5 Why the market reserve is not enough

Lessons from the diffusion of industrial automation technology in Brazilian process industries[1]

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> *It is not possible to come to grips with the complexities of technology, its interrelations with other components of the social system, and its social and economic consequences, without a willingness to move from highly aggregated to highly disaggregated modes of thinking. One must move from the general to the specific, from technology to technologies. One must be even prepared to 'dirty one's hands' in acquiring a familiarity with the relevant details of the technology itself.*
>
> Nathan Rosenberg (1982)

1 INTRODUCTION

This chapter is concerned with the diffusion of electronic automation technology among Brazilian industrial users and its implications for industrial modernisation. It is argued that the new technologies have been adopted by Brazilian firms in an inadequate fashion, referred to here as *passive modernisation*.

Although the diffusion of industrial electronic equipment has been relatively quick in Brazilian process industries, they are far from reaping the potential technological and economic benefits. In the petrochemical industry, the focus of this case study, the adoption of digital control systems (based on Information Technology) has been mainly regarded as a solution to the problems resulting from the previous crop of control equipment available in Brazil, rather than as a technological strategy to improve firms' competitive position. The major determinants of this situation are the technological fragility of both users and suppliers, and the lack of institutional support in the process of diffusion.

The main policy conclusion is that, if upgrading of Brazilian industry is to be pursued, the Brazilian information technology policy should not be restricted to the development of the electronics industry, but should widen its scope to the actual use of its products in the economy. This requires the integration of the policy for the electronics industry into a broader industrial policy strategy.

The chapter starts by directing the reader's attention to the importance of the diffusion of the new technology in Brazilian process industries (Section 2). Section 3 presents the empirical investigation on the diffusion of digital control technology in the Brazilian petrochemical industry. The research was based on a survey of eighteen petrochemical firms, users and non-users of the new technology, located in the states of São Paulo and Bahia. The survey comprised extensive interviews with engineers and industrial managers, visits to plants, and informal conversation with workers.

It is shown that the diffusion of digital control techniques has been relatively fast given that this occurred during a period of uncertainty and unstable economic activity (Section 3). This diffusion process is not unproblematic, however. In the assessment by user firms, a great many of the difficulties they face in the adoption of digital control technology originate in problems related to the supply of the new technology. Major problems are the high prices and sometimes inadequate quality of Brazilian equipment, and the lack of technological capability of suppliers.

While the adoption of new technology is extensive, in most cases it amounts to little more than *passive modernisation*, that is equipment replacement motivated by obsolescence. The new techniques are used mainly to perform conventional control functions. Only a few firms were adequately exploiting the potential of the new technology: that is, improving efficiency through the use of more complex software for plant optimisation and using the digital basis for process simulation. This is referred to as *under-utilisation* of the new technology.

The major determinants of passive modernisation and under-utilisation are then examined. They stem mainly from the technological limitations of both Brazilian suppliers and users of the new technology. The effects of these technological limitations are aggravated by insufficient supply of engineering services and lack of institutional support to the process of diffusion.

The theoretical and policy implications of the case study are presented in Section 4. The broad conclusion is that countries in which import substitution was the basis of industrialisation face specific problems in order to adapt to the requirements of the new technologies. The technological limitations of both suppliers *and users* have been obstacles to the development of synergies in their interaction. Thus, it is concluded that effective assimilation of previously imported technologies is an important factor for the successful adoption of the new technologies.

Finally, it is argued that a market reserve for suppliers of digital equipment is not enough and that policy should be equally concerned with diffusion. Facilitating resources are required in order to enable firms to successfully adopt new technologies and improve their competitiveness. Such support should be provided in a context in which government seeks to create a competitive environment and integrates information technology policy with other industrial and macro-economic policies.

2 THE MARKET FOR INDUSTRIAL ELECTRONICS EQUIPMENT IN BRAZIL: PROCESS INDUSTRIES AS MAJOR USERS

This section shows that process industries[2] are the main users of micro-electronics-based industrial equipment in Brazil, a fact little explored by academic literature and the media.[3] Demand from process industries accounted for at least two-thirds of the Brazilian market for industrial electronic equipment during the 1980s and is likely to continue to be high in the 1990s.

The Brazilian market for electronic industrial automation equipment boomed in the 1980s, despite the economic crisis. The average annual rate of growth (imports excluded) between 1984 and 1988 was 25 per cent, the value of annual sales rising from US$86 million to US$255 million in this period (SEI 1989).

Growth in this market has been a story of business success for national firms. Between 1981 and 1984, SEI extended its market reserve policy in order to protect Brazilian producers of industrial electronic equipment. Imports of such equipment have been kept under strict control by SEI; they have been permitted only in the case of products which Brazilian firms cannot supply. Hence the bulk of the local market for industrial automation equipment has been supplied by national firms. These multiplied rapidly from ten firms in 1982 to over ninety in 1987. Subsidiaries of foreign firms have participated only in the segment of CAD/CAE systems, in which they supply large systems.

Throughout the 1980s there was great concern in Brazil with the economic and social implications of the diffusion of electronics-based automation in local industry. Research fuelled by this concern focused on the engineering industries such as machine tools, motor vehicles and electronics.[4] However, the actual diffusion of microelectronics-based industrial equipment in Brazil suggests that the major users of the new technology are process industries rather than engineering industries. Electronic equipment for process control accounts for over 70 per cent of the total market for industrial electronics-based automation[5] equipment.

Even if we do not take Programmable Logic Controls (PLCs) into account (since they are utilised in both engineering and process industries), sales of process control electronic equipment (US$79.4 million) were more than twice those of equipment for automation of manufacture (US$37.7 million) in 1988. Sales of Digital Distributed Control Systems (DCSs) (equipment to 'computerise' process control in the chemical/petrochemical, steel, pulp and paper and food industries) alone were comparable in monetary terms to sales of CNCs, robots and CAD systems together. The smaller and cheaper Control and Supervision Systems, used mainly in the electricity and mining industries, sold as much as CNCs, for which a vast range of applications exists in machinery for discrete production.

In 1989, sales of DCS rose to US$100 million (*Química e Derivados*, Jan./Feb. 1990), making this equipment the single most sold industrial electronic equipment in the Brazilian market and revealing an acceleration of the diffusion of industrial electronic equipment in the process industries, particularly in the pulp and paper and in the chemical/petrochemical industries.

Apparently this trend seen in the Brazilian process industries is reproducing diffusion trends in developed countries (OECD 1985). Therefore, what seems to be different in Brazil is not the rapid diffusion of industrial electronic equipment in process industries, but the much slower response of engineering industries in adopting electronics-based industrial automation.[6]

The concern in this section is to emphasise that, *in Brazil, the diffusion of industrial electronic equipment in process industries has been considerably more dynamic than in the engineering industries*. This has occurred for the following reasons.

The first is that investment in computerised control systems need not be high. In process industries, the adoption of digital control does not entail major changes in *manufacturing* equipment, but rather the incorporation of new *control* equipment to plants which are already highly automated. Thus, investment in digital controls represents on average only 10 to 12 per cent of global investment in plant.[7] Given that efficiency gains affect the global performance of the plant, investment return is rapid.

Second, the bulk of the users of process control equipment operate in the energy and intermediate goods industrial sectors. Generally, they are highly capital-intensive firms, with the financial ability to undertake investment of the type under discussion here. It should be noted that state participation, and particularly Petrobrás participation, is very pronounced in the industrial sectors which are the major users of industrial electronics equipment for process control.[8]

Finally, there were major technical and economic difficulties in the local supply of the previous control systems, motivating an early replacement by digital systems. This was an unintended outcome of the policy of the former Brazilian CDI (Council for Industrial Development), aimed at the substitution of imports of conventional control equipment.[9]

Considering the influence of these forces, it is not surprising that Brazilian process industries forecast a high and steady demand for industrial electronic equipment in the 1990s (SEI 1988). The building of new plants and the modernisation of existing ones, in the pulp and paper, steel, chemical/petrochemical, and electricity sectors, will account for the bulk of the market. This is why DCSs are expected to continue to be the equipment with the highest sales (*Guia de Automação Industrial* 1990, No. 7).

Therefore, the micro-electronics-based modernisation of Brazilian process industries has already reached significant proportions, and is likely to become even more important in the near future. This process of technical change entails major implications for both user firms and suppliers of automation equipment and services. These will be addressed in the following section which is based on a study of the adoption of digital control technology in the Brazilian petrochemical industry.

3 THE PROCESS OF DIFFUSION OF DIGITAL CONTROL TECHNOLOGY IN THE BRAZILIAN PETROCHEMICAL INDUSTRY: QUANTITATIVE AND QUALITATIVE ASPECTS

The purpose of this section is to present the main findings of the case study and to analyse the social and economic forces behind them. In addition to a quantitative account of the diffusion of hardware, a qualitative assessment is also presented. This is a necessary task, since the new technology can be employed in different ways and for different purposes. The analysis of economic and institutional determinants follows at the end of this section.

The quantity of new technology incorporated by Brazilian firms: rapid diffusion

The diffusion of the new control techniques in the Brazilian petrochemical industry began in the early 1980s and has been rapid during a period of uncertainty and low economic activity. At the time of our research, 15 per cent of all petrochemical plants had already adopted DCSs in their plants. More importantly though, in the years to come, 80 per cent of the planned investment in control equipment, either in new plants or in the modernisation of existing plants, is to be realised using digital techniques. The diffusion of industrial process computers has been much slower, however. This reveals that, in spite of relatively rapid diffusion of digital control hardware, the current systems are unable to carry out the more complex tasks of integration and control.

According to data provided by ABIQUIM (the Brazilian Association of Chemical Industries), in 1987/88 approximately 10 per cent of the total number of loops installed in Brazilian chemical/petrochemical plants were digitally controlled, 8 per cent being controlled by DCSs. This is a modest share, yet it is impressive if we consider that in 1982 only one chemical/petrochemical firm in Brazil used this technique. This number had increased to eighteen firms by the time of this research. Evidence of the importance of electronic industrial equipment in the Brazilian petrochemical industry also comes from the use of Programmable Logic Controls (PLCs) in safety loops. ABIQUIM data show that, in 1987, 22 per cent of the total number of points of logic control in the chemical/petrochemical industry were controlled by PLCs.

Most users of DCSs in the Brazilian chemical industry are large firms producing petrochemicals. All but one are firms with more than 500 employees, based in capital-intensive, highly automated plants. Most of them operate continuous-flow production processes. Within the population of petrochemical firms defined for this research, fourteen companies have already adopted DCSs. Out of these, six are firms associated with the Petroquisa group (controlled by Petrobrás, the state-owned oil monopoly). Two are fertiliser producers controlled by Petrobrás, four are MNC subsidiaries, and only two are wholly controlled by Brazilian private groups. This is in line with the comments in this chapter on the high profile of state-controlled firms (and particularly that of Petrobrás and affiliates) in the shaping of demand for industrial electronic equipment in Brazil.[10]

Data on planned investment in process control equipment are perhaps more revealing of the trend for digital, integrated control systems to completely replace conventional techniques in the Brazilian chemical industry. For instance, investment intentions documented by ABIQUIM at the time of the research and confirmed by fieldwork showed that, for the period 1987–90, 97 per cent of all planned investment in room control equipment (approx. US$100 million) was to be realised in digital controls, being 86 per cent in complex, integrated control systems (DCSs). Investment in conventional control techniques was only to be significant (approximately US$25 m.) in field controls.

Table 5.1 shows the diffusion of digital process control technology within my sample of petrochemical firms. Firms A to H are users of DCSs. Firms F and G are recently built plants (1988), having introduced DCSs comprising all process loops from the start. Firm C

Table 5.1 Hardware technologies used in process controls[a] in selected Brazilian petrochemical plants, 1988

	% of process loops per type of technology			*% of safety controls*		*Number of process computers*[f]
Firms	*Analog pneumatic*[b]	*Analog electronic*[c]	*DCS*[d]	*Conventional relays*	*PLC*[e]	
A	–	84	16	54	46	3Mn
B	–	50	50	50	50	1Mn, 1Mc
C	38	–	62	15	85	–
D	2	48	50	100	–	1Mc
E	74	6	20	50	50	–
F	0.5	1.5	98	–	–	–
G	–	–	100	50	50	–
H	75	5	20	98	2	–
I	80	20	–	30	70	12Mc, 2Mn
J	35	64	–	87	13	4Mc
K	99	1	–	100	–	–
L	95	5	–	(nd)	(nd)	–
M	80	20	–	100	–	2Mc
N	95	5	–	90	10	–
O	50	50	–	100	–	–
P	100	–	–	100	–	–
Q	100	–	–	–	–	–
R	–	100	–	–	–	

Notes: a. It includes equipment used in room control functions; it does not comprise field instrumentation.
b. Analog, pneumatic instrumentation used in room control.
c. Analog, electro-electronic instrumentation used in room control.
d. Distributed digital control systems.
e. Programmable Logic Controls.
f. Mn stands for minicomputers; Mc stands for microcomputers.

Source: Author's survey of firms

first introduced a DCS under a project to expand the plant, based on the introduction of a new process for higher value-added products. Other users have introduced DCSs within projects for the modernisation of their control equipment.

So far most DCS users have partially adopted the new technique, that is, only a percentage of their process loops are digitally controlled. Though partially covering the plant, DCS is always a comprehensive system, in that it controls all loops (therefore, all industrial operations) in the equipment of the plant in which it is introduced. For instance, in the case of firm C, 62 per cent of its monitoring and control loops, which correspond to the major product stream of the plant, are controlled/monitored by one DCS. This firm expected to introduce a second DCS before 1991, in order to modernise control of its older area and to integrate 100 per cent of plant control into a digital control *system*. Therefore, partial adoption of digital control may only mean a step towards the full 'electronisation' of plant control.

This would be exactly the case with most partial users of DCSs in the sample, if their investment plans for the modernisation of process control until 1992 were confirmed (Table 5.2). Combined with Table

Table 5.2 Planned investment in process control equipment in selected Brazilian petrochemical plants, 1988–92 (US$ million)

	Value of investment per type of technology				*Type of investment*
Firm/ year*	*Anal. pneu.*	*Anal. elect.*	*DCS*	*Process computer*	
A (88/89)			15		Complete replacement
B (88/91)			12	1.6	Complete replacement
C (88/91)			2.9		Complete replacement
E (88/90)			23		Complete replacement
I (88)		0.056		O.06	
J (88/92)			19.4		Modernisation
K	Future investment in digital control; no fixed date				
L	Future investment in digital control; no fixed date				
M			0.3		Cont. pilot plant
P					
Total		0.056	72.6	1.66	

* Firms D, N, O, Q, and R have not given information on this topic.

Source: Author's survey of firms

5.1, data from Table 5.2 reveal two important tendencies. First, most firms which were already users of the new technology (except for H) presented plans to completely replace conventional control with decentralised digital systems. This suggests that, once it has begun, the tendency is for a full-length, radical change of control technology.

Second, it seems that non-users will continue to lag behind for some time. With the exception of firm J, non-users have not yet made plans for the future introduction of digital technology. Firm J is a MNC subsidiary, which is drawing on its parent company's experience to define its strategy for a complete change of control instrumentation. Firms K to N, also part of the Petroquisa group, declared that they are aware they will have to change their control equipment in the years to come (their current controls are based on the most conventional and problematic pneumatic technology) and that they are very likely to shift to digital controls, though not necessarily integrated ones (DCSs). But no clear decisions have yet been made.

To conclude this section, it is worth stressing the considerable importance already attained by micro-electronics-based industrial automation in Brazilian petrochemical industries. Further evidence is given by the extensive use of PLCs in safety control (see Table 5.1).

However, the survey has also revealed that there has been very little diffusion of industrial process computers (Table 5.1) and of advanced control software. This was confirmed in the studies carried out by ABIQUIM (ABIQUIM 1986). The low level of diffusion of process computers reflects the fact that the new technology has been used mainly for conventional functions, as well as the limits of suppliers' capability in basic software. We will return to these points later in this chapter.

The next section examines what user firms have considered to be factors holding back diffusion. Although users and non-users have considered Brazilian digital control systems to be more reliable than conventional ones, they have pointed to a number of problems in their experience with the new technology, which have inhibited a faster diffusion. Among these, they have stressed those which have been often associated with the effects of Brazilian IT policy: price and quality of equipment, and the technological capability of suppliers.

How user firms assess Brazilian suppliers of industrial electronic equipment

Before examining the adoption of new technologies in petrochemical user firms, we should ask how these users assess the suppliers of their

Table 5.3 Rating* of obstacles to the adoption of DCS/computerised process control in selected Brazilian petrochemical firms

High cost of Brazilian equipment	126
Obstacles created by PNI	112
Firm's staff lacks confidence in suppliers' future technological capability	92
Benefits do not off-set costs	92
Inadequacy of human resources policy for informatics area	87
Shortage of the right skills for devising and implementing digital control project	86
Inadequacy of government industrial policy	67
Quality of Brazilian hardware	66
Shortage of services	63
Maintenance problems	59

Source: Survey of firms.

* Total number of respondents: 16.

technology. One of the most striking issues during fieldwork was the engineers' criticism of the Brazilian informatics policy. This is also revealed in the high rating given to the item 'obstacles created by PNI (Política Nacional de Informática)', in their assessment of the obstacles to a greater diffusion of digital control technology (Table 5.3).

The formulation is admittedly vague, but is presented in this form in order to attain the respondents' general feeling about the policy. Such a result is useful for a political assessment, at least. One would expect to hear staff of MNC subsidiaries blaming the policy. But most firms in the sample belong to the Petroquisa group, in which the influence of nationalist values inherited from Petrobrás by engineers is very strong.

Criticism is more concrete in the form of the other points listed in Table 5.3. In fact the table works in two directions, since the factors receiving lower scores could be interpreted as the ones in which Brazilian industrial electronic equipment performs best. In this section we will comment on those related to the supply of industrial electronics equipment.

High cost and low quality of Brazilian equipment

The first three factors in Table 5.3 have been singled out as the most problematic by all groups of firms in the survey: national users (eight firms), national non-users (seven firms), and MNC subsidiaries (three firms). The high cost of Brazilian digital control systems was at the top of the list of most firms. Prices of installed Brazilian DCSs varied between US$2 and US$5 million, depending on the size of equipment. Given the large range of sizes, as well as of alternative peripheral components, it is difficult to compare national prices with international ones. Some of the respondents mentioned that national equipment, including installation services, were two and a half to four times more expensive than installed imported equipment. A similar evaluation was made in an interview with a technical advisor to ABIQUIM.

In spite of their higher prices, a number of users and potential users would prefer equipment assembled in the country to imported equipment, owing to maintenance convenience. However, high prices have contributed to the delay of decisions to introduce digital control equipment. This is an aspect particularly singled out by non-users. Expensive equipment is an additional factor in causing potential users to delay decisions in this area until the obsolescence of conventional equipment, rather than pursuing a strategy based on technological upgrading. In this sense, the higher costs of Brazilian digital control systems have contributed to holding back diffusion.

As far as prices are determined by production costs, a number of cost determinants deserve comments. Producers of digital equipment complain about two factors: the high tariffs imposed by the Brazilian government on imported electronic components and the small volume of the Brazilian market for digital control systems, which does not make up for minimum scales of R&D.[11] To a great extent, these problems are less a result of market protection of an infant industry in general and more the way it has been managed.

Consider the issue of market size and minimum scales. Its effects would have been lessened if the policy of the licensing of producers had taken into account this aspect and, thus, had licensed fewer producers. Nevertheless, five producers of DCSs were licensed by SEI to produce DCS with licensed technology. A sixth producer entered the market with its own technology, and two more submitted requests to enter the market with licensed technology at the time of this research. Since these have been accepted also, the Brazilian market for DCS, US$100 million per annum, will be shared by eight producers, not taking into account three other producers who entered the lower segment of the market, with small-size DCSs based on microcomputers. This accounts for average annual sales of four medium-size DCSs per firm.[12]

Would not this proliferation of firms bring about 'healthy competition in an expanding market'? This argument reveals a lack of comprehension of the basic characteristics of the Brazilian market for DCS and other industrial electronic equipment. First, competition is limited from the first sale, because each Brazilian producer has based its product design on a distinct technology[13] and these technologies are not compatible among themselves, unless through costly investment in additional equipment and software. Once a user firm has installed the first DCS, it is bound to order from the same supplier for future equipment investment. This is why users commonly say that they are 'captive' to suppliers, a feature that has raised a fierce debate between Brazilian users and producers about the adoption of communication protocols.

Second, in spite of very good prospects for the next five years, high rates of growth in the internal market for DCS will decline at some point in the future. As is the case with other electronic goods used in industrial automation (and in contrast to data-processing equipment for general use), applications of DCS are limited to a relatively small number of industrial sectors. Once the process of replacement of conventional controls is concluded, the dynamism of the internal market will fade substantially. Thus, an outlet to external markets is a requirement for long-term survival in this segment of the electronics industry. As such, this feature should be the main one to be taken into account in a policy for this segment. The market for industrial electronic equipment is not the market for microcomputers; thus, policies which have worked in the latter may not succeed in the former.

The question of an export outlet touches upon the problem of tariffs on components and the coordination of trade and industrial policy. Producers of DCSs complain that high tariffs on the value of imported electronic components are a major cause for final products being expensive. This seems to reveal a lack of coordination within the government departments. Since SEI defines deadlines for the nationalisation of production of most components of digital controls, it would seem reasonable that tariffs on components should be lowered during the transition phase, in order not to overburden end users. In the medium and long term, however, tariff reduction could be a useful tool to motivate Brazilian producers to export.

A further critical point raised by user firms is the quality of equipment. Problems here are more localised within certain specific products and suppliers. In general, the quality of performance of Brazilian digital control equipment seems to be very uneven, varying between good and bad according to the specific product, as the assessment by ABIQUIM's Process Control Commission indicates (Table 5.4).

Table 5.4 Quality assessment of Brazilian digital control equipment by the ABIQUIM process control commission, 1986

Product	*Assessment*
Process minicomputers	Insufficient
Process superminicomputers	Insufficient
Process microcomputers	Insufficient
Single-loop digital controls	Insufficient
Programmable logic controls (PLC)	Excellent
Data-loggers	Insufficient
Sequential event controller	Good
Process chromatographers	Very bad
Digital distributed control systems	Good

Source: ABIQUIM (1986)

However, it is important to note that the most diffused equipment (PLCs and DCSs) are rated as very good and good, respectively, in ABIQUIM's assessment. In our survey of petrochemical firms, problems with the quality of DCSs were raised, but seemed localised to two particular suppliers. Apparently, the most problematic areas in Brazilian DCSs are not in the hardware but in basic software.

Basic software for process control is also the motive behind ABIQUIM's assessment (as insufficient) of industrial micro-, mini-, and superminicomputers. In this case, basic software was simply non-existent in the Brazilian market. As will be seen, limitations in the supply of basic software for process control is a major bottleneck in the development of applications of digital control technology in Brazil.[14]

The problem of technological capability of producers

Proliferation of firms, and the consequent non-economic R&D scales, is not compatible with the technological strength necessary to develop external markets. The issue here is technological updating, a crucial weapon in the competition for servicing external markets. As Table 5.3 shows, user firms are sceptical about the technological capability of Brazilian producers. Producers recognise this as a major challenge.

Technologies embodied in Brazilian digital control systems were, and remain, close to the technological frontier when the first licences were approved (1983). The problem, as producers and users have put it, is that the pace of innovation in this area is very fast. The technological trend is for the greater integration of DCSs with process computers, and with digital process analysers (in what is called 'hierarchical systems of digital control'). If Brazilian producers are to follow this path, they will need to be capable of adapting basic software.

The capability of adapting basic software is crucial for the quality of service producers can supply. Basic software is at the core of digital control systems technology, and is responsible for the basic functions of the system, such as enabling the configuration of the system to work, generating control screens, and processing and recording information. In contrast to most basic software for microcomputers, the basic software for DCSs are complex pieces, which 'require an enormous engineering effort to be digested', as a respondent put it. Nevertheless, 'digesting' licensed basic softwares is an indispensable step *if producers are to adapt digital control systems to users' needs*, and not merely transfer the licensed package.

Insofar as our respondents are well informed, basic software is one of the weakest points with Brazilian producers of digital control systems. This is a point which requires further investigation, as does the whole issue of industrial automation suppliers' capabilities. Yet user firms have given enough indication of the problems. A great number of engineers declared that they did not consider suppliers capable of adapting/updating basic software, although they attributed importance to this quality. Some of them expected suppliers to access new developments through new technology licences in the future. According to an informer's detailed comment, the only supplier which has undertaken some development in this area is the one whose system is based on a network of microcomputers. In three plants in our sample, problems which led to a stoppage of the system (and of the plant) were primarily attributed to the supplier's lack of knowledge of basic software.

The example of basic software is useful in illustrating the technological challenges national producers have to face. According to users and producers, developing capability in this area is something that requires enormous investment. In these circumstances, reaching a minimum R&D scale seems to be a necessary step in the creation of a competitive industry in this segment of the market.[15]

Some users expressed concern about the absence of an institutional mechanism to monitor/control suppliers' commitment to R&D activities. In the words of one respondent, 'suppliers are doing little in terms of technological improvement; today, the policy is one of protecting suppliers without requiring them to meet performance targets'. The real commitment of suppliers to R&D is an issue beyond the aim of this paper. However, this statement reveals a perception by users, that market reserve should be combined with the requirement of producers' commitment to achieve defined standards in terms of quality, costs and technological capability.

The limitations of the supply of digital control techniques is one of the factors which shapes the way in which the new technology is used in the Brazilian petrochemical industry. Brazilian petrochemical firms have not exploited the most important opportunities offered by digital control technology, under-utilising the potential of the new technology. The logic of such a strategy is analysed in the following section.

Why and how firms adopt the new technology: passive modernisation and under-utilisation

Given the limitations of the supplier side, what leads Brazilian petrochemical firms to adopt digital control systems? What are their strategies towards the new technology? This section shows that, with a few exceptions, firms investigated have pursued a *passive strategy of modernisation*, in which the adoption of the new technology is primarily determined by the need to replace obsolete or faulty existing control systems. Within such an approach, the introduction of new technology is regarded as equipment replacement and digital control systems are used mainly to perform conventional control strategies. Passive modernisation has resulted in *under-utilisation* of the full potential of the new technology.

The point of departure of management's logic behind passive modernisation is that the adoption of digital control systems is primarily motivated by the complete obsolescence of existing control equipment and the greater problems presented by alternative technologies. This is clear from the importance attributed to the 'need to change obsolete controls' by engineers involved in the decision-making process concerning the adoption of digital control techniques, when asked to rate motives for adoption and to comment on them. Five firms out of nine pointed to the obsolescence of their previous control equipment as the single most important factor. In some of these firms, the condition of pneumatic controls had deteriorated to the point of jeopardising plant performance. The importance of the obsolescence factor as a driving force was definitely confirmed amongst non-users. Firms K to O declared that the timing and the nature of a future decision about changing control equipment was subordinated to the evolution of the (already detected) deterioration of their conventional systems.

Firms A and D were the only ones in which the decision to introduce digital control systems in existing plants was primarily motivated by the specific economic benefits and technological opportunities expected from new technology. None of them were under pressure to replace faulty instruments; with the change of control systems they primarily aimed at a 'reduction of raw material costs' (firms A and D) and at 'increased control over the production process'. At firm A, cost reduction was expected from the introduction of advanced softwares for plant optimisation, a feature which has been part of its automation plans from the beginning.

In the passive modernisation approach, once the decision about replacement (or to equip a new plant, as in the case of firms F and G) has been made, the decisive factors in favour of digital technology *vis-à-vis* conventional technologies have been *price*, *reliability*, and the *maintenance convenience* of control equipment. For reasons mentioned in Section 2, the local production of conventional process control instruments in Brazil has left a great number of problems for users in the petrochemical industry.

Many respondents stressed the problems of conventional controls supplied by Brazilian firms. Brazilian instrumentation industry, they said, has not been able to internalise the production of a crucial number of components, particularly those depending on fine mechanical technology. It follows that the supply of conventional control instruments to the chemical industry remained dependent on Brazilian products with a high import content or on imports of instruments *per se*. In each case, costs have been high owing to tariffs imposed on imports. Moreover, dependence on imports very often has resulted in delays of much needed replacements, due to the usual bureaucratic barriers to importation in Brazil. Finally, a number of respondents have also criticised the quality of Brazilian conventional control equipment. All these replacement problems have contributed to the acceleration of obsolescence of all of the conventional control systems.

Considering this background, users of DCSs have perceived digital technology as a better deal, in economic and technical terms, than the conventional alternatives. As an engineer from firm H put it: 'We had to change the control equipment anyhow, because of obsolescence; we have gone for digital controls because they are cheaper and better than analog instrumentation.' This is not entirely accurate; according to ABIQUIM data, in the case of control systems comprising more than 100 loops (which is the case of most petrochemical plants), digital control systems available on the Brazilian market are slightly more expensive than conventional controls. Other respondents in user firms confirmed that adopting conventional equipment would have cost slightly less.

Given the small cost differential, the decisive factor leading to the option for digital systems has been the technical performance of the equipment. Here, engineers stressed the expected easier maintenance and better performance of Brazilian digital systems *vis-à-vis* their conventional counterparts. Firms expected digital systems would reach a higher level of national content, a strategic aspect as far as maintenance is concerned, given the problems already mentioned with imports of parts. Effective maintenance is a crucial issue in highly capital-intensive, automated plants, such as the ones in the petrochemical industry. They cannot afford unexpected downtime.

Finally, firms were also aware of the potential intangible benefits of the new technology (a factor stressed by engineers), such as increased control of the production process, improvement in product quality and increased plant safety. For such a small price difference, and given the maintenance advantages, it was worth paying to see whether the intangible became tangible.

However, in the choice between DCS alternatives, only firms A and B have decided on the basis of the technological potential of equipment (for instance, compatibility of hardware to run optimisation software available for a specific process). Price and the need to sustain the market for an associated supplier have been the most decisive factors. Two of the respondents clearly declared that they have decided in favour of a certain supplier on the grounds that such a supplier had offered the cheapest deal.

What we can conclude from such analysis is that the adoption of digital *equipment* has been very much influenced by the import substitution policy context of the country. The former CDI policy for import substitution of conventional control equipment and SEI's market reserve policy have worked together to create a leap from pneumatic control technology directly to digital control technology, with a relatively rapid diffusion of the latter. CDI policy has worked in a negative way, since it contributed to the acceleration of the obsolescence of conventional equipment; besides, it was not able to reduce the costs of conventional equipment or to overcome the problems that undermined the confidence of users.

In this context, the policy implemented by SEI in this sector – namely, the inclusion of digital control systems in the market reserve for national firms and restrictions on imports – has had the effect of organising this problematic market, offering an alternative to the difficulties resulting from the previous policy for control instruments.

With a promising market for digital control systems, a number of private local groups were attracted to enter it in the early 1980s. Access to technology was not problematic, since international producers were, and still are, interested in some form of access to the Brazilian market. Market reserve itself had contributed to the Brazilian private sector's early accumulation of some technological capability in IT, an important starting point in the process of nationalisation. These factors explain users' relatively higher confidence in Brazilian digital control systems *vis-à-vis* their conventional competitors.

In short, if the Brazilian IT policy has problems, it cannot be criticised for a lack of supply of technologically updated industrial electronic equipment for process control. On the contrary, it has been a major force behind the organisation of such a supply. From the user's point of view, the *internalisation of equipment production* has been a very positive outcome of this policy. If this were its main objective in the area of industrial automation, the policy can be considered successful.

However, if the internal supply of digital control equipment has been a major contribution in avoiding downtime in petrochemical production, it has not (and will not) *by itself* lead user firms to a real technological upgrading, one which will allow them to reap the best technological opportunities offered by the new systems technology (Aliperti 1987).

In fact, the basic limitation of passive modernisation is that firms adopting this strategy have been using the new control systems to carry out basically the same control functions as those of conventional controls. In this sense, they are *under-utilising* the new technology since they have not explored its more sophisticated functions, those which can lead to the upgrading of plants in terms of integration, efficiency, product quality and innovation.

What is referred to as under-utilisation of digital control technology in this chapter is precisely the non-exploitation of the most innovative possibilities opened up by the application of IT to industrial process control. Firms under-utilise the new technology when they employ it only to perform ordinary control functions, when they do not take advantage of the new techniques to perform more advanced tasks such as plant optimisation, process simulation, and plant integration.

As Table 5.5 (Column I) shows, only three of the sample of

Table 5.5 Use of digital control technology, automation strategy and capability in process technology in a sample of Brazilian petrochemical firms, 1988

Firms	*Current use of digital control technology*	*Responsible for automation*	*Automation plan*	*Technological capability in process design*
A	Ordinary control + data acquisition + imported optimisation softwares tendency register	Own automation division	6 years, 3 stages	Full assimilation and major innovation in 2 processes; partial assimilation in the others
B	Ordinary control + data acquisition + tendency register	Own department for computerisation engineering	3 years	5 new processes developed and patented; partial assimilation of the others
C	Ordinary control + register	Instrumentation division in engineering department in charge	No	All processes, partial assimilation, minor innovations
D	Ordinary control	Ad hoc informal organisation; maintenance in charge	No	Partial assimilation of 1 (one) process; no assimilation of the other
E	Ordinary control + tendency register	Ad hoc, informal group, various departments	3-stage strategy	Little assimilation of major process; partial assimilation and minor innovations on others
F	Ordinary control + register	Mostly in hands of supplier (associate)	No	Process engineers on training–expectation – they will master design in future
G	Ordinary control	No particular area in charge	No	Partial assimilation; few innovations
H	Ordinary control	Current initiatives come from maintenance department	No	No assimilation of major process/partial assimilation of other
I	Ordinary control + data acquisition + advanced control + digital direct control + optimisation of plants	Process control group at plant level; inter-department committee at national level	5 years	All processes proprietary

petrochemical firms (A, B and I) were using digital control technology to perform tasks beyond ordinary control functions. Firm A (associated with the Petroquisa Group) and firm B had already reached the stage of using the system for data acquisition (a data bank with information on process performance). At the time of research, firm A was implementing an optimisation software.[16]

Firm I, a subsidiary of a multinational chemical group, is a unique case in the sample (and possibly in Brazil) in that it has introduced computerised control without changing conventional control equipment, introducing an interface between the latter and a computer network. Firm I's reports suggest that it is one of the most advanced firms in Brazil in terms of the adaptation and use of advanced software for process control, drawing on solutions developed in its foreign plants.

All the other user firms in the sample were employing digital control technology to perform basically the same control tasks they used to perform (or would perform, in the case of new plants) under conventional control equipment (Table 5.5, first column).

The performance of ordinary control was said to have improved with the new control systems in most, but not all, firms. Engineers confirmed this by showing that digital controls are more accurate than analog ones, enabling greater precision in control operations. They also praised the automatic tendency register which comes with most DCSs.

But the most emphasised quality of the new systems was their potential to considerably increase management's control over the labour process, particularly through the automation of supervisory tasks and through the register of operators' interventions.[17] It would seem concern with control could only assume such importance in engineers' assessment of the new technology in the absence of more sophisticated and profitable uses of the new techniques.

To sum up the argument, we can draw on the words of one of the experts interviewed: so far the use of digital control systems in the Brazilian petrochemical industry is reminiscent of 'using cannons to kill birds'.

The under-utilisation of digital control technology was found to be in line with firms' strategies towards automation. Table 5.5, second and third columns, show that firms A, B and I again were the only ones to present a strategy for automation with clear long-term objectives, an automation plan and the setting of specific organisational arrangements to deal with this issue.

In this respect, firm A reported a very ambitious and well documented automation plan, which aimed at global automation and integration of the firm, with large utilisation of optimisation techniques, over six years.[18]

Firm B, which was still concluding the implementation stage of the first DCS at the time of research, also presented a broad strategy towards the new control technology. It had planned to reach global automation and integration of the plant within three years. In parallel with the Automation Division initiative of firm A, this company was putting a special division in charge of development/adaptation of optimisation and simulation software.

In all the remaining user firms, the issue of planning for the adoption of digital control technology received less attention or resources than in firms A, B and I. In most cases, the matter was the responsibility of ad hoc informal groups, with the participation of different areas of engineering and maintenance departments. These groups were concerned, rather, with the purchase of equipment and its implementation, with little or no attention given to software applications.

Among non-user firms, considerations about future adoption of digital technology were the exclusive concern of maintenance departments. The very fact that maintenance departments had such a high profile in the process of decision-making regarding the adoption of digital technology (in contrast to the more important role of process engineering departments in the case of firms A, B, and I), is further evidence of passive modernisation. The adoption of digital control systems in these firms was regarded merely as the replacement of control equipment. Within this approach, in which adoption is subordinated to the evolution of the deterioration of existing equipment, there is no use for a comprehensive plan for factory automation and integration.

However, this lack of planning is not a neutral factor. Experts have insisted that hasty, non-planned decisions as to what equipment to adopt and how to utilise it may lead to future problems, either hindering the future increase of automation and integration or requiring the scrapping of previous investment (Vibranovski 1987; Aliperti 1987). In this sense, the simple adoption of a DCS does not lead, by itself, to the technological upgrading of a firm, just as the diffusion of hardware does not say much about the process of modernisation of an industry.

Explaining passive modernisation: some suggestions on the technological limitations of users and suppliers

In the previous sections, we have seen that although diffusion of hardware has been relatively fast, in most firms it has occurred within a strategy of passive modernisation. The adoption of new technology is rather a response to pressures to replace old equipment and so the potential of the new technology has not been adequately exploited. The aim in this section is to present an interpretation of the main economic and institutional forces which have brought this about.

Literature on the diffusion of micro-electronics-based equipment in Brazilian engineering industries has emphasised the recent deterioration of the macro-economic environment and the relative costs of capital (high) and labour (very low) in Brazil as the major economic factors holding back faster diffusion (Laplane 1988; Peliano *et al.* 1988; Prado 1989). However, in the shaping of the pattern of diffusion in the petrochemical industry, these factors do not seem to have had as important a role.

As discussed in Section 2, the volume of capital required by investment in digital control systems is relatively low in the context of capital-intensive, process industries. Moreover, the share of direct labour costs in the global operational costs of the petrochemical industry is much lower than the average in the engineering industries. Thus, relative factor prices have not been as important an influence on the pace and quality of diffusion in this industry as they have in the case of engineering industries.

The increasing uncertainty faced by the Brazilian economy has certainly contributed to holding back investment in new technologies. It could be argued that passive modernisation has been a product of economic crisis, in the sense that firms have assumed a conservative attitude towards investment and, therefore, have only considered the adoption of digital controls under strong pressure of obsolescence. However, this argument could not explain why the actual users of digital control systems did not invest a bit more in order to benefit from higher-level applications, which could have yielded *faster return* over total investment.

Thus, not dismissing the relevance of the recent economic crisis in Brazil, it could be suggested that the major determinants of the automation strategy prevailing in the firms investigated are rather related to structural features of Brazilian industry. It would appear, *passive modernisation of industry and under-utilisation of the new technology stem from the technological limitations of both Brazilian suppliers and users of new technology*. Moreover, the effects of these technological limitations are aggravated by the insufficient supply of relevant engineering services and by the lack of adequate institutional support to the process of diffusion.

Let us examine each of these aspects. We have already seen some of the major technological shortcomings of Brazilian suppliers of digital control equipment. They have restricted the possibilities for users to adopt automation strategies aiming at the optimisation and higher level of integration of plants. Suppliers' lack of capability in basic software has limited the chances of tailoring the configuration of DCSs to users' needs, resulting in the adoption of inadequate or over-elaborate systems design (Vibranovski 1987).

At the time of this research, none of the suppliers of digital control systems were able to offer engineering services aiming at plant integration. Only one of the suppliers was offering some support for user firms to draft plans and strategies for automation. Therefore, the very nature of supply has reinforced the idea that the new technology is embodied in a piece of equipment.

However, if the technological fragility of suppliers has been an important variable in explaining passive modernisation, the evidence of this research suggests that users' own technological limitations are no less important. Here we are referring to users' own ability to identify the opportunities of new technologies, to make an appropriate choice of equipment and software and, most important, to make the best possible use of them. This idea corresponds to what Edquist and Jacobsson (1988:185–9) put forward as the 'information and knowledge factor' in the process of diffusion, referring to users' level of information about the new technology and to their capability to develop/adapt and use adequate applications. What is suggested here is that passive modernisation and poor utilisation of digital control systems are also a product of the inability of users to take a different route.

The limitations of users' knowledge in respect to the development, adaptation, and use of new technology applications are rooted in factors which are both internal and external to firms. In the case under investigation, the major internal factor has been users' limited capability in the core technology of the industry, that is, technology for process design. In turn, this limitation is reflected in users' overall technological strategy.

The *development* of software for plant optimisation and process simulation in the chemical industries requires a great deal of knowledge of the specific process to which the software applies, since this is based on the modelling of process dynamism. This is why software available in the international market has usually been developed and licensed by firms which are also the proprietors (or their associates) of the respective processes. Even the adaptation and use of licensed software requires a considerable knowledge of the process.

The situation of firms A, B, and I is a good illustration of this interaction between the knowledge of process technology and the capability in computerised advanced control techniques. Since its process is a very diffused one, firm A found it more convenient to license an optimisation software from a foreign specialist company (which is associated with the proprietor of the process formerly licensed by firm A), rather than developing one in-house. Nevertheless, the advanced stage of assimilation of process technology by firm A (see Table 5.5, fourth column) was crucial in order to enable this firm to participate in the adaptation of the imported software within a training program provided by the foreign supplier. The training program was meant to lead firm A to become autonomous in maintaining and further improving the licensed software.

In the case of firm B, at least part of the optimisation software this firm intended to use would have to be developed in-house. This could not have even been thought of, were not firm B one of the two most advanced Brazilian petrochemical firms in terms of process design (this firm has developed a number of proprietary processes). Firm I is a subsidiary of a large international group which utilises its own process technologies.

However, firms A and B, in their effective assimilation of imported process technologies and in the importance they attach to technological innovation in their competitive strategy, are exceptions in the context of the Brazilian petrochemical industry. Other research has already shown that the process of technological learning in this industry has been generally limited (partial assimilation). Particularly in respect of the core technology of the industry, most firms have not gone beyond the stage of minor improvements, that is, very few firms have assimilated technology to the point of becoming capable to develop new processes or products (Teixeira 1985, 1987; Bastos 1989).[19]

This situation is a product of historical circumstances and of the objectives of the policy which have oriented the development of this industrial sector in Brazil. The bulk of Brazilian petrochemical plants were built during the 1970s, in the last (and problematic) phase of the import substitution strategy. As such, the main objective of the implementation of a local petrochemical industry was to quickly build up productive capacity to supply the internal market. The development of local technological capability in process design and basic engineering did not receive priority in the initial phases of implementation. Teixeira (1985) has shown that it was not before the third (and last) wave of investment that Brazilian negotiators and firms started to seek technological transfer agreements which included some form of transfer of knowledge of process design.

Soon after this was completed, the Brazilian petrochemical industry faced the downturn of the early 1980s. In the initial years, massive government subsidies enabled output excess to be diverted to the international market. Later, under pressure of subsidy-cuts, firms accelerated the search for increased efficiency via minor improvements, which led to savings of energy and raw materials and to an impressive increase of effective capacity (Carvalho *et al.* 1989; Teixeira 1987). According to Teixeira (1987), the potential for minor innovation has now been mostly exhausted and the time will have come for more ambitious investments in R&D. However, owing to the managerial, technological and financial limitations of Brazilian petrochemical firms, only a few have managed to place technological innovation at the centre of their corporate strategy.

In this respect, the sample of firms examined here is representative of the situation in the industry. As Table 5.5 shows, with the exception of firms A and B, national petrochemical firms have only partially assimilated the process technologies on which their plants are based. But what is most relevant for us in Table 5.5 is *the correspondence between firms' level of assimilation of process technology and the level of sophistication in adopting digital control technology*. Firms with greater accumulated capability in process design (A and B) showed more advanced use of and more ambitious plans for automation, whereas firms at a lower level of capability in process technology tended to be the ones using new technology only for ordinary control.

This tendency seems to have a dual significance. On the one hand, it reflects the fact that the most advanced use of digital control technology requires that user firms have certain skills in process design. Thus, firms which have not progressed much in the assimilation of process technology have not been *capable* of searching for, adapting, and using advanced techniques based on digital controls (e.g. plant optimisation).

On the other hand, this tendency also suggests that firms with more aggressive strategies in respect of core technology show greater willingness to adopt more complex applications of the new control technology. Regarding this point, it is important to add that firms with partial assimilation of process technology are not bound to use the new control techniques exclusively for ordinary control. Certain applications can be devised precisely as tools to help users to develop a deeper knowledge of the process (for instance, the development of a data bank with information on process behaviour). If these opportunities have been seldom explored by users of DCS in the Brazilian petrochemical industry, this could be due to managerial rather than technological limitations.

Users' limitations have not just been a product of their intrinsic weakness. They have also stemmed from the poor development of basic externalities required by the process of diffusion. Two aspects stand out in this respect: the precarious diffusion of information about the new technology and the shortage of human resources with adequate skills.

Lack of information about the new technology was singled out by user firm engineers as a serious obstacle to adoption on a larger scale. One respondent in a user firm admitted that nobody knew how to specify the equipment needed when the decision was taken to introduce digital controls. He added that even seeing the equipment in operation in another firm was not an easy procedure to organise. Users have complained that suppliers have not provided further information about the technical and economical possibilities of the new techniques.[20]

In turn, suppliers of equipment have blamed users, arguing that they lack 'information technology culture' (SEI 1989). This would lead to the choice of the wrong equipment. As one supplier put it, 'today users purchase equipment knowing less than 20 per cent of what they should know. Thus they are not able to properly assess equipment and end by choosing the cheapest'.[21] Suppliers tend to see this as a problem of the development of human resources.

The fact is that users do lack information about the technical and economic aspects of the new technology. The flow of information to users, either via the training of engineers or via the dissemination of technical information is precarious, depending mostly on the initiative of each firm or industrial association. There is no institutional support to the dissemination of information for users. The Brazilian IT policy has taken the diffusion of information about IT for granted. The importance of this diffusion was stressed by Edquist and Jacobsson (1988), particularly for local firms in developing countries, which have much less access to technological information than multinational companies.

Shortage and/or inadequacy of human resources are also real constraints. Most user firms have recently created posts for electronics engineers in maintenance departments. A smaller number of jobs were created in engineering departments for electronics engineers and process control engineers who would be in charge of the planning and implemention of digital control systems. Firms have not found the right people for at least 30 per cent of these jobs.

In the case of engineers, shortage seems to be a consequence of inadequacy of education too. The area of instrumentation and process control engineering is interdisciplinary and has been traditionally a weak one in Brazil. Implementing/maintaining digital systems requires electronics engineers who master knowledge of industrial instrumentation and control, in general, and of digital controls, in particular. This is a knowledge engineers acquire only superficially at university. Firms which are starting with the new technology are not able to train engineers in-house. So, they look for experienced engineers, who are very rare in the labour market.

Finally, user firms cannot get much help from engineering consultancy firms. As far as sophisticated applications are concerned, Brazilian engineering firms seldom master the knowledge of the process dynamism models necessary to develop such applications (owing to the same limitations suffered by user firms themselves) (ABIQUIM 1986). However, according to a number of respondents, even for less demanding support tasks, such as the elaboration of the detailed project of implementation of a DCS, external consultancy firms have not shown familiarity with the new technology.

To conclude, the lack of technological strategy and the technical limitations of user firms combine with the precarious state of externalities to shape a pattern of diffusion in which most users do not (and, to a certain extent, cannot) exploit the best opportunities of the new technology.

A further question to ask is to what extent the features of diffusion found in the petrochemical industry can be generalised to other process industries. It is hard to answer this question, owing to the lack of comparable research covering other industries. However, there is some evidence that such a generalisation is valid at least in the case of other Brazilian process industries based on complex processes (e.g. steel and electricity). According to the report of SEI's Commission No. 29 for Industrial Automation (SEI 1988), the industries mentioned have stated problems with the use of digital controls which are similar to those presented above, particularly as to the difficulties in developing/purchasing more sophisticated software applications.

4 CONCLUSIONS

One of the broadest conclusions this case study seems to suggest is that countries such as Brazil, in which the behaviour of economic agents and the practice of industrial policy is rooted in decades of experience with import-substitution industrialisation, face particular problems in adapting to the requirements of restructuring their economies on the basis of exploiting new technologies.

The diffusion of digital controls in the context of the Brazilian economy has occurred under typical import-substitution conditions. The central concern of Brazilian information technology (IT) policy in this area has been with *the production of industrial electronic equipment* by national firms. Suppliers' effective assimilation of technology, particularly in the area of software, has been a distant secondary goal in spite of all words spoken to the contrary. The quality of use of the new technology – marked by under-utilisation within a strategy of passive modernisation – shows that, with a few exceptions, fast diffusion of equipment has neither substantially altered user firms' corporate strategies, nor led to substantial technological upgrading.

The limitations of the newly industrialised countries (NICs), previously oriented to import-substitution industrialisation, in dealing with the new technologies have already been commented on by Unger (1988). He stresses that the interaction of user and producer in industrial innovation, an aspect emphasised elsewhere in this book, is rather weak in most of these countries, owing particularly to the lack of a sufficiently strong capital goods sector.

The point this research could add to the debate is that the limitations these countries face in dealing with information technology relate not only to the suppliers' weakness, but also to the users'. Our case study shows that the technological fragility of suppliers *and users* of the new technology hinders the development of synergies in the user–supplier interaction.

The question of users' technological limitations takes us to the discussion of the importance of accumulated technological capabilities for the diffusion of IT applications. This research shows that, as far as *users* of IT industrial applications in the NICs are concerned, a firm's previous accumulation of technological capability is a major advantage in the exploitation of the opportunities of the new technology. The development of applications of IT in industries other than electronics requires the generation of knowledge which draws heavily on previously accumulated experience with the core technology of the industry.

The degree to which this is the case seems to depend on the complexity of the core technology. In industries based on simpler processes/products (e.g. machining of non-complex parts, the food industry, etc.), the development of IT applications seems to be usually less problematic and even tends to be standardised, whilst in the more complex sectors (chemicals, steel, cars), applications are more customised and their development requires a great deal of formal knowledge relative to the specific process/product. What this research has shown is that the most advanced applications in complex industries require *effective assimilation* of the core technology, rather than just a 'superficial' knowledge.[22]

The technological fragility of firms is an economic factor which should be understood in relation to the environment created by import-substitution policies. Our case study shows how the feeble technological strategies of both suppliers and users originated in an environment created by policies concerned primarily with import substitution, but with little concern for competitiveness. As Perez put it,

> Firms were not designed to evolve. The majority were meant to operate mature technologies, supposed to be already optimised . . . Firms were not expected to reach competitiveness on their own. The import substitution policies and instruments got managers accustomed to having profitability determined by exogenous factors, such as tariff protection, subsidies, and other forms of government help, rather than by the firm's own capability to increase productivity or quality.
>
> (Perez 1988)

How the protected environment created by import-substitution policies has affected the capability of firms to innovate is an issue which deserves priority in the current research agenda. However, as far as policy is concerned, the available evidence is enough to suggest that sectoral policies designed to support (with fiscal and credit incentives, for instance) the development of technological activities in firms can be undermined by the absence of competitive pressures upon them.

This point touches upon an urgent and challenging policy issue faced by countries such as Brazil, which are seeking to move from import substitution to competitive restructuring: namely the need to coordinate industrial and technological policies with macro-economic policies, and particularly with trade policy. Temporary protection and planned liberalisation, as in the case of Japan (Nagaoka 1989), or the binding of protection to export performance, as in South Korea, have proved to be, in the historical contexts of these countries, useful instruments to create a competitive environment for local firms. However, industrial and technological progress in these countries seems to owe a lot to the fine co-ordination, at sectoral level, of trade policies with policies for the promotion of industry and technology (Nagaoka 1989; Luedde-Neurath 1988).

Therefore, an active industrial policy seems to be necessary, if the objective is to steer competitive restructuring in such a way as to make the most of the economic and technological potential of local firms. As Perez has argued, the simple elimination of state intervention in order to let the best firms survive, 'risks drowning many potential winners before giving them a chance to learn how to swim' (Perez 1988:25). Removing the obstacles and allowing competition is important, but firms require learning time and support, in the form of 'facilitating resources' (Perez 1988), in order to become innovative and competitive. These resources are adequate financing and the development of externalities (for instance, provision of human resources and of an adequate infra-structure of technological services) necessary to enable firms to successfully generate/adopt new technologies and new organisational techniques. The role of industrial policy is to provide these resources or to create conditions in which they can be provided by the private sector.

In providing facilitating resources for the diffusion of information technology, special attention should be given to user firms outside the electronics sector, particularly in the case of developing countries. At least this is what the findings of this study suggest. Brazilian user firms are still struggling to master the technologies they have licensed in the past. Their knowledge is imperfect, their engineering areas are fragile. They do not have the appropriate conditions to spontaneously develop the right internal environment, the 'IT culture', to incorporate new technology correctly. Suppliers too are swamped by their own difficulties in mastering licensed technology and are unable to provide help for users in respect of their deficiencies. Such a situation requires specific state intervention aimed at 'bridging' the gap between users and producers.

One basic finding of this research is that in order to be 'good users' of industrial applications of information technology, firms have to master the core technologies on which production is based. The implication of this for technology policy in the NICs is that concern with new technologies, which certainly have a highly strategic role in the process of restructuring, should not (and need not) increase at the cost of a lack of policies for and concern with the effective assimilation of 'mature' technologies. The Korean experience seems to offer a very useful lesson in this respect, since they have developed very aggressive policies and institutions for the electronics sector without abandoning their efforts to complete the 'course of adoption' of imported technologies in other industries (Enos and Park 1988).

To conclude, the task of promoting the diffusion of IT outside the electronics sector is complex and may involve a number of programs and institutions. An information technology policy concerned with this issue should not limit itself to the development of the electronics industry, as the Brazilian informatics policy has done so far. Certainly promoting the electronics industry should be at the core of any industrial policy concerned with the development of indigenous capability for the generation and use of IT-related innovations. However, in the face of the need to adapt the rest of the economy to the new technology, the policy should widen its scope and integrate the objective of development of the electronics industry with other objectives of industrial policy, otherwise there is a risk that IT policy may be regarded by the potential beneficiaries outside the electronics sector as a policy to attend to the interests of a particular industrial sector. IT policy is too important an issue to be reduced to such a politically weak position.

NOTES

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2 Process industries are defined here as those based on production processes aimed at the transformation of the physical/chemical structure of materials, such as oil refining, chemicals, steel, pulp and paper, electricity, glass, food and drink, etc. In most cases, production in such industries is considerably automated and organised in continuous flow systems.

3 For a fuller discussion of these issues, see Carvalho (1990).

4 See for example: Tauile (1984 and 1987), Silva (1988), Fleury (1988), Peliano *et al*. (1988), Laplane (1988), Prado (1989), Neder *et al*. (1988), Carvalho (1987), Schmitz and Carvalho (1989), Carvalho and Schmitz (1989). The emphasis on engineering industries in these studies is not

surprising, since electronics-based innovation affects these industries more radically. For thorough discussions of the economic and social implications of the diffusion of electronics-based innovations in industry see, for instance, Kaplinsky (1984) and Edquist and Jacobsson (1988).

5 SEI groups (electronic) industrial automation equipment produced in Brazil into two main categories: products for process control and products for manufacturing automation.

6 In fact, comparative data on the diffusion of NCMTs, robots and CAD/CAM systems suggests that Brazil is lagging behind not only *vis-à-vis* developed countries, but also with respect to some of the Asian NICs in which, as in Brazil, the diffusion of the new technology in industry only took off in the 1980s. For empirical evidence, see Carvalho (1990:5–6)

7 Information obtained in interviews with plant engineers and with the technical advisor to ABIQUIM.

8 The very fact that state-owned/state-controlled industries are major users of industrial electronic equipment in Brazil represents an important policy tool for IT and industrial modernisation policies, one which, in my view, has been little exploited.

9 This is a long story, which has not yet been properly investigated, but is briefly explained in Carvalho (1990), a previous extended version of this chapter.

10 For an account of the political development of Petroquisa, see Suarez (1986).

11 Interview with the President-Director of UNICONTROL, *Química e Derivados*, Aug. 1987.

12 The situation in the PLC market is similar. Presently there are twenty producers (for an annual US$40 million market); but another twenty have submitted requests to be licensed by SEI.

13 Yokogawa, Leeds, Fisher, Hitachi, and Asea-Brown Boveri are the proprietors of technology licensed early by current producers. Honeywell and Valmet account for the new licences recently approved by SEI. Comsip is the national supplier operating with in-house developed technology.

14 Since 1982, users' associations and state-owned user firms have demanded that SEI create a permanent assessment commission which would be in charge of testing and setting standards for Brazilian electronic equipment for process control. Such a group would include representatives of government agencies, a user firm association, technical societies, and state-owned firms (Siderbrás, Eletrobrás, Petrobrás). At the time of this research, this was still a proposal.

15 As the director of ABCPAI, the association of Brazilian suppliers of industrial automation equipment and services, puts it: 'We cannot expect that the licensee of technology will be able to carry out significant product improvement in a few years. In such a small market as ours, investment in research is too heavy a burden for firms to carry' (*Guia de Automação Industrial*, 1990, No. 7).

16 Firm A's engineers have estimated that the optimisation project would yield a 0.1 per cent saving in raw materials and a 1 per cent saving in energy, in a pessimistic forecast. Not taking into account other tangible economies, such as increase in effective capacity, engineers expected an

annual return of US$8 million, with a period of return no longer than two and a half years. Software represented 40 per cent of the global investment of the project.

17 This seems to reveal that Taylorist management conceptions still prevail among managerial/engineering staff in these plants, in spite of all the advances in automation. For further analysis of the labour implications of the diffusion of digital controls in the Brazilian petrochemical industry see Carvalho *et al.* (1989) and Carvalho (1989).

18 See Carvalho *et al.* (1989) for a detailed examination of Firm A.

19 For the conceptualisation of the process of adoption and assimilation of foreign technologies in developing countries, see Bell (1984), Fransman (1986), and Enos and Park (1988).

20 See 'Falta diálogo entre fabricante e usuário', in *Revista Petro & Química*, May 1987.

21 Interview with the President-Director of Ecil P&D, *INSTEC*, April 1987.

22 A parallel could be made here with the issue of equipment design limitations of Brazilian producers of capital goods for process industries, as proposed by Erber (1982). He showed that the lack of local capability in process design is usually associated with the lack of local capability in equipment design.

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