Skilled Labour in R&D: A Case Study of the Brazilian Computer Industry

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DPP Working Paper Nº 15

Development Policy and Practice Research Group

Faculty of Technology

The Open University

June 1989

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Contents

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This paper is about the use of human resources in research and development (R&D). It explores the following questions: 1. What is R&D in the context of developing countries? 2. What are the social and economic implications of such activities when they take place?

The computer industry is taken as a case study because it is recognised as being a knowledge intensive industry requiring a ready supply of highly skilled engineering and technical labour. Internationally, the computer industry has sustained a remarkable growth for at least three decades. The levels of (financial and human) resources devoted to R&D are substantial and the rate of technical change in and around the industry continues to be very high. The focus on human resources in R&D stems from the fact that highly skilled labour is a key prerequisite for R&D to take place but also a bottleneck due to labour shortage. The study of R&D, in turn, is an important way of examining levels of technological capacity and learning.

The paper examines the experience of a developing country, Brazil, in entering (and surviving in) the computer industry and questions the crucial role that R&D plays in the sustainability and future viability of the industry.[1]

The paper is structured as follows: Section 1 gives a brief overview of the development of the computer industry in Brazil, the policy environment and the industry's remarkable growth in the last ten years. Section 2 examines some of the literature on developing country R&D activities, indicating the inadequacies of standard indicators of science and technology. Section 3 then takes a closer look at R&D in Brazilian electronics, relating it to stages of learning. The following section 4 links this process of learning to the human resource base in the computer industry and discusses some of the barriers to R&D. The paper concludes by assessing the evidence.

1. The Development of the Brazilian Computer Industry

This section gives a short account of the background and development of the computer industry in Brazil. Until the late 1970s, Brazil's computer industry was in the hands of foreign firms which either imported finished products or carried out the final assembly of goods locally. By the mid 1980s, this situation had changed almost out of all recognition. In 1986, the number of firms operating in the *nationally-owned* computer and

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1 The paper is based on research carried out in Brazil in 1985/6.

peripherals market increased to 310 from 4 in 1977. Employment in these firms grew from just 4000 in 1979 to over 40,000 in 1986.

The computer industry was responsible for 40% of the US$8 billion total sales of electronics equipment in Brazil in 1986. As shown in Table 1, this represents the largest electronics market segment in Brazil (superseding that of consumer electronics and telecommunications). Within computer production, it is the national firms which have undergone the fastest growth in output of 300% from 1981 to 1986. Indeed, by 1986, national firms had passed a watershed by attaining 51% of the total computer market (Piragibe 1987).

Table 1 Sales of Electronics Equipment in Brazil: 1981/1986 - US$millions

	1981	1986
Computing	1008	3200
Consumer electronics	1845	2900
Telecommunications	749	1200
Instrumentation/Control	99	200
Others	34	500
Total	3735	8000

Source: Piragibe (1987)

By any standards, this is an impressive growth. It has resulted from the creation of a reserved market. Foreign corporations were not excluded from the Brazilian computer market. Rather, they were limited to specific market segments. Other segments were reserved for Brazilian private capital.

The principal tool of policy has been the creation of a reserved market for mini- and microcomputers and their peripherals. This policy is carried out by the Special Secretariat for Informatics (SEI) which is a specialised government agency subordinated to the Ministry of Science and Technology.[2] The policy instruments used by SEI are: the control of electronics imports; the concession of manufacturing licences to national firms; and the supervision of the demand for electronics goods and services by state organs and enterprises. Foreign firms are restricted to the production of mainframe computers. They are also controlled by SEI to the extent that the granting and withholding of import licences can force these firms to have increasing indices of nationally produced inputs in their final products and also to show positive export balances (Piragibe 1985).

2 Initially, computer policy came under the National Security Council. With the abolition of the Ministry of Science and Technology in October 1988, the control of SEI was moved to the President's Office.

These policies began in 1972 with the creation of the Commission for the Coordination of Electronic Processing Activities (CAPRE) which had a regulatory role over information technology. Control over computer imports began in 1975, at which time also a number of complementary policy measures were set in motion.[3]

At the same time, government concern and recognition that the computer industry was to be a key area of local development prompted the creation in 1974 of the state firm Computadores e Sistemas Brasileiros (COBRA) to develop and manufacture 'national' computers. COBRA produced two minicomputers under licence, one for military use and one for civilian use. With the experience obtained, the firm was then able to produce the first almost wholly Brazilian designed minicomputer in collaboration with the Universities of São Paulo (hardware) and Rio de Janeiro (software).

COBRA was conceived as being a 'national champion' for the local computer industry and as a training ground for technical and engineering labour (Tigre 1983:66).[4] COBRA, however, ran into serious difficulties as a commercial enterprise. Therefore, the decision was taken against state involvement in production, although the state retained control over the areas in which firms could operate. To this end, minicomputer production, then peripherals and, subsequently, microcomputer production was put to tender in 1977 for *national* firms.[5] This was the beginning of the market reserve.

Just as the preference for *private* national enterprise in computer production stemmed from the experiences of COBRA, the emergence of SEI was a result of the experiences of CAPRE. CAPRE moved from being an 'administrative and pedestrian' body (Evans 1986) to one which established the market reserve for mini- and microcomputers. In 1979 it became transformed into SEI with a wider mandate. The protected market for national firms under SEI's guidance gradually spread to other areas such as, superminicomputers, automation equipment, microelectronic components, software, digital instruments and others.[6] In 1984, the market reserve and complementary measures were enshrined in the 'Informatics Law'.[7]

The market reserve, protecting an infant industry, has been instrumental in national firms taking such a large slice of a lucrative and expanding market. However, rapid growth and market share is not in itself a sufficient indicator of success. We also need to

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3 These have been amply documented in a number of texts, for example, see Piragibe (1985 and 1988), Tapia (1984), Tigre (1983).

4 See Helena (1984) for a detailed account of the formation and development of COBRA.

5 The *national ownership* of the computer firms has a strict definition: they are corporations established in Brazil, under permanent, exclusive and unconditional direct and indirect control (over managerial decision making power, technological development and stock ownership) of individuals resident in Brazil or of domestic public entities (Frischtak 1986:8).

6 It is this wide range of activities related to data processing through machines which is termed 'informatics' in Brazil, and not just the computer industry itself.

7 For details see Piragibe (1988).

question the competitiveness of the industry.[8] The evidence from research gives us a qualified picture of success. It tells us that, yes, Brazil's computer industry is behind international levels of price. What matters is whether the price gap decreases over time. This is occurring but not in a linear way. The pattern which seems to emerge is that when Brazilian firms have almost caught up, international competitors make a new leap forward and a new round of catching up begins. In the context of this paper, however, we need to take a longer term perspective and look at the process of learning which is taking place through the use of highly skilled labour and its involvement in R&D.

2. Measures of R&D capacity

How has R&D capability been measured in developing countries? The standard measures work at an aggregate country level, drawing on more general science and technology indicators. Such indicators include: total R&D expenditure, R&D expenditure per capita and as a percentage of GNP, numbers of scientists and engineers per capita, and so on.[9] Such measures have some use in international comparisons - they are the only comparative data available - but there can be wide discrepencies and they tell us no more than degrees of magnitude.

A reaction to these aggregate measures can be found in the proliferation of literature on 'technological capabilities'.[10] A central conclusion of this literature is that R&D is only a small part of the process of acquiring technological capability in developing countries. An exclusive focus on R&D misses the more significant learning which takes place through *incremental* changes in technology, particularly in the production process. As O'Connor points out:

> '...the strength of R&D capabilities in a given country is not a function simply of the existence of formal research institutes and laboratories. Perhaps equally important is the accumulated informal and frequently undocumented knowledge acquired by the indigenous work force through a protracted process of learning by doing and transmitted through formal or informal on-the-job training'.
>
> (O'Connor 1985:324)

The benefits of learning through production should not be dismissed but, in emerging industries such as electronics (and, more recently, biotechnology and new materials) the research component takes on a renewed importance

8 For an analysis of the diminishing gap between Brazilian and international levels of price and quality see Schmitz and Hewitt (1989).

9 See, for example, Teital (1987) and Bowonder and Miyake (1988). Other indicators include: the technological balance of payments, numbers of obtained patents and international citations.

10 An extensive survey of this literature can be found in Bell (1982).

'The computer industry is essentially a knowledge-intensive industry wherein skilled, highly trained scientific, engineering and technical labour power is probably the single most important asset. Without such labour, even access to adequate financial resources and material inputs would not be a decisive advantage in a country's effort to develop an indigenous industry'.

(O'Connor 1985:325)

Production of computers is a relatively simple process of assembly of off-the-shelf parts and components. Designing systems and software, configuring them for particular applications, etc... is a more complex process. Thus, in the case of computers, it is necessary to look beyond the production process and explore the process of learning which takes place through R&D.

If the industry is to move beyond the assembly of electronics goods - an aim explicitly stated in Brazil's informatics policy - there is a need to invest in the understanding of the technology. Beyond rhetoric, however, there is little indication of what is involved in understanding. The effort is primarily based on the availability of skilled labour to carry out research/product development. The following section is an attempt to set out what is meant by R&D activities.

3. What is R&D in the Context of Brazilian Electronics

There are no precise measures of the extent of R&D in Brazil's electronics industry. Part of the reason for this lies in a confusion over what constitutes R&D itself. By conventional definitions,[11] research and development in all segments of the Brazilian electronics industry is limited,[12] but such aggregate measures obscure important pockets of R&D.

To give some idea of the kind of R&D investment in Brazilian electronics, contrast the following three sub-sectors: mainframe computer producers, consumer electronics producers, and small and medium computer and peripherals producers.

Foreign computer firms producing mainframes rely on research carried out in parent companies and have very restricted local R&D activities. In Brazil, their R&D is limited to the development of some application software, interfaces for nationally produced

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11 'R&D is usually defined as work undertaken to acquire "new" scientific and technical knowledge or to produce "new" materials, products or processes, and is usually seen as an activity which starts with basic scientific research' (Chantramonklasri 1985:115). Bell (1982:98) points out that R&D does not produce technical change as such, but produces the knowledge upon which technical change can be based.

12 In fact, by international standards, R&D in Brazil as a whole is limited. To put the situation in perspective, compare the US$1702 million which Brazil invested in all R&D in 1982 (UNESCO 1986:Table 5.9) to the US$2053 million invested globally by just one US firm, IBM, in the same year (O'Connor 1985:324). Nevertheless, there has been a consistent commitment on the part of policy makers to promote science and technology. The share of the national budget devoted to this increased from 0.84 in 1970 to 3.64 in 1982. Similarly, R&D expenditure as a proportion of GNP grew from 0.24 in 1971 to 0.65 in 1979 and the number of scientists and engineers engaged in R&D per million population rose from 75 in 1974 to 208 in 1978 (Frischtak 1986:3).

peripherals and work in the area of increasing 'nationalisation' of their products (see Dados e Idéias, Oct. 1985). The technological complexity of their products makes these activities no simple task. The engineers and technicians involved (often trained in the parent company)[13] are highly qualified in their particular field. However, they only dominate a *small part* of the R&D process due to the absence of research facilities in Brazil.

In consumer electronics, foreign firms based in the Manaus Free Zone (MFZ) control a large segment of the market, particularly televisions.[14] National firms tend to act more in the audio market. However, in both cases, product technology comes from overseas, mainly Japan.[15] R&D in MFZ is strictly limited to nationalisation/regionalisation and quality control activities. This is when it exists at all. Many consumer electronics firms claimed to have R&D activities based in the South East of Brazil. I was told that the major R&D activities there were 'features' (or cosmetic) modifications and the adaptation of nationally produced inputs. In other words, not basic research or product development, but very minor product modification. This is reflected in the almost complete lack of engineers in this sub-sector (see below).

By contrast to the foreign-owned firms in mainframes and consumer electronics, it is those firms whose ownership of capital is wholly national which employ far and away the most human and financial resources in R&D. In 1986 more than 5000 professionals were employed in R&D by national firms and their R&D expenditure reached US$154.1 million which amounted to approximately 10.1% of total sales (Piragibe 1987). Relative to the size of the national industry, this is a significant sum. However, in absolute terms it is still little, even when allowing for wage differentials of R&D personnel in Brazil and the United States.[16] Similarly, the absolute number of people in R&D is small by international standards, although in the industry they represent approximately 10% of the total labour force (Data News 4.2.86).[17]

There are those that have dismissed R&D by national computer firms in Brazil as simply 'reinventing the wheel' and, as such, a waste of valuable resources which could

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13 IBM, for example, maintains a team of 20 Brazilian technicians in the Glendale N.Y. laboratories. Burroughs and ABC-Bull have similar programmes.

14 Virtually all production of consumer electronics goods now takes place in the Manaus Free Zone.

15 With some minor exceptions (for example Philips), R&D for consumer electronics the world over is centred in Japan (Arnold 1985:121).

16 Two US firms which operate in the same product lines as the national computer industry, Data General and Apple, spent US$84 and US$38 million in R&D respectively in 1982 in the US (Frischtak 1986:22).

17 To give an idea of the magnitude of investment of these resources, take the case of IBM and its global R&D activities. In 1985 it is estimated that IBM invested US$2.7 billion (6% of total sales) in R&D. This quantity was spread between three basic research institutions of 2,500 employees (amongst which count 1000 PhDs) and numerous other research centres employing more than 50,000 people (700 PhDs) (Data News 4.2.86).

be employed more productively in areas more appropriate to Brazil's existing endowments (Ayres and Guanães 1985:58). The industry certainly faces enormous barriers but, contrary to this view, I would argue that learning about existing technologies through R&D is a cumulative process which passes through various stages of capability, and that what is occurring has to be viewed in a dynamic, longer term sense.

In an attempt to grasp what was meant by R&D when used by both primary and secondary sources in the course of my research, the term was broken down into component parts ranging from basic research through to such routine activities as quality control.[18] On my questionnaire I specified different categories of R&D activity: basic research, product development, product adaptation, process development, process adaptation, tests and experiments, and quality control. This was a necessary precaution because the term R&D tends to be used very loosely by firms and has repercussions for the claims for financial and human resources devoted to R&D activities.[19]

This classification corresponds approximately to a division of R&D made by Tigre (1986), namely, activities resulting in imitation, modification, redesign and innovation.[20] The labour requirements for these activities differ. For example, imitation requires mainly manufacturing (or even just assembly) and organisational skills, and, with the progression towards innovation, the skill requirements increase accordingly with more and more emphasis on design capability.

The distinction between *imitation* and *modification*, or what has been termed 'creative imitation', is stated clearly by Tigre:

> 'It is important to distinguish between simple copying, often with clandestine import of components, and creative imitation. The latter consists of more than merely making a carbon copy of the original product. Rather, it is an improvement, correcting eventual faults and adapting the product to local needs. In many cases, the requirement to incorporate national components necessitates redesign of the equipment since local parts do not always abide by the specifications of the original manufacturer overseas. Thus, the activity offers opportunities for learning which could eventually be used to develop own designs [i.e. to innovate]'.
>
> (Tigre 1986:154)

Carbon copy imitation has become a standard practice in microcomputer production. This is a world-wide phenomenon facilitated by the use of standard off-the-shelf

18 These are similar to the distinctions made by studies of R&D in developed economies. See e.g. Haug, Hood and Young (1983), Pearce (1987).

19 Evans (1979:173) points out that '...there are major methodological problems with using self-report to evaluate a firm's investment in R&D. It might be argued that multinationals have higher standards for what they are willing to label "R&D" and therefore under-report their efforts relative to local firms'. The same argument applies to the reported allocation of labour to R&D.

20 Bell et. al. (1984:34) employ a similar schema: replicative copying, minor improvements and modifications, formalised overall redesign, and innovation through R&D.

components (particularly microprocessors) by the major manufacturers.[21] The microprocessor, evolving rapidly in terms of lowering price and increasing performance, has made the 'development' of computers accessible to firms other than the world's giants. Thus, the microprocessor is perhaps the single most significant reason that has allowed Brazilian firms to enter the computer market since it simplified the development process in a way previously unimaginable.

These integrated circuits are available on the international market, produced by such firms as Intel and Motorola, and have revolutionised the computer market world-wide. Since the major functions of the computer are embodied in the chip itself, the development of the rest of the system is simplified. The open architecture of such equipment has the added advantage of making the use of a much wider range of software possible. This is due to the increasing standardisation of the functions of such equipment and explains the boom of IBM compatibles on the market. For example, in Brazil, in 1985 there were no less than 37 firms producing models of the IBM microcomputer family (PC, PC-XT and PC-AT) (Informática Hoje 15.10.85/16).

To the extent that the major international microcomputer manufacturers have been able to establish *de facto* world standards in hardware and, more importantly, in software,[22] '...the strategy of reverse engineering ... seems to have become the only possible form of survival in the micro[computer] market ... [and it] should not be seen as "technological pirating" but as a way of entering a concrete market situation' (Tigre 1986:142-3).

To counteract these trends, however, ease of entry into the microcomputer market has resulted in intense internal competition between national firms. It is those firms which understand the technology which have a better chance of moving to new product ranges.

Given the specific market conditions of Brazil - with IBM and other international manufacturers effectively removed from local microcomputer production - imitation offers short run advantages to Brazilian firms: product prices can be (and are) above international levels, the product life-cycle can be (and is) stretched beyond international levels and, crucially, profit levels can be high with relatively little initial investment.

The more that microprocessors assume the basic functions of the computer (including application software embedded in hardware, or firmware), the more the computer becomes a technological black box. This would seem to limit the R&D viability of Brazil's computer industry. Nevertheless, it is important to note the various instances of reverse engineering encountered in interviews with industrial R&D centres. The process was one of simulating the functions of a given microprocessor through combining a series of

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21 Amongst the 150 manufacturers of microcomputers in the US, there are at least 20 so called 'compatibility houses' producing copies of the IBM-AT alone (PC Mundo Feb. 1986:13). There are many more spread around the world, particularly in East and South East Asia.

22 Both operating systems and application software.

integrated circuits on a printed circuit board - called 'breadboarding'. Once understood, a new circuit was designed using computer aided design (CAD) and the various elements integrated once again onto one chip.

This is a lengthy, ad hoc process and may seem a waste of time when the component already exists. However, the benefits of the learning process may define the future competitiveness of those firms which are undertaking this kind of R&D. In addition, the growing use of customised and semi-customised integrated circuits, forecast to occupy 20-50% of the integrated circuit market by 1990 (Tauile 1985), makes knowledge of chip technology a pressing competitive element.

The situation was summed up by one engineer interviewed, who stressed that the benefits of copying are relative to the form that it takes:

> '...the question of copying a micro or a peripheral is relative and depends to a great extent on the strategy of the firm. If the aim is to make "fast money", suffice to keep copying. However, this strategy is limited by rapid changes in product technology. If you decide to go further, then you have to understand how the black box functions. This is a lengthy process and one which takes place through a series of modifications to copied products'
>
> (Interview).

Copying *and* understanding[23] is not a task that can be underestimated in its complexity, neither can the returns in terms of learning for those engineers and technicians involved in the process. As one research engineer put it '... the process of learning has been massive in the last six years. People entering the labour market today who have not experienced this accumulation of practical knowledge are finding it more difficult than before when the industry was less consolidated' (Interview). This is not only a long term process, but one which is plagued by mistakes as part of the process of learning. As one research engineer put it: '...everything that is happening in the computer industry in this decade is simply a preparation of the labour force for the next decade when there will be people with 10 years of errors under their belts' (interview).

There are also limits to this kind of learning: '... the maximum that can be achieved in the case of [microcomputer] compatibles is to make modifications and minor improvements, always within the limits of compatibility' (Data News 4.2.86:23). Even this may become difficult if there is a greater move towards the use of proprietary components in the newer generations of microcomputers (Frischtak 1986:22).

The *redesign* of already existing products may be viewed as a form of 'minor innovation'. It appears that those firms which have, in the past, invested considerably in technological learning through creative imitation are in a position to redesign products to enter niche markets. This, for example, is the case for firms which have developed specialised applications for microcomputer hardware and software such as the

23 Having know-how *and* know-why in Lall's terminology (Lall 1984).

development of a 32-bit microcomputer compatible with the UNIX operating system by one national firm, Scopus (Tigre 1986:139), the more recent development by the same company of a DOS-like operating system or Cobra's development of a UNIX-like operating system for minicomputers.

Innovation represents the highest level of R&D activity and, according to some observers, is not yet a viable proposition for Brazilian firms:

> 'The Brazilian market does not seem to be sufficiently large to support firms which, in isolation, would have the financial means to conduct R&D in the scale and depth necessary to introduce major innovations; neither would most firms be able to undertake the efforts to go inside the "black box" and unlock the proprietary technologies characteristic of newer systems. In fact, technological activity and expenditures need to be substantially increased if the technological lag is to maintained in the 2-4 year range'
>
> (Frischtak 1986:22)

I have argued that copying or imitation are the only ways to enter the microcomputer market and that it is also an effective means of beginning the process of learning. But, innovation in the *general purpose* computer market is a tall order for all but the few leading firms in the world.

Innovation has, nevertheless, been characteristic of *market niches* in Brazil's computer industry, particularly in the area of banking and commercial automation systems. Banking automation equipment in 1985 accounted for 30% of computer sales (Tauile 1986:104). Amongst the ten largest national firms, five are directly or indirectly controlled by financial institutions. The banking automation systems developed by these firms are unique as they are specific to the needs of Brazil's financial system (Tigre 1986:135).[24]

Brazilian firms have been able to keep reasonably close to technological changes and product up-dates. Initially, the output of the industry was not sufficiently different to what was available internationally to enable exports of niche market products. This situation is now changing and the export of Brazilian designed systems are beginning. National firms are exporting locally-designed service automation systems to Europe and Latin America (Tigre 1988, Botelho 1987). While such exports are small compared to those of foreign computer producers, there seems to be a future for Brazilian exports in some niche markets where independent design strategies are a real possibility. To a great extent, this will depend on the continued development of technological capability by national firms. More recently, some have argued that this process would also be aided by a more *selective* approach to import duties on intermediate components which Brazil

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24 In a highly inflationary economy such as Brazil's, it becomes viable to invest in and develop technology which increases the speed of circulation of money such as on-line terminals and electronic fund transfer systems.

does not yet have the capacity to produce competitively (Evans and Tigre 1988a:12, Perez 1985:IV).[25]

The *limits* to innovation are no more apparent than in the recent moves to produce so-called superminicomputers in Brazil. Despite the existing capacity to develop these machines, as exemplified by Cobra's previous experience with the 500-series minicomputer, the decision was taken to license already existing technology.

Three out of seven national firms had put forward proposals for their own development of superminicomputers. However, when SEI granted licensing arrangements to the other four, the former were forced to back down and obtain their own licences from foreign producers (Rosenthal 1987:216). Once SEI had accepted projects based on licensed technology it became unfeasible for firms to compete on the basis of their own technology because of the much greater costs involved and of the greater time it would have taken them to put their products on the market. Thus, the barriers to innovation were *economic* and *political*, not *technological*. [26]

Despite these limitations and barriers, it is fairly clear that at least part of the computer industry has moved beyond the clones of the late 1970s, More importantly, it is evident that the experience gained from copying international standards is bearing some fruit. There has been substantial learning through trying to understand black boxes rather than merely assembling them.[27] The basis of this learning has been the build up of a skilled labour force.

4. Human Resources in Brazilian Electronics R&D

The national computer industry, originating from CAPRE and the setting up of the state firm COBRA, was the result of a particular alliance of political forces. This included the military, technologists and economists. The glue was *nationalism*.

It was an unlikely alliance because it occurred at a time when the Brazilian economy was in a phase of internationalisation. In this developmental coalition there was, first, a small caucus of highly skilled engineers trained in technology institutes and universities

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25 Particularly components which rely on precision engineering such as drive and printer mechanisms and those inputs whose cost depends on third parties (such as fine chemicals essential for locally produced printed circuit boards)

26 One dimension which could not be pursued in this paper was a comparison with countries such as Argentina, Mexico, India or South Korea. Lack of space did not permit this. However, brief mention should be made of a recent comparison between Brazil and South Korea, the most advanced Third World computer producer. Evans and Tigre (1988a and 1988b) show that, overall, Brazil had a larger computer industry than South Korea in 1986 and, more significantly, that Brazil has progressed further in designing and producing 'non-commodity' computers which can be exported to specialised markets. On the other hand, they show that South Korea is more competitive in the production of 'commodity computers' (PC clones).

27 Of course, there continue to be firms that rely on productive efficiency to gain a slice of the market and which employ few resources in R&D.

in Brazil whom Evans (1986:792) has called 'frustrated nationalist technicians'. They were neither satisfied with working as salespeople for foreign computer manufacturers nor did they want to remain in universities. Their ambition was to find a commercial outlet (and, therefore, real test) for their prototype computer designs.

These engineers found political and financial support from three groups in the state apparatus. In the national development bank (BNDE) there was a group of economists who were keen to promote a national capital goods industry. The Federal data processing agency, SERPRO, had been doing their own hardware and software development to suit their particular needs and supported the creation of a national industry which could supply equipment to their specifications. Finally, the navy was keen to see the development of a national computer technology to supply its frigates and thus avoid a technological dependency in what was considered to be a strategic and sensitive military area (ibid.:793).

Nevertheless, the nationalist technicians were the impetus behind future R&D efforts. Until 1975 there was a virtual absence of local production of computers. As Piragibe (1985:3) points out, the industry 'was born internationalised', based as it was on the import of final products or, as in the case of IBM and Burroughs, restricted to the final assembly in Brazil of products with high import content.

The supremacy of foreign firms in the Brazilian computer market, based on ample technological, commercial and financial resources, imposed considerable entry barriers to local firms. In the opinion of Piragibe (1985:113) it also 'inhibited both the development of technology in the country and the creation of skilled employment in these activities'.

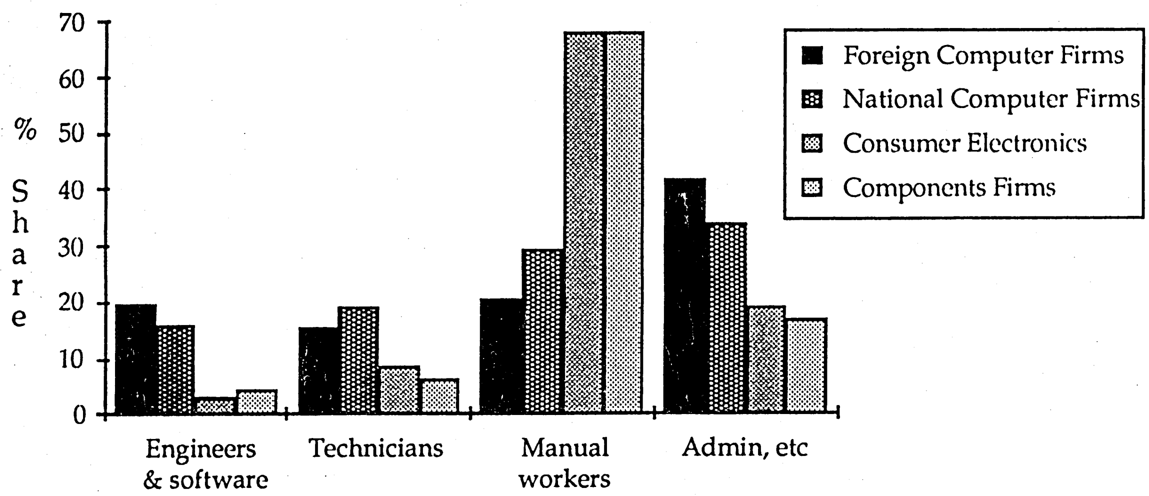
This situation had direct implications for the kind of employment which the industry created. The most qualified professionals, such as hardware engineers, programmers and systems analysts, were employed in marketing and technical assistance to end users, very often trained by the manufacturers themselves and unable to obtain a wider experience in the design/development of hardware and software (Piragibe et al 1983:6, Tigre 1983:5).

There was, nevertheless, a sizeable body of engineers and scientists working in Brazilian universities, in multinational electrical and electronics firms in Brazil and in the United States in the field of digital electronics (Tigre 1983:65). In the initial stages, this pool of highly skilled labour would provide the basis for setting up the nationally-owned computer industry. Many of the quality control and process engineers and technicians came from the communications industry which, due to cuts in government expenditure at the time, was making many redundancies. Similarly, marketing skills could be acquired from personnel who transferred from foreign computer firms. These sources, however, were limited and the rapid expansion of the industry post-1975 soon drained the available supply of human resources. This was particularly the case in the crucial area of research and development (Tigre 1983:111).

The occupational composition of the labour force in the three sub-sectors is illustrated in Figure 1. It shows that the presence of engineers and technicians is low in consumer electronics and most marked in the computer industry (foreign and national). These data, however, do not tell us which activities these professionals carry out within the firms. Engineers in foreign computer firms are often involved in activities other than production such as marketing, management and administration. Still less are they involved in R&D. National computer firms, by contrast, employ much of their engineering staff in both production and, more importantly, in R&D. Piragibe et al. (1983) conclude that R&D accounts for only 3% of those employed by foreign computer firms; national firms, by contrast, employ 14.3% in R&D. My research tends to confirm these findings. For example, while a representative sample of national firms interviewed employed 12.5% of their labour force in R&D, foreign firms only employed 3.7%.

Figure 1

Labour Force Composition by Occupation and Sector
(% Share) - 1984



Source: Computed from data provided by the Ministry of Labour (RAIS)

There is an even lower incidence of R&D employment in the largely foreign-owned consumer electronics (1.9% of the labour force). As Figure 1 shows, the bulk of the labour force in consumer electronics (and components) carries out manual work. Most of this consists of semi-skilled assembly work.[28]

Thus, there is a pattern of employment which *differs systematically* between sub-sectors of the industry both in quantitative and qualitative terms. Most significant is the substantial growth in employment in the national segment of the computer industry and its high percentage of skilled engineering and technical labour. The build up in

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28 For a detailed account of occupational and skill composition in the various sub-sectors of the Brazilian electronics industry, see Hewitt (1988).

human expertise in electronics has occurred precisely because of the market reserve for the national computer industry which does not have parents to turn to and which is now accumulating its own technological experience. The above data cannot prove the case, but it nevertheless suggests that such a fostering of talent and human resources would not have occurred if foreign firms had been allowed to enter this industry.[29]

Despite these stark differences, the national computer industry still faces human resource barriers. Since the early days of the computer industry, there was a shortage of skilled engineers and technicians for R&D in Brazil. Foreign computer firms, as shown above, had few employees in R&D and so those engineers that did move to national firms had no in-depth experience in research and product development of international producers.

The principal supplier of R&D labour, according to Tigre (1983:111), was the post-graduate and research programmes in computer science of the university system. However, through lack of industrial experience, the training of these graduates had to be supplemented by training abroad in industrial courses and with technology suppliers. Some form of overseas experience had been gained by at least some engineers in most of the national computer firms interviewed. The contracting-in of foreign engineers was not an option encountered during interviews.

The rapid expansion of the industry since the 1970s has exacerbated this supply shortage and led to high wages in the industry and to high turnover of professionals between firms.

The human resource needs in computing are still substantial. This is highlighted by the projected state expenditures for the three years 1985-87 for university research in computing. Of an estimated US$19.6 million, some 66% would be spent on human resources (SBC 1985). It should be said that these financial resources are still low compared with the kind of resources invested by developed country states.[30]

Apart from being the principal supplier of qualified labour for the electronics industry, the university system is also the centre of research, with the advantage over industry that it is one step away from the short term requirements of the market. However, the university system has suffered in terms of being deprived of adequate resources for research into electronics in Brazil.

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29 Apart from the example of the consumer electronics industry which has experienced two decades of the free market without showing any signs of the build up of technological capabilities, the case of Argentinian electronics industry is illustrative. What was once a burgeoning sector under national control is now virtually non-existent due, it seems, to the opening up of sector to uncontrolled imports of electronics goods (Tigre 1988).

30 For example: the 5th generation project in Japan has invested US$500 million, the Alvey programme in the UK is counting on investment of US$500 million over 5 years, the ESPRIT programme of the EEC invests US$220 million p.a.

To illustrate this, a study carried out by the Ministry of Science and Technology notes '... an enormous lack in the training and development of human resources for informatics in the country relative to that required to reach national technological capacity in the area' (MCT 1986:1). This problem has its roots in the lack of technical and financial resources in the principal centres of labour training which '... cannot meet the vigorous demand for "informatics" professionals adequate to the requirements of the labour market' (ibid.:3). In the words of one university researcher, '... at the level of human resources, the situation is catastrophic. We are paying the price of the lack of foresight of the last ten years' (Interview).

The dilemma facing the computer industry is the following: temptation (often necessity) to follow international standards through acquiring or copying products from abroad pushes considerations of national creativity to one side (ibid.:4). This is clearly illustrated by an electronics engineer from the University of São Paulo:

> '... one of the principal criticisms of the informatics law is precisely its excessive preoccupation with marketing aspects...while fundamental areas such as technological research and the marginalisation of universities were put in second place. Despite the current euphoria [about the computer industry], in the long run it will not be possible to maintain market domination if an effective technological culture in informatics is not developed and consolidated'
>
> (Dados e Ideias, Nov. 1985).

A study by the Brazilian Computer Society (SBC)[31] shows that academic research resources in informatics are sadly lacking as a result of inadequate planning. Moreover, industry drains the universities of the best people. SBC points to the low wage levels in universities and to the better working conditions in industry as being the principal reasons for the migration of highly qualified engineers and technicians from the former to the latter in recent years (SBC 1985). Another study by the University of São Paulo, for example, shows that more than 50% of national computer firms turn to university research departments as a source of R&D engineers (Maximanio et al 1984:28).

The reasons for the increasing increasing evacuation of qualified university staff can be summarised as follows (MCT 1986:4):

- Low wages relative to those paid in industry and services;
- The lack of an adequate research infrastructure;
- The discontinuity and unpredictability of resources for training professionals.

In an attempt to counteract these developments, the government set up a research centre in Campinas, the Technological Centre for Informatics (CTI). As of end of 1986, four institutes of CTI were functioning: computation, microelectronics, automation and

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31 An independent group composed mainly of the academic and research community in computing.

instrumentation. Of these, the microelectronics one is the most ambitious. It carries out encapsulation of ceramic chips and plans to set up mask production. This is financed by the Ministry of Science and Technology, since the return on investment in this area is slow (15 years) and thus not of interest to private firms. There are a number of 'joint-ventures' of CTI with private or state firms with the greatest emphasis in the area of software.

CTI does not have a direct role in the training of human resources, although there are a number of undergraduates and postgraduates from UNICAMP who are working on their theses there and working as trainees. However, strong connections with universities do not exist except through informal links with UNICAMP/USP. CTI still has a scarcity of human and financial resources for more ambitious projects. At the time, 50% of their capital came from relatively small contracts from firms for specific projects.

Given the general paucity of R&D in universities, much of the onus for research lies in the private sector. According to information from SEI (1986) there was a slight increase in the percentage of total employment of the national computer industry in R&D activities: from 13.0% in 1983 to 14.5% in 1984. Of these latter, 63.1% were of university level (i.e. engineers) and 35.9% of secondary level education (i.e. technicians). By any standards, this is a high proportion of the labour force to be involved in R&D, even though it may not be so large in absolute terms. Unfortunately, it is not possible to tell from this information what kind of R&D activity these reported levels of labour utilisation include.

In line with this increase in employment, was an increase in spending on R&D:[32] from 9.8% of sales in 1983 to 10.8% of sales in 1984 (US$73.2 million). While these figures must be treated with caution due to the problems of extracting R&D costs from total costs, this is a high proportion of sales. However, in absolute terms, compared to international levels, it is not a great deal. Considering that this small quantity is spread between a large number of firms (with little or no inter-firm cooperation) then the impact of these sums is even more diluted.

Table 2 shows that there is a difference in the relative levels of R&D investment depending on the type of product.

From interviews, this proportion of financial investment appears to be of the same order of magnitude as human resources invested in R&D. The large (and growing) investment in microcomputer R&D indicates that the creative imitation which characterises this market segment is a process which requires considerable technological effort. That is, creative imitation is not an automatic process.

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32 Defined by SEI as '...financial resources applied to the development of new products or in the improvement of already existing products' (SEI 1986:). This is a more restricted definition than the one used in my research.

Table 2 Percentage Share of Sales Invested in R&D by National Firms by Product - 1984

Minicomputers	10.9%
Microcomputers	15.5%*
Peripherals	5.2%
Modems	6.1%
Others	5.8%

Source: SEI (1986)
* From 12.2% in 1983.

Minicomputer and peripherals producers command smaller, although still considerable, investments in R&D due, it would appear, to the more widespread use of licensing agreements for technology in these market segments.

Whether or not either of these different approaches yields results in terms of technological learning depends on the strategies (creative imitation, licensing, etc...) adopted by the firms. During fieldwork, I encountered a wide variety of attitudes towards the pay-off of different strategies ranging from pessimism to optimism. The concensus was, however, that fostering and consolidating innovative capacity was a long term strategy which required consistent and substantial investment of human and financial resources.

5. Conclusions

This paper has explored the nature of R&D in the Brazilian computer industry and discussed some of the implications of R&D for the future viability of the industry and its labour force.

An important conclusion appears to be that the future of the industry depends not only on its competitiveness in terms of productive efficiency. Competitiveness also requires 'innovative capacity' which is founded on the availability and use of skilled engineers and technicians.

The brief excursion into this question has shown that the term 'innovative capacity' has to be treated in a broad way if it is to make any sense in a Brazilian context. The notion of 'learning' through activities such as imitation, modification and redesign is a useful way of interpreting what has been happening in the national computer industry.

The dilemma facing the industry has been to find an effective means of learning with a limited supply of financial and human resources and a technological target which does not stand still. Various strategies have been adopted: reverse engineering, licensing, product adaptation and redesign and entry into niche markets. To some extent, the strategy adopted has been dictated by the nature of the product - copying microcomputers was feasible, copying printers and hard disks was not. In addition, economic and political aspects have played a role.

What does seem to be clear, however, is that managing to put any product on the market is no guarantee of future success. As one researcher has pointed out,

> '...technological accumulation and catching up is by no means a passive, mechanistic process, but a painstaking, costly and deliberate effort on the part of successful firms, governments and nations'.
>
> (Hobday 1986:84)

Most of the firms interviewed acknowledged this. At the same time, there were doubts that Brazilian firms could keep up with the rapid changes in product technology.

Although financial and human resource investment has been high by Brazilian standards and seem sufficient given the existing protective policies, they are still small by international standards. As one outside observer has argued,

> '...A larger and more focussed deployment of R&D resources will be probably needed to significantly reduce in the future the price differentials between the national and international markets and avoid a widening of the technological gap'
>
> (Frischtak 1986:26).

Equally important, at present these are *fragmented* investments which are based on competition between small individual firms for a protected market. 'Joint-ventures' in R&D between national firms themselves in conjunction with research institutions, such as CTI, and the newly emerging components firms would considerably increase the scale and efficiency of R&D.

At the time of fieldwork, this was not a widespread strategy. As pressures increase to become competitive on international markets (offering products that are in some sense innovations) and as the present structure of the market reserve nears its end (in 1992), greater research cooperation and collaboration between firms and research institutions seems essential.

This view is echoed by the former chair of the Special Secretariat for Informatics (SEI), Edison Dytz, who has suggested that the phase of stimulating the creation of new national firms is over.

> 'We need to launch a second phase, encouraging the association among firms, universities and research centres with well defined technological goals. After some time of supporting producers and researchers, we would have to assess what we have obtained and then select the most successful areas for continued support. Those areas in which our support has not lead to adequate local capability will have to be supplied from abroad, even if this means the elimination of some national firms'.
>
> (*Globo*, 7.6.87; quoted from Bastos, 1988).

This said, the gains to date in terms of learning through R&D have provided a foundation for the future. In addition, it is human capacity in R&D which plays a significant role in the viability and competitiveness of the electronics industry. In other words, survival in what we know to be a knowledge intensive industry depends on 'innovative capacity'. This, in turn, is founded on the use and availability of a highly skilled engineering and technical labour force.

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