in firms other than the ones mentioned above, we found signs of increment in plant capacities, even though the information collected at these firms was not complete enough to allow the estimate of such an increase. At AIR-BRAKES, for instance, the value of sales per employee rose from US\$ 37 thousand in 1985, when the adoption of new technologies began to accelerate, to US\$ 62 thousand, in 1989, and then to US\$ 88 thousand, (see Table 7) just after the implementation of organisational innovations. Considering that, in this firm, 1- the product range and complexity did not change so substantially (as compared to the case of OIL-HYDRO, for instance), 2- management declared that the market has not allowed any increase in prices of finished products and 3- management also reported the existence of greater idle capacity in the 1990s as compared to the 1980s, then it seems that output and plant capacity grew in line with sales per worker. Yet, the fact that AIR-BRAKES has substantially increased the subcontracting of component manufacturing does not allow us to estimate capacity growth drawing merely from the sales/employment ratio.

The case of SMALL-SERVICES-A is a different situation. In this small firm the value of sales per worker increased from US\$ 18.7 thousand to US\$ 24 thousand, in the same period, which amounts to a 28 per cent growth. Management revealed that this figure is in line with the expansion in output (tons of parts machined) and that, although the firm is machining a greater variety of parts, there was no increment in the average complexity of them. SMALL A is the final tier in the subcontracting network of the car component industry and has not put out any machining operation. Thus, in this case, we can conclude that capacity expansion is close to the variation in sales per employee. At MEDIUM-SERVICES-B, no information on variation in output and idle capacity was given, but management informed that one of the reasons for the incorporation of CNC machines was to add new production capacity in order to supply increasing export sales.

The overall conclusion we can draw from the evidence above, is that, in most sample firms, plant scales have increased since the diffusion of new technologies started. In some of these firms, this expansion was planned, whereas in others it was an unanticipated result. This research has also

produced evidence that growing plant scales are connected to the diffusion of industrial electronic automation and to the introduction of new concepts in the organising of work. This is further discussed in the following.

IV.2.2 Factors determining changes in plant scales

In the sample firms, new technologies and new forms of production organisation are connected to the increase in plant scales in four aspects. Firstly, the increase in machine speeds and decrease in number of machines involved per part contributed to the reduction of the average processing time, at a given level of output. At SMALL-SERVICES-A, management reckoned that the total reduction in processing time of the plant was 30 per cent, after the introduction of CNCs. Although we were not given access to indicators of total plant processing times in the other sample firms, examples of substantial gains in machining speeds were obtained for single parts and were presented in Table 9 (section IV.1.1). The contribution of shortening machining cycles for increase in plant scales was more significant in firms like OIL-HYDRO, WATER-HYDRO, AIR-BRAKES and MEDIUM-SERVICES-A, where the density of diffusion is high as compared to the other sample firms (see Table 8).

Second, increments in plant capacities are partially due to gains in total plant efficiency stemming from decreases in total setting up times. Table 13, below, presents indicators of these gains, in terms of the estimated ratio of total setting up times to total machining times, for some firms.

TABLE 13
Indicators of Efficiency Gains in Total Plant Setting up Time for
Selected Brazilian Engineering Firms (1985 x 1994)

Firm	(%)	
	Ratio Total Setting up Time/ Total Machining Time	
	1985	1994
OilHydro	35	11
WaterHydro	40	20
AirBrakes	25	7

Source: Interviews.

Further evidence was found at PISTON-RINGS, which reported a 20 per cent reduction in total setting up times, at

MEDIUM-SERVICES-A, which estimated 30 per cent gain in total set up and at SMALL-SERVICES-A (also 30 per cent). MEDIUM-SERVICES-B pointed in the same direction, but did not provide precise information.

The data above suggest that workers are less occupied with setting up activities, in relation to the time they spend on machines, thus contributing to increase capacity. Another interesting example was found at TRANSMISSIONS. This firm keeps records of the average setting up time in the plant, since the introduction of technological and organisational innovations. In 1985, the average setting up time was 1.8 hour. Following the introduction of the organisational technique called SMED (Single Minute Exchange Die), this was reduced down to 1.5 hour in 1987. However, according to the industrial director's account, the reduction in this indicator really progressed after the acceleration of the diffusion of CNC machines and the reduction in batch sizes (from 1987). In 1990, the number was down to 0.92 hours, and was further reduced to 0.4 hours, in 1992.

The third factor contributing to increase plant scales is the reduction in the percentage of rejected parts and in the time dedicated to re-work. In this respect, the incorporation of CNC machines is important, but the most significant examples in this survey are related to the adoption of new quality control techniques. At PISTON-RINGS, the percentage of rejected rings fell from eight per cent to just one per cent, following the introduction of the Total Quality Programme. Management stressed that this change led to a 10 per cent increase in output. At AIR-BRAKES, the reduction in rejected parts went down from 7,300 to 1,900 parts per million.

Fourthly, workers' greater dedication and the intensification of work constitute an important contribution to reducing downtime and, therefore, increase output and capacity. As mentioned before, the larger and more organised sample firms have been implementing new forms of work organisation and new practices of labour control. Two of these new practices are important for the purpose of this section. At TRANSMISSIONS, PISTON-RINGS, WATER-HYDRO, AIR-BRAKES and DIESEL-ENGINES managements introduced multi-tasking in job design, resulting in workers' enlarged capability to take on different tasks related to the same or to different machines. Greater labour flexibility has reflected directly in work intensification and downtime reduction. Another way to increase workers' contribution is the

adoption of suggestion schemes. TRANSMISSIONS, AIR-BRAKES and PISTON-RINGS are successful cases, in this respect. Some of workers' suggestions are significant for gains in plant efficiency. For instance, AIR-BRAKES reported a number of examples of reductions in setting-up times (up to 90 per cent reduction), coming from changes in set up procedures suggested by workers.

IV.2.3 Changes in unit costs

The section above showed that the incorporation of new technologies in sample firms has been associated with increasing plant capacities. Moreover, this increment is, in most cases, the result of gains in plant efficiency which were brought about by new technologies and new organisational forms. In short, sample firms' plants are now able to operate more efficiently and at larger output scales. However, this evidence alone is not enough to contest the de-scaling argument. The question is whether the increase in plant capacities and output scales is important for cost reduction in sample firms. This is the crucial point regarding the argument of reduced minimum economic scale. In order to address this question, it is necessary to examine the evolution of cost structures in sample firms, as well as the implications of new technologies for cost factors. This is done in the following sections of this paper.

Our experience in this survey revealed some hints about cost control practices in Brazilian industry. Even though case studies are not representative of average practices, it is important to emphasise from the beginning that cost control seemed to be the weakest management area in most firms visited. For a number of important items, firms simply had no control of real costs. For example, in the pumps and valves firms, labour costs involved in manufacture are estimated from the parameters (standard times) established by engineers for process routes, rather than from the knowledge of manufacturing real times. A similar practice is adopted to estimate the cost of raw materials, consumables, and so on. At SMALL-SERVICES-B, management reported that the firm subcontracts an accountant to estimate costs and prices and this information can not be used for managerial purpose, since management has no understanding of cost estimate procedures and of the meaning of cost figures. Therefore, information on costs in this survey should always be regarded with caution.

While high inflation was mentioned as a major obstacle to the improvement of cost control, some of our interviewees admitted that the little competition environment, which prevailed until recently in Brazilian economy, was responsible for firms' lacking interest in placing greater priority to cost control. "The market just accepted that we passed our inefficiencies on to prices; so, controlling costs with precision was not a priority." This may help explain why this was the most difficult topic for us to obtain information about.

Taking these limitations into account, let us first examine cost structures in the firms which provided detailed data on unit costs. They are presented in Table 14, below.

TABLE 14
Unit Cost Structure in Selected Brazilian Engineering Firms (1985 X 1994)

Firm	OilHydro (US\$/Ton ^a)		Machi.Serv.A (US\$/Ton)		AirBrake (US\$/Unit ^b)	
	1985	1994	1985	1994	1985	1994
Total Production Costs	8711	11884	7354	6889	11,62 ^c	10,36 ^c
Capital	1227	1815	1198	1437	-	-
Equipment			1036	1310		
Building & Vehicles			162	127		
Labour	2697	4057	2997	2736	1,77	1,69
Raw Materials	3448	4370	2673	2107	7,21	6,84
Consumables	907	931	243	280	0,82	0,94
Energy	63	298	162	189	0,63	0,38
Repairs	369	413	81	140	1,19	0,51
Overheads						
Marketing	2024	3037	202	126	1,28	0,89
Administration	2530	3061	421	154	1,32	0,76
R & D	510	640	-	-	-	-
Total	13775	18622	7977	7169	14,22	12,01

Source: Interviews.

^a Unit cost structure per ton of output.

^b Unit cost structure per product unit.

^c Capital costs not included.

The data presented in Table 14 reveal that unit costs have fallen in two sample firms, since technological and organisational change started. Total cost reductions obtained at MEDIUM-SERVICES-A and AIR-BRAKES, 10 per

cent and 15 per cent respectively, were not so large as the ones reported from the experience of advanced industrialised countries (Alcorta 1993). At MEDIUM-SERVICES-A, major reductions in unit costs occurred in overhead costs and in the consumption of raw materials and labour, in this order. They were offset by increase in capital, maintenance, consumables and energy costs. At AIR-BRAKES, cost reductions occurred in most items, except for consumables (information about capital costs was not provided). These data show that change in cost structure varies from firm to firm, due to reasons which will be discussed in next section. *Still, the data also reveal a potential for further gains, because these firms were operating with significant idle capacity (see Table 12 above); thus, in case of output growth, capital and overhead unit costs would be further reduced.*

The OIL-HYDRO case confirms that sample firms present a considerable variation between them, in terms of changes in the cost structure. Contrasting with the other two cases, OIL-HIDRO revealed a substantial increase in production and total costs (around 35 per cent). However, when examined from the angle of the quality of its output, OIL-HYDRO in 1994 is an entirely new firm, in comparison with what it used to be in 1985. As was demonstrated in section IV.2.1, now there is more capital (related to the increase in number of machining operations) and more skilled labour per ton of output. This is why capital and labour unit costs increased. However, the increase in total unit costs is also connected with the presence of large idle capacity. To put it another way, OIL-HYDRO may well offset rising costs in case of attainment of full capacity (and a larger output scale), given that this would lead to a reduction in fixed unit costs.

Cost reductions were also reported at PISTON-RINGS, TRANSMISSIONS and SMALL-SERVICES-A, even though these firms refused to provide detailed cost data. At PISTON-RINGS, operational costs were cut down from a level of 60 per cent of sales, in 1986, to 43 per cent in 1993, which represents almost 30 per cent reduction in operational costs. The most important contribution to cost efficiency was labour productivity increase, which reduced labour unit cost. This point will be further explored in this paper. This firm has kept a high level of investment in R & D (3 per cent of sales) along the past 15 years, but it was successful in reducing other indirect costs as percentage of costs and sales. According to management, the substantial growth in

output and sales, since 1985, has been important to reduce the weight of indirect costs per product. This change has allowed PISTON-RINGS to face the toughening of international competition in recent years.

Total unit cost decrease was reported at TRANSMISSIONS too (15 per cent). At this firm, the greater contribution to cost reduction was also increase in labour productivity. Even though capital cost has not changed its share in total unit costs, the reduction in labour unit cost was partially offset by a substantial increase in all items of indirect costs. Thus, as in the cases of OIL-HYDRO and MEDIUM-SERVICES-A, TRANSMISSIONS would benefit from reductions in indirect unit costs, in case it operated at a larger output scale, occupying the idle capacity estimated for 1993.

At SMALL-SERVICES-A, management reckoned a 15 per cent decrease in total unit costs, mark-up and prices. Again, the major contribution to this change came from labour productivity increase and reduction in labour unit cost, which more than compensated for increases in capital, energy and training costs. Were SMALL-A not producing and selling at a larger scale, it would not be able to compensate for increases in fixed unit costs. In fact, the importance of increasing output scales for cost efficiency, following the introduction of new technologies, was felt even more in the case of small sample firms. The reasons for this are examined in the next section.

The more general conclusion we can draw from the analysis of unit cost structures presented in this section, is that *the occurrence of increases in fixed production costs and overhead costs, in the presence of substantial idle capacity, reinforces the importance of sample firms expanding output scales in order to reduce costs.*

IV.2.4 The impact of new technologies on unit costs and firm scales

The changes considered in the previous section are, to a large extent, determined by the diffusion of new technologies. This is examined in the following.

Impact on capital unit costs

The evidence produced in this survey suggests that firms which intensified the adoption of new technologies suffered the impact of increasing capital costs. This was the case at OIL-HYDRO, MEDIUM-SERVICES-A and SMALL-SERVICES-A. The

increment in capital costs was primarily determined by the higher cost of CNC machine tools and machining centres.

According to data collected at sample firms, CNC machines (imported or locally produced) are more expensive than conventional machine-tools, in Brazil. Prices of CNC machine-tools have fallen dramatically in the past two years, but increased in hard currency during the 1980s. It is important to remind that the greater part of investment in new technologies was realised in the late 1980s. OIL-HYDRO, for instance, reported to have paid US\$ 138,000 for an INDEX/ GE42 NC automatic lathe, made in Brazil, in 1981. In 1983, the purchase of the same machine model cost US\$140,000 and, in 1986, the cost was US\$ 220,000. The prices of ROMI CNC lathes, made by the largest Brazilian maker, also went up in the 1980s, about 50 per cent. In the late 1980s, ROMI launched a simpler model (ROMI Cosmos) costing approximately US\$ 90,000. Prices of the simpler conventional machine-tools varied from US\$ 40,000 (universal manual lathes) to US\$ 80,000 (single-spindle automatic lathes). The direct comparison between different machines is problematic, since they are not able to perform the same tasks. WATER-HYDRO paid US\$ 500,000 to import a CNC MAZAK SQT30 with laser micrometer, but this machine is superior to any locally produced machine-tool. Still, our estimate is that the simpler CNC machine-tools produced in Brazil were at least 50 per cent more expensive than the simpler conventional lathes, until recently.

This estimate helps explain why capital costs increased in the sample firms which accelerated adoption of new technologies. In this respect, the case of OIL-HYDRO is a special one among sample firms. Beginning in 1983, this firm stepped up its outlays in new technologies. As seen before, in the past ten years the firm replaced most conventional automatic lathes by CNC equipment. From 1983 to 1986, OIL-HYDRO expenditures in CNC equipment amounted to US\$ 5.69 million, while the equivalent figure for the period 1987/1991 totalled US\$ 4.18 million. The average of 1.1 million dollar annual investment in new machines, in the entire period, was well above the previous record of capital investment in the firm. Therefore, increases in capital unit costs at OIL-HYDRO reflected the impact of this investment effort on depreciation costs. Although the shift to CNC machines also yielded savings on building space, this had no impact on OIL-HYDRO unit costs. Capital unit costs could be reduced only if OIL-HYDRO produced to a larger output scale, further occupying the current idle capacity.

In the case of MEDIUM-SERVICES-A and SMALL-SERVICES-A similar factors accounted for the rise in capital costs. However, the case of small sample firms deserve some additional attention. In the case of firms like SMALL-SERVICES-A, the shift from conventional to CNC technology implies a *necessary increase in capital costs and outlays*. This is because the trade-off is not between conventional automated machines and programmable automation, but between conventional, manual lathes and CNC machine-tools. If a firm is moving from conventional automation to programmable automation, it may happen that the former, if not cheaper, imply a greater concentration of capital outlay in time, than the latter. For instance, at DIESEL-ENGINES, management declared that one further reason for adopting CNC machines to build the new engine line was that the investment could be divided in time, allowing a more interesting cash-flow, in comparison with the adoption of rigid, automated transfer-lines, which would imply greater expenditure in the short run. Yet, the move from conventional manual lathes to flexible automation always entails an increase in capital investment outlays.

The situation in the three firms discussed above is not representative of WATER-HYDRO and of the majority of the auto parts firms in the sample (TRANSMISSIONS, PISTON-RINGS and AIR-BRAKES). The latter firms reported a more conservative policy of investment in new equipment. Their common policy was to invest annually the equivalent of the historic annual depreciation cost. Annual investment in new machines was primarily oriented to microelectronics-based equipment. These circumstances explain why investment in new technology has had little impact on capital unit costs in these firms. Yet, there is room for reduction in capital unit costs, since most of these firms operate with substantial idle capacity.

Impact on labour unit costs

Except for the OIL-HYDRO case, labour unit costs decreased in all sample firms, following the adoption of new technologies and new organisational practices. As seen before, the majority of firms which reported falling total unit costs attributed this to decreases in labour unit costs derived from gains in labour productivity. Labour productivity gains reflected the various aspects of plant efficiency enhancement which were commented in this paper. They were related to the improvement in setting up and machining times, to the intensification of work which is

associated to multi-tasking and to better management of product flows, and so on. Labour productivity growth, in sample firms, appeared in the form of a general drop in employment volumes, with steady or growing output. As shown already in Table 7, employment decreased from 1985 to 1993 in all firms which provided information for both years, except for SMALL-SERVICES-A. As sales remained at the same level (case of producers of hydraulic devices) or even increased (case of auto parts producers and service firms), the picture is one of a general growth in productivity in sales per employee. Table 7 reveals that sales per employee presented increases varying from 18 per cent (OIL-HYDRO) to 154 per cent (TRANSMISSIONS). In the sample firms where data about physical productivity was available, the tendency was confirmed. Gains in physical productivity, between 1985 and 1993, represented 12 per cent, at WATER-HYDRO, and 28 per cent, at MEDIUM-SERVICES-A.

Labour productivity increase was the main reason behind the decline in labour unit costs as observed in Table 14 and in other sample firms. The impact on labour unit costs was not greater because an increase in direct and indirect wages may have partially offset productivity gains. MEDIUM-SERVICES-A reported that total hourly wage (including direct wage plus social taxes) increased from US\$ 3.50 to US\$ 5.00, in the period considered in this research. PISTON-RINGS presented wage costs which are roughly the same. TRANSMISSIONS, AIR-BRAKES and SMALL-SERVICES-A also informed rising hourly wages in the period considered. The following factors contributed for such increase. First, the operators of CNC machines and workers involved in cellular manufacturing are considered more skilled than their colleagues working under previous technologies. In fact, if not more skilled, they undergo larger training programmes. So, they receive a differential wage for this. Second, indirect wages generally increased in Brazil in recent years, because the Brazilian government created new taxes affecting firms' payrolls, compensating for the decline in the total value of payrolls. Third, metal-workers in the engineering industry are among the most organised workers in Brazil, and their unions were able to improve their wage situation in the late 1980s. Fourth, an important aspect of rising indirect labour costs refers to the substantial increase in the amount of training and education expenses in most firms visited (including the medium services firms). As put radically by an interviewee, at MEDIUM-SERVICES-B, "in the last five years we invested more in training than we had

done in the previous twenty years." If this might be regarded as an exaggeration, it reflects the urgency firms have recently been putting on training

The case of OIL-HYDRO is different from the other sample firms, because, as already discussed in this paper, it took a completely distinct route, increasing substantially the value added to output, through the process of product complexification. This additional value is added not only by greater use of physical capital, but also by the use of more skilled labour. Production workers at OIL-HYDRO, in 1994, were more skilled and earned higher wages, than workers who were employed in 1985. Moreover, physical productivity (as measured in tons of output per worker) changed little in Oil-Hydro. The combination of these aspects account for the significant increase in labour unit costs in this firm.

Impact on input unit costs

Most firms in the sample agreed in that the new technologies and new organisational methods contributed enormously to efficiency in the use of raw materials. Scrap was reduced and better quality in production processes requires a lesser amount of re-work. This was behind the fall in raw material unit costs in MEDIUM-SERVICES-A and in AIR-BRAKES (Table 14). In the assessment of MEDIUM-SERVICES-A management, the fall in raw material costs is also associated with decreasing raw material international prices, in the period considered. Major savings in raw material were reported at PISTON-RINGS and attributed to the Total Quality programme. In 1992, they represented US\$ 2.5 million. At MEDIUM-SERVICES-B, management also stressed the contribution of new technologies for a 20 per cent raw material savings.

In terms of consumables, though, most sample firms suggested that their cost per unit increased. Table 14 reveals that the cost of consumables were greater at OIL-HYDRO, AIR-BRAKES and MEDIUM-SERVICES-A, following the introduction of new technologies. This is mainly related to more expensive tooling. WATER- HYDRO, for instance, reckoned that the cost of tools went up from US\$ 0.48 to US\$ 1.20 per machining hour, in the shift from conventional automatic lathes to CNC machines. For MEDIUM-SERVICES-B, the increase in unit tool costs was approximately 50 per cent. As to energy consumption, most firms also reported increases in costs. This the case of OIL-HYDRO and AIR-

BRAKES, as shown in Table 14. Management at WATER-HYDRO informed that the energy cost of one machining hour is US\$ 1.85, for CNC machines, in comparison with US\$ 0.29 per hour, for conventional automatic lathes. MEDIUM-SERVICES-B and SMALL-SERVICES-A also reported rising energy unit costs, of 25 and 40 per cent, respectively. Finally, and in contrast with the advanced countries' experience, most firms reported that maintenance expenses per unit of output rose after the introduction of new technologies. The exceptions were AIR-BRAKES (see Table 14) and WATER-HYDRO.

Impact on overheads and firm scales

Even though detailed data about unit cost structures were not accessible in most sample firms, it was possible to gather information on the evolution of overhead costs (marketing, R & D and administration) in a number of them. In this respect, the general conclusion we can draw from the survey is that increasing competition and technical change are leading sample firms to face increasing overhead costs related to R & D, engineering, marketing and services to clients. This tendency is clearer among the larger firms in the capital goods and auto parts industries. But service firms which have not been able to increase their marketing and engineering efforts are lagging behind.

In the case of pumps and valves firms, the need to provide a more customised product and client oriented service led OIL-HYDRO (see Table 14) and WATER-HYDRO to expand project (R & D), marketing and client service activities. At WATER-HYDRO, two thirds of employment were in indirect activities, at the time of research. Management reckoned that at least one third were involved with marketing and project activities. As put by an interviewee, 'this firm is more and more becoming like a project firm'. In the case of OIL-HYDRO, the most significant change was in marketing. The firm intensified marketing related expenses (50 per cent increase), in order to obtain new clients and take advantage of its recently developed production flexibility.

As regards auto part producers, the new marketing and R & D requirements have not been less. These firms are under the pressure of car makers to diversify products, to shorten product life cycle and to assume a greater share in design expenditures. Moreover, the advance of global sourcing requires the intensification of marketing efforts abroad. Thus, it is not surprising to learn that a firm like

TRANSMISSIONS increased indirect expenses from 4.2 per cent of sales, in the mid eighties, to 8.3 per cent of sales, in the early 1990s. This rise in indirect costs can be broken in the following items: (process) engineering, from 2 to 4 per cent; marketing and sales expenses, from 1.3 to 2.3 per cent; technical assistance to clients, from 0.14 to 0.36 per cent; and R & D from 0.7 to 1.6 per cent. At PISTON-RINGS, general indirect costs were reduced in the period, but R & D expenses kept the level of 3 per cent of sales. Management mentioned that outlays in R & D are increasing due to clients' demanding of performance and new materials. So, it is only through increasing sales (and scales) that PISTON-RINGS can face these new competition conditions. The situation is similar, at DIESEL-ENGINES, where management declared that it took about US\$ 20 million, in four years, for this firm to develop the new truck engine. This firm's R & D expenses have been around 7 per cent of sales, in recent years. Therefore, as regards overhead costs, the situation of falling unit costs at AIR-BRAKES seems rather the exception. Among other factors, this is due to the fact that all AIR-BRAKES project activities are developed abroad.

Finally, let us examine the case of service firms. One of them — MEDIUM-SERVICES-B — reported increasing overhead costs. Management mentioned that clients are now requiring some further 'technical content' in machining services, meaning that it is better for business if the subcontractor can also provide an improvement (even if it is just a small improvement) in the client's design. This is why MEDIUM-SERVICES-B was implementing a product project department, at the time of our visit. In contrast, MEDIUM-SERVICES-A was following the opposite route, slashing down overhead costs (Table 14) and presenting no plans for project upgrading. However, differently from the previous case, this firm had no intention (and chance) to enter external markets. In the case of the smaller firms, no significant change in overhead costs was mentioned. Yet, it was easy to observe, during our visits, that the small entrepreneurs were too busy (and apparently lost), trying to perform all the new activities which clients now demand from them, that is, quality control measuring and reporting, training workers, attending clients, and so on.

The main implication of the tendency presented in this subsection for our discussion on scale and scope is straightforward. In the current market conditions, firms are required to substantially increase their outlays in R & D, engineering and marketing, which represents a further burden on overhead costs. In order to compensate for it

(and avoid increasing overhead unit costs), firms need to expand output scales. In short, at the level of the firm, the minimum economic scale is larger now than before new technologies.

V. CONCLUSION

INDUSTRIAL RESTRUCTURING, NEW TECHNOLOGIES, SCALES AND THE PROSPECTS FOR LOCATION OF PRODUCTION IN BRAZIL

In the following, an attempt is made to bring together the main findings of these case studies as well as to draw conclusions from them.

1. Leading firms in the Brazilian engineering industry and their suppliers are making a substantial effort to restructure their product and production policies, in order to adapt to changes in the economy and economic policy and to become more competitive. However, in doing so, not all of them have equally succeeded. A clear gap was noted in this research, between the larger and better structured firms in the segments of car components and hydraulic devices, on the one hand, and the smaller and more fragile firms in the machining services business, on the other. The latter showed much less capability and not to possess all the technical and financial resources required to undertake a balanced process of technological and organisational change.
2. In addition to changes in their product strategies, the leading firms studied in this research implemented (and continue to implement) a broad transformation in their production concepts and practices. This comprised a combination of the adoption of microelectronics based forms of automation and the introduction of new management practices, inspired in the Japanese experience. The case studies revealed that the diffusion of new technologies has been growing. The fact that the largest part of sample firms' investment in new equipment has been oriented towards new technologies, suggested that the prospects are for accelerating diffusion in case of a stepping up in investment. *The study showed evidence that, in the leading firms, in which technical change was comprehensive and systemic, technological and organisational innovations were part of an integrated process. Advance in one stream required simultaneous progress in the other.* The particular pattern of adoption of new technologies and the combination with organisational change seemed to depend on firm's market insertion and choice of competition strategy.
3. The leading firms started the process of adoption aiming primarily at the attainment of quality improvement and at increased flexibility (of product and process). This was necessary to adapt to the new conditions of competition prevailing in their markets. Moreover, they

required their suppliers to initiate the process of adoption. The new technologies enabled the sample firms to succeed in the attainment of quality and flexibility. Our case studies showed substantial gains in terms of decrease in setting up times and machining cycles, which favoured a substantial reduction in batch sizes and lead times, and increases in product diversity. The result *was falling product scales*.

4. However, smaller product scales were not followed by the reduction in plant scales in the sample firms. On the contrary, in most sample firms, *plant capacities increased as a result of the incorporation of new technologies and new organisational methods*. Such an increment stemmed from the speeding up of machining cycles and from gains in plant efficiency associated to falling setting up times and lead times. Since demand in Brazil stagnated since the early eighties, and since most firms in the sample exported only to a limited extent, the increase in plant capacity entailed an addition of idle capacity. Whereas in a few cases the growth in plant capacity was one of the objectives of the process of technical change, in the other firms this result was not planned and this affected their possibilities of reaping benefits associated to the reduction in unit costs. In the group of machining service firms, we found examples of ill-planned processes of adoption, in which firms overestimated their need for CNC machines. Overall, firms could benefit from some of the benefits related to decrease in variable costs (mainly labour unit costs and raw material unit costs). However, *only with the expansion of output and operating close to full capacity will they be able to compensate for increasing capital costs and overhead costs, which are associated with the adoption of new technologies*. Therefore, the evidence provided in this research suggest *that optimal scales are increasing, in the Brazilian engineering industry*.
5. A number of implications for location of production in developing countries derive from the fact that the diffusion of new technologies is not associated to de-scaling. Firstly, if the access of developing country firms to the new technologies is facilitated by the greater divisibility of investment (new technologies can be gradually or selectively incorporated), it does not follow that scale ceased to be a barrier to entry. The case studies presented in this paper suggest that for developing countries to reap the benefits of economies of scope associated with falling product scales, it is required that demand for total output is large enough to allow the full utilisation of increased plant capacities. Secondly, the problematic experiences faced by machining service firms with the adoption of new technologies reinforces the scale argument, since this experience is in contrast to the better results obtained by the larger firms of the sample. Apparently, it is easy to learn how to operate the new technologies. However, it seems much more difficult to become a good user. Requirements such as the technical capability for planning for adoption, the simultaneous adoption of organisational innovations, and the resources necessary to

keep a well trained workforce may be beyond the reach of medium and small local firms.

6. The conclusions presented above suggest some policy implications. The first one is related to macroeconomic policy. Import liberalisation and the promotion of competition are proving to be important incentives to accelerate the adoption of new technologies by firms located in Brazil. Yet, economic policy should not lose sight of the crucial role played by the expansion of demand in terms of enabling firms to reduce idle capacity and reap the cost benefits associated with diffusion. Secondly, the limitations presented by small firms in our case studies suggest that special care should be devoted to them. In this respect, it would seem opportune that the current emphasis placed by Sebrae (the Brazilian Service for Support of the Small and Medium Enterprise) on organisational issues were enlarged, in order to give support to these firms in their process of adoption of microelectronics-based automation as well. Finally, it would seem appropriate to suggest that large firms have an important role to play in the process of strengthening the capabilities of small and medium firms, by establishing trustful links with them, based on technical cooperation.

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