Strategic Management of Technology in the Chemicals/Materials Industry: Policy Recommendations for Brazil

by

PAULO ROBERTO BELLOTTI

B.S., Escola Politécnica da Universidade de São Paulo, 1988
S.M., Escola Politécnica da Universidade de São Paulo, 1990

Submitted to the Department of Chemical Engineering in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE
in
TECHNOLOGY AND POLICY

at the

Massachusetts Institute of Technology, January, 1994

Signature of the Author ....
Paulo Roberto Bellotti
Department of Chemical Engineering, January 1994

Certified by ....
Professor Edward B. Roberts
Thesis Supervisor

Accepted by ....
Professor Richard de Neufville
~~Chairman~~, Technology and Policy Program

Accepted by ....
Robert E. Cohen
Chairman, Committee for Graduate Students

Strategic Management of Technology in the Chemicals/Materials Industry: Policy Recommendations for Brazil

by

PAULO R. BELLOTTI

Submitted to the Department of Chemical Engineering
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Technology and Policy

Abstract

The chemicals/materials industry is likely to face significant challenges in the years to come. Structural changes in the industry and in society at large are causing a fierce industrial competitive environment in which few companies are able to offer attractive opportunities for investors. The process of successfully overcoming these challenges has many managerial dimensions. Among those, sound management of technology practices can provide an organization with sufficient institutional capabilities for survival and growth in the years ahead.

This thesis has four main objectives. First, it aims at establishing a series of benchmarks on Strategic Management of Technology in the chemicals/materials industry. In doing so, management practices are surveyed in four regions of the world: Europe, Japan, North America, and Latin America. Second, it tries to identify specific management policies that improve the innovation process across all these regions. Third, regional benchmarks are established as a means of identification of policy opportunities for the Brazilian industry. Finally, it explores the issues involved in the implementation of these policy opportunities through the suggestion of an implementation strategy.

The analyses show that the innovation capabilities of the Brazilian chemicals/materials industry will increase with the improvement or adoption of the following policies: formulation, communication, and acceptance of technology strategy; linkage between technology and corporate-level strategies; participation of the Chief Executive Officer in the R&D process; use of multi-functional teams in technology planning, research and development activities; accountability of R&D and project managers; early market test of new products; and total quality management approaches. These policies, however, demand considerable organizational-wide efforts. Managers are encouraged to start implementing them through changes in the organization's procedures, division of responsibilities, communication patterns, and culture.

Thesis Advisor: Professor Edward B. Roberts
David Sarnoff Professor of Management of Technology
Sloan School of Management

Acknowledgments

I would like to express my gratitude to Professor Edward Roberts for his constructive comments and insightful suggestions during the development of this thesis. Thanks also to the Brazilian, European, Japanese, and North American managers who took a portion of their valuable time to fill a rather extensive questionnaire.

The execution of this work has drawn support from many institutions, both here in the U.S. and in Brazil. In the U.S., a special note of thanks goes to the staff, faculty, and students of the MIT's Technology and Policy Program. They have provided me with the most fruitful educational experience of my life. In Brazil, I would like to acknowledge the financial support provided by CNPq and Poliolefinas S.A.

I am also grateful to a group of special people. My parents, Ilona and Paolo, have encouraged and supported me during the difficult days of the last two years. Luis and Juan Pablo have been a source of true friendship and encouragement. Finally, my wife Marcia has helped me through the last two years with boundless elegance, love, and intellectual stimulation. This work is dedicated to her.

Contents

	Page
Title Page	1
Abstract	2
Acknowledgments	3
Table of Contents	4
List of Tables	6
List of Figures	7
Chapter One: Introduction	9
Chapter Two: The Chemicals/Materials Industry	13
2.1) Introduction	13
2.2) Structural Analysis	13
2.3) Chemicals/Materials Industry: Challenges and Opportunities	18
2.4) Innovation in the Chemicals/Materials Industry	21
2.5) Summary	23
Chapter Three: Innovation Process, Survey and Hypotheses	25
3.1) Introduction	25
3.2) The Innovation Process	25
3.3) Survey Methodology	28
3.4) Hypotheses	30
3.5) Evaluating R&D Performance	41
3.6) Summary	42
Chapter Four: Statistical Analysis	44
4.1) Introduction	44
4.2) Stakeholders of the Innovation Process	44
4.3) R&D Performance	47
4.4) Product Commercialization and Process Implementation	53
4.5) Summary	55
Chapter Five: Survey Results and Regional Analysis	59
5.1) Introduction	59
5.2) The Chemicals/Materials Industry and the Innovation Process	59
5.3) Management of Technology Benchmarks	76
5.4) Summary	110
Chapter Six: Policy Options	116
6.1) Introduction	116
6.2) A Brief Word on the Brazilian Context	116

6.3) Research Methodology 118
6.4) Policy Options 120
6.5) Summary 126

Chapter Seven: Implementation Strategy 128

7.1) Introduction 128
7.2) An Organizational Approach 128
7.3) An Implementation Strategy 133
7.4) Summary

Chapter 8: Conclusions 143

8.1) Sound Policies for Improving R&D Performance 143
8.2) Policy Opportunities for the Brazilian Industry 144
8.3) Implementation Strategy 146
8.4) A Final Word 147

Appendix I 148

Appendix II 166

Bibliography 169

List of Tables

	Page
Table 2.2.1: Industry analysis	16
Table 2.3.1: Industry challenges and opportunities	19
Table 3.6.1: Formulated hypotheses related to R&D performance	43
Table 4.2.1: Impact of policies on stakeholder's satisfaction	46
Table 4.2.2: R&D stakeholders and policy options	48
Table 4.3.1: Correlation matrix	49
Table 4.3.2: Hypotheses and R&D Performance	51
Table 4.3.3: Multiple linear regression analysis results	52
Table 4.4.1: Most used practices to move prod/proc to market	54
Table 4.4.2: Correlation matrix among policies HGj	56
Table 4.4.3: Policy options and time from concept to implementation	57
Table 4.5.1: Summary of Policy Options	58
Table 5.2.1: Overall R&D performance across components and regions	74
Table 5.3.1.1: Technology strategy formulation	80
Table 5.3.2.1: CEO activities and regions	93
Table 5.3.2.2: Role of the Chief Technology Officer	95
Table 5.3.2.3: Use of customer input in the innovation process	98
Table 5.3.2.4: Mechanisms used to move products to market	102
Table 5.3.3.1: Monitoring activities across regions	107
Table 5.3.3.2: Use of university programs per activity	112
Table 5.4.1: Possible policy options	115
Table 6.6.1: Policy options for the Brazilian chemicals/materials sector.	127
Table 7.2.1: Policy options	129
Table 7.3.4.1: Constituency of the innovation process	138

List of Figures

	Page
Figure 3.2.1: Strategic management of technology framework	27
Figure 5.2.1: Companies perceived as the most innovative	60
Figure 5.2.2: Respondents' regional average sales	62
Figure 5.2.3: Regional technology strategies	62
Figure 5.2.4: Technology portfolio's balance	63
Figure 5.2.5: Average R&D spending by region as a percentage of sales .	65
Figure 5.2.6: Average regional ratio R&D spending and net income	65
Figure 5.2.7: R&D spending and net income	66
Figure 5.2.8: Funding and management support of R&D organizations	68
Figure 5.2.9: Maturity of key technologies	69
Figure 5.2.10: Average maturity of technologies in each region	69
Figure 5.2.11: Fulfillment of stakeholders' needs in different regions	70
Figure 5.2.12: Regional R&D performance	73
Figure 5.2.13: Perceptions against competitors	75
Figure 5.3.1.1: Form., com. and acceptance of technology strategy	77
Figure 5.3.1.2: Corporate technology strategy development	79
Figure 5.3.1.3: Linkage between technology and corporate strategies	82
Figure 5.3.1.4: What is important to technology strategy?	83
Figure 5.3.1.5: Key executives and technology strategy	84
Figure 5.3.2.1: Organization of R&D at the Corporate level	86
Figure 5.3.2.2: Organization of Development at the Corporate level	86
Figure 5.3.2.3: Organization of R&D at the business-unit level	88
Figure 5.3.2.4: Organization of Development at the business-unit level ...	88
Figure 5.3.2.5: Budget allocations at Corporate R&D	89
Figure 5.3.2.6: Budget allocations at the business-unit R&D	89
Figure 5.3.2.7: Main funding mechanisms of R&D at corporate level	90
Figure 5.3.2.8: Corporate R&D funding mechanisms per region	90
Figure 5.3.2.9: Use of multi-functional teams per region	91
Figure 5.3.2.10: Use of multi-functional teams for different purposes	91
Figure 5.3.2.11: Involvement of the CEO in the R&D process	93

Figure 5.3.2.12: The role of the CTO in different regions 95
Figure 5.3.2.13: Use of customer input in the phases of the R&D process . 97
Figure 5.3.2.14: Use of customer input by region 98
Figure 5.3.2.15: Process of obtaining customer input 100
Figure 5.3.2.16: Mechanisms to obtain customer input - research 101
Figure 5.3.2.17: Mechanisms to obtain customer input - development 101
Figure 5.3.2.18: Most used mechanisms to move innovations to market 102
Figure 5.3.2.19: Meeting target dates for product/process innovations 103
Figure 5.3.2.20: Meeting target dates in Brazil 103
Figure 5.3.3.1: Mechanisms of technology monitoring 105
Figure 5.3.3.2: Companies using technology monitoring activities 106
Figure 5.3.3.3: Use of university programs in each region 108
Figure 5.3.3.4: Use of university programs 109
Figure 5.3.3.5: Mechanisms to obtain technology 111
Figure 5.3.3.6: Changes in skills of technical employees 113
Figure 5.3.3.7: Reliance on external technologies 113
Figure 6.2.1: Policy options and reported R&D performance for Brazil 119
Figure 7.4.1: Implementation strategy 142

Chapter One: Introduction

The chemicals/materials industry is passing through a major worldwide business downturn. Structural changes in the industry and in society at large are causing a fierce industrial competitive environment in which few companies are able to offer attractive opportunities for investors. The fall of the Soviet Union, the integration of the European Community, enlarging excess capacity, world economic recession, relaxation of trade barriers, growing environmental awareness, and increasing costs of research and development are some of the challenges that the industry is likely to face during the next couple of years.

In fact, turbulent environments are not new to the chemicals/materials industry. Indeed, it has undergone through critical changes over the last two decades. In the seventies, the industry's supply chain and demand patterns were altered by two oil shocks (1973 and 1979). During the eighties, installed overcapacity and the reduction of trade barriers put the industry again under strain, motivating merges, acquisitions, and downsizing.

The process of successfully overcoming the challenges ahead has many managerial dimensions. This thesis focus on management of technology as an important dimension that, if properly done, can increase chances of firm survivability and growth.

The thesis is aimed at assessing the current management of technology practices in the chemicals/materials industry in Brazil[1], Japan, Europe, and

[1] We originally intended to assess management of technology practices in the entire Latin American region. The data collected through the questionnaire in Latin America, however, was comprised mostly of Brazilian firms (around 90%). In this context, we re-focused the thesis to the Brazilian industry. On the other hand, we believe that most of the suggestions developed herein can be applicable to other countries in Latin America as well.

North America[2]. It has three main parts. The first one involves a global benchmark of management of technology practices. Statistical tests are conducted to identify the most relevant practices and their impact in the innovation process. The second part comprises an analysis of management of technology practices at a regional level and the elaboration of policy options that would improve the innovation process in the Brazilian industry. Lastly, the issues involved in the implementation of those policies in different organizational settings are explored.

The study is entirely focused on strategic management of technology at the firm level. The innovation process is perceived as having three main components: (i) posture and direction; (ii) systems; and (iii) adjustment processes. To explore these components, a questionnaire was designed and sent to leading companies in Europe, Japan, Latin America, and North America[3]. The answers to the survey provided the necessary input to assess global and regional practices of strategic management of technology in the chemicals/materials industry.

More specifically, the thesis explores the following questions:

- What are the structural characteristics of the chemicals/materials industry that make it different from other industries?

- What are the main challenges that the industry is likely to experience in the years ahead?

- How is the chemicals/materials industry organized in terms of innovation management in Europe, Japan, North America, and Brazil?

- Is there any evidence that explain better R&D performance in the chemicals/materials industry on the grounds of specific management of technology practices?

---

[2] United States and Canada.

[3] The questionnaire was developed jointly by the Management of Technology and Innovation Group at MIT and Pugh-Roberts Associates.

• If yes, are there opportunities for the Brazilian industry to improve R&D performance using these policies? Are there opportunities for Brazilian firms?

• In doing so, whose interests would be at stake and how these policies could be implemented?

In order to determine the structural characteristics of the chemicals/materials industry and the challenges that it will most likely face in the years ahead, chapter 2 presents an industry analysis. Likely patterns of industrial innovation are also assessed. Strategic management of technology is identified as a means to increase possibilities of survivability and growth.

Chapter 3 introduces the framework used in assessing the innovation process at the firm level. It also discusses the survey methodology that was used to determine practice and performance benchmarks in strategic management of technology in the European, Japanese, American, and Latin American chemicals/materials industries. Since the objective is to determine if specific management of technology practices can account for R&D performance, research hypotheses are developed. These hypotheses establish relationships between specific policies and R&D performance.

In chapter 4, statistical analyses are conducted to determine significant relationships between management of technology practices and performance of research and development. In doing so, multiple linear regression analyses are applied to test the research hypotheses developed in chapter 3 against the empirical data collected through the survey.

Chapter 5 presents the survey results and identifies differences in the management of technology across different regions. Although opportunities for improvement seem to exist in all regions, emphasis is given to the Brazilian context. The objective is to uncover policy opportunities at the firm level for the local chemicals/materials sector.

In chapter 6, policy options to increase R&D performance in the Brazilian chemicals/industry are shown. In addition, policy options to decrease time from concept to market are also described. The implementation of those policies involve a considerable amount of organizational intent and strength. Chapter 7 discusses strategies for the implementation of those policies, considering the stakeholders of the policy process, namely management, labor force, customers, equity and debt holders, and customers. Finally, chapter 8 presents the conclusions of this work and draws some recommendations for further research.

Chapter Two: The Chemicals/Materials Industry

2.1) Introduction

This chapter presents a brief structural analysis of the chemicals/materials industry and tries to identify the main challenges and opportunities that the industry is likely to encounter in the near future. The intention is to assess how the industry economics affects patterns of innovation and how innovation can be useful for the industry in the anticipated environment.

2.2) Structural Analysis

It is difficult to define the chemicals/materials industry, mainly because of its complexity. According to the United Nations (1992)[4], the chemicals/materials industry is constituted of many segments: inorganics; fertilizers and agrochemicals; petrochemicals; artificial fibers and synthetics; pharmaceuticals; and others.

Although those products hardly match the strict definition of an industry -- groups of firms whose products are close substitutes to each other -- the economics of these segments have some similarities that support some important generalizations. The only exception is the pharmaceutical industry, which has different structural characteristics in terms of regulation (product, process, and price), intellectual property protection, and research and development orientation. For these reasons, this work does not include the pharmaceutical industry as part of the broader category called chemicals/materials industry.

---

[4] United Nations, "Annual Review of the Chemical Industry", 1992.

Annual worldwide sales from inorganics, fertilizers and agrochemicals, petrochemicals, and artificial fibers and synthetics are around $1.2 trillion. Production is widespread, with developed countries accounting for 65% and less developing countries producing 35% of total consumption (United Nations, 1992)[5].

The chemicals/materials industry can be segmented in synthesis and formulation. Basically, synthesis involves the production of molecules or substances through chemical and mechanical processes. Formulation involves the production of substances through mechanical operations, without changing the basic structures of molecules. Historically, firms operating in synthesis were among the firsts to support company-owned research laboratories. These investments have not only created new products to sustain growth but also new low-cost manufacturing processes, both of which have traditionally given the industry its particularly dynamic characteristics. Formulation firms are more focused on development, adapting product characteristics to meet customers' needs. This activity usually require a high degree of service. Industry forces normally have different magnitudes whether the firm operates in synthesis or formulation. The thesis focus is mainly on firms operating in the synthesis segment.

Another artifice that would facilitate the analysis is the segmentation of the chemicals/materials industry in commodities and high value added products (specialties). Commodities are products sold on the basis of well-defined characteristics, targeting non differentiated market segments that have high price elasticity of demand. Specialties are products sold on the basis of performance, targeting differentiated markets that have low price elasticity of demand. Specialty status most often occurs in the early years of the product's life cycle and commodity status occurs in later years. As it is the case of synthesis and formulation, firms that produce commodities are subjected to a different set of industry forces relative to firms that produce specialty substances.

[5] Op. cit.

The analysis of the chemicals/materials industry is done by using the 5 forces framework developed by Michael Porter (1980)[6]. According to Porter (1980), five forces determine the competitive level or attractiveness and, consequently, long term profitability in an specific industry: (i) entry; (ii) threats of substitutes; (iii) bargaining power of buyers; (iv) bargaining power of suppliers; and (v) rivalry among competitors. Below, we briefly assess each one of these five forces for the chemicals/materials industry. Table 2.2.1 depicts the results of the analysis.

Barriers to Entry

Potential entrants face significant barriers to entry. In commodities, entry normally requires high capital investments[7] and manufacturing scale. In specialties, proprietary technology and service/marketing networks are the limiting factors. Dynamic economies of scale (learning) have also an important effect in raising entry barriers. It should be noticed, however, that barriers to entry are reduced in commodities because of the low switching costs faced by buyers and, in specialties, because of product differentiation.

Substitutes

Products that can perform the same function in each one of the segments of the chemicals/materials industry can limit pricing possibilities. As the industry matures, substitution within the chemicals/materials industry itself is increasingly a factor[8]. In general, the development of new products will generate new markets for the industry as whole, since differentiation is becoming more and more important. In the long run, however, substitution seems inevitable due to society's pressures for a cleaner and safer

---

6 Porter, M, "Competitive Strategy: Techniques for Analyzing Industries and Competitors", Free Press, 1980.

7 The cost of a new plant can be estimated to be around $300 million. However, due to high co-specialization among different plants, new entrants may have to build one plant for the processing of raw materials and other intermediary products.

8 For example, high performance polymers and blends of materials with increasing electrical, optical and mechanical properties may substitute for glass in specific applications. Biotechnology also represents an array of challenges and opportunities for the existing industry. In addition, natural products are also important substitutes.

Table 2.2.1: Industry Analysis

Industry Forces	Commodities	Specialties
Barriers to Entry	High: economies of scale, learning, large capital investments	High: proprietary technology, branc identity, and learning
Substitutes	Increasingly a factor (health, environment, and finite raw materials	Important but enlarging size of the market
Power of Buyers	Strong: price sensitive, low switching costs, and alternative sources	Inconclusive: fewer alternatives, higher switching costs, but quality sensitive
Power of Suppliers	Inconclusive: backward integration, alternative supply, but always sensit to changes in the international regime	Low: alternative sources, low switching costs
Rivalry	High: slow market growth, high fixed costs, large additions of capacity, lov differentiation, high exit barriers	Low: differentiation, assets are nc specialized, and market growth
Overall Assessment	Fairly attractive Growth shape-out phase	Attractive

environment and to the fact that industry's raw materials come mainly from finite non renewable sources (minerals and petroleum)[9].

Bargaining Power of Buyers and Suppliers

Buyers are typically in more numbers than sellers. Buyers of commodities have usually a strong bargaining position since they have alternative sources, face fewer switching costs, and are price sensitive. Specialty products are more attractive in this context, since specialty buyers are less price sensitive, do not have a large number of alternatives, and are more co-specialized with the supplier (i.e., the chemicals/materials producer). Buyers generally do not pose a threat of backward integration since barriers to entry are high for them. As the products' life cycle matures and more and more substitutes become available, the bargaining power of buyers increase.

Supply is extremely important to the producers of commodities. To guarantee a reliable source of raw materials most companies are integrated backwards and/or count on government intervention. In the case of specialties, companies have alternative sources and are less sensitive to the bargaining power of suppliers. Price of raw materials, however, is constantly an issue. Remember the effects on industry profitability of the two oil shocks in the 1970s.

Rivalry

Intensity of rivalry in the industry is determined by: number and size of players; industry growth; cost structure; differentiation and switching costs; exit barriers; and size of capacity increase.

According to Stobaugh (1988)[10], sellers of a particular product are typically few enough in number to constitute an oligopoly. Commodities sellers are in more number than specialty sellers, which increases rivalry in commodities.

---

9 There are not obvious near-term pressures on the supply of raw materials though. In fact, the price of oil is in its lowest level since the 70s (approximately $12,00 a barrel).

10 Stobaugh, R., "Innovation and Competition: The Global Management of Petrochemical Products", HBS Press, 1988.

The present state of slow industry growth also increases rivalry in the industry, since profitability is more a function of market share than market expansion. Rivalry can be further increased by two reasons. First, commodities have a high fixed cost component relative to value added, which have forced managers to reduce price and operate at full capacity to achieve a break-even point. Second, economies of scale demand capacities to be added at large amounts. The addition of these capacities in the chemicals/materials industry are chronically disruptive to the industry's supply/demand balance.

Rivalry in commodities is much higher than in specialty materials due to the lack of differentiation, the number of players, and the relative low switching costs experienced by buyers. In addition, barriers to exit are usually higher in commodities than specialties since assets are more specialized to produce a larger amount of a specific product; fixed costs to exit are relevant; and governments may impose restrictions due to co-specialization and social costs.

Overall Assessment

The industry is attractive in the specialty products segment and still somewhat attractive in the commodity segment, which can be characterized as being in the growth "shape-out" stage. Consolidation is starting to occur as competitors exercise their market power.

2.3) Chemicals/Materials Industry: Challenges and Opportunities

This work is not aimed at developing a comprehensive analysis of all the facts and policy outcomes that may affect the industry. This section tries, however, to present some trends that may have an important effect on the industry's dynamics and innovation patterns in the near future. Table 2.3.1 summarizes the levels of analysis, facts, and main challenges and opportunities faced by the industry in the near future[11]. Three levels of analysis are considered: changes in the international regime; regional changes; and industry events.

[11] This discussion is based on various articles that appeared in the Financial Times during the months of July to December of 1993.

Table 2.3.1: Chemicals/Materials Industry: Challenges and Opportunities

Levels of Analysis		Facts	Challenges/Opportunities
International Regime		Fall of the Soviet Union	rivalry in commodities/investment opportunities
		World Recession	increased rivalry, substitution, and capacity cuts
		Successful Uruguay Round	increase rivalry, long term growth opportunities
Regional	**EC**	Integration - Maastrich	reorganization, relocation, M&As/investment in special
		Incorporation of Eastern Europe	increased rivalry/cheaper raw materials
	NA	NAFTA	reorganization, relocation, long term growth opportunit
		Slow recover of recession	
	SA	Privatization	reorganization, M&As
		Lower trade barriers	Rivalry/Productivity increase
		Perspectives of growth	possible investments
	Japan	Recession	capacity cuts/move to specialties
	ME	Low oil prices	investment cuts
	SEA	Rapid growth	opportunities for high profitability
		Overcapacity (Korea)	low profitability now
Industry		Slow Market Growth	price wars/move specialties
		Overcapacity	cost cutting strategies
		Buyers' power	rivalry and freer trade
		Environment, Safety, and Quality	ISO 9000, innovation and quality improvement
		Rising risks and costs of innovati	industry consortia, external technological reliance

Sources: Financial Times (various issues between July 93 and December 93) and author's analysis.

Note:
EC: European Community
NA: North America (Mexico, USA, and Canada)
SA: South America
MEA: Middle East
SEA: South East Asia including China

Three events are worth noticing in the international regime level of analysis. First, the fall of the Soviet Union and the current political and economic turmoil in the Commonwealth of Independent States have increased the number of players in the commodities sector. Rivalry has increased as Europe has given free trade access for firms that have distorted cost structures and need for hard currencies. Second, world recession has diminished margins, increased opportunities for substitution, fostered capacity cuts and mergers, and pushed organizations to look for more profitable segments (like specialties). Third, the possibility of the successful completion of the Uruguay Round of the GATT can increase rivalry even further[12]. On the other hand, a multilateral agreement that decreases world trade barriers generates long-term growth and investment opportunities.

A brief regional analysis shows that important changes are also occurring in different parts of the globe. All of those changes drive for a major reorganization of the chemicals/materials industry. In commodities, the next years seem to indicate low profitability, price wars, capacity cuts, mergers and acquisitions, and internationalization of manufacturing towards regions with low factor costs[13]. Low profitability also drives firms to move to specialty segments, where rivalry is less intense and price premium strategies can be followed.

In addition to the above events, industry characteristics alone impose considerable challenges to managers. Overcapacity and slow market growth foster low price competition in high fixed costs segments. Rivalry is also increased by the strong bargaining position of chemicals/materials buyers. The automobile and construction industries are the most important buyers of the industry. Those industries have been particularly hit by the world recession and have a strong lobbying position considering the high levels of unemployment experienced in the world at the moment. Finally, the industry will also have to cope with environmental, safety, and quality issues.

---

[12] This increase of rivalry, however, can be neutralized by the more extensive use of anti-dumping legislation by the European and North American industries.

[13] Energy, raw materials, labor, and less volatile exchange rates.

Although the industry faces significant challenges in the years ahead, opportunities do exist. Management of technological innovations is an important managerial dimension in the industry's process of reorganization. A good technology strategy can help firms to reduce costs through process innovations and to move into more attractive markets through new product development. To develop sound technology strategies, however, one has to understand how industry dynamics can influence the innovation patterns in the chemicals/materials industry. The next section explores this issue.

2.4) Innovation in the Chemicals/Materials Industry

Innovations can be divided into product and process innovations. Product innovation is the set of activities that start with basic knowledge and end with either a new commercial product or an improved version of an existing product (Stobaugh, 1988). The firm that first produces a commercial product is called product innovator. Initially, the innovator is the sole manufacturer of the product and acquires monopoly profits from its innovation.

The profitable monopoly attracts the attention of other firms that then try to enter in the new economic sector. These firms can enter in the new business through process innovations, i.e., producing the same product via a different process, through imitation or, when possible, technology purchasing. As these new economic agents manage their insertion into the business, the monopoly is changed to an oligopoly, and, subsequently, to a competitive industry. At this stage, the profits are not so high and may attract new investments only to fulfill the needs of demand. Not only entrepreneurs, seeking monopoly profits, innovate. Innovation can also be a response to a specific problem, constraint or threat, such as excessive costs (royalties or raw materials) or difficulties in process operation, or a new, more stringent, regulation.

Innovation may have an important role in chemicals/materials firms survival and growth. In the commodities segment, strong rivalry pushes firms for cost reduction. In addition, stricter environmental or health standards demand product and process redesign. In specialties, new processes and products are a requirement for entry. Furthermore, product development, marketing, and service capabilities are prerequisites for long term profitability.

In the chemicals/materials industry, an innovation seldom derives principally from the unique knowledge of basic research. Rather, it results mostly from the large number of interrelated activities required to produce a product for a selected market. Stobaugh (1988) pointed out that the needs of commercial firms for fundamental knowledge are so diverse and unpredictable that it is not economical for them to produce this knowledge themselves. Thus, commercial monopoly in the industry is typically not built upon control over basic research. Monopolies of product innovators are based on their ability to build upon basic knowledge and to develop markets and production processes by which the products could be made at satisfactory costs[14].

Commodity producers seldom compete in the same market with different product concepts. Chemical/material products are usually well defined molecules or substances, with specific performance characteristics. As a result, commodities allow little product experimentation. Competitors or new entrants do not have other choices than to explore different process concepts. Once the product innovator has established a market, other firms may enter in the business, in a relative short time, by developing a new process to make the product[15]. These firms are called process innovators.

The rewards of a process innovator and the effects of its innovation in the industry are dependent on the extent that the new process is better than the older and on the degree of competition in the industry. If the process innovation is truly radical, old plants are closed and dismantled. The specialized nature of the chemicals/materials plants[16] makes the conversion of old plants into the new process uneconomical[17].

---

14 Since product innovation is a result of both engineering problem solving and market concept specification and building, large markets and industrialized countries have advantages over small and less developed countries.

15 Although product innovations may take a considerable amount of time, process innovators usually follow product innovators by a short period. Stobaugh (1988) estimated that period in 6 years for petrochemicals.

16 This is an important characteristic of the commodities segment. The process is designed to be rigid, since it is initially developed to continuous production of large volumes and to meet specific criteria. The use of new raw materials, other reaction and

New processes, however, do not always cause existing plants to shut down. Sometimes, the capital intensive nature of the chemicals/materials industry make the marginal costs of operating existing plants lower than the average costs involved in building and operating a new plant. Moreover, even a less efficient new plant can be built to operate in an oligopolistic market. The coexistence of old and new processes is then feasible[18].

Process innovations can be divided into major and minor. Major innovations are fundamentally different from existing processes, involving different raw materials and/or radically different reaction conditions. Major innovations are more important to competitive advantage because they are more likely to make existing process obsolete than minor innovations. The importance of minor innovations, including improvements due to the learning process, should not be underestimated though[19]. Actually, they play an important role in a mature industry, changing the competition and trade pattern (Stobaugh, 1988).

2.5) Summary

Changes in the international regime, in regional institutions and policies, and at the industry level are not conducive to high profitability in the chemicals/materials industry in the near future. Furthermore, the structural characteristics of the industry seem to complicate the situation and impose further burdens on firms worldwide.

---

separation mechanisms usually require completely different vessels, flow patterns and control strategies.

17 In 1960, for example, Standard Oil introduced a new process to manufacture acrylonitrile and subsequently cut the price from US$ 0.26/lb to US$ 0.18/lb, thereby causing widespread shut downs of existing acrylonitrile plants (Stobaugh, 1988).

18 An example of such pattern involves the polyolefins segment, where high pressure processes continue to coexist with low pressure, catalytic processes.

19 Hollander (1965) has shown the importance of minor process innovations in productivity growth in the Rayon industry. For more information, please refer to Hollander, S., "The Sources of Increased Efficiency: A Study of Du Pont Rayon Plants", The MIT Press, Cambridge, Massachusetts, 1965.

Although region/country advantages may shift dramatically over the next years, managers should work to compensate opposing changes at the regional/national level by creating organizational-level capabilities. These organizational capabilities require the implementation of new management systems at the firm level.

As pointed out above, the structural characteristics of the chemicals/materials industry shapes its innovation patterns. If the firm creates major or minor innovations to create competitive advantage is not the main focus of this thesis, however. The idea is that innovations can be extremely important to support a firm's strategic intent of either reducing costs or moving to new, less price sensitive markets or both.

Innovations do not appear from nowhere, however. A carefully designed and managed process of innovation is much more likely to support the strategic objectives of an organization. Indeed, we believe that such process is a critical step in the larger endeavor of building organizational-level capabilities, which can further counteract negative movements at a regional or national level.

Chapter Three: Innovation Process, Survey and Hypotheses

3.1) Introduction

Chapter 2 highlighted the chemicals/materials industry characteristics and pointed to the relevance of innovation to firms' survivability and growth. This chapter explores the elements of the innovation process more extensively. First, a discussion of the innovation process at the firm level is presented. The idea is to develop a framework that could be used at assessing innovation from a process perspective.

Second, the chapter presents the research methodology that was developed to explore the innovation process in the chemicals/materials industry in four different regions of the world.

Finally, an elaboration of research hypotheses is conducted. The objective is to make explicit the relationships between specific management of technology practices and the innovation process. In the next chapter, these research hypotheses are tested against the empirical data collected in the Japanese, North American, Brazilian, and European chemicals/materials industries.

3.2) The Innovation Process

Adler at al. (1992)[20] proposed a general framework for analyzing the process of innovation in organizations. According to these authors' research, three elements emerge repeatedly as indicators of sustained technical

---

[20] Adler, P. S., McDonald, D. W., and MacDonald, F., "Strategic Management of Technical Functions", *Sloan Management Review*, Winter 1992, pp. 19-37.

accomplishment and business success: posture and direction; systems[21]; and adjustment processes.

Figure 3.2.1 illustrates the proposed framework. Rather than a definitive standard, the framework is an instrument used in this thesis to assess the process of technology management in the chemicals/materials industry[22]. The framework conceives three related elements: posture and direction; systems; and adjustment processes.

Posture and Direction

Posture and direction of the R&D function comprise the formulation of a technological mission and strategy, the communication and acceptance of this mission and strategy to and by the whole organization, and the compatibility between technology strategy and overall corporate-level strategy. Underlying the acceptance of the technology strategy by the whole organization is the issue of how the culture of the organization perceives and shapes the technology strategy process.

Systems

Systems involve all the structures that are required to support the innovation process. They can be grouped into three other categories: structures; roles; and linkages.

Structures are the result of the formal organization of assets, resources, and responsibilities. As examples, structures involve: the organization of technology resources at the corporate and business unit levels; the allocation of funds across technical functions (research, development, and engineering); the use of multi-functional teams; the configurations used to

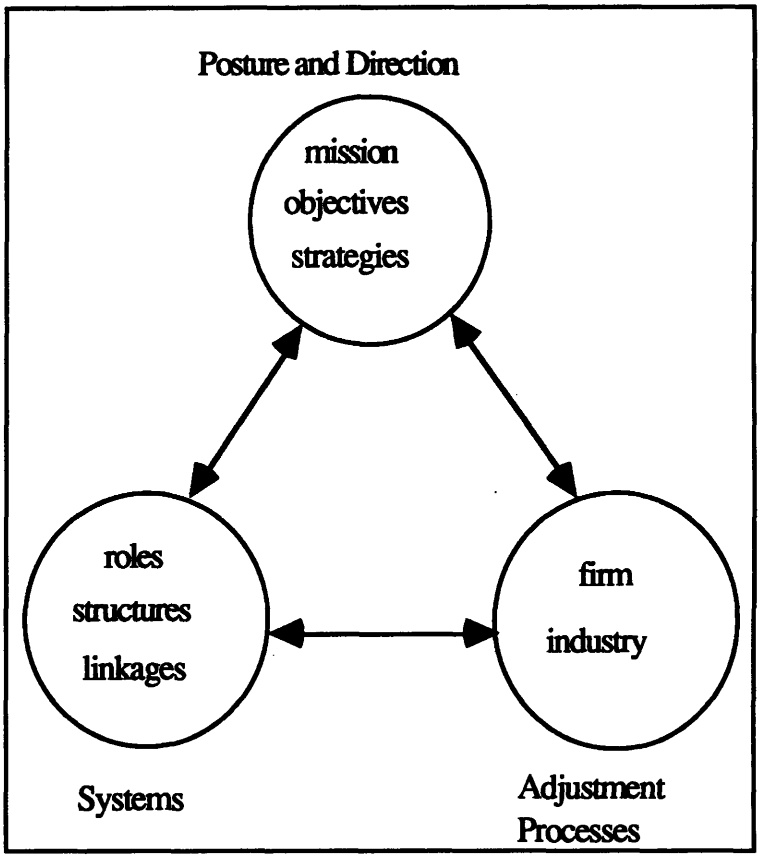
---

21 The authors call this second element policies. We preferred to call it systems to avoid any confusion that may arise with the policy options developed in this thesis, which apply to all the three elements of strategic management of technology.

22 Managers are encouraged to tailor this framework according to their firm and industry characteristics.

move products from concept to implementation; the decision-making forums; and R&D facilities and equipment.

Figure 3.2.1: Strategic management of technology framework



Those structures are formal mechanisms that help to shape the pattern of communication in the R&D process. Management, however, can exert a more extensive and direct control over the volume, content, and direction of information flows depending on its roles in adapting the various administrative systems, hierarchical channels and informal relationships. For example, important roles in the R&D process are: the degree of involvement of the CEO; the participation of the CTO in corporate strategy formulation; the participation of the marketing executive in the technology strategy process; and so on.

The R&D organization cannot stand alone. It has to be embedded in a larger context, either internally, as a function of a specific organization, or externally, as recipient and supplier of technical information and innovations. In this context, linkages involve both the external and internal bonds of the R&D function. Internally, it includes interfunctional linkages with other functions, like manufacturing, marketing, finance, etc. Externally, it entails linkages with customers, universities, consortia, experts, etc.

Adjustment Processes

Adjustment processes are aimed both at identifying threats and opportunities in the industrial environment and strengths and weaknesses at the firm level. It involves technology monitoring and assessing; analysis of competition; and answers to global technological issues, like internationalization of R&D and external sources of technology.

These three elements -- posture and direction, systems, and adjustment processes -- form a triad that supports the innovation process in organizations by complementing each other. The assessment of strategic management of technology practices in the chemicals/materials industry is conducted by having this framework as a basis of analysis.

3.3) Survey Methodology

Strategic management of technology practices in the chemicals/materials industry were assessed through the distribution of a questionnaire. The survey was conducted in leading European, Japanese, Brazilian, and North American companies.

The questionnaire was developed in a joint effort between the MIT Management of Technology and Innovation Group and Pugh-Roberts Associates. In the end of 1992, this questionnaire was sent to leading companies in Europe, Japan, and the US that have investments in research and development of more than $100 million per year. In that survey, 20 answers were returned -- 5 from Japan, 7 from Europe, and 8 from the US[23].

The purpose of this thesis is to use the data collected in the end of 1992 and extend the study of management of technology practices in the chemicals/materials industry to Brazilian companies. To do that, some minor modifications were implemented in the questionnaire to suit the characteristics of the Brazilian industry. In addition, a new section was designed to assess Brazilian firms' perceptions of the role of governments in commercial technology development.

The questionnaire is divided into three major parts. Part I aims at establishing benchmarks in management of technology practices. It has seven subparts that were designed to assess the three elements of strategic management of technology at the firm level: posture and direction; structures; and adjustment processes.. Part II aims at assessing the firm's experience of managing technology within the current economic climate. Finally, the objective of Part III is to assess the firm's perception of the role of government in fostering commercial technology development[24]. A sample of the questionnaire is presented in appendix I at the end of this thesis.

The modified version of the questionnaire was then sent to 56 companies in Latin America -- 30 in Brazil, 11 in Mexico, 5 in Colombia, 5 in Venezuela, and 5 in Argentina. Due to the smaller relative size of these economies, the sample was drawn from companies that invest approximately $10 million or more in research and development per year. From the initial 56 questionnaires, 10 answers were received, which amounts to 18% of the initial target population. From these ten answers, nine came from Brazil and one from Mexico.

---

23 An analysis of these answers was presented in Nelson Martinez's Thesis in June 1993, which focused in the relationships between the corporate strategy process and management of technology at the firm level. See Martinez, N., "Management of Technology and Corporate Strategy in the Chemical Industry", Unpublished Master Thesis, Sloan School of Management, Massachusetts Institute of Technology, June, 1993. .

24 The idea is not to provide elements for the evaluation of the impact of specific government policies in the R&D process, but to gather information about the perception of Brazilian firms about the role of government in fostering commercial technology development. Due to the limited amount of data collected on this section, however, only a limited analysis is conducted on chapter 7.

Considering the large predominance of Brazilian firms in the Latin American sample, the scope of the thesis was redesigned. Instead of looking for policy opportunities in the Latin American chemicals/materials industry, the focus of the thesis was changed towards the Brazilian industry. We believe, however, that most of the results presented herein may be applicable to the Latin American chemical/materials industry at large.

The final sample comprises 9 companies from Brazil, 5 from Japan, 7 from Europe, and 8 from the US. The nine Brazilian respondents represent approximately 30% of those sampled.

In the next section, the structure of the questionnaire is used as framework to the development of specific hypotheses that relate management of technology practices and R&D performance. In chapter 4, these hypotheses are tested against the empirical data obtained through the survey.

3.4) Hypotheses

Hypotheses were developed to test the impact of specific management of technology practices (or policies) in the innovation process. The formulation of hypotheses tries to involve the three elements of the strategic management of technology framework developed above – posture and direction; structures; and adjustment processes.

Posture and Direction

Posture and direction of strategic management of technology at the firm level is explored in subsection A of the questionnaire. Specifically, subsection A is aimed at understanding the nature of the firm's technology strategy, how it is communicated and understood in the organization as a whole and how it is linked with overall corporate-level strategy and with business unit strategy. It also assesses the frequency in which corporate technology strategy is developed, reviewed, and adjusted. Finally, it explores the firm's perceptions of the importance of diverse issues to technology strategy (total quality methods in R&D, of meeting market needs, of decrease time to commercialization, and of managing R&D with constrained resources).

One would expect that a well formulated, broadly communicated and accepted technology strategy would increase R&D performance[25]. A shared vision of posture and direction would facilitate agreement and work among different parts of the organization, increasing overall R&D performance. In this context, the answers to question A.1 give information to evaluate the following hypothesis[26]:

> **H.A.1**: There is a positive, non-random correlation between a well developed, communicated, and accepted technology strategy and R&D performance.

One would also expect that a strong link between technology strategy and corporate-level strategy would increase R&D performance, since technology strategy would fit better with the overall purposes of the organization. In this context, we can formulate another hypothesis[27]:

> **H.A.2**: There is a positive, non-random correlation between a strongly linked technology strategy to corporate strategy and R&D performance.

H.A.1 and H.A.2 are the two main hypotheses that are assessed regarding posture and direction of technology strategy in the chemicals/materials industry. In a broader sense, they can be viewed as an approximation of the interactions between the culture of the organization and its interactions with the innovation process.

---

[25] A more complete discussion of the meaning of R&D performance is conducted in chapter 4. For now it is sufficient to think of R&D performance as a measure of efficiency and effectiveness of the R&D organization in meeting its strategic objectives.

[26] The degree of development, communication, and acceptance of technology strategy is calculated by averaging the answers to question A.1 for each respondent.

[27] The degree of linkage of technology strategy to overall corporate-level technology strategy is provided by question A.4 in part I.

Systems: Roles, Structures and Linkages

As it was pointed out earlier, structures, roles, and linkages are important elements of the systems that support the innovation process. Roles, structures, and linkages supporting strategic management of technology are assessed in subsections B, D, and G of the questionnaire.

Subsection B assesses the structures and roles that support the development and use of technology in the organization. It explores the degree of control of technology resources over time; the organization of technology resources at the corporate and business unit levels; the allocation of funds among research, development, product and process technical support; funding mechanisms of corporate-level R&D function; the roles of the Chief Technology Officer (or equivalent) and the Chief Executive Officer in the innovation process; and the use of multi-functional teams in the innovation processes. Four hypotheses are developed from subsection B.

First, one would expect causality between the use of multi-functional teams and R&D performance. Indeed, many scholars have pointed that multi-functional teams can be an important organizational approach to address the question of linking R&D results to commercial exploitation. A multi-functional team creates a mini-business organization, where members drawn from other functions of the total business work together to develop and implement a new product or process. Roberts (1979)[28] indicates that,

> The team should be multi-functional in composition, drawing volunteers from R&D, manufacturing, marketing and even finance. When non-R&D contributors are brought together with technically innovative people they end up designing, developing and implementing a very different kind of product and product line. It's not the same product that would have been created had the technical group worked initially by itself and later transferred responsibility to another function of commercial exploitation. *It's a product that instead has already taken marketing issues into account, has already considered production costs, and has already rationalized the investment requirements.*[29]

---

[28] Roberts, E. B., "Stimulating Technological Innovation - Organizational Approaches", *Research Management*, November, 1979.
[29] Emphasis added.

In this context, a hypothesis can be formulated stating that:

H.B.1: There is a positive, non-random correlation between the use of multi-functional teams and R&D performance.

Second, we would expect correlation between the role of the Chief Technology Officer (CTO) and R&D performance, as she/he is a major instrument in shaping the flow information, linking technology strategy with overall corporate-level strategy, and molding the strategic management of technology process. In this context, the CTO can have a downward influence in the organization if either he/she sits in the board of directors (link) or if he/she is active in formulating and coordinating the whole technology process. Two hypotheses follow,

H.B.2: There is a positive, non-random correlation between the participation of the CTO in the board of directors (or the main management board) and R&D performance.

H.B.3: There is a positive, non-random correlation between the role of the CTO[30] and R&D performance.

Finally, the participation of the CEO in the strategic management of technology may also be correlated with R&D performance because of her/his role in both developing and linking technology strategy with overall corporate-level strategy and in shaping the whole innovation process. In this context, the fourth hypothesis is formulated:

---

[30] The role of the CTO is calculated by averaging the answers to question B.6 for each respondent. More specifically, the following activities are considering in estimating the role of the CTO: participation in overall corporate strategy development; formulation of corporate technology strategy development; review of corporate technology strategy; control of resource allocation between corporate and business unit R&D; control of R&D resource allocation across business units; formulation of business unit technology strategy development; review business unit technology strategy development; participation in business unit technology strategy development; management of the corporate R&D organization; monitoring external technology; determination of company's investment in outside technologies, and assessment of technical strengths of external partners; and liaison to outside organizations.

H.B.4: There is a positive, non-random correlation between the role of the CEO[31] and R&D performance.

Subsection D deals with how firms utilize input from external customers and the market place in the R&D process. It explores how direct customer input is used in technology strategy development, setting program objectives, obtaining innovative ideas, concept development, prototype development, testing, product refinement and commercialization, and product improvement. In addition, it tries to assess the structure of the process of obtaining customer input, as well as the role and performance of the organizational entities that participate in the process (R&D, marketing, sales, etc.).

Customer input is important not only as a source of competitive advantage in determining customer's needs and fulfilling them in time with high quality products at the least possible cost. Customer input can have a major impact in the innovation process as a source of new ideas and product concepts.

Von Hippel (1988)[32] has documented that manufacturers are not the sole sources of innovation. Users develop most innovations in some fields. In others, suppliers of innovation-related components and materials are the typical sources of innovation. Users innovate when they face needs to do so in their marketplace and are positioned to benefit significantly (through economic rents, for example) by obtaining a solution to those needs. The implications of this fact for technology management are far reaching. As von Hippel (1988) puts it:

> Firms organize and staff their innovation-related activities based on their assumptions regarding the sources of innovation. Currently, I find that most firms organize around the conventional assumption that new products are - or should be - developed by the firm that will manufacture them for commercial sale. This leads manufacturers to form R&D departments capable of fulfilling the entire job of new product development *in-house* and to organize market research departments *designed to search for needs instead of innovations*.

---

31 The role of the CEO is calculated by averaging the answers to question B.8 for each respondent. More specifically, the activities considered are: technology strategy development; project selection/prioritization; establishment of overall R&D budget; internal technology resource allocation; and selection of outside technology investments.
32 Von Hippel, E., "The Sources of Innovation", Oxford University Press, 1988.

> Indeed, if a manufacturer depends on in-house development of innovations for its new products, then such arrangements can serve well. But if users, suppliers, or others are the typical sources of innovation prototypes that a firm may wish to analyze and possibly develop, then these arrangements can be dysfunctional. (*For example, one cannot expect a firm's R&D group to be interested in user prototypes if its engineers have been trained and motivated to undertake the entire product development themselves*)[33].

Not all users can contribute with innovative ideas to the firm though. Only a small segment of users can do so. Those users are named by von Hippel as lead users. Lead users are industry participants that experience market and industry conditions that will be common place to other industry members in 3 to 5 years. In addition, they have some means to appropriate their innovation efforts.

Following von Hippel's research, one could expect that firms with high degree of use of lead user input in their innovation process might have better R&D performance. In this context, another hypothesis can be formulated:

> **H.D.1:** There is a positive, non-random correlation between the use of customer input in the innovation process[34] and R&D performance.

Other structures, roles and linkages can be of importance to the innovation process, mainly in moving ideas to market. The last section of Part I is aimed at understanding the practices used in moving a product or process from concept to implementation. It evaluates the effectiveness of different approaches in moving concepts to markets, e.g., early formation of multi-functional teams, specially designated idea generators, senior management sponsors, computer-aided design/engineering, transfer of key individuals with a project as it moves from development into manufacturing, and so on. The section also assesses the companies' perception of the degree of success in which they

---

33 Emphasis added.

34 Customer input is calculated by averaging answers to question D.1 for each respondent. Customer input can occur in each of the following activities: technology strategy development; setting program objectives; obtaining innovative ideas; concept development; prototype development; testing; product refinement and commercialization; and product improvement.

meet or exceed target dates for product commercialization and process implementation.

Subsection G also provides important information regarding the relevance of certain mechanisms in improving the process of moving concepts to market. A considerable number of hypotheses can be developed. To facilitate the analysis, firms were asked to identify three approaches that they have found most effective in shortening the time it takes to move a product to market. We then selected a number of practices and tested the general hypothesis:

> **HGJ**: Approach J is non-randomly correlated with a better record in meeting target date for product commercialization and process implementation.

Those hypotheses are presented and tested against the empirical evidence in chapter 4.

Adjustment Processes

Adjustment processes comprise the analysis of industry's threats and opportunities and firm's strengths and weaknesses. Subsection E (monitoring and assessing), part II (adjustment processes in the current economic climate), and subsection C (responding to global technological issues) provide a considerable amount of data to test the effects of certain adjustment policies in R&D performance.

Subsection E explores how firms monitor technology and acquire the requisite technologies and skills to ensure success in the markets in which they compete. More specifically, the questionnaire is aimed at assessing: (i) the degree of a firm's reliance upon different mechanisms of technology monitoring; (ii) the reliance on internal or external sources of technology over time; (iii) the reasons that support acquisition of technologies; (iv) the use of university programs for monitoring and acquisition activities; and (v) perceived changes in the necessary skills of technical employees.

As it was pointed out in chapter 2, commodity producers in the chemicals/materials industry are facing meager returns in their operations. These low returns have fostered the interest in the higher returns experienced in the specialty segment.

The capability of monitoring external technological opportunities to either enter growing specialty markets or to defend itself from competition in other segments is extremely valuable to the firm. One would expect firms that use monitoring mechanisms to have more chances of success in their R&D efforts. It is important to notice, however, that technology monitoring has to be coupled with the firm's corporate strategy and strategic intent to be effective. One can then formulate the following hypothesis:

> **H.E.1**: Monitoring activities[35] is non-randomly and positively correlated with R&D performance

If one takes this rationale one step further, it could be argued that there is a difference between monitoring activities conducted by internal technology steering groups and monitoring activities that incorporate external sources of information (science/technology advisory boards, university/industry consortia, customer panels, etc.).

Research done in the field of organizational psychology has proven that professionals work to minimize uncertainty in the surrounding environment. Those professionals develop unconscious underlying assumptions that are very difficult to be surfaced and challenged. In this context, one would expect internal technology steering groups to make decisions based on assumptions that diminish uncertainty. This can have disastrous effects for the

---

[35] Monitoring is calculated by averaging the answers to question E.1 for each respondent. Monitoring may be conducted by the following mechanisms: science/technology advisory boards; university research consortia; industry-based consortia; internal technology steering groups; customer panels or input; university liaison/affiliate programs; venture capital funds; and industry suppliers.

organization since important threats can be overlooked. As put it by Katz (1980, 1982)[36],

> In fact, one of the most important assumptions underlying human behavior within organizations is that people are strongly motivated to reduce uncertainty. As part of this process, individuals, groups, and even organizations strive to structure their work environments to reduce the amount of stress they must face by directing their activities and interactions toward a more predictable level of certainty and clarity. Over time, then, engineers and scientists are not only functioning to reduce technical uncertainty, they are also functioning to reduce their "personal and situational" uncertainty within the organization. In the process of gaining increasing control over their task activities and work demands, three broad areas of biases and behavioral responses begin to emerge (problem-solving processes, communication and information processing, and cognitive processes). And the more these trends are allowed to take place and become reinforced, the more difficult it will be for the organization to consider seriously the potential, long-term advantages of the many new and different technologies that are slowly being developed and worked on by the larger outside R&D community.

The addition of external sources of information may help to surface unrealistic assumptions and foster a more critical evaluation of threats and opportunities that surround the firm. In this context, the following hypothesis can be developed.

> **H.E.2**: Firms that use external sources in their monitoring process have higher R&D performance than firms that either use only internal steering groups or do not use any mechanism at all.

Not only monitoring activities can serve as a driver for adjustments in the R&D organization. The R&D organization can change by responding to modifications in the external environment that go beyond the development of new technologies. Those are changes that involve the economic or even political climate in the regions that a specific firm operates.

Part II of the questionnaire was designed to assess the firm's overall experiences with the current economic climate. This part has two sections. First, there is an attempt to evaluate how constrained are the resources

---

36 Katz, R., "Time and Work: Toward and Integrative Perspective", *Res. Org. Behav.*, 2, 1980, 81-127, and Katz, R., "The Effects of Group Longevity on Project Communication and Performance", *Admin. Sci. Q.*, 27, 1982, 81-104.

normally applied to the innovation process. This is done by asking firms about: (i) their actual and expected changes in total R&D expenditures, R&D capital investments, and size of the R&D staff from 1987 to 1994; (ii) the breakdown of R&D expenditures (product/process maintenance, short-term development projects, longer-term development projects, and research activity) for 1989, 1991 and 1994; and (iii) the involvement of different decision makers in setting business unit R&D budgets today compared to 2 years ago.

The second section assesses the management practices that have been putting in place to adjust the firm for an era of fewer resources. Four levels are addressed by the questionnaire: strategic elements; programs; productivity; and funding. The data collected in this part of the survey is used to establish the effects of those management policies in R&D performance. Importantly, these results should be interpreted with care, since there is a possibility that most of these practices were implemented recently and have not yet affected the perception of R&D performance. In this context, some hypotheses were developed involving measurements that may have a faster effect on R&D performance. Those measures are: (i) stronger accountability; (ii) stronger identification of R&D contribution to profits; (iii) increased automation and other non-human resources in R&D; (iv) streamline the R&D organization; (v) increased attempts to explore existing technologies; (vi) focus on core technologies, whether for new markets or new products; (vii) increased external acquisition of technology; and (viii) more stringent requirements for program start-up and continuation. These hypotheses are summarized below[37]:

H.PII.1: There is a non-random correlation between focusing on core technologies and R&D performance.

H.PII.2: There is a non-random correlation between increasing external acquisition of technologies instead of internal development and R&D performance.

[37] All practices are measured by each respondent's answers to question B.1 in part II.

H.PII.3: There is a non-random correlation between stronger accountability and R&D performance.

H.PII.4: There is a non-random correlation between increasing automation and R&D performance.

H.PII.5: There is a non-random correlation between streamlining the R&D organization and R&D performance.

H.PII.6: There is a non-random correlation between adopting stricter criteria for new program start-up and R&D performance.

H.PII.7: There is a non-random correlation between adopting more stringent requirements for program continuation and R&D performance.

H.PII.8: There is a non-random correlation between adopting tighter measurements and R&D performance.

H.PII.9: There is a non-random correlation between searching additional sources of external funding and R&D performance.

Finally, subsection C of part I explores the internationalization of the R&D process. The idea is to gather information on: the countries in which non-domestic technological activities are conducted; the types of technological activities that are conducted (licensing, joint technology development, acquisition of companies, own laboratory research); the changes in the percentage of activities that are based in foreign locations over time; the roles and activities of non-domestic R&D centers; the methods used to transfer technology to other countries; the degree and type of technology monitoring activities in other countries; and the reasons for deciding to utilize some forms of non-domestic R&D.

One hypothesis is developed from subsection C. One would expect that global markets would require global capabilities from chemicals/materials firms. Regarding the innovation process, a global presence of R&D activities may foster the ability of companies to learn from different markets, since ideas are equally likely to originate in Japan, Europe or the US. This may leverage firm competitiveness if the firm is capable of employing this knowledge in other markets. In this context,

H.C.1: There is a positive, non-random correlation between the level of non-domestic activity[38] and R&D performance.

3.5) Evaluating R&D Performance

R&D performance is the key measurement used in the evaluation of the hypotheses developed above. The evaluation of R&D performance, however, is a subjective undertaking which involves the personal beliefs and perceptions of the evaluator. To gauge these beliefs and perceptions of R&D performance, subsection F of the questionnaire asked each firm to evaluate its R&D organization relative to their most important competitor[39].

Several measures are used to construct an index of R&D performance. This index is used throughout the statistical analysis to test the significance of the hypotheses developed herein. Overall performance is assessed in terms of: (i) effective use of R&D resources; (ii) efficient use of R&D resources; (iii) percentage of company's revenues derived from products/processes/services not existing 5 years ago; and (iv) success in reducing company's cost of production over the past 5 years. An index of R&D performance is then calculated for each respondent by averaging its ratings in these four dimensions[40].

Subsection F may provide a basis for the development of another hypothesis. One would expect that a well-balanced technology portfolio might contribute to R&D performance. One could argue that short-term focus provides quick-

---

[38] The level of non-domestic activity is calculated by averaging the answers to question C.2 for each respondent.
[39] Although this procedure does not eliminate entirely the problem of subjectiveness, we consider that it is a reasonable way to account for R&D performance considering the limitations involved in this type of research.
[40] Timeliness is a fifth dimension of R&D performance mentioned in the questionnaire. It is used separately to test hypotheses HGjs.

responses to unexpected opportunities, but medium and long term projects are needed to ensure presence in new promising markets. In the same manner, unfamiliar focus contributes to learning and prepare the organization for new challenges. Product orientation is a requirement for customer needs satisfaction and a leverage for price premium strategies, whereas process research is tantamount for cost reduction and safety and quality improvement.

R&D performance, however, depends on the overall corporate-level strategy. If a specific company's strategy is to focus on niche high value added markets, we would expect them to focus more in product innovations rather then process cost reduction. This unbalanced research portfolio does not mean that the company will have a low R&D performance, quite the contrary. Moreover, more process focus should lead to cost reduction, which may be the right thing to do in a specific industrial segment. As a result, it is not possible to assume that a more balanced technology portfolio will generate better indexes of R&D performance, since this is highly dependent on the strategic objectives of the companies.

3.6) Summary

This chapter described the survey methodology and developed research hypotheses based on the framework of the innovation process described by Adler et al. (1992)[41]. Those hypotheses are aimed at identifying important management practices to the innovation process. Table 3.6.1 presents the hypotheses developed according to Adler's framework.

Chapter 4 will test the validity of these hypotheses against empirical data using multiple regression analysis.

---

[41] Op. cit.

Table 3.6.1: Formulated hypotheses related to R&D performance

Policy Level	Hypotheses	Correlation with R&D Performance
Posture and Direction	**H.A.1**	formulation, communication, and acceptance of technology strategy
	H.A.2	linkage between technology strategy and corporate strategy
Systems	**H.B.1**	use of multi-functional teams in the R&D process
	H.B.2	participation of CTO in the board of directors
	H.B.3	the role of the CTO in the R&D process
	H.B.4	the involvement of the CEO in the R&D process
	H.D.1	use of customer input in the R&D process
Adjustment Processes	**H.C.1**	level of non-domestic R&D activities
	H.E.1	use of monitoring activities in the R&D process
	H.E.2	use of external sources for monitoring in the R&D process
	H.PII.1	focus on core technologies
	H.PII.2	increased external acquisition of technologies instead of int. investment
	H.PII.3	stronger accountability
	H.PII.4	increased use of automation
	H.PII.5	streamlined R&D organization
	H.PII.6	stricter criteria for new program start-up
	H.PII.7	more stringent requirements for program continuation
	H.PII.8	tighter measurements
	H.PII.9	search for additional sources of external funding

Chapter Four: Statistical Analysis

4.1) Introduction

The objective of this chapter is to determine if there are statistically significant management of technology practices that either increase R&D performance or increase the capability of an organization to diminish time from concept to implementation. In doing so, it uses the research hypotheses developed in chapter 3.

Statistical analyses were also conducted to explore the management of technology practices in the chemicals/materials industry and their relations with the needs of the stakeholders of the innovation process. The idea here is to develop a "map", which could serve as an orientation for managers in the use of a specific policy to increase satisfaction of a certain stakeholder need.

The next sections present the research results, starting with the needs of the innovation process' stakeholders.

4.2) Stakeholders of the Innovation Process

Three stakeholders of the innovation process were identified: (i) end-use customers; (ii) corporate strategy; and (iii) manufacturing. The objective is to identify possible correlations between management of technology practices and the satisfaction of these stakeholders' needs. Most importantly, we are trying to find causality in these correlations, so it will be possible to better meet stakeholder's needs through specific policy changes.

All policy options, i.e. management practices, developed in chapter 3 were considered. The analysis was conducted through the calculation of multiple linear regressions between the different policy options and the perception of each firm of the satisfaction of stakeholders' needs relative to competitors[42]. Appendix II illustrates the multiple linear regression techniques.

Table 4.2.1 shows that there are specific policy options that can improve satisfaction of end-use customers[43]. According to the analysis, those options are: a well structured, communicated, and accepted technology strategy (p=0.027); use of multi-functional teams (p=0.07); use of customer input in the R&D process (p=0.065); stricter criteria for program start-up (p=0.06); and slow the pace of some programs (p=0.006)[44]. In this context, an organization that finds itself with a low degree of satisfaction of end-use customers should consider an increase in the use of multi-functional teams and customer input in the innovation process. In addition, work in the R&D organization's posture and direction should also be conducted, mainly by improving acceptance of technology strategy and linkage with overall corporate-level strategy.

High fulfillment of corporate strategy needs may be caused by: the utilization of multi-functional teams (p=0.042); a well developed, communicated and accepted technology strategy (p=0.065); by active and participant CTOs (p=0.10 and p=0,035) and CEOs (p=0.033); by a strong link between technology strategy and corporate-level strategy (p=0.04); and by the use of permanent project managers (p=0.065) and the transfer of professionals (p=0.075). Causality relationships can not be established if the current economic climate is framing corporate strategy to exploit the use of existing technologies (p=0.089), increase acquisition of external technologies (p=0.098), and streamline the R&D organization (0.061). Interestingly, the data show that there is a negative correlation between satisfying corporate strategy objectives for technology and less ambitious strategic objectives for technology (p=0.005). This may mean that firms with a higher degree of

42 Data for these tests are given by question F.2.a in part I.

43 P-value indicates the level of significance of each policy.

44 Note that a causality relationship can not be argued between end-use customers and slowing the pace of some programs. One can argue that either slower programs cause better fulfillment of end-use customers or that companies that satisfy end-use customers have been slowing the pace of some programs during the current economic climate. This rationale is also applicable to the use of stricter criteria for new program start-up.

Table 4.2.1: Impact of Policies on Stakeholders' satisfaction

Policy Options	End-User Customers (p-value)	Corporate Strategy (p-value)	Manufacturing (p-value)
Acceptance of Technology Strategy	**0.027**	**0.065**	**0.08**
Linkage Technology and Corporate Strategie	0.125	**0.04**	0.245
CTO sits on the management board	0.39	**0.035**	0.145
CTO's role	0.145	**0.1**	**0.075****
Multi-functional teams	**0.07**	**0.042**	**0.068**
CEO's role	0.5112	**0.033**	0.387
Customer input	**0.065**	0.7075	0.623
Highly structured customer input	0.915	0.348	0.269
Technology monitoring	0.827	0.458	0.232
Less ambitious objectives for technology	0.421	**0.005****	0.395
Focus on core technologies	0.331	0.898	**0.085**
Increase external acquisition of technologies	0.349	**0.098**	0.688
Exploit existing technologies	0.734	**0.089**	**0.085**
Stricter criteria for new program start-up	**0.06**	0.573	0.726
More stringent requirements prog. contin.	0.453	0.841	0.947
Slow the pace of some programs	**0.006**	0.385	0.574
Reduction in number of products/processes	0.3	0.202	0.979
Tighter measurements (RD $/employee..)	0.308	0.484	0.431
Stronger accountability	0.389	0.433	0.629
Stronger ident. R&D contribution to profits	0.274	0.393	0.271
Increased automation in R&D	0.885	0.324	0.281
Streamline R&D organization	0.817	**0.061**	0.219
Additional Funds	0.145	0.619	0.329
Idea Generators	0.87	0.375	0.324
Product champions	0.242	0.231	0.587
Senior sponsors	0.319	0.355	0.965
Permanent project managers	0.498	**0.065**	0.429
Stage gate	0.217	0.388	0.378
Simultaneous engineering	0.699	0.437	0.378
Total Quality Management	0.455	0.197	0.888
Flexible manufacturing systems	0.633	0.635	0.281
Rapid prototyping techniques	0.583	0.874	0.51
CADE/CAM	0.994	0.532	0.397
QFD	0.517	0.169	0.915
Early concept freezing	0.549	0.903	0.722
Early market test	0.708	0.442	**0.081**
Reduce number of parts	0.197	0.819	0.738
Transfer of professionals	0.652	**0.075**	0.928

** negative correlation

fulfillment of corporate strategy needs may not adopt less ambitious strategic objectives for technology.

Regarding the needs of manufacturing, a considerable number of policy options are available to increase their fulfillment: multi-functional teams (p=0.068); early market test (p=0.081); development, communication and acceptance of technology strategy (p=0.08); focus on core technologies (p=0.085); and exploit existing technologies (p=0.085). Notice that a technology portfolio that focuses entirely on unfamiliar technologies would limit the organization's capability to satisfy manufacturing needs. Importantly, the role of the CTO is negatively correlated with satisfaction of manufacturing needs (p=0.075). This indicates a reasonable gap between CTOs and manufacturing objectives and interests.

Table 4.2.2 summarizes the important policy options and their impact on stakeholder's needs. Now that the relationships between some policy options and stakeholders' have been established, it would be useful to investigate the importance of each policy option to R&D performance.

4.3) R&D Performance

This section use multiple linear regression techniques to evaluate the validity of the hypotheses developed in chapter 3. Before doing so, however, it is important to evaluate the degree of correlation among the various hypotheses. This is a critical step, since highly correlated hypotheses will limit the possibility of conducting a multiple linear regression test.

Table 4.3.1 presents the auto-correlation matrix of the hypotheses developed in chapter 3. Hypotheses **H.E.1** and **H.E.2** are highly correlated (0.98). A high correlation is also observed between hypotheses **H.PII.6** and **H.PII.7** (0.81).

The high degree of correlation between **H.E.1** and **H.E.2** shows that it is impossible to distinguish, for statistical purposes, between the sample's internal and external mechanisms of technology monitoring. This happens because firms that use external mechanisms also rely heavily in internal

Table 4.2.2: R&D stakeholders and policy options (order of highest significance)

End-Use Customers	Corporate Strategy	Manufacturing
Slow the pace of some programs	Less ambitious obj. for tech.**	Multi-functional teams*
Dev., Com., and Acc. of TS*	Role of the CEO in the R&D process*	Early Market Test*
Customer Input*	CTO sits management board*	Dev., Com., and Acc.. of TS*
Multi-functional teams*	Linkage of T.S. and C.S.*	Focus on core technologies*
Stricter criteria program stup	Multi-functional teams*	Exploit existing technologies*
	Dev., Com., and Acc. of TS*	
	Streamline the R&D organization	
	Permanent Project Manager*	
	Transfer of Professionals*	
	Increase ext. acquisition of tech.	
	Exploit existing technologies	
	Role of the CTO*	

* suggests causality
** negative correlation

Table 4.3.1: Correlation Matrix

	H.A.1	*H.A.2*	*H.B.1*	*H.B.2*	*H.B.3*	*H.B.4*	*H.D.1*	*H.E.1*	*H.E.2*	*H.PII.1*	*H.PII.2*	*H.PII.3*	*H.PII.4*	*H.PII.5*	*H.PII.6*	*H.PII.7*	*H.PII.8*	*H.PII.9*
H.A.1	1.00																	
H.A.2	**0.79**	1.00																
H.B.1	0.25	0.29	1.00															
H.B.2	0.12	0.25	0.25	1.00														
H.B.3	0.30	0.20	0.46	0.33	1.00													
H.B.4	0.19	0.27	0.62	0.11	0.25	1.00												
H.D.1	0.13	0.09	0.34	0.07	-0.10	0.42	1.00											
H.E.1	0.26	0.22	0.48	-0.08	0.31	0.45	0.41	1.00										
H.E.2	0.20	0.14	0.48	-0.07	0.30	0.42	0.39	**0.98**	1.00									
H.PII.1	-0.28	0.04	-0.23	0.09	-0.38	-0.01	0.31	-0.05	-0.05	1.00								
H.PII.2	-0.13	-0.03	-0.03	-0.07	-0.18	0.15	0.15	-0.22	-0.20	0.33	1.00							
H.PII.3	-0.02	0.17	0.28	0.24	0.13	0.39	0.24	0.13	0.12	0.09	0.41	1.00						
H.PII.4	0.05	0.23	0.31	0.24	0.00	0.47	0.47	0.44	0.41	0.28	0.29	0.47	1.00					
H.PII.5	0.15	0.28	0.03	-0.01	-0.17	0.15	0.23	0.16	0.06	0.03	0.15	0.20	0.56	1.00				
H.PII.6	-0.01	0.31	0.14	0.43	0.12	0.34	0.21	0.04	0.06	0.35	0.23	0.48	0.50	0.03	1.00			
H.PII.7	-0.17	0.05	0.05	0.30	-0.04	0.28	0.27	-0.02	0.00	0.34	0.29	0.48	0.55	0.15	**0.81**	1.00		
H.PII.8	-0.19	0.02	0.16	0.06	-0.05	0.35	0.52	-0.03	-0.01	0.39	0.58	0.42	0.27	-0.03	0.24	0.36	1.00	
H.PII.9	-0.08	0.14	-0.11	0.02	-0.14	-0.16	0.06	-0.04	-0.10	0.20	0.14	-0.12	0.03	0.29	-0.06	-0.02	0.20	1.00

mechanisms of monitoring. In this context, **H.E.2** is eliminated and test only hypothesis **H.E.1** is tested.

Table 4.3.1 also tells that most companies that have adopted more stringent criteria for new program start-up (**H.PII.6**) also adopted more stringent requirements for program continuation (**H.PII.7**). Hypothesis **H.PII.7** is eliminated and the test includes only **H.PII.6.**

Table 4.3.2 summarizes the hypotheses that were tested against the empirical data collected through the survey. Multiple linear regression analysis was used to determine the statistical significance between a specific hypothesis and R&D performance[45]. The statistical test involves a two-tail hypothesis test when no direction of causality is expected and a one-tail hypothesis test when a specific direction is expected.

R&D performance is estimated by a compound index of each firm's perceptions of its R&D performance against competitors in four dimensions: (i) effective use of R&D resources; (ii) efficient use of R&D resources; (iii) percentage of company's revenues derived from products/processes/services not existing 5 years ago; and (iv) success in reducing company's cost of production over the past 5 years. The index is determined by averaging the firm's responses to these questions.

Table 4.3.3 depicts the results of the multiple linear regression analysis[46]. Two broad conclusions can be drawn. First, four management of technology policies - development, communication, and acceptance of technology strategy; linkage between technology strategy and corporate-level strategy; involvement of the CEO in the R&D process; and use of multi-functional teams - are positively correlated with R&D performance with 90% or higher confidence levels.

---

[45] In the regression analysis, explicit models involving the management of technology practice and R&D performance were used.

[46] P-value indicates the level of significance of each hypothesis. For example, there is 0.0057% chance that a well developed, communicated and understood technology strategy is <u>randomly</u> correlated with R&D performance (or a 99.995% chance that it is <u>non-randomly</u> correlated).

Table 4.3.2: Hypotheses and R&D performance

Policy Level	Hypotheses	Correlation with R&D Performance
Posture and Direction	H.A.1	formulation, communication, and acceptance of technology strategy
	H.A.2	linkage between technology strategy and corporate strategy
Systems	H.B.1	use of multi-functional teams in the R&D process
	H.B.2	participation of CTO in the board of directors
	H.B.3	the role of the CTO in the R&D process
	H.B.4	the involvement of the CEO in the R&D process
	H.D.1	use of customer input in the R&D process
Adjustment Processes	H.C.1	level of non-domestic R&D activities
	H.E.1	use of monitoring activities in the R&D process
	H.PII.1	focus on core technologies
	H.PII.2	increased external acquisition of technologies instead of int. investment
	H.PII.3	stronger accountability
	H.PII.4	increased use of automation
	H.PII.5	streamlined R&D organization
	H.PII.6	stricter criteria for new program start-up
	H.PII.8	tighter measurements
	H.PII.9	search for additional sources of external funding

Table 4.3.3: Multiple linear regression analysis results

R&D Performance Index

Hypotheses	Correlation	t-Student	p-value
H.A.1	Technology strategy	3.001	0.006
H.A.2	Linkage TS and CS	2.459	0.022
H.B.4	CEO involvement	2.149	0.041
H.B.1	Multi-functional teams	1.69	0.1
H.PII.6	Stricter criteria	1.2804	0.211
H.PII.3	Stronger accountability	1.254	0.221
H.E.1	Monitoring	1.057	0.3
H.PII.1	Core technology focus	1.025	0.314
H.PII.5	Streamline the R&D org.	0.9679	0.342
H.PII.4	Increased automation	0.857	0.398
H.D.1	Customer input	0.827	0.415
H.C.1	R&D Internationalization	0.82	0.423
H.B.3	Role of CTO	0.73	0.47
H.B.2	CTO in the board	0.46	0.64
H.PII.8	tighter measurements	-0.449	0.656
H.PII.9	additional funding sources	0.29	0.767
H.PII.2	external tech. acquisition	-0.2537	0.802

Second, there are management practices that do not seem to be non-randomly correlated with R&D performance. This is the case for: the role of the CTO; CTO in the board; tighter measurements; additional funding sources; and external technological acquisition. Importantly, that does not mean that these policies are irrelevant. Statistical limitations of our data may have limited the establishment of more confident correlations. In the case of the role of the CTO, for example, the data show that most companies' CTOs have very similar roles. This limits our ability to distinguish among firms' practices and their respective R&D performance, which consequently limits our ability to assess the correlation between these variables[47]. In addition, the size of the sample (30 data points) may have limited a more accurate evaluation of those management practices.

4.4) Product Commercialization and Process Implementation

This section assesses the relationships between management of technology practices and the capability of the firm to meet product commercialization and process implementation target dates. We use the hypotheses HGJ developed in chapter 3 and test them against a lumped index of the firm's capability to meet target dates for both product commercialization and process implementation. The statistical tests are based on multiple linear regression analysis and follows the same rationale of the tests conducted in section 4.3.

Recalling chapter 3, we had:

> **HGJ**: Approach J is non-randomly correlated with a better record in meeting target date for product commercialization and process implementation.

As it was pointed out, the questionnaire asked firms to list three approaches that they had found most effective in shortening the time it takes to move a product or process from concept to implementation. Table 4.4.1 presents the seven most used approaches to move innovations faster from concept to

[47] In this case, it would be hard to argue that active CTOs do not make a difference in R&D performance.

Table 4.4.1: Most used practices to move products/processes to market

Policy approaches	Times listed in the Sample	Hypotheses	Correlation with
Multi-functional teams	17/30	H.G.1	Time from concept to implementation
Transfer of professionals	13/30	H.G.2	Time from concept to implementation
Early market test	8/30	H.G.3	Time from concept to implementation
Senior sponsors	7/30	H.G.4	Time from concept to implementation
Accountability	7/30	H.G.5	Time from concept to implementation
Total Quality Management	5/30	H.G.6	Time from concept to implementation
Simultaneous Engineering	4/30	H.G.7	Time from concept to implementation

implementation and the respective hypotheses that were tested against the empirical data.

A correlation matrix was built to assess the relationships among these hypotheses. Table 4.4.2 depicts the results. Note that there are not high correlation between the hypotheses. As a result, a multiple linear regression analysis should include all of them.

Table 4.4.3 illustrates the results of the regression analysis. High confidence levels (1-p) indicate that there are positive, non-random correlation between some specific policy approaches and capability of a firm to meet target dates for process implementation and product commercialization. Those policy options are accountability, multi-functional teams, early market test, and total quality management. Other mechanisms - like transfer of professionals, senior sponsors, and simultaneous engineering - should also be considered at the policy level, although their statistical significance is not so high. Importantly, the size of the sample limits the test of other policy approaches[48], although they may have important influences in reducing time from concept to implementation.

4.5) Summary

Table 4.5.1 summarizes policy options that have statistically significant effects on R&D performance and time from concept to implementation. Policy approaches that have an important impact on the R&D process do not require extensive financial investments. On the other hand, they involve considerable organization-wide efforts.

The next chapter evaluates the current management of technology practices in Japanese, North American, European, and Brazilian organizations. The main objective is to identify policy opportunities for the Brazilian chemicals/materials industry. Chapter 7 addresses the issue of policy

48 Listed in the questionnaire but not included in table 4.4.1.

implementation, considering the large efforts that are required in that process.

Table 4.4.2: Correlation matrix among hypotheses HGj

	H.G.1	*H.G.2*	*H.G.3*	*H.G.4*	*H.G.5*	*H.G.6*	*H.G.7*
H.G.1	1						
H.G.2	0.01	1					
H.G.3	0.13	0.27	1				
H.G.4	0.19	0.13	0.34	1			
H.G.5	0.36	0.32	0.34	0.47	1		
H.G.6	0.44	0.3	0.41	0.48	0.33	1	
H.G.7	0.08	0.17	0.28	0.45	0.33	0.53	1

Table 4.4.3: Policy options and time from concept to implementation

Hypotheses	t-Student	p-value
Accountability	2.3	0.0285
Multi-functional teams	2.1348	0.04
Early market test	1.88	0.069
Total Quality Management	1.687	0.101
Transfer of professionals	1.37	0.18
Senior sponsors	1.1575	0.256
Simultaneous Engineering	1.041	0.306

Table 4.5.1: Summary of Policy Opportunities

Policy Approaches	Effect on	p-value
Well structured technology strategy	R&D performance	0.0057
Linkage technology-corporate strat.	R&D performance	0.0218
CEO involvement in the R&D process	R&D performance	0.0407
Use of multi-functional teams	R&D performance	0.1
Stronger accountability	Innovation time	0.0285
Use of multi-functional teams	Innovation time	0.04
Early market test	Innovation time	0.069
Total Quality Management	Innovation time	0.101

Chapter Five: Survey Results and Regional Analysis

5.1) Introduction

This chapter presents the survey results and an analysis of management of technology practices on a regional basis. The objective is to identify, in light of the findings of the previous chapter, possible policy candidates that would improve the R&D process in the Brazilian chemicals/materials industry.

The chapter has two main parts. Initially, data on strategic management of technology in the chemicals/materials industry is presented and discussed on a regional basis (R&D investment, average break-even time, size of companies and diversification, portfolio balance, so on). Following that, regional management of technology practices are assessed and presented for the three main components of the R&D process -- posture and direction; systems; and adjustment process.

5.2) The Chemicals/Materials Industry and the Innovation Process

This section aims at assessing differences in R&D investment, firms' size, technology strategies, R&D portfolio balance, maturity of technologies, and performance measurements across the regions surveyed.

Before presenting the analysis, it would be insightful to know what is the perception of survey respondents about the most innovative firms in the industry.

The questionnaire asked firms to indicate their perception of the top 3 companies worldwide in R&D performance in the chemicals/materials. Figure 5.2.1 depicts the results. Du Pont is perceived as the most innovative company

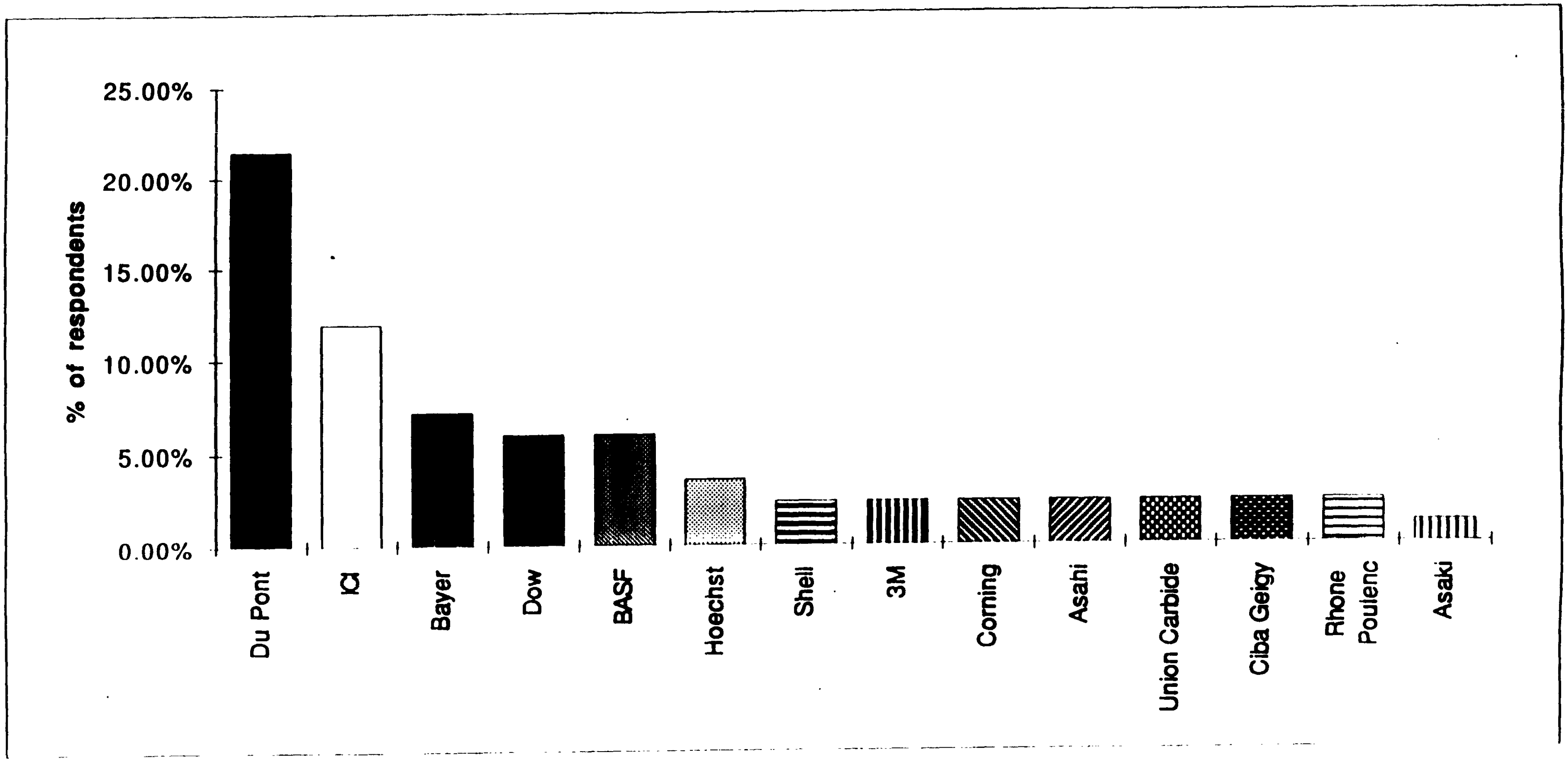


Figure 5.2.1: Companies perceived as the most innovative in the chemicals/materials industry

in the industry, followed by ICI, and Bayer. The data also showed that no significant biases exist across the regions surveyed on this matter. Only Japanese respondents cite more Japanese companies as among the world's most innovative though.

Notice that few Japanese companies are perceived as important innovators in the industry. No Latin American company was cited. This suggest that Brazilian companies should have different characteristics relative to Japanese, American, and European companies.

Indeed, companies in Brazil have a much lower size than companies in Europe, Japan, and the US. Whereas firms in developed countries have regional average sales varying from $6 to $9 billion, firms in Brazil have average sales of only $350 million (figure 5.2.2). Those companies may well follow different technology strategies when compared with their larger counterparts[49].

In this context, it is not surprising that almost 75% of Brazilian respondents classify themselves as late technology followers[50] (see figure 5.2.3). In addition, as depicted in figure 5.2.4, Brazilian respondents concentrate a higher degree of R&D activities in short-term (<3 years) or medium-term (3-7 years) projects, and in familiar technologies. On the other hand, they try to sustain a balanced portfolio between product and process innovation[51].

Firms in the North hemisphere seem to follow more similar technology strategies though. Sixty percent of American respondents perceive themselves as technology leaders and 75% of Japanese respondents believe that they are on par with competition. Few companies in Europe and Brazil see themselves as

---

49 Importantly, however, the findings of the last chapter continue to be relevant for Latin American companies, since they address systemic issues that should improve R&D performance in different strategic settings. Those issues are, for example, linkage between corporate strategy and technology strategy, formulation, development, and acceptance of technology strategy, use of multi-functional teams, and so on. We believe that those policy options are relevant regardless of the content of the technology strategy and its objectives. This issue is discussed deeper in chapter 6.

50 Data on technology strategy and technology portfolio were obtained through questions 4 and 7 in subsection F.

51 Although a smaller amount of Brazilian companies have a balanced portfolio in product/process relative to their survey counterparts, they are split among themselves between product and process focus.

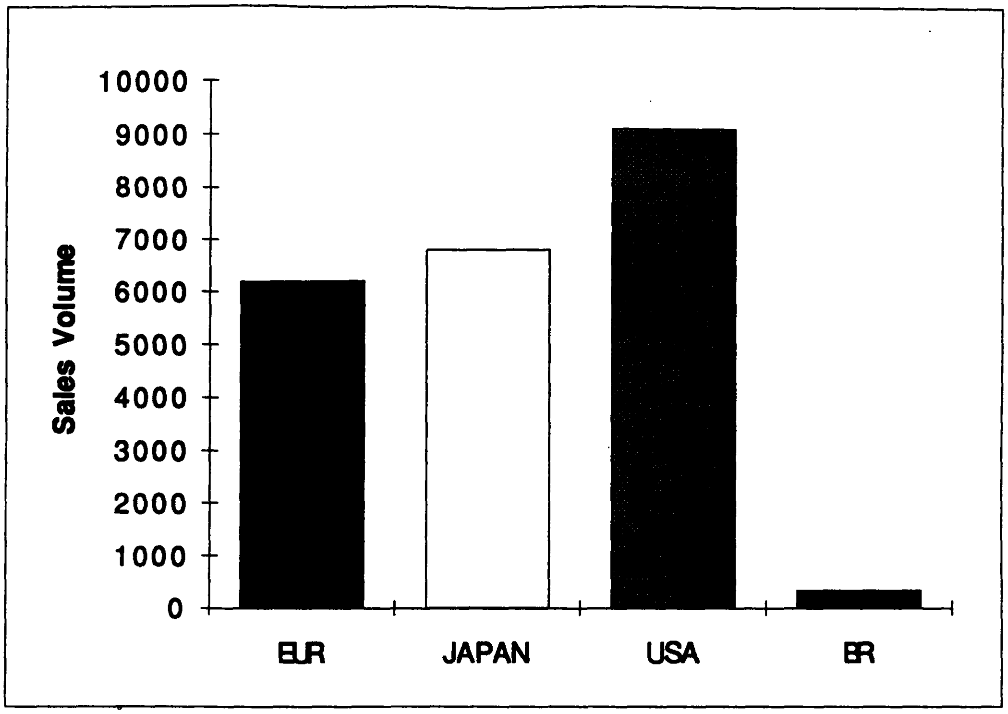


Figure 5.2.2: Respondents' regional average sales

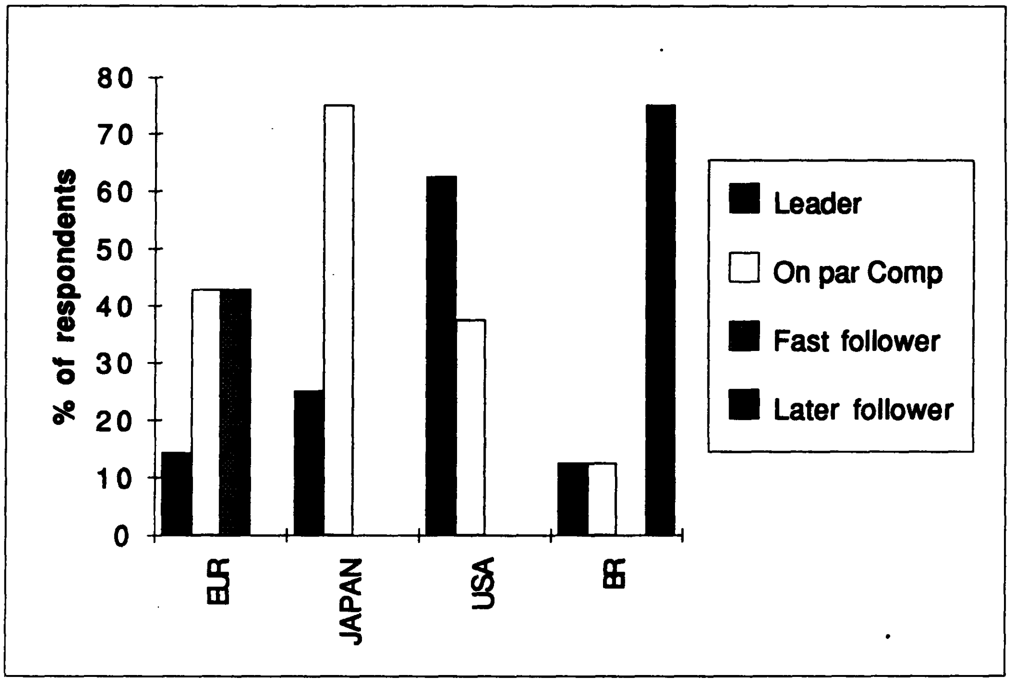


Figure 5.2.3: Regional technology strategies

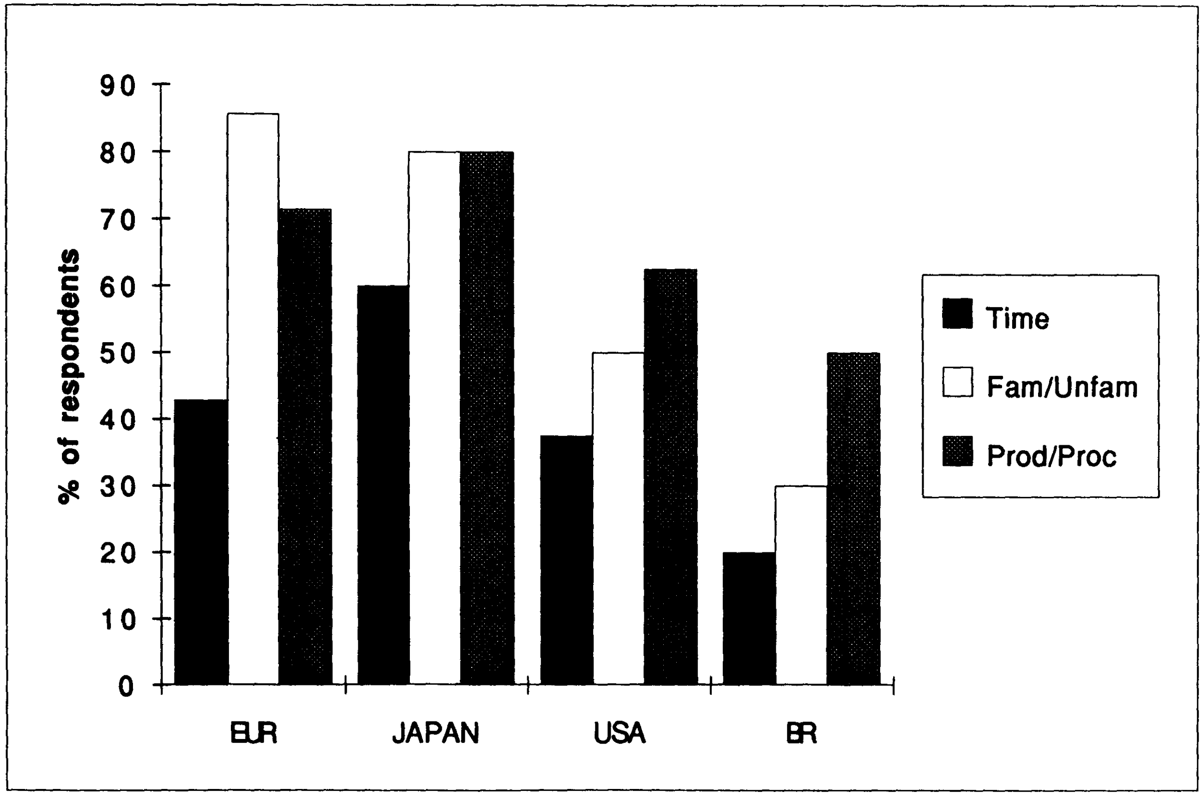


Figure 5.2.4: Technology portfolio's balance

technology leaders. European respondents, however, have a larger number of firms that are on par with the competition relative to Brazilian firms.

Regarding technology portfolio, Japanese respondents invest more in long-term projects (>7 years), whereas European respondents invest more in unfamiliar technologies. Importantly, it seems that both European and Japanese respondents have a better balance in their technology portfolio.

Figure 5.2.5 shows an average index of R&D spending for each region. Japanese respondents invest an average of 4.4% of their sales volume in R&D. They are followed by Americans respondents (with 3.5%), then by European respondents (with 2.65%) and by Brazilian respondents (with 2.08%). Overall R&D spending in the chemicals/materials industry has an average of 3.18% with standard deviation of 1.68%.

Two hypotheses can be formulated to explain why Japanese and, to a lesser extent, American respondents have a higher index of R&D spending as a percentage of sales. First, they may have more ambitious technology strategies, comprising more unfamiliar and long-term projects. On the other hand, it may be that respondents in those two regions are presented in more technology intensive segments of the chemicals/materials industry, like pharmaceuticals or specialty materials, for example.

Other measurements of R&D investment can provide more information about innovation management in different regions. Figure 5.2.6 presents the average regional R&D spending relative to net income for survey respondents. Japanese firms invest, on average, 1.7 times their net income on R&D, whereas other firms in other regions invest almost half of their net income on R&D. This number should be interpreted with care, however. There is a possibility that the Japanese sample is biased towards chemicals/materials firms that have activities on the pharmaceutical sector. In this context, one would expect them to have higher R&D investments relative to net incomes despite the fact that they describe themselves as chemical/materials companies. The differences among Brazilian, European, Japanese, and American respondents are illustrated in figure 5.2.7.

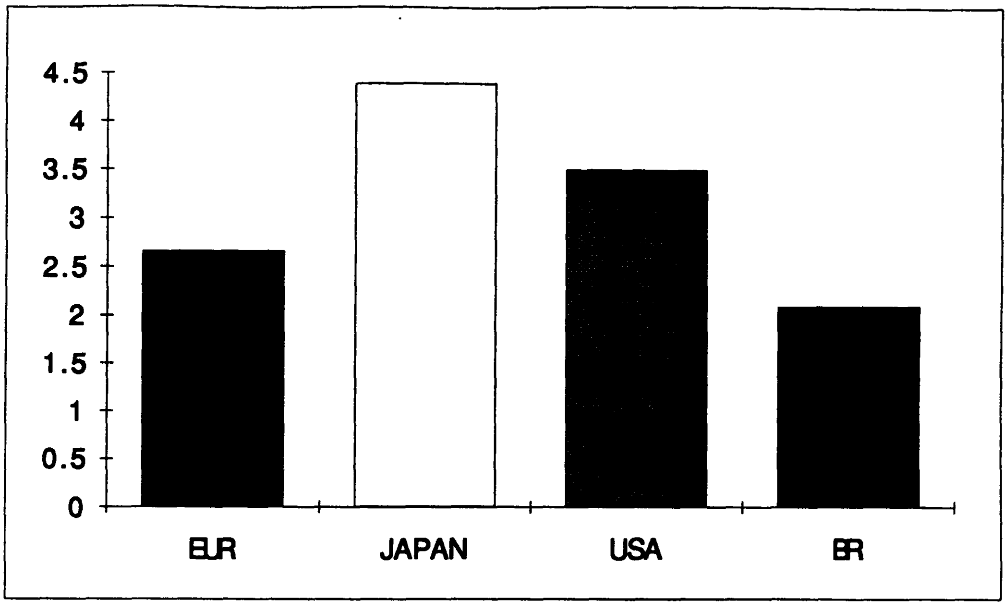


Figure 5.2.5: Average R&D spending by region as a percentage of sales

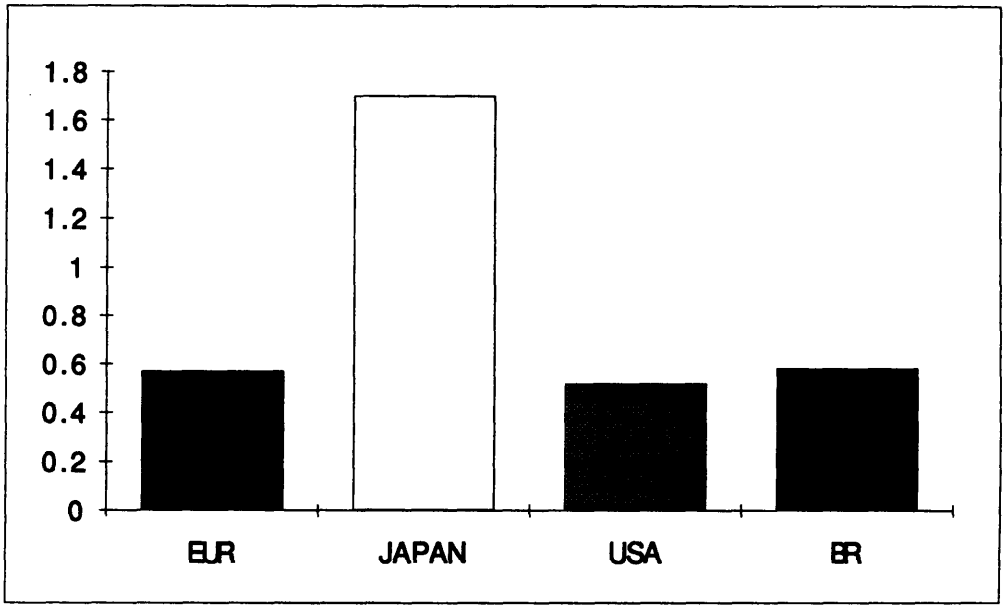
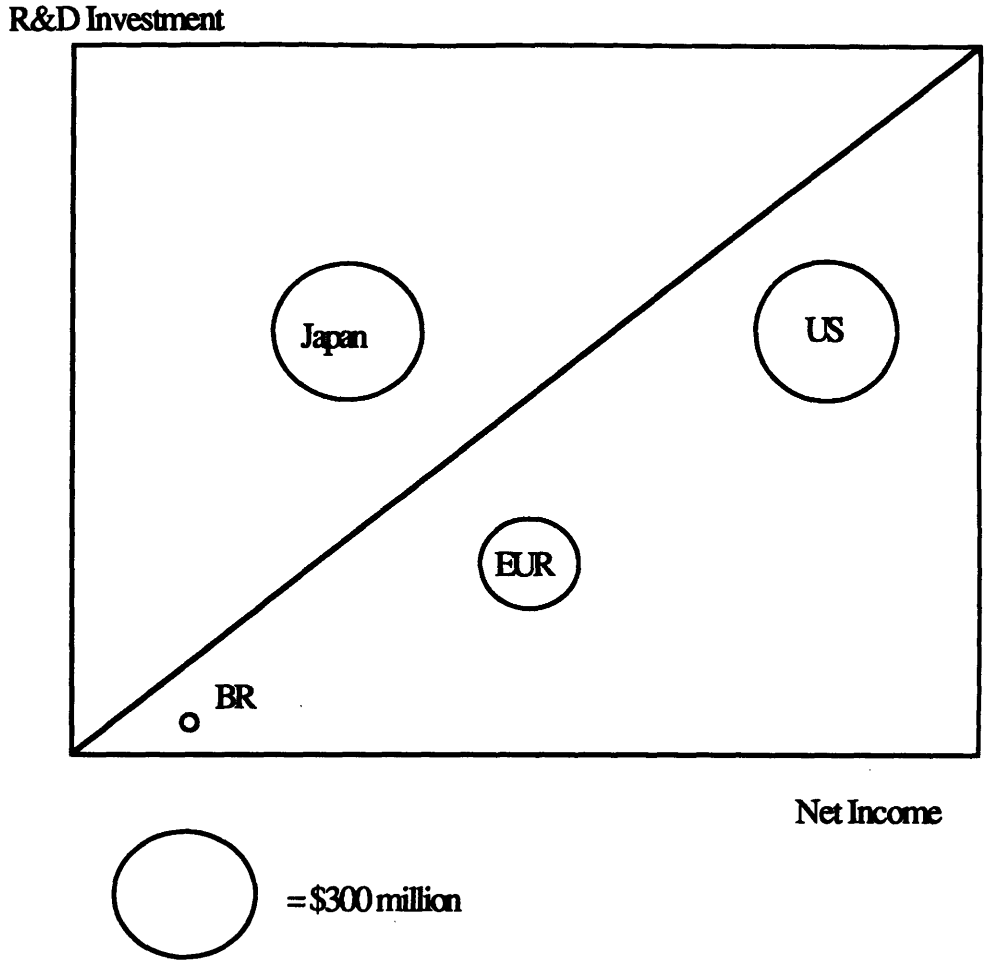


Figure 5.2.6: Average regional ratio between R&D spending and net income

Figure 5.2.7: R&D spending and Net Income



Another important index is the average break-even time of new products from date of first market release. Although this number varies extensively among respondents, an average of 32 months with standard deviation of 27 months was determined for the overall sample. Importantly, the data on average break-even time do not comprise the initial sample of 30 data points, but only 13. This sample size should be remembered when considering this result (32 months) for benchmarking purposes.

The financial and managerial support given to the R&D organization by top management is more important than funding statistics. Firms were asked to indicate if R&D gets the amount of money it requests and if top management attitude toward R&D is supportive or not. Figure 5.2.8 illustrates the results.

In general, relatively few respondents reported high values for R&D financial support and for top management's attitude toward R&D. Japanese executives whose firms answered the survey have the most supportive attitude towards R&D. American executives, however, indicated that a weak support towards R&D. Regarding financial support, the indexes are comparable among European, Japanese, and American respondents. Few Brazilian respondents indicate that R&D typically gets the financial resources that it requests. In addition, a supportive top management's attitude towards R&D is also not pervasive among Brazilian respondents.

It is somewhat surprising to report a relative high number for R&D investments as a percentage of sales for Japanese and American respondents considering the maturity of technologies in the chemicals/materials industry. In general, technologies in the industry are very mature, as it is illustrated in figure 5.2.9. In addition, figure 5.2.10 shows that the average maturity of technologies among American respondents is lower relative to Japanese, European, and Brazilian respondents[52].

Regarding performance measurements, two dimensions were assessed: the capability of the R&D organization to successfully satisfy the needs of stakeholders (end-use customers, corporate strategy and manufacturing); and the overall performance of the R&D organization relative to the firm's competitors.

Figure 5.2.11 illustrates the percentage of respondents indicating high fulfillment of stakeholders' needs for the regions surveyed. Firms report a higher fulfillment of end use customer needs. Importantly, corporate strategy needs are not highly addressed by European, Japanese, and American respondents.

---

[52] An anova test was conducted, reporting a p-value of 0.004.

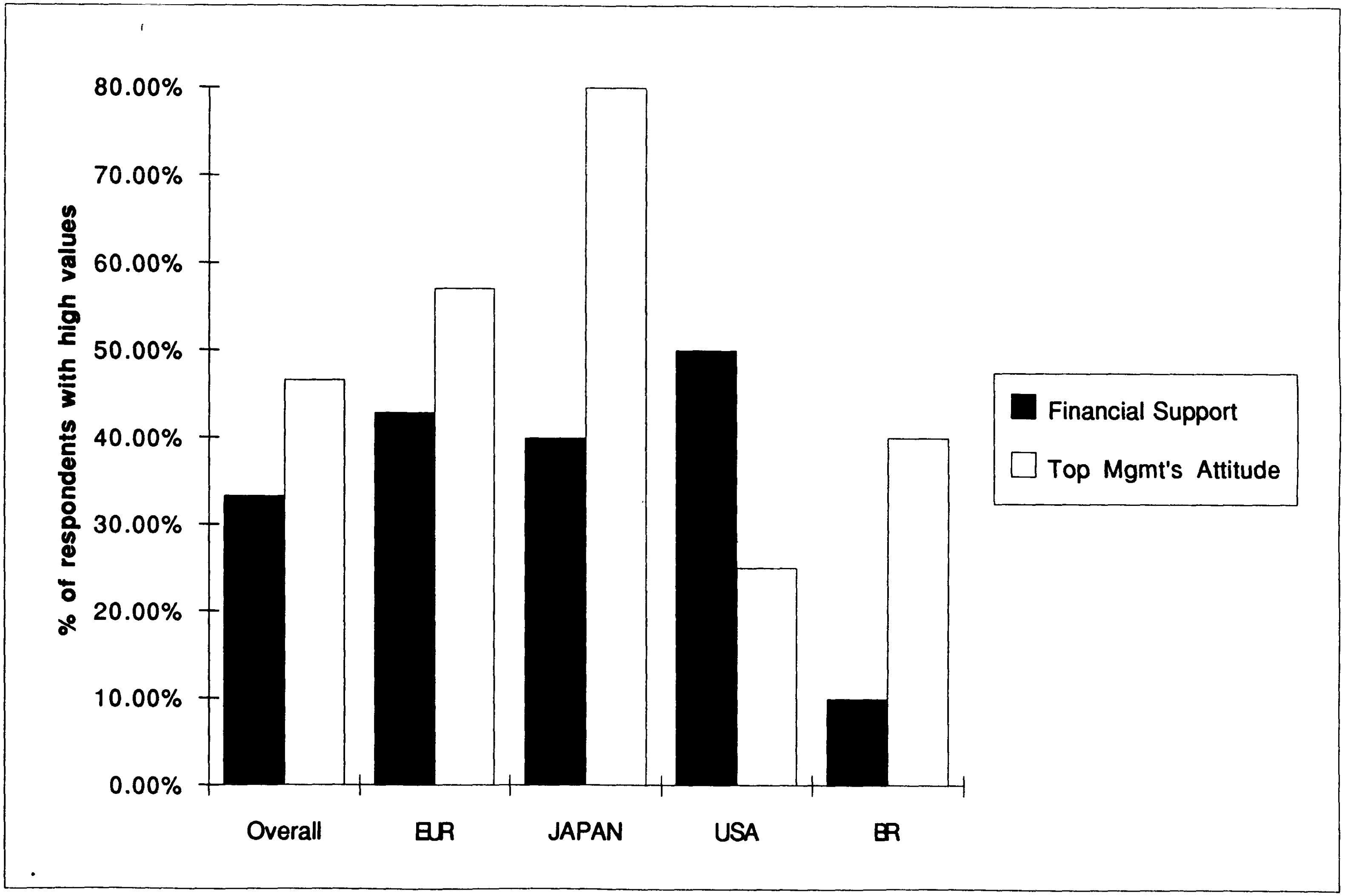


Figure 5.2.8: Funding and management support of R&D organizations

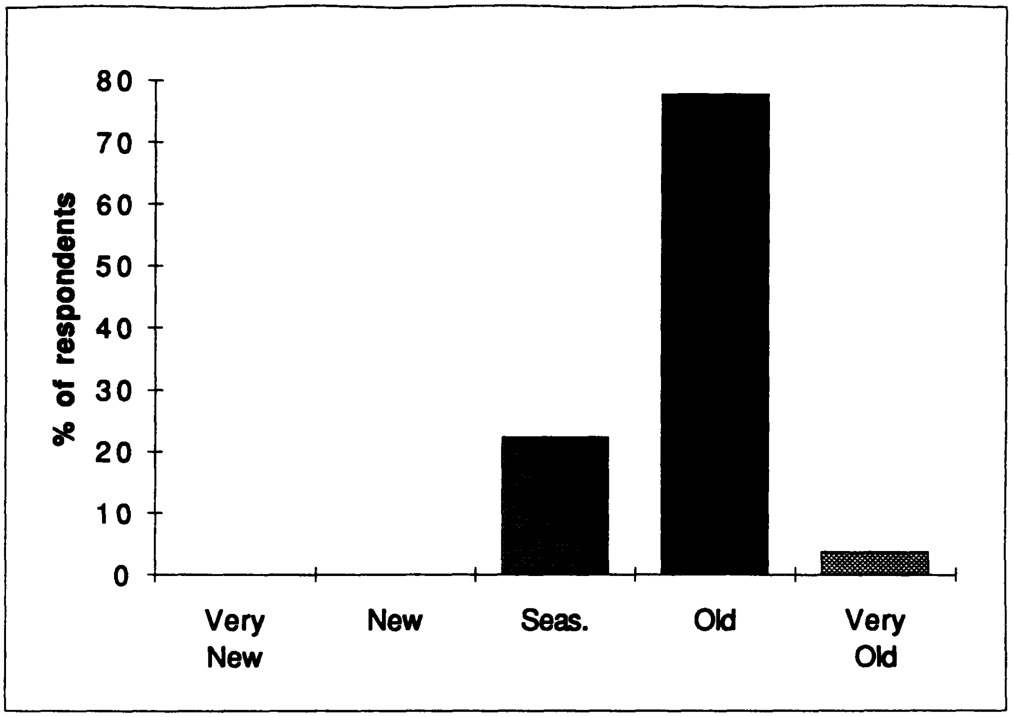


Figure 5.2.9: Maturity of key technologies

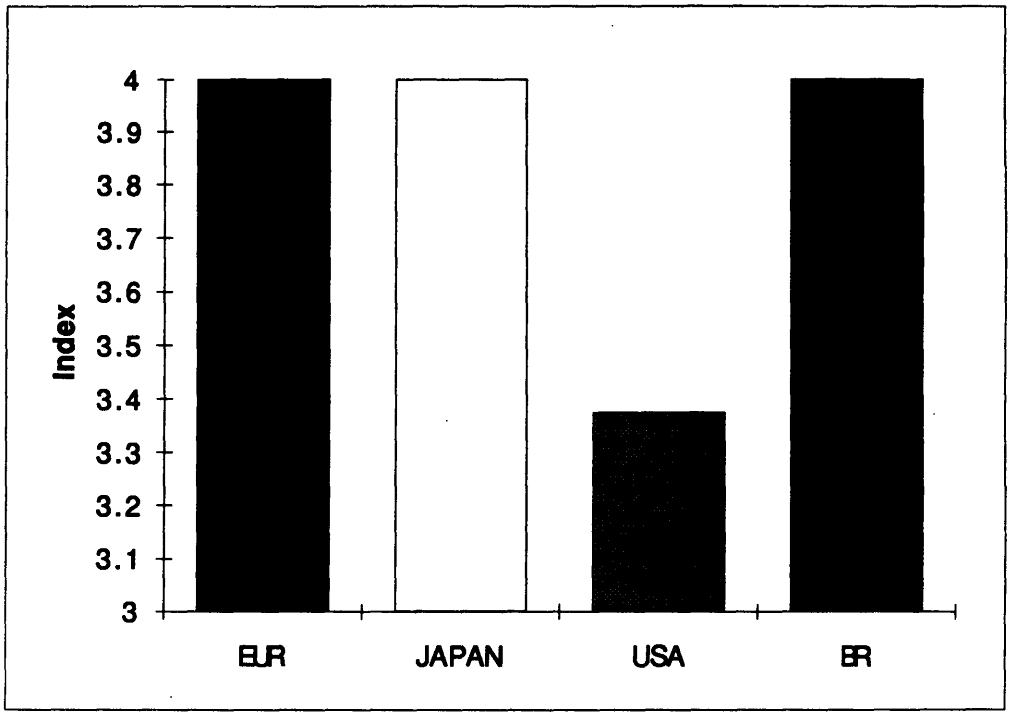


Figure 5.2.10: Average maturity of technologies in each region

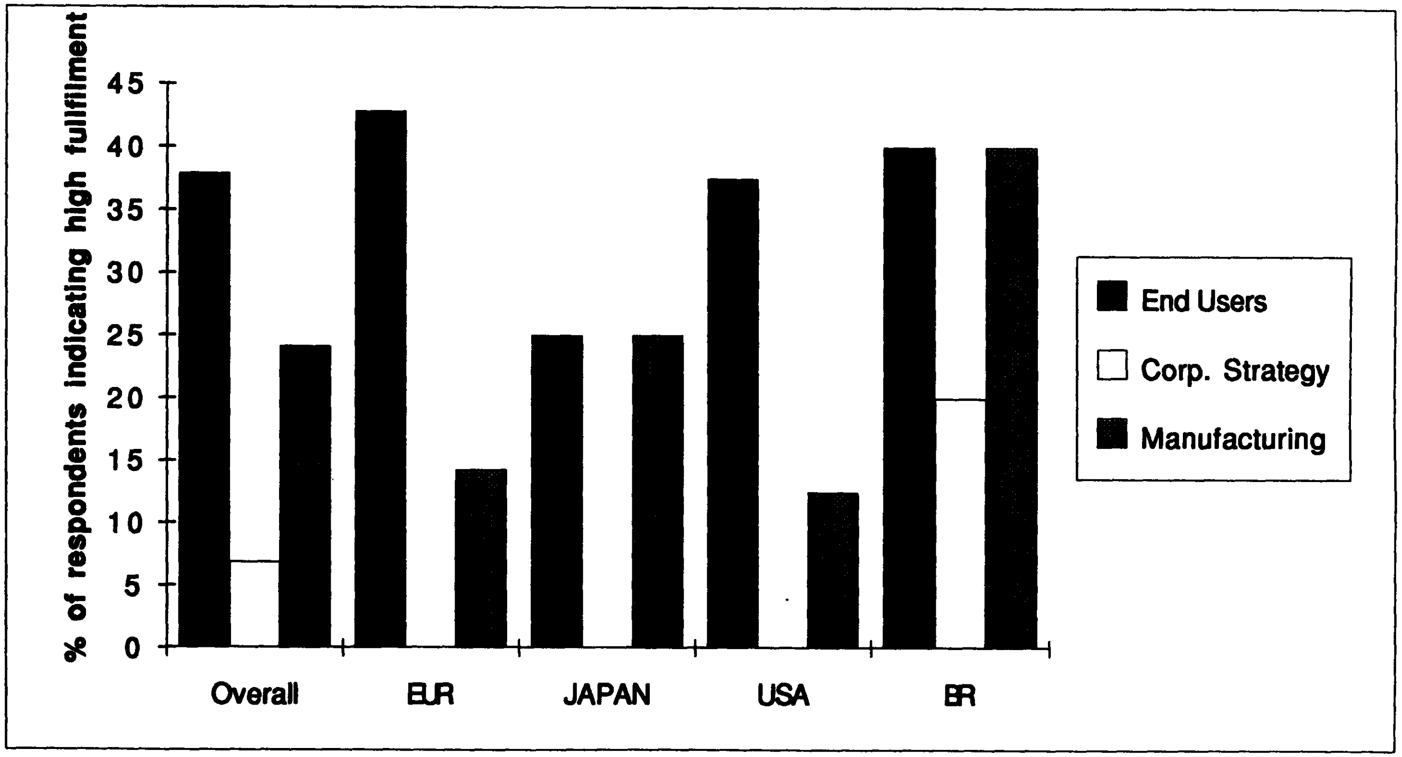


Figure 5.2.11: Fullfilment of stakeholders' needs in different regions

A larger percentage of Brazilian respondents report high fulfillment of stakeholders' needs. Two hypotheses can be formulated to explain this fact. These two hypotheses are discussed in the next section of this chapter.

- Brazilian respondents are more active users of the policies that were identified in chapter 4 as important to achieve high fulfillment of stakeholders' needs. In this case, one would expect to see a higher number of firms with high fulfillment indexes; or

- Since fulfillment of stakeholders' needs are measured against competitors, we could argue that Brazilian companies do not experience yet strong foreign competition. If they would be comparing themselves against foreign competitors, one would expect a lower number of firms reporting high fulfillment of stakeholders' needs. In this case, the results reported by Brazilian respondents are not meaningful as a basis of comparison with the overall sample.

A larger number of Japanese respondents indicate high fulfillment of manufacturing stakeholders relative to European and American respondents. This may indicate a larger gap between R&D and manufacturing interests and interactions in those two latter regions.

On the other hand, a larger percentage of European and American respondents indicate high fulfillment of end use customers needs. Considering the analysis developed below, however, these results do not seem to be very meaningful. It is probable that American and specially European respondents face milder competition relative to Japanese respondents. They would had reported lower indexes of end-use customer satisfaction if they were in a more competitive environment. As a result, the data shown in figure 5.2.11 should be interpreted with care.

The analysis conducted in chapter 4 provide some policy suggestions for the whole industry, given the low percentage of companies reporting high fulfillment of corporate strategy. These policies comprise: more active participation of the CEO in the R&D process; participation of the CTO in the main management board; improved linkage between corporate and technology strategies; use of multi-functional teams; better acceptance of technology strategy; the transfer of professionals; and the use of permanent project managers.

An index of R&D performance was calculated using the answers of question F.2.b for each respondent. The index compounds the perceptions of a specific firm about its: effective use of R&D resources; efficient use of R&D resources; revenues derived from products/processes/services not existing 5 years ago; and success in reducing company's cost of production over the past 5 years. A regional average of this index is shown in figure 5.2.12. Although this measurements look different, there is not sufficient statistical evidence to assert that they are not similar ($p>0.10$).

Table 5.2.1 gives more information by illustrating the regional perception of R&D performance in terms of its different components[53]. Japanese respondents perceive themselves a having lower efficiency but higher effectiveness in using R&D resources. On the other hand, North American respondents perceive themselves as more efficient but less effective as competitors. Brazilian firms have perceived a low performance in generating revenues derived from products/processes/services not existing 5 years ago. Again, comparisons across regions should be conducted with care since data is given relative to competitors but competitors are not the same for every respondent.

Figure 5.2.13 plots overall indexes of R&D performance and stakeholder needs for the entire sample[54]. As pointed out earlier, opportunities exist for better fulfillment of corporate strategy and manufacturing. In addition, firms should concentrate more in increasing revenues from new products/services/processes and in reducing time to market.

Although this section describes important benchmarks of R&D investment and technology strategy. It does little in advancing what are the states of strategic

53 Although timeliness is not used to calculate the R&D performance index, which was used in chapter 4 to test the hypotheses developed in chapter 3, the table shows this measurement for illustration purposes.

54 The index is calculated by averaging the responses for question F.2, part I.

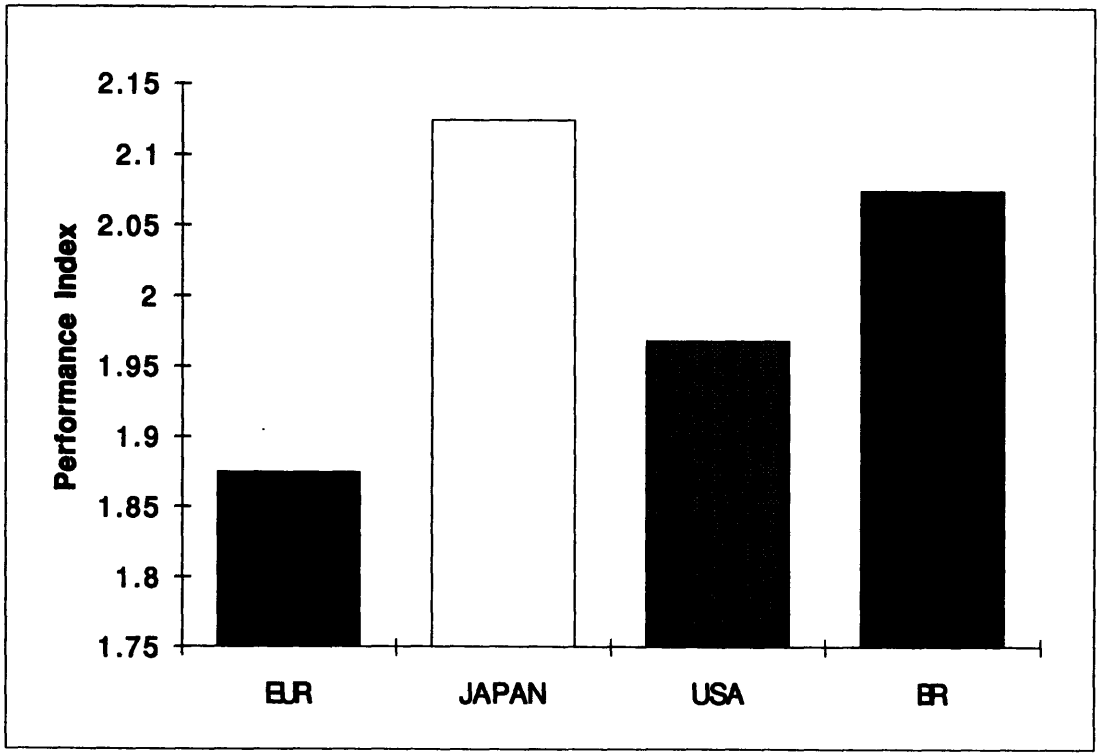


Figure 5.2.12: Regional R&D performance

Table 5.2.1: Overall R&D Performance across components and regions

Regions	Overall R&D Performance (% indicating higher than competitor)				
	Effectiveness	Efficiency	Timeliness	Revenues	Cost
Overall	20.69	24.14	24.14	17.24	34.48
EUR	14.29	14.29	28.57	14.29	14.29
JAPAN	25.00	0.00	25.00	25.00	25.00
USA	12.50	37.50	0.00	25.00	25.00
BR	30.00	30.00	40.00	10.00	50.00

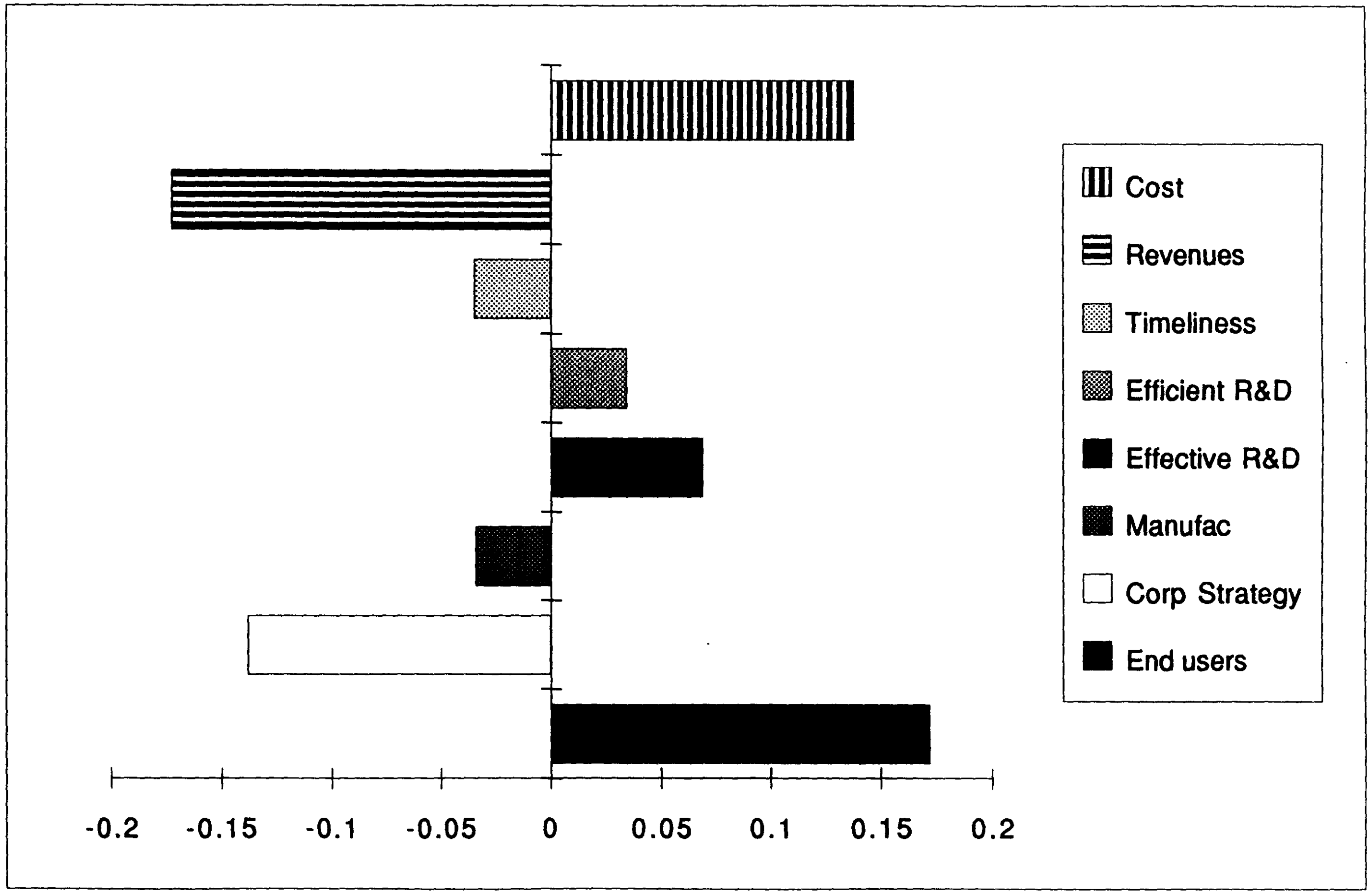


Figure 5.2.13: Perceptions against competitors

management of technology in the different regions under analysis. This issue is developed in the following section.

5.3) Management of Technology Benchmarks

This section presents an assessment of management of technology practices adopted by Japanese, European, North American, and Brazilian respondents. The analysis follows the framework established in chapter 4: posture and direction; systems; and adjustment process.

5.3.1) Posture and Direction

As it was pointed out in chapter 3, posture and direction involves the formulation and communication of a technological mission, the statement of objectives, and the establishment of robust links between technology strategy and overall corporate-level strategy. Importantly, posture and direction can be related with the culture of the organization as well as its relations with technology.

The analysis on chapter three indicated that a well formulated, communicated and accepted technology strategy was a key policy both to satisfy stakeholder needs, i.e. end-use customers, corporate strategy, and manufacturing ($p=0.027$; $p=0.065$; and $p=0.08$, respectively) and to improve R&D performance ($p=0.0057$).

Figure 5.3.1.1 depicts a compound index of formulation, communication, and acceptance of corporate technology strategy among firms in the sample for each region[55]. A single-factor analysis of variance test (anova) was conducted to determine the significance of those indexes[56]. Japanese respondents have the highest degree of technology strategy formulation, communication, and acceptance among companies in the sample ($p=0.10$). Brazilian respondents have the lowest index. American and European firms have comparable values.

---

[55] calculated by averaging the answers for question A.1 part I.

[56] Appendix II gives more details about the anova test.

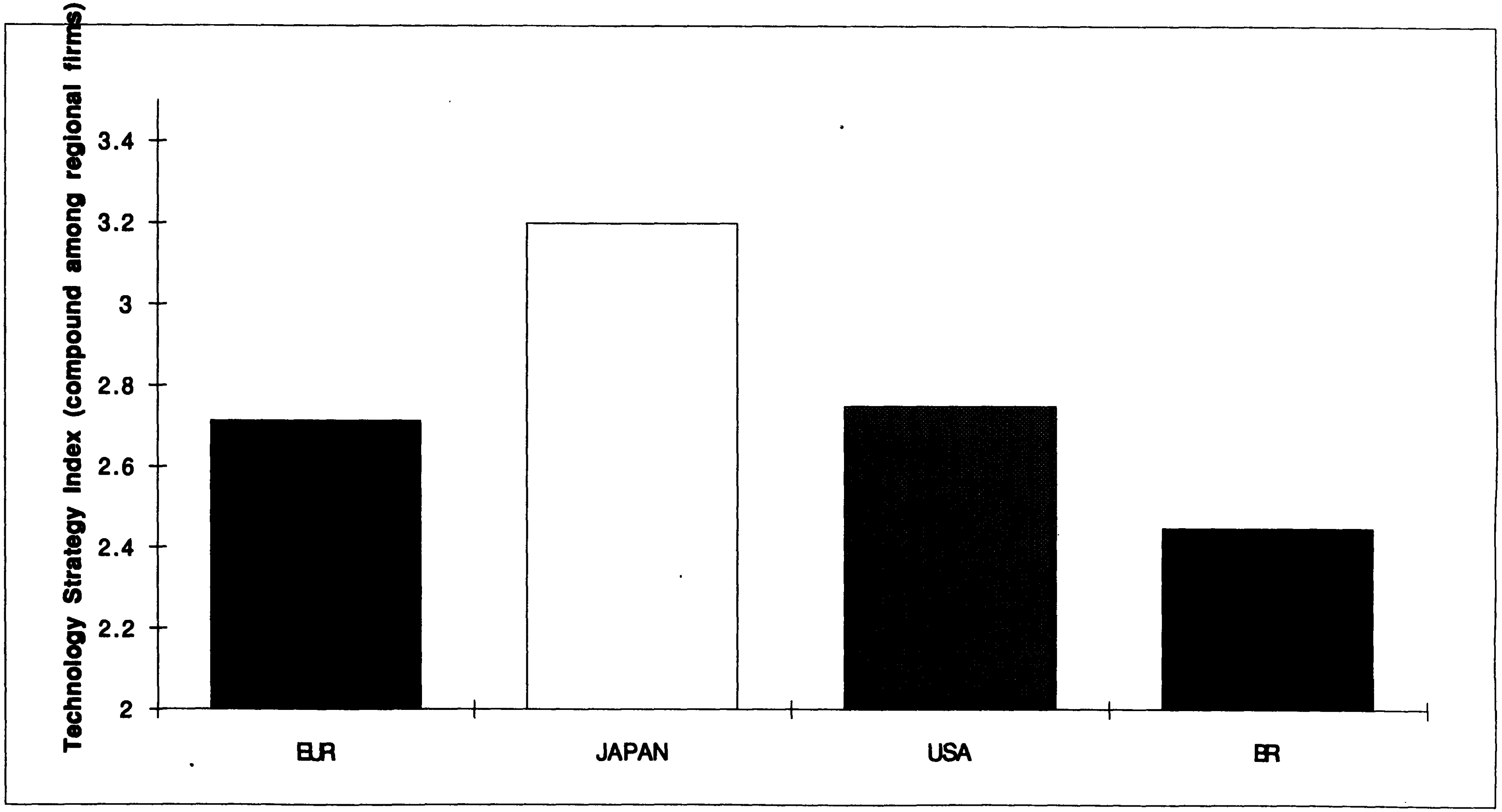


Figure 5.3.1.1: Formulation, communication, and acceptance of technology strategy in different regions

It is possible to measure the sophistication of corporate technology strategy through the analysis of its different components. Those elements, described in question A.2 of the questionnaire, are: technology mission statement; competitive technology position; consideration of internal customer requirements; consideration of external customer requirements; definition of core technical strengths and competencies; analysis of life cycle stages of technologies; evaluation of alternative competing technologies; development of criteria for internal development vs. external access; and analysis of the technology portfolio balance. Averaging[57] those elements for each firm gives an idea of the degree of corporate technology strategy development.

According to figure 5.3.1.2, only 16% of chemicals/materials firms have a high degree of technology strategy development[58]. This number is low comparing with an overall value of 40% reported for 18 other industrial sectors[59]. In Brazil, 70% of companies have a medium degree of corporate strategy development but only 10% have a high degree of development. European companies follow close. Twenty five percent of American companies in the sample have a high degree of technology strategy development, but almost 40% of American respondents have a low development degree.

Table 5.3.1.1 describes the percentage of respondents in each region that a have high formulation of the different elements of technology strategy. Few companies in Brazil have a high formulation of a technology mission statement. On the other hand, Brazilian emphasis is placed both on the criteria that orient internal development or external acquisition of technologies and

---

57 Although some elements of corporate technology strategy are more important than others, the "weight" of each element varies across organizations. As a first approximation, an average of these elements is used for the analysis.

58 Low is assigned for companies with averages between 0 and 1.67; medium values to companies with values between 1.67 and 3.34; and high for companies with values between 3.34 and 5.

59 Reported in Martinez, N., "Management of Technology and Corporate Strategy in the Chemical Industry", Unpublished Master Thesis, June, 1993. The sectors are: aerospace; automotive; computer equipment and software; consumer/household durables; consumer non-durables (excluding food); containers/packaging; electrical equipment; electronic components and equipment; financial services; food, beverages and tobacco; machinery; medical equipment and supplies; office products/automation; petroleum; pharmaceuticals; photographic and scientific equipment and supplies; telecommunications products and services; and travel/leisure/entertainment.

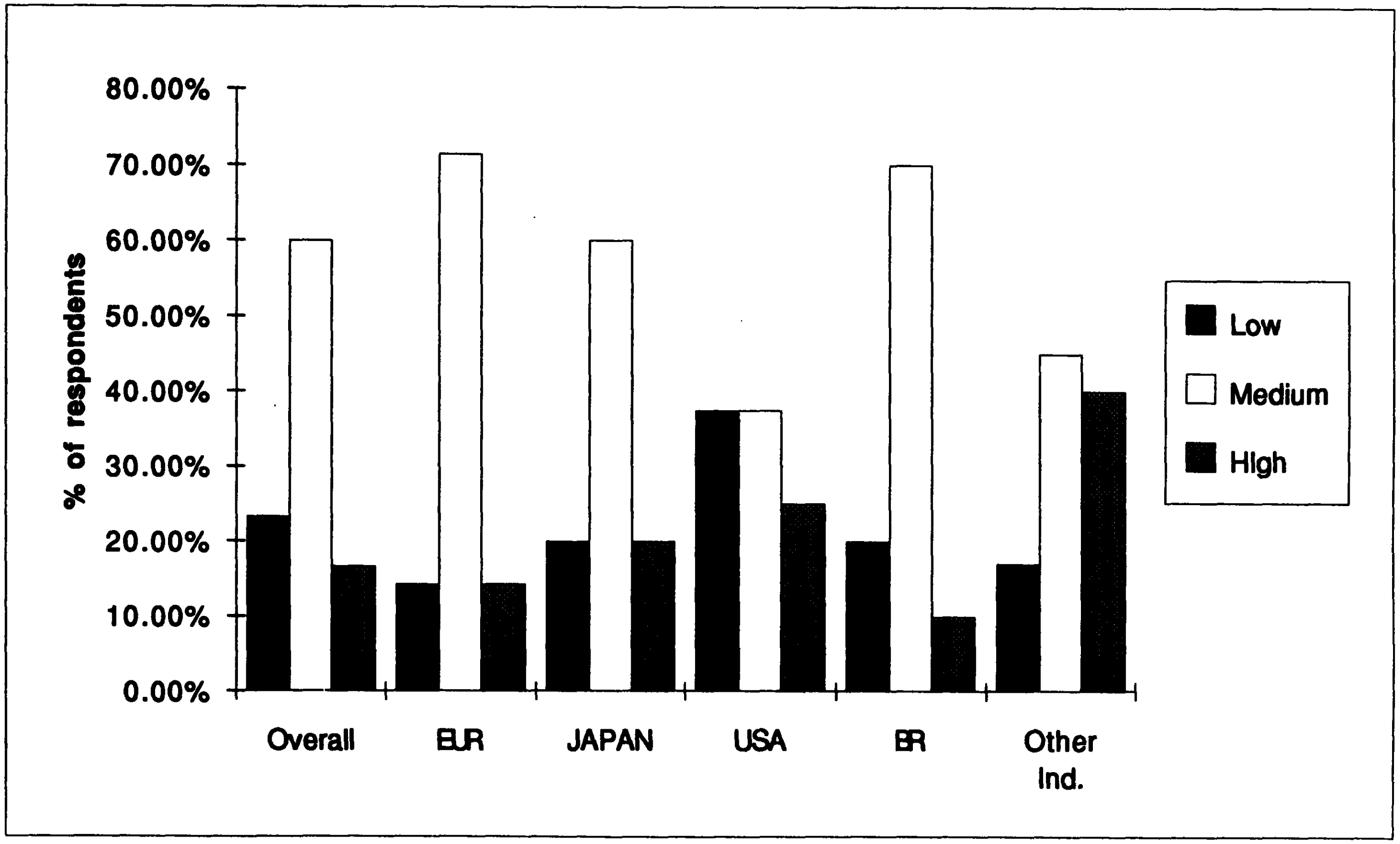


Figure 5.3.1.2: Corporate technology strategy development in different regions

Table 5.3.1.1: Technology strategy formulation

Region	Technology Strategy (% of respondents indicating high formulation of)								
	Mission Stat.	Tech. Position	Int. Customer	Ext. Customer	Core Comp.	Life Cycles	Eval. Competitors	Int. vs Ext.	Port. Balance
EUR	42.86%	71.43%	42.86%	28.57%	57.14%	14.29%	57.14%	14.29%	14.29%
JAPAN	80.00%	60.00%	80.00%	60.00%	100.00%	20.00%	60.00%	20.00%	40.00%
USA	75.00%	37.50%	37.50%	37.50%	50.00%	0.00%	25.00%	25.00%	25.00%
BR	20.00%	50.00%	60.00%	90.00%	40.00%	30.00%	40.00%	50.00%	20.00%

external customers requirements. The ubiquitous presence of internal vs. external criteria may be a consequence of the high dependence of Brazilian companies on external technologies. Note the low level of formulation of external customers requirements in the European respondents.

Chapter four's statistical analyses have shown the importance of a strong linkage between corporate-level strategy and technology strategy to overall R&D performance (p=0.0218). Question A.4 asks firms to rank the strength of the linkage between corporate-level technology strategy and overall corporate strategy. Figure 5.3.1.3 illustrates the results. Japanese and European respondents have a strong linkage between technology and overall corporate strategy . Brazilian companies have a lower linkage and American respondents have the lowest level of all regions[60].

The questionnaire also assessed firms' perceptions of the most important issues to technology strategy[61]. Four issues were suggested: total quality methods in R&D; matching R&D to market needs; decreasing time to market for new products; and managing R&D with constrained resources.

Figure 5.3.1.4 depicts the percentage of respondents that indicated the highest importance for each one of those issues. Almost 60% of respondents indicated that matching R&D to market needs was the most important issue to technology strategy today. Despite that fact, the impact of marketing VPs in the R&D process is small. As seen in figure 5.3.1.5 the involvement of marketing VPs in corporate technology strategy formulation is minor. Although they are more involved in business unit technology strategy, their participation is still small compared with R&D VPs and business units managers.

Figure 5.3.1.4 also shows that managing R&D within the current economic climate and that implementing total quality methods in R&D are important issues to technology strategy. Reducing time to market is an important issue to approximately 25% of the respondents.

---

60 It should be noticed that only 4 from 8 American respondents answered this question. The result may not be representative of the overall American sample.

61 question A.3, part I.

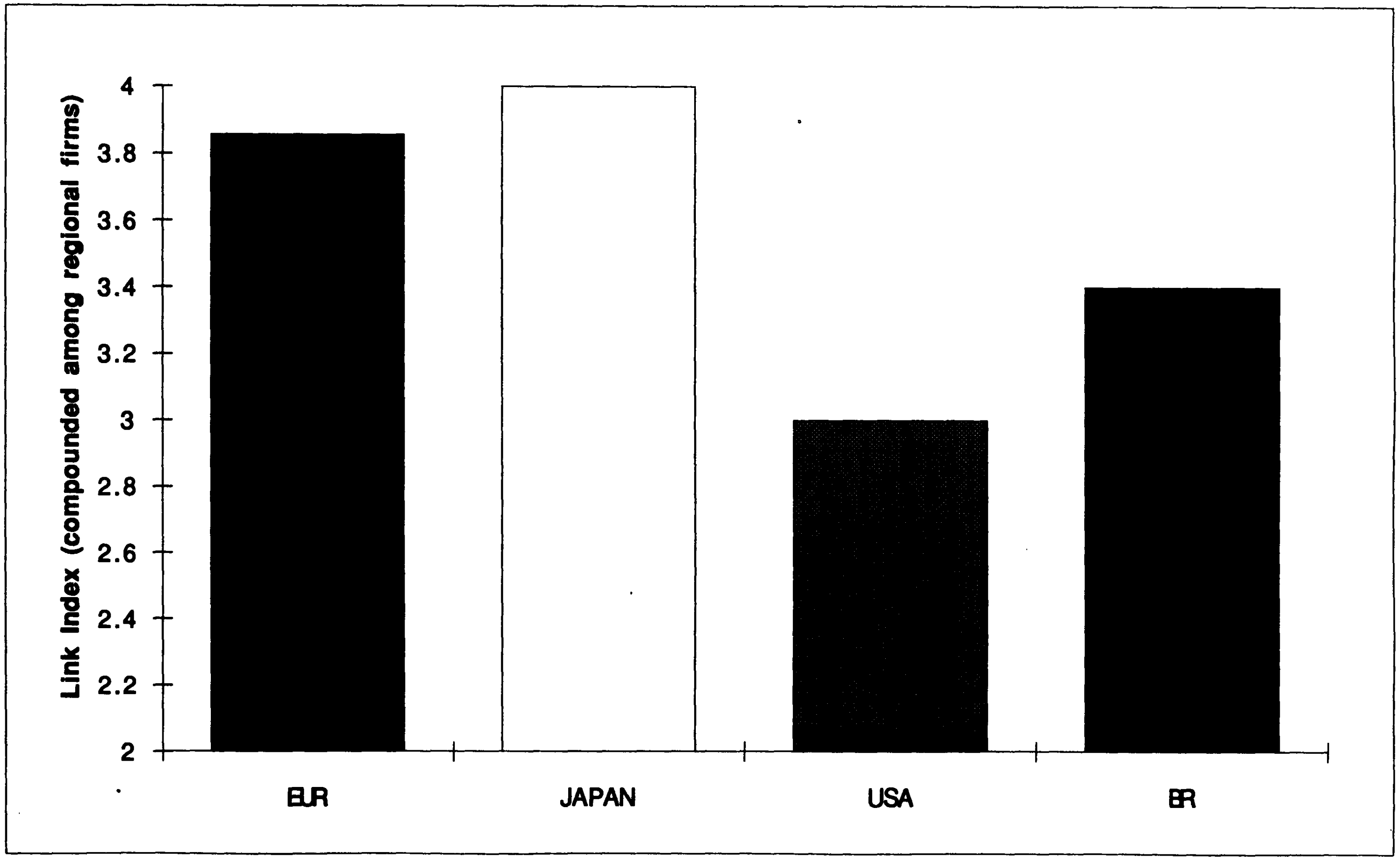


Figure 5.3.1.3: Linkage between technology strategy and overall corporate-level strategy

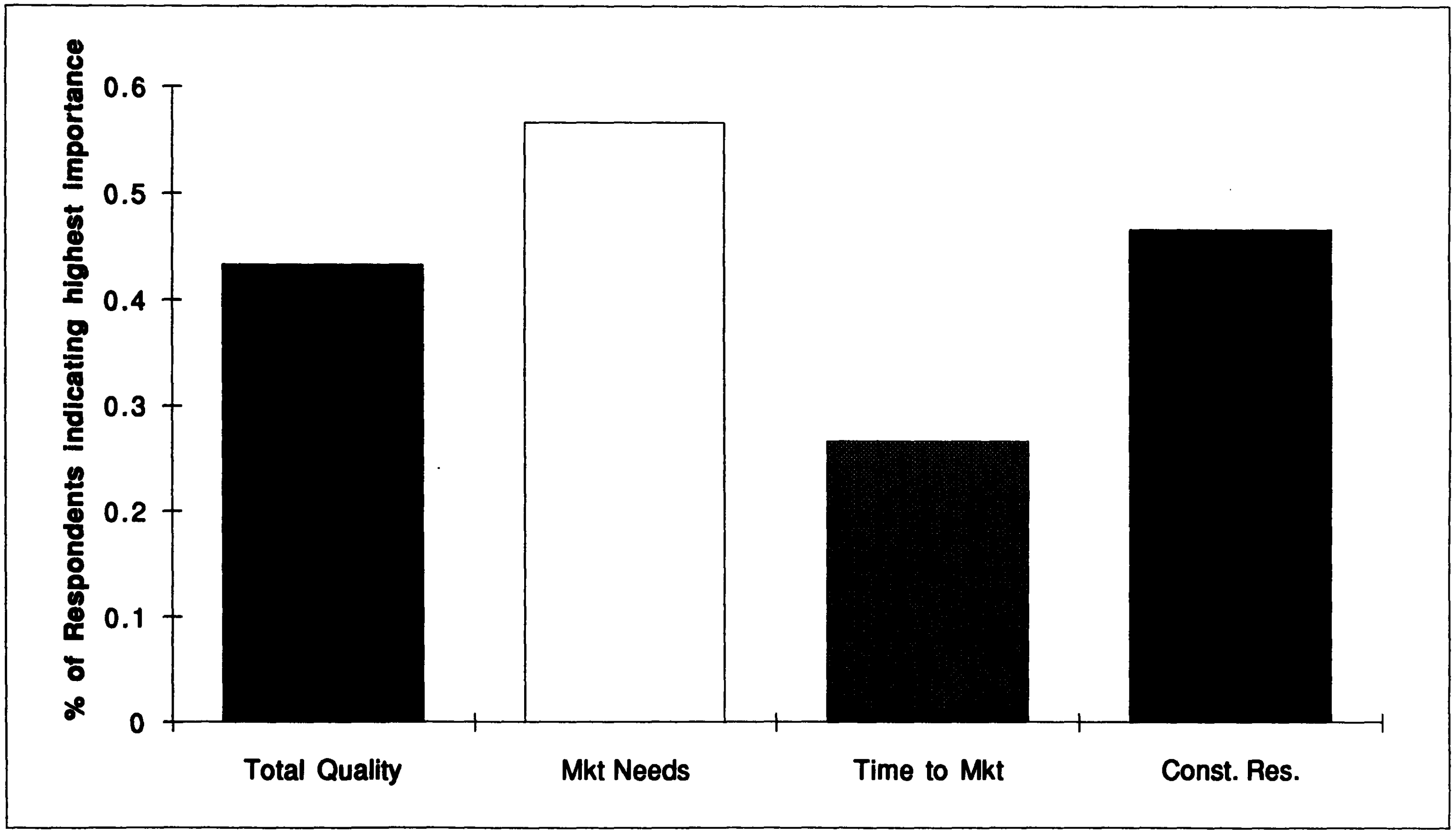


Figure 5.3.1.4: What is important to technology strategy ?

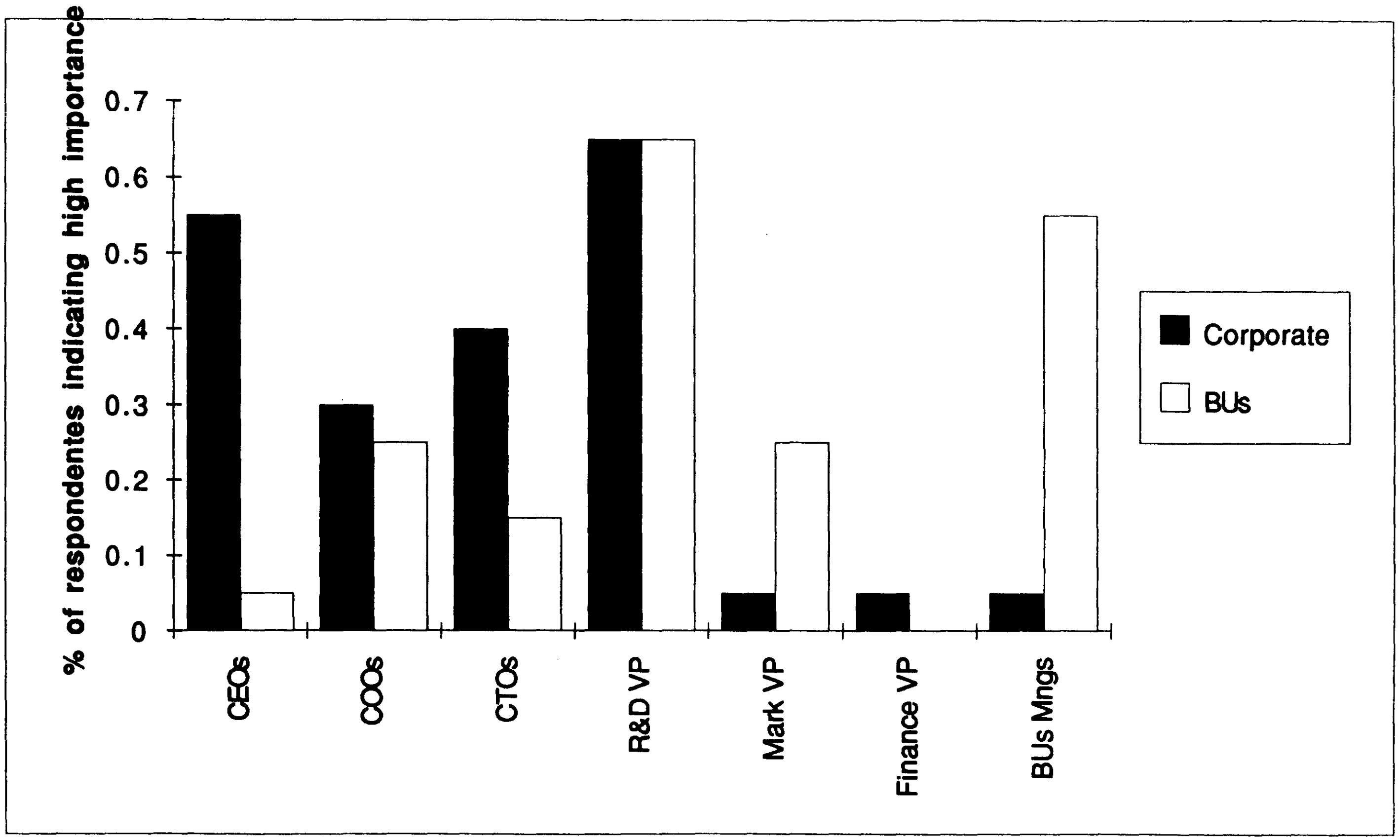


Figure 5.3.1.5: Key executives and technology strategy

In terms of posture and direction, Japanese respondents are the best positioned in the industry. They have both the highest level of technology strategy development, communication, and acceptance and the strongest links between corporate technology strategy and overall corporate strategy.

Posture and direction is one of the important elements of strategic management of technology. The next sections will explore the other two elements: systems; and adjustment processes.

5.3.2) Systems

Systems involve all the organizational structures, roles, and linkages that are required to support the innovation process. This section benchmarks these dimensions for the regions under analysis.

Structures

Structures comprise the organization of assets and resources that serve as inputs to the R&D process. This section explores how R&D organizations are designed and through which mechanisms they are funded across the different regions considered.

Figure 5.3.2.1 depicts the organization of research and development activities at the corporate level. There is a preference to organize research around technical subjects (40% of respondents). Development activities, however, are mainly organized around business units (35% of respondents). Figure 5.3.2.2 explores the organization of development activities at the corporate level on a regional basis. Sixty percent of Japanese respondents have development activities at the corporate level organized around business units. Interestingly, neither American nor Japanese respondents, and only 10% of European respondents organize development activities around technical disciplines. On the other hand, 60% of Latin American corporate development resources are organized around technical disciplines. This form of organization have different effects on the communication patterns between the R&D organization and the other business functions of the firm. It can also be a reflection of the small size of Brazilian firms, which do not have more

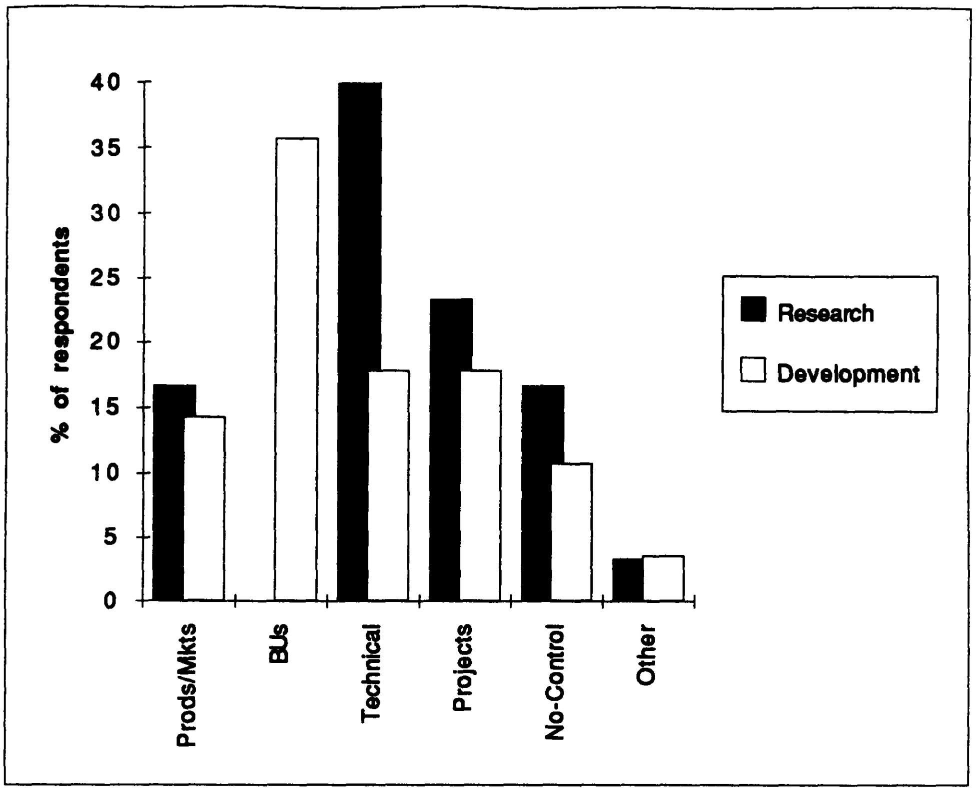


Figure 5.3.2.1: Organization of R&D resources at the corporate level

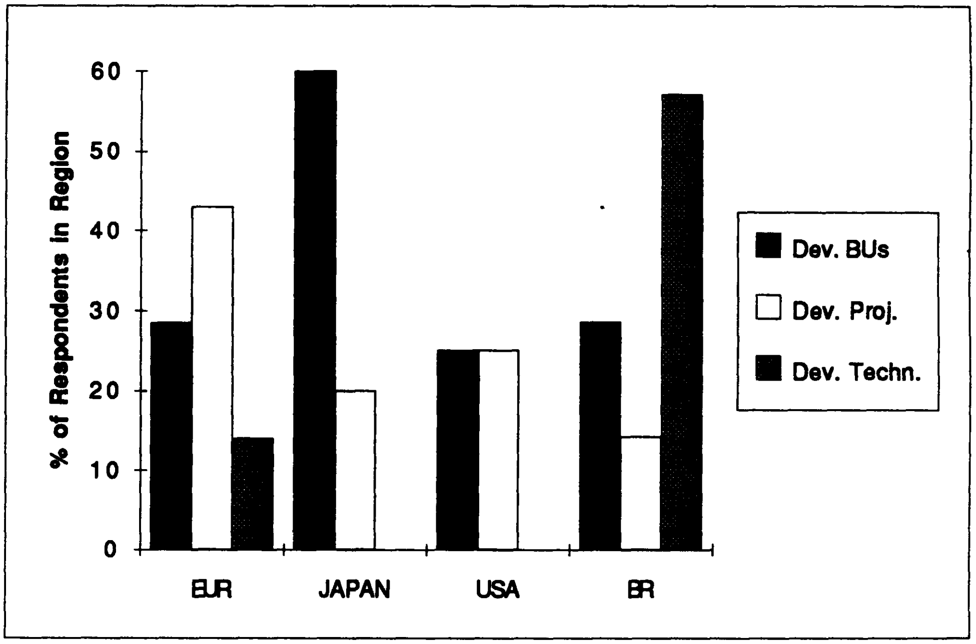


Figure 5.3.2.2: Organization of Development resources at the corporate level

than one business unit. Development, however, could still be organized around projects.

At the business unit level, research is generally organized around product/markets. Development is also organized around products/markets but at least 40% of respondents also organize development at the business unit level around projects (see figure 5.3.2.3). Figure 5.3.2.4 illustrates the regional organization of development activities at the business unit level.

Not only organizational structures are important for the R&D process. Division of activities and funding mechanisms are also of interest. Figures 5.3.2.5 and 5.3.2.6 depict the allocation of funds among research, development, and engineering (RD&E) at both corporate and business unit levels. Corporate RD&E is focused more on research and, to a lesser extent, on development. Business unit RD&E is more equally split between engineering and development. Japanese respondents do more engineering at a corporate level than American and European respondents. European firms in the sample do less research and more engineering at a business unit level than other regions. Unfortunately, few Brazilian respondents answered question B.4, which is the basis of figures 5.3.2.5 and 5.3.2.6.

Corporate funding is the most common source of resources to corporate R&D functions (see figure 5.3.2.7). This is particularly true among American respondents (figure 5.3.2.8). Other regions experiment more with different funding mechanisms, which may help to establish a closer linkage between business units and corporate R&D functions.

Another important organizational devise that would both improve R&D performance ($p=0.10$) and diminish time from concept to implementation ($p=0.04$) is the use of multi-functional teams. Figure 5.3.2.9 illustrates the percentage of respondents that extensively use multi-functional teams as part of their R&D process. Figure 5.3.2.10 depicts the use of multi-functional teams by activity on a regional basis.

In general, multi-functional teams are more used in development than in technology planning. A larger number of Japanese respondents use multi-

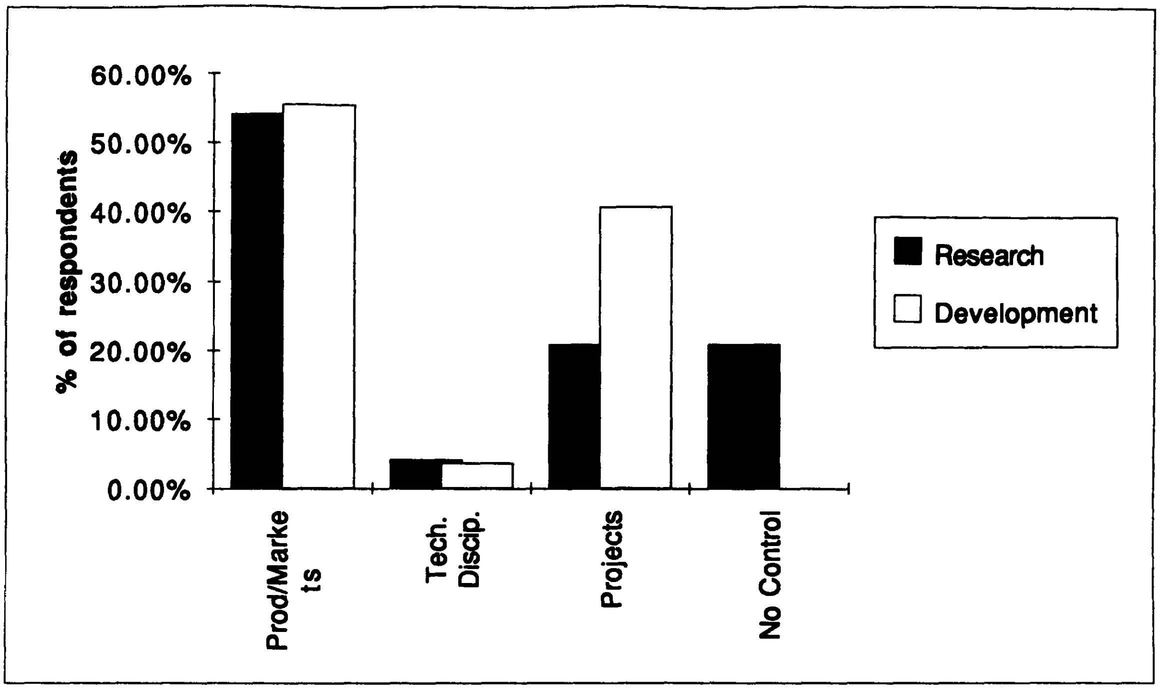


Figure 5.3.2.3: Organization of R&D resources at the business-unit level

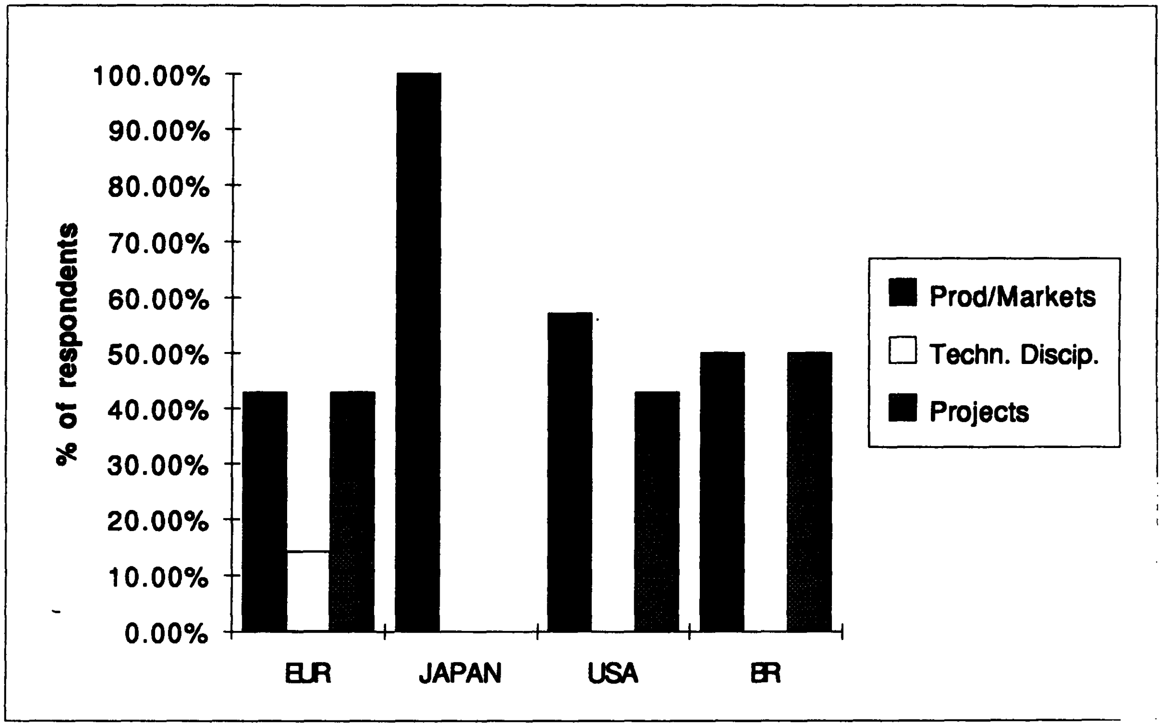


Figure 5.3.2.4: Organization of Development at the business-unit level

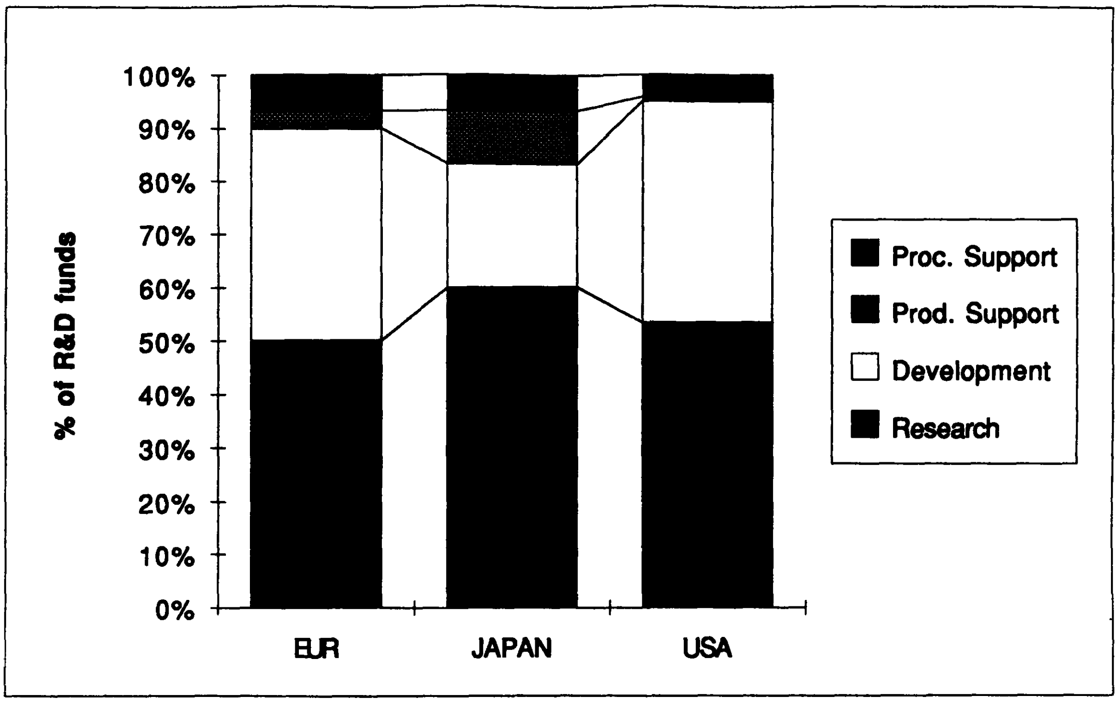


Figure 5.3.2.5: Budget allocations at Corporate R&D

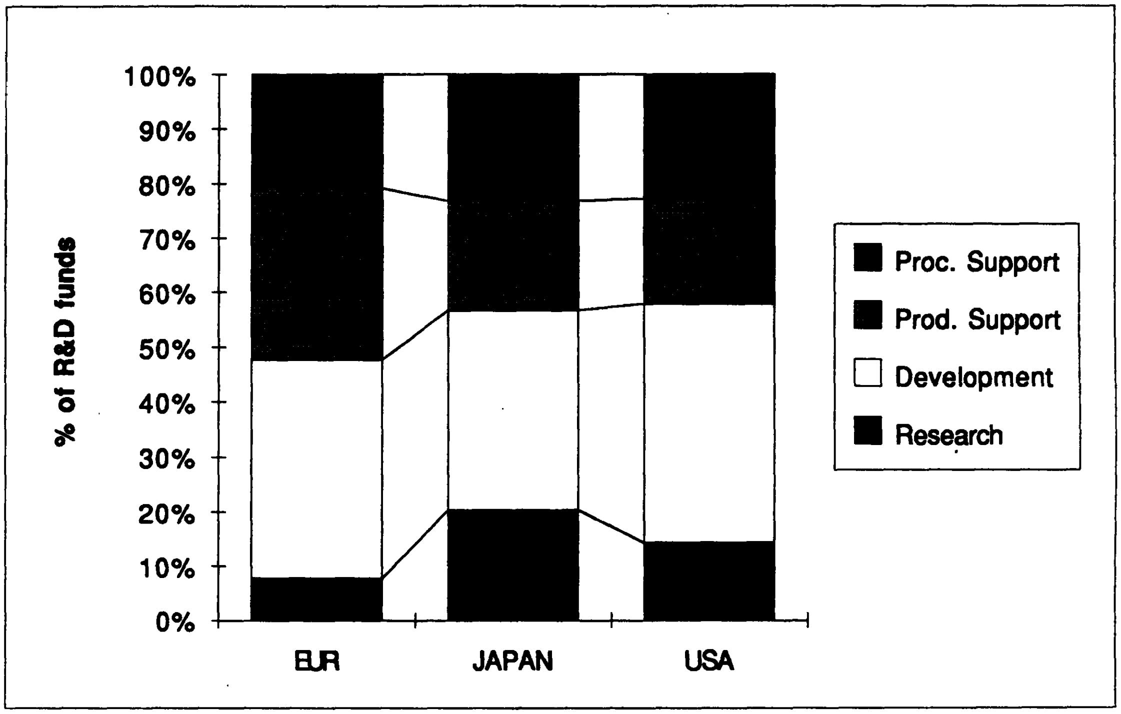


Figure 5.3.2.6: Budget allocations at business-unit level R&D

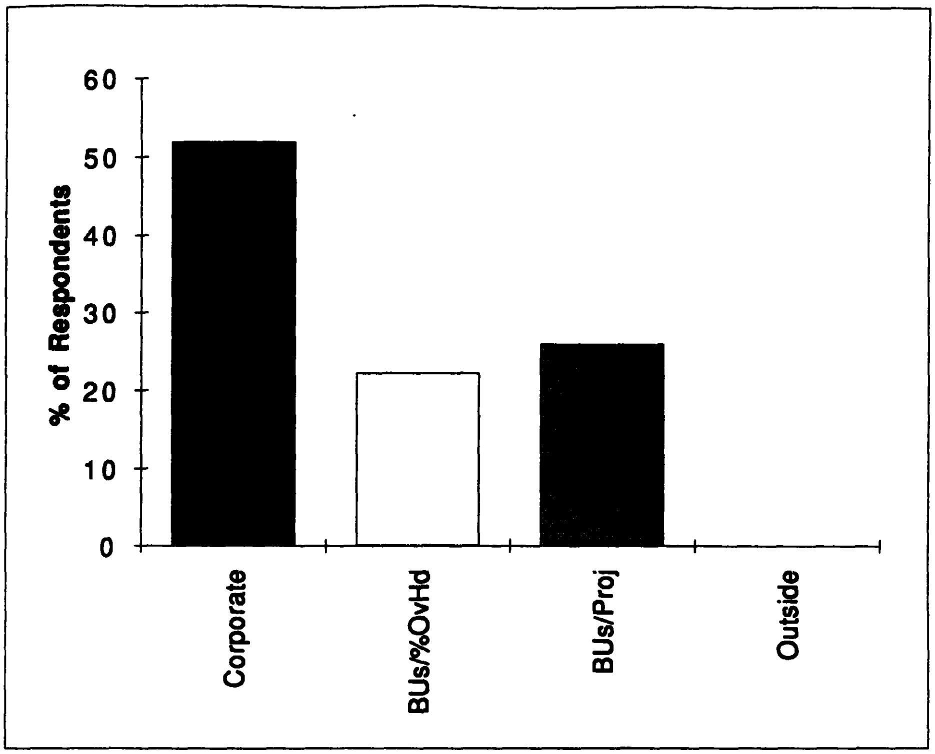


Figure 5.3.2.7: Main funding mechanisms of R&D at the corporate level

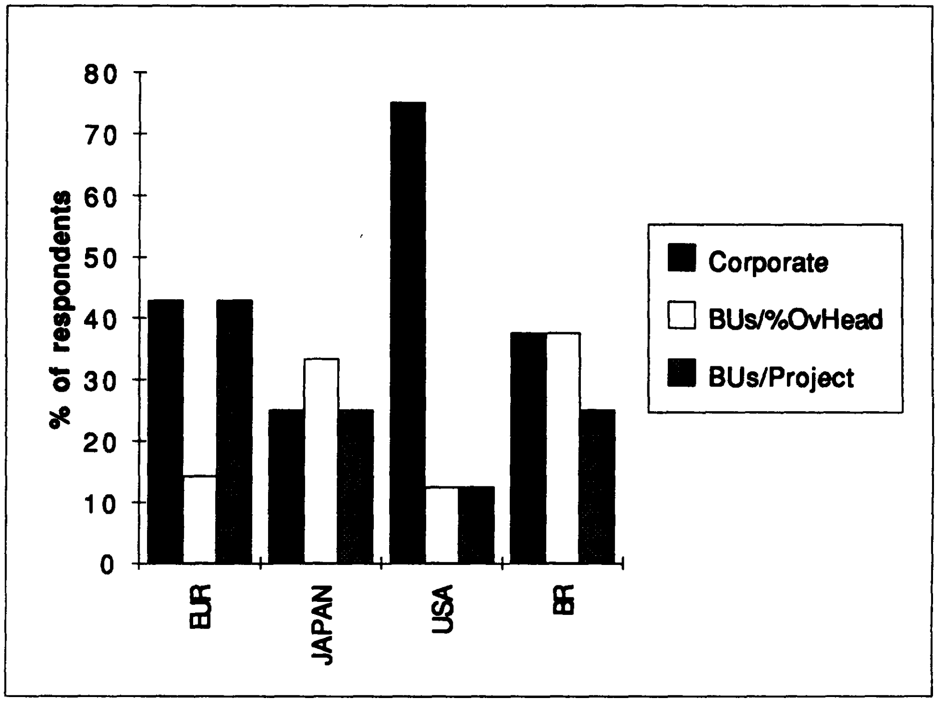


Figure 5.3.2.8: Corporate R&D funding mechanisms per region

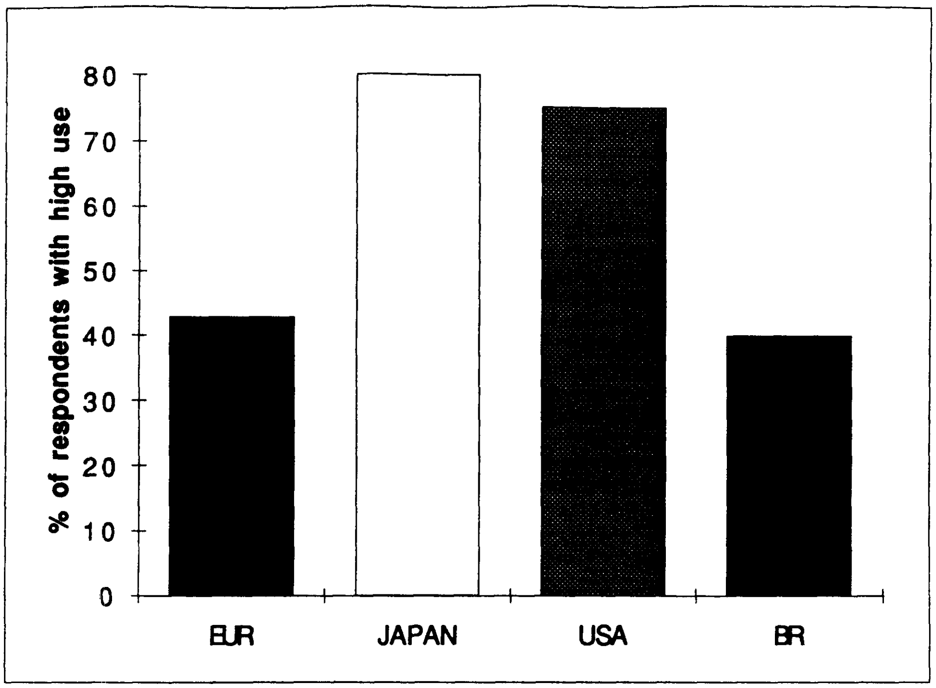


Figure 5.3.2.9: Use of multi-functional teams by region

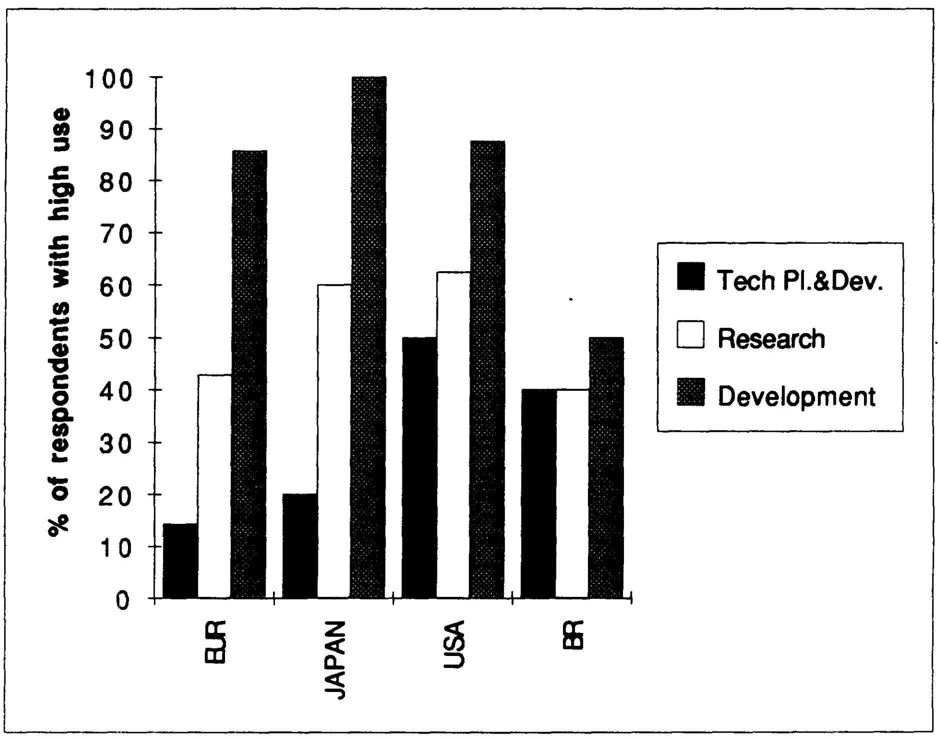


Figure 5.3.2.10: Use of multi-functional teams for different purposes

functional teams in development activities. A larger number of American respondents use multi-functional teams in technology strategy planning and development. Although Brazilian companies are on par with companies from other regions in the use of multi-functional teams in research and technology strategy planning and development, relatively few Brazilian respondents use multi-functional teams for development activities.

Roles

Chapter four had showed that a high involvement of the CEO in the R&D process is correlated with a high level of R&D performance (p=0.047). An index of involvement of the CEO in the R&D process was calculated by averaging each firms response to question B.8. The activities suggested on that question were: technology strategy development; project selection/prioritization; establishment of overall R&D budget; internal technology resource allocation; and selection of outside technological investments. Figure 5.3.2.11 shows the involvement index for each region. To obtain a higher insight about the CEO roles in each region, her/his participation was broken in those different activities. Table 5.3.2.1 illustrates the results.

CEOs of Japanese respondents are highly involved in all activities of the R&D process. American CEOs in the sample do not participate in project selection/prioritization and participate very little on internal technology resource allocation. Quite impressive is the small participation of European CEOs in the R&D process. Despite establishing an overall R&D budget, European CEOs in the sample are totally absent of high involvement in other R&D important decision activities.

Most important for us, however, is the degree of involvement of CEOs of Brazilian respondents. Although the involvement index of Brazilian CEOs is high, it is mostly a reflection of their high involvement in the selection of outside technological investments, which, may be explained by the strategy followed by Brazilian companies, their size, and their dependence on external sources of technology. Importantly, Brazilian CEOs are not substantially involved in other R&D decisions.

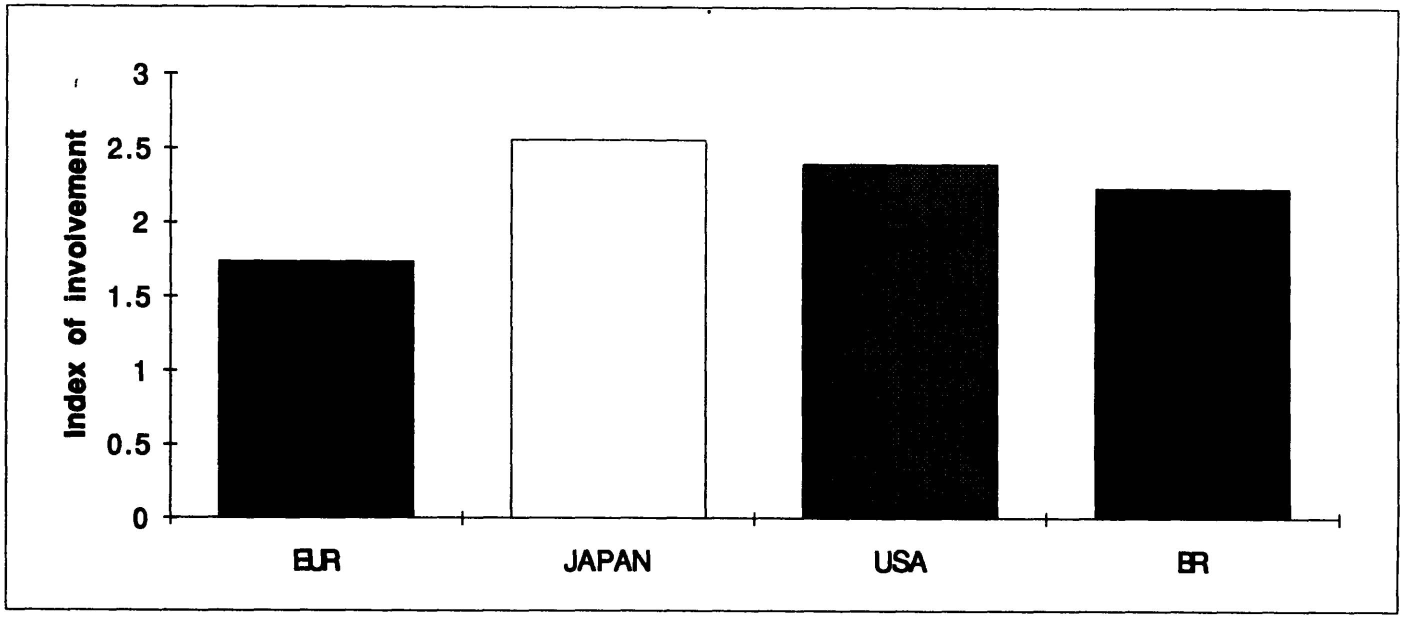


Figure 5.3.2.11: Involvement of the CEO in the R&D process

Table 5.3.2.1: CEO activities and regions

Activities	CEO Role in Technology Strategy (% of CEOs highly involved)			
	EUR	JAPAN	USA	BR
Technology Strategy Development	17%	60%	50%	33%
Project Selection/Prioritization	0%	40%	0%	22%
Establishment of Overall R&D Budget	50%	80%	88%	22%
Internal Technology Res. Allocation	0%	40%	13%	11%
Selection of Outside Tech. Investments	0%	60%	38%	67%

An activity index was calculated using the answers obtained in question B.6 of the survey to assess the role of the CTO in the R&D process. Figure 5.3.2.12 plots this index for different regions. Table 5.3.2.2 breakdowns the role of the CTO in different activities and depicts the percentage of CTOs that are highly involved in a specific activity in each region. CTOs of Brazilian respondents have a low involvement in both corporate strategy development and in the direction of corporate technology strategy formulation. In addition, they generally have low discretionary power to allocate resources between corporate and business unit R&D. Note also that they have low command in the allocation of R&D resources across business units, mainly when compared with Japanese and European respondents.

Linkages

This section deals with how firms utilize input from external customers and the marketplace in the R&D process. In addition, it explores the systems that are in place to support the process of moving products to market.

Customer input can be used in different phases of the R&D process. Figure 5.3.2.13 shows an overall index of customer input[62] in the following activities: technology strategy development; setting program objectives; obtaining innovative ideas; concept development; prototype development; testing; product refinement and commercialization; and product improvement. Customer input is higher in the last phases of the R&D process and in setting program objectives. Interestingly, the idea that customers can have an important impact in R&D performance by providing innovative ideas seems not to be explored in depth by respondents.

Figure 5.3.2.14 depicts the percentage of respondents with high use of customer input in the R&D process for each region. A larger number of Japanese respondents indicate a high use of customer input in their R&D process. A considerable number of American firms in the sample also indicated a high use, whereas only 30% of Brazilian and European firms use customer input as part of their R&D process.

---

[62] Calculated by averaging answers for question D.1, part I.

Linking Activities	Role of CTO (% of CTOs highly involved)			
	EUR	JAPAN	USA	BR
Corporate strategy development	57.14	80.00	100.00	50.00
Directs corporate tech. strategy development	57.14	80.00	85.71	60.00
Controls resource allocation (Corporate/BUs)	42.86	60.00	71.43	10.00
Controls R&D resource allocation across BUs	28.57	40.00	14.29	10.00
Directs BUs technology strategy	14.29	20.00	0.00	20.00
Participate in BUs technology strategy	14.29	60.00	28.57	40.00
Directs corporate R&D organization	57.14	60.00	100.00	80.00
Monitors and assesses external technologies	42.86	60.00	42.86	60.00
Determine investments in outside techologies	42.86	60.00	71.43	40.00
Serves as liaison to outside organizations	42.86	60.00	57.14	70.00

Table 5.3.2.2: Role of the Chief Technology Officer

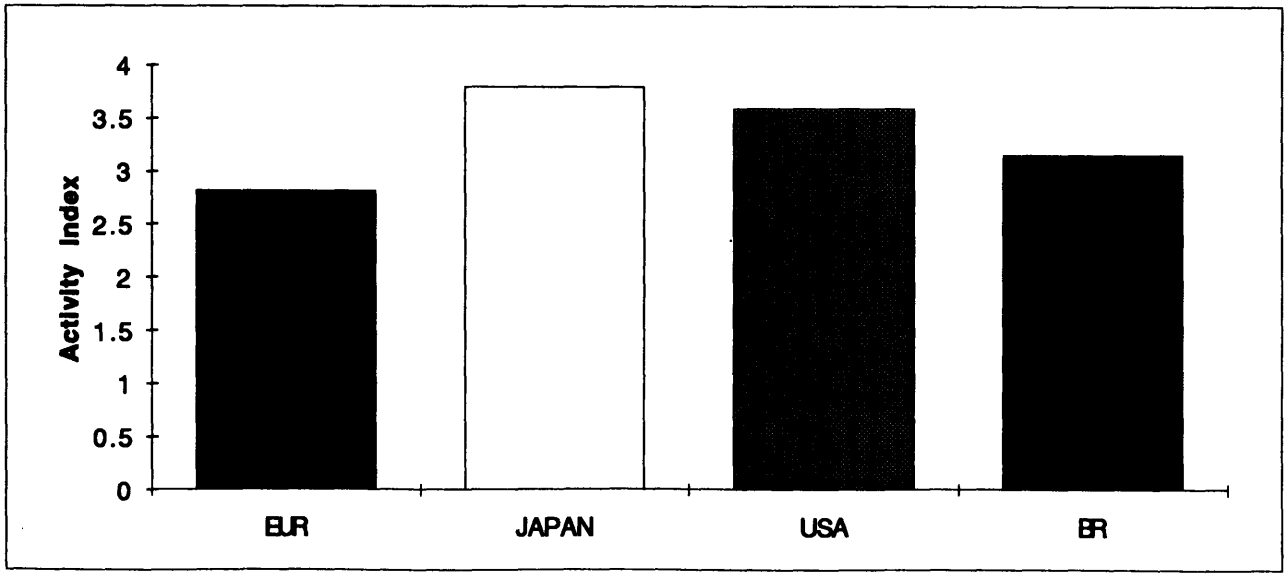


Figure 5.3.2.12: The role of the CTO in different regions

Table 5.3.2.3 breaks down the use of customer input in each activity for each region. Although Japanese industry have a higher overall use of customer input in the R&D process, no Japanese firm in the sample use customer input to obtain innovative ideas and to develop new concepts. Also very interesting is the low number of Brazilian firms that use customer input in the latter phases of the R&D process. In addition, opportunities exist in Brazil to increase the number of companies that use customer input in concept development, technology strategy formulation, and setting program objectives.

Customer inputs can be obtained through either formal, structured processes or informal, ad hoc processes. Figure 5.3.2.15 depicts an average index of organization of customer input in each one of the regions studied. In a scale of 1 (ad hoc, informal) to 5 (structured, formal) respondents have very similar "organization" indexes. On average, however, American respondents use more structured processes for obtaining customer input.

Figure 5.3.2.16 illustrates how firms obtain customer input for research activity. In general, R&D organizations identify and obtain customer input in 40% of respondents. In almost 15% of organizations, marketing is responsible for identifying customer input, but does an inadequate job in obtaining and transferring the information. This number is higher among American respondents, where 25% of firms acknowledge that marketing does an inadequate job in obtaining and transferring information to R&D organization. In Brazil, respondents have a higher participation of marketing entities in the research process. This may reflect the fact that Brazilian respondents have a research portfolio more focused on short-term projects (<3 years).

Figure 5.3.2.17 illustrates the process of obtaining customer input for development activities. Overall, R&D does not obtain the information that it needs. Other organizational entities, such as marketing, have an important role in obtaining and transferring customer input to R&D entities. In North America and Brazil, respondents report a higher percentage of marketing organizations that do not perform an adequate job in obtaining and transferring customer input to R&D. In Japan, more than 70% of respondents report that marketing does an adequate job in obtaining and transferring

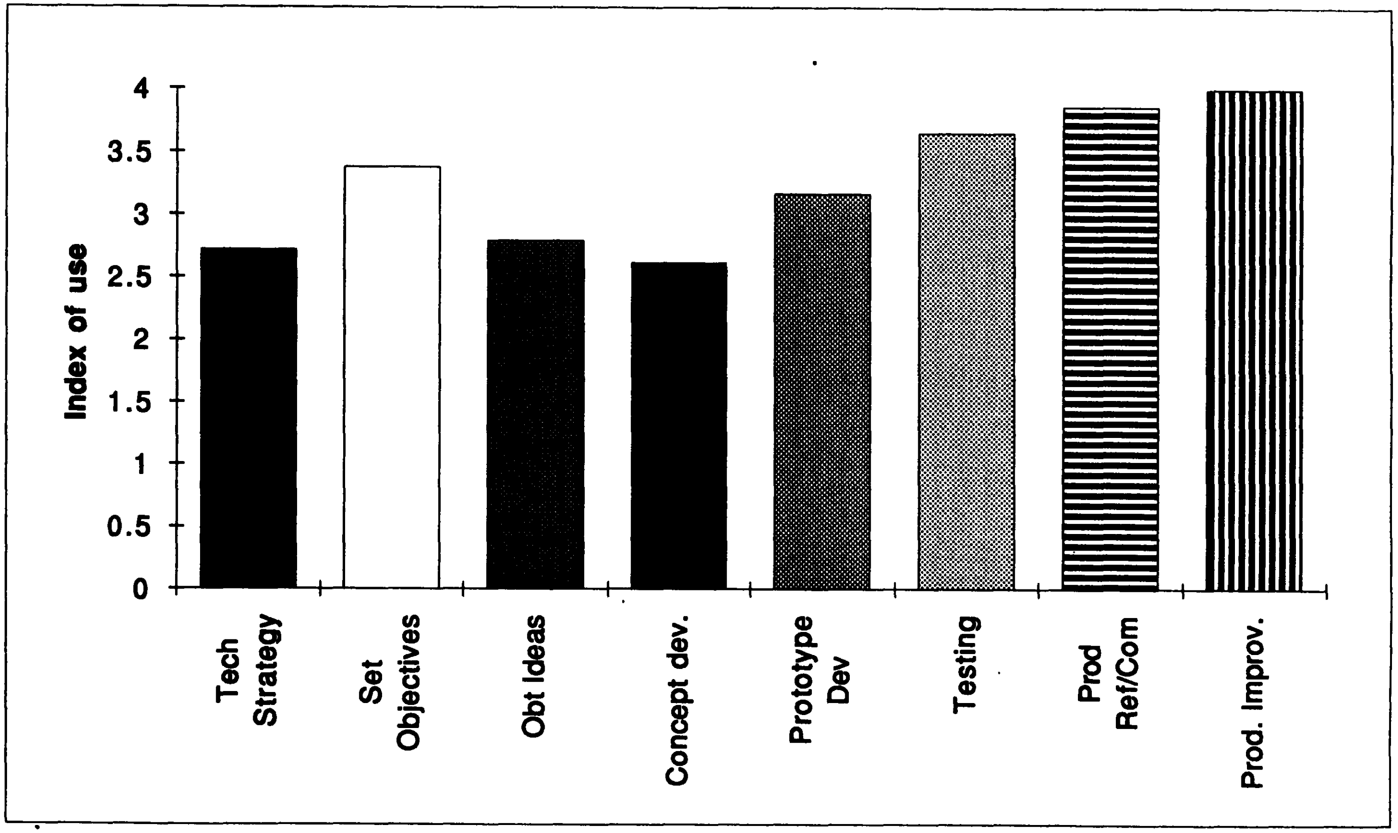


Figure 5.3.2.13: Use of customer input in the different phases of the R&D process

Table 5.3.2.3: Use of customer imput in the activities of the innovation process in each region

	Use of Customer Input (% of respondents with high use)							
Region	Tech. Strategy Development	Setting Program Objectives	Obt. Innovative Ideas	Concept Development	Prototype Development	Testing	Product Ref. Commerc.	Product Improv.
EUR	28.57%	28.57%	28.57%	0.00%	42.86%	71.43%	85.71%	71.43%
JAPAN	50.00%	75.00%	0.00%	0.00%	75.00%	75.00%	75.00%	75.00%
USA	37.50%	87.50%	25.00%	50.00%	62.50%	62.50%	75.00%	87.50%
BR	40.00%	40.00%	30.00%	10.00%	20.00%	30.00%	50.00%	70.00%

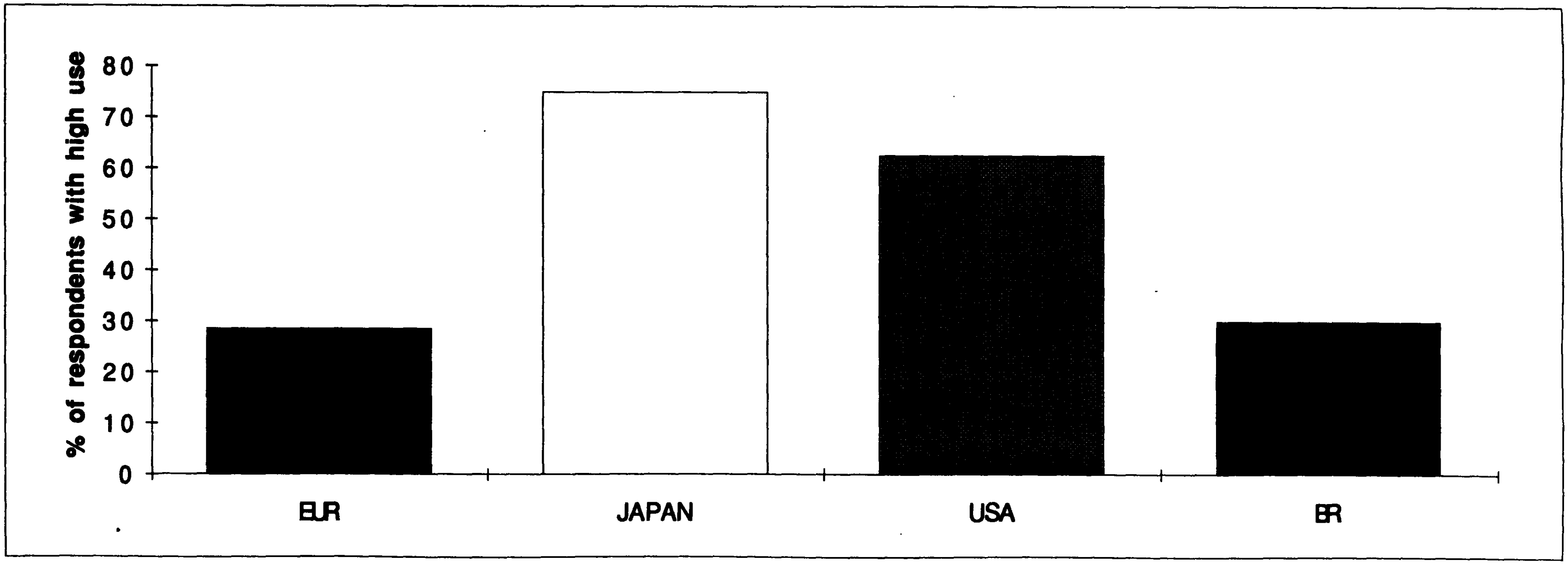


Figure 5.3.2.14: Use of customer input by region

customer input to R&D. Importantly, this index is relatively high among Brazilian respondents (around 55%).

Although customer input is an important element to the R&D process, the consistency in which firms meet target dates for product commercialization or process implementation is also extremely valuable. As presented in chapter 3, a series of practices can be used to move a product or a process from concept to implementation. Figure 5.3.2.18 depicts the most used ones based on an index of "use", which is calculated by averaging the answers for question G.1 across regions.

Table 5.3.2.4 breaks the use of different practices at the regional level. According to the analysis conducted in chapter 4, these practices have an important effect in the ability of the organization to move products or processes from concept to implementation. Only 10% of Brazilian respondents actively use accountability of assigned managers to shorten time from idea to implementation (p=0.0285[63]). In addition only 40% use multi-functional teams (p=0.04), 30% use early market test (p=0.069), and 10% use senior sponsors (p=0.25) or simultaneous engineering methods (p=0.30). Regarding the transfer of professionals with a project as it moves from development into manufacturing, only 37% of American respondents use this practice relative to 60% and 50% of respondents in Japan and Brazil respectively.

Figure 5.3.2.19 indicates the success of respondents in meeting target dates for either product commercialization or process implementation at a regional level. As expected through the analysis conducted above, Brazilian companies have the lowest index of success relative to their counterparts. Importantly, one could argue that constant economic shocks and political instability in Brazil would affect this index. We believe that this has indeed an effect. On the other hand, Brazilian companies have, among themselves, highly successful firms in moving products/processes from concept to implementation as demonstrated in figure 5.3.2.20.

---

63 This and the following p-values refer to the effect of the specific policy in the time from idea generation to product or process implementation.

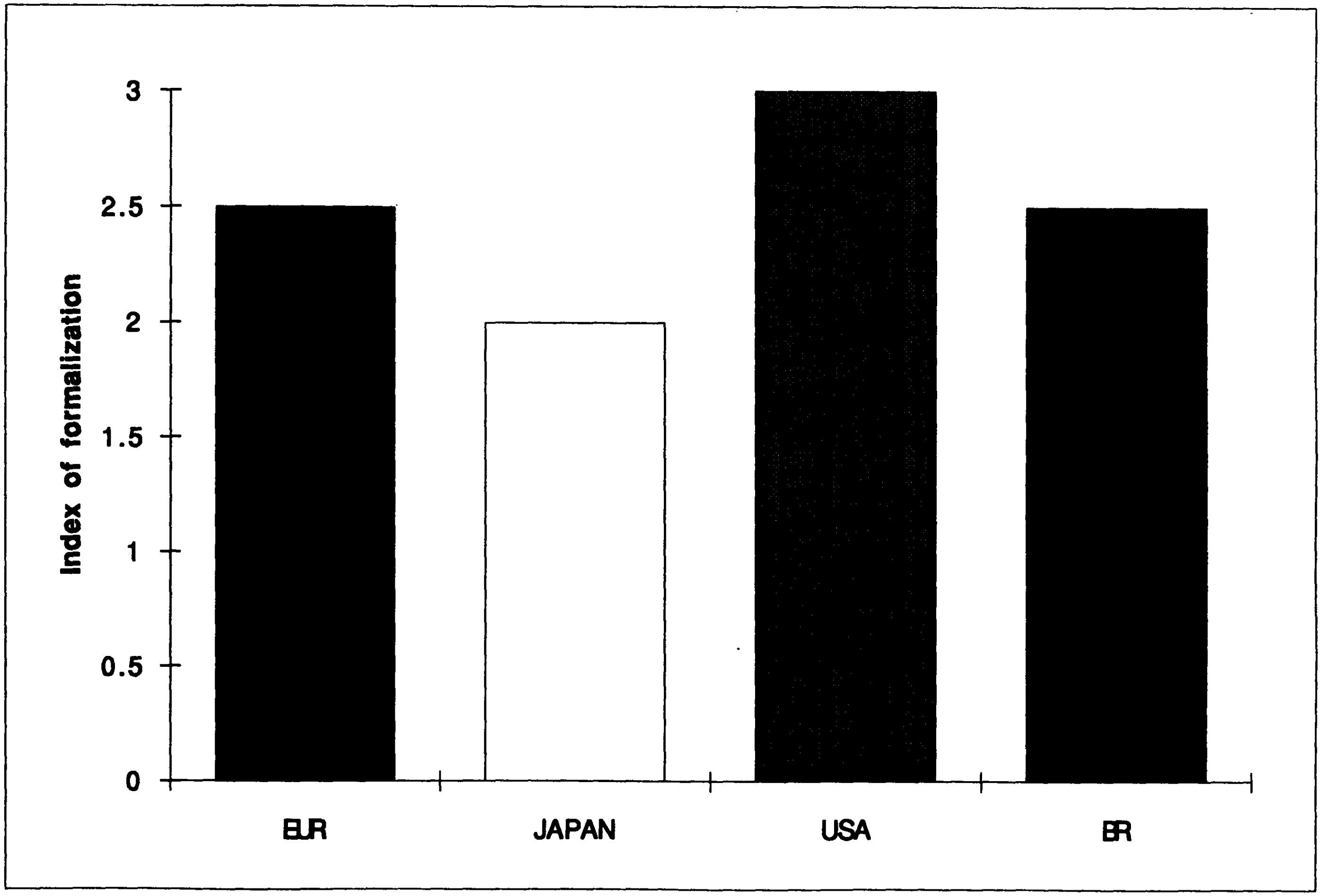


Figure 5.3.2.15: Process of obtainning customer input

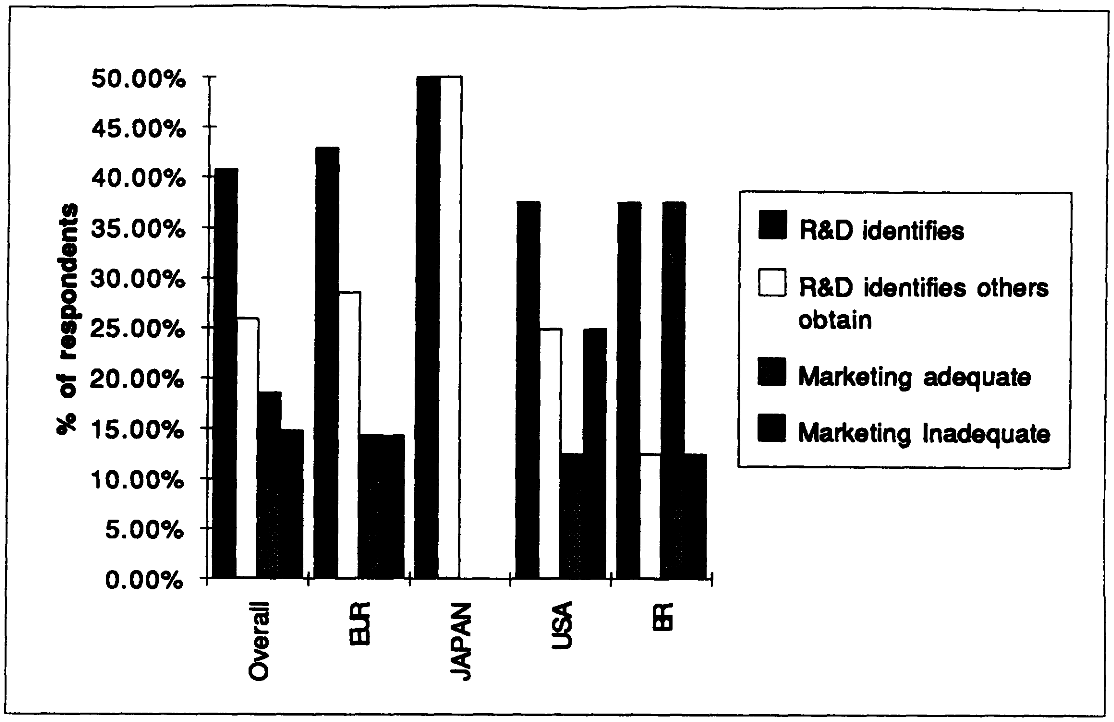


Figure 5.3.2.16: Mechanisms to obtain customer input - research activities

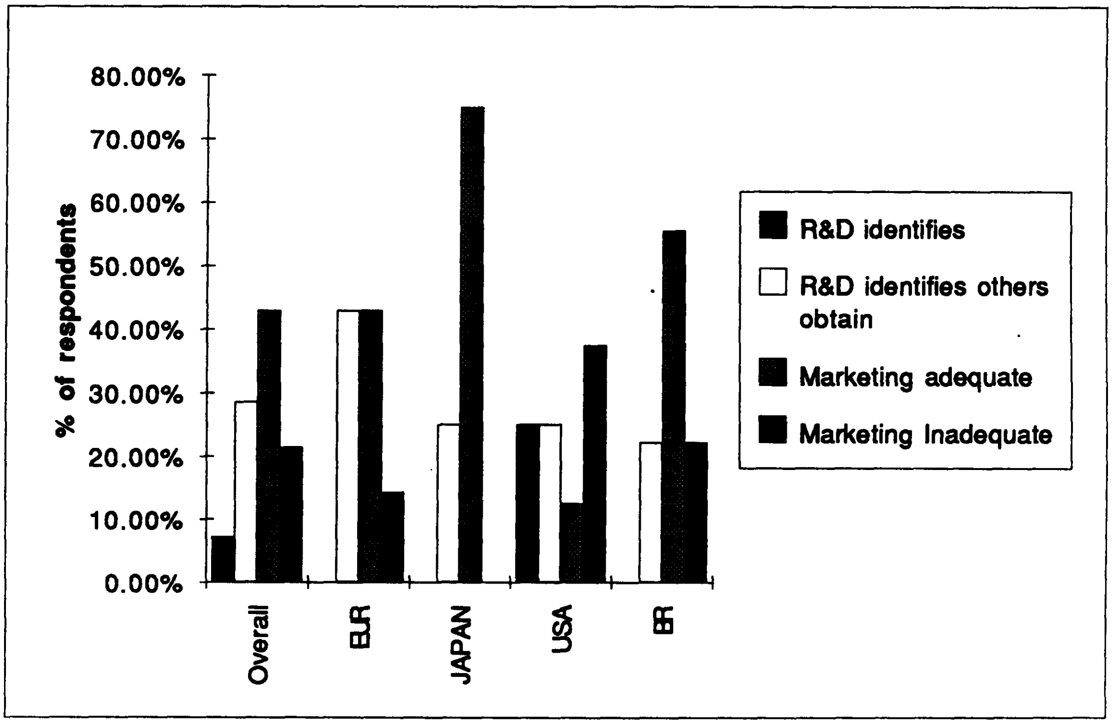


Figure 5.3.2.17: Mechanisms to obtain customer input - Development activities

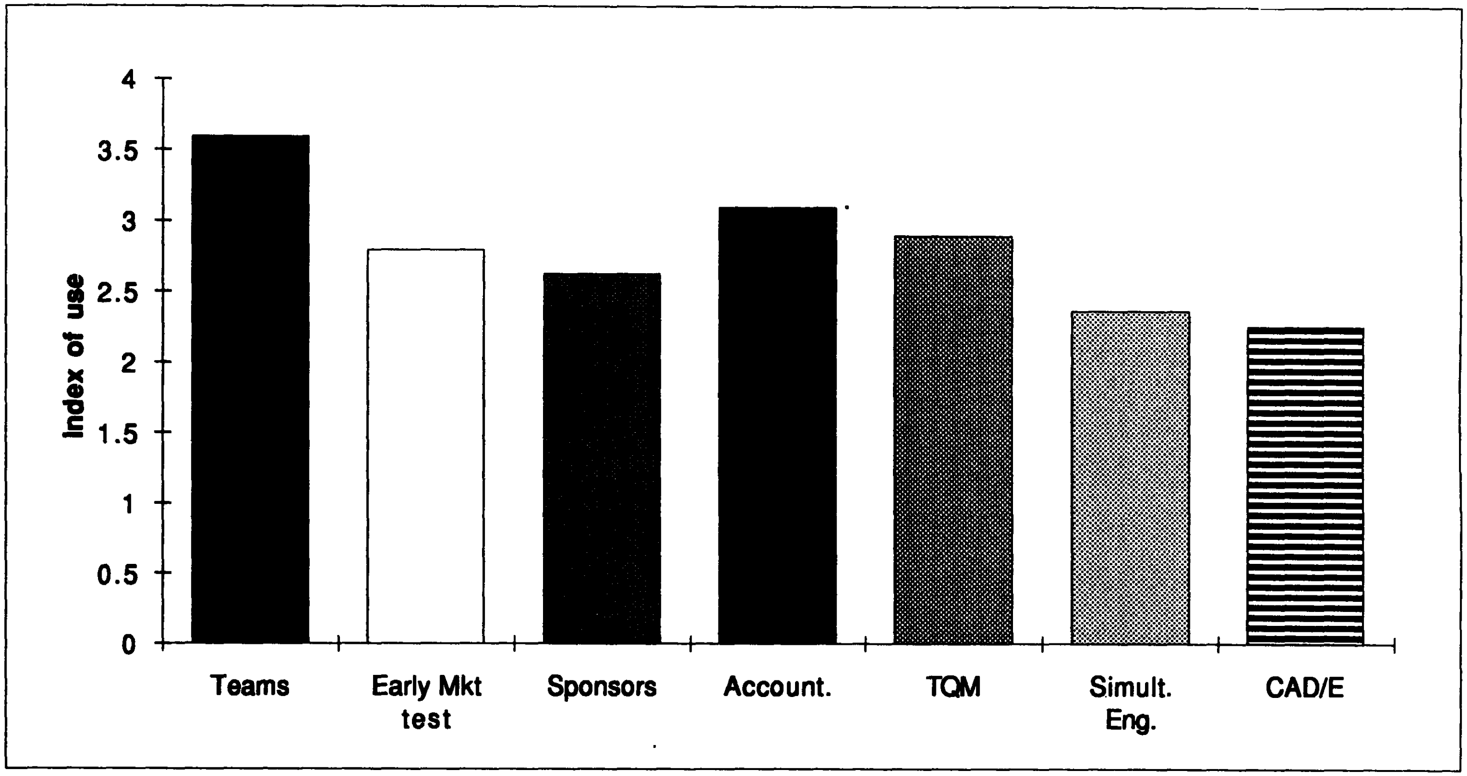


Figure 5.3.2.18: Most used mechanisms for moving innovations form concept to implementation

Table 5.3.2.4: Mechanisms used to move products to market

Regions	Moving Products (% of respondents indicating high use of mechanism)						
	Teams	Early Mkt Test	Sponsors	Account.	TQM	Simult. Eng.	Transfer
EUR	57.14	42.86	28.57	57.14	14.29	0.00	42.86
JAPAN	80.00	80.00	60.00	60.00	20.00	40.00	60.00
USA	87.50	25.00	62.50	62.50	50.00	50.00	37.50
BR	40.00	30.00	10.00	10.00	40.00	10.00	50.00

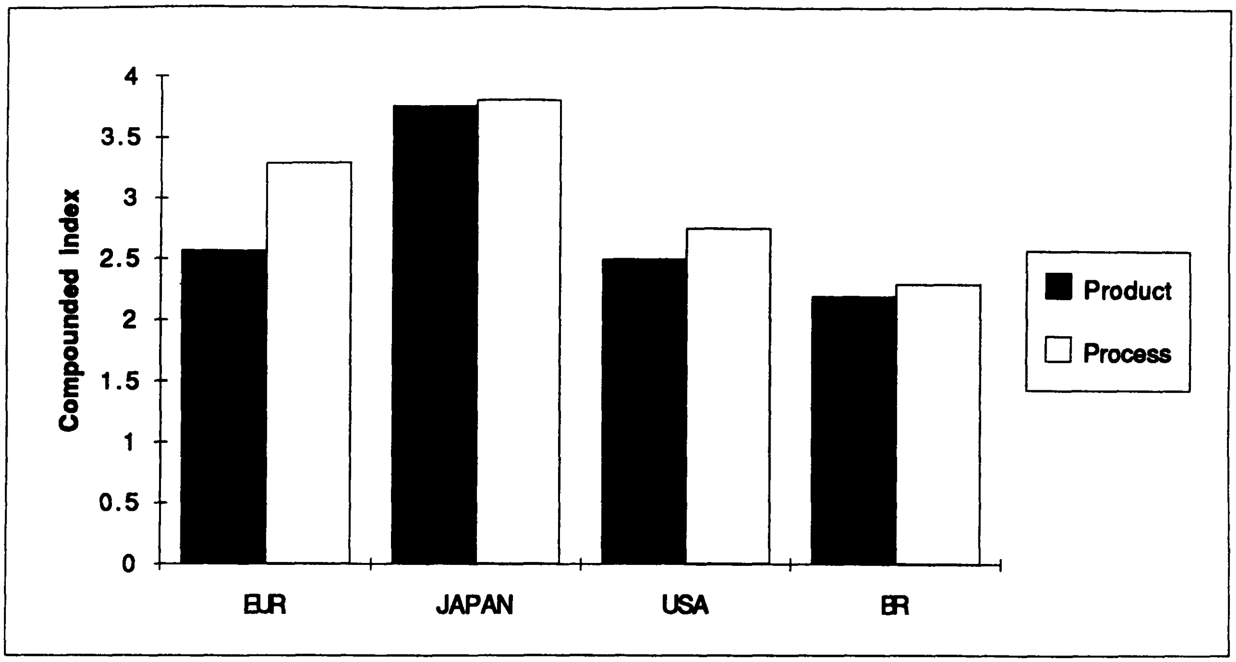


Figure 5.3.3.19: Meeting target dates for product/process innovations

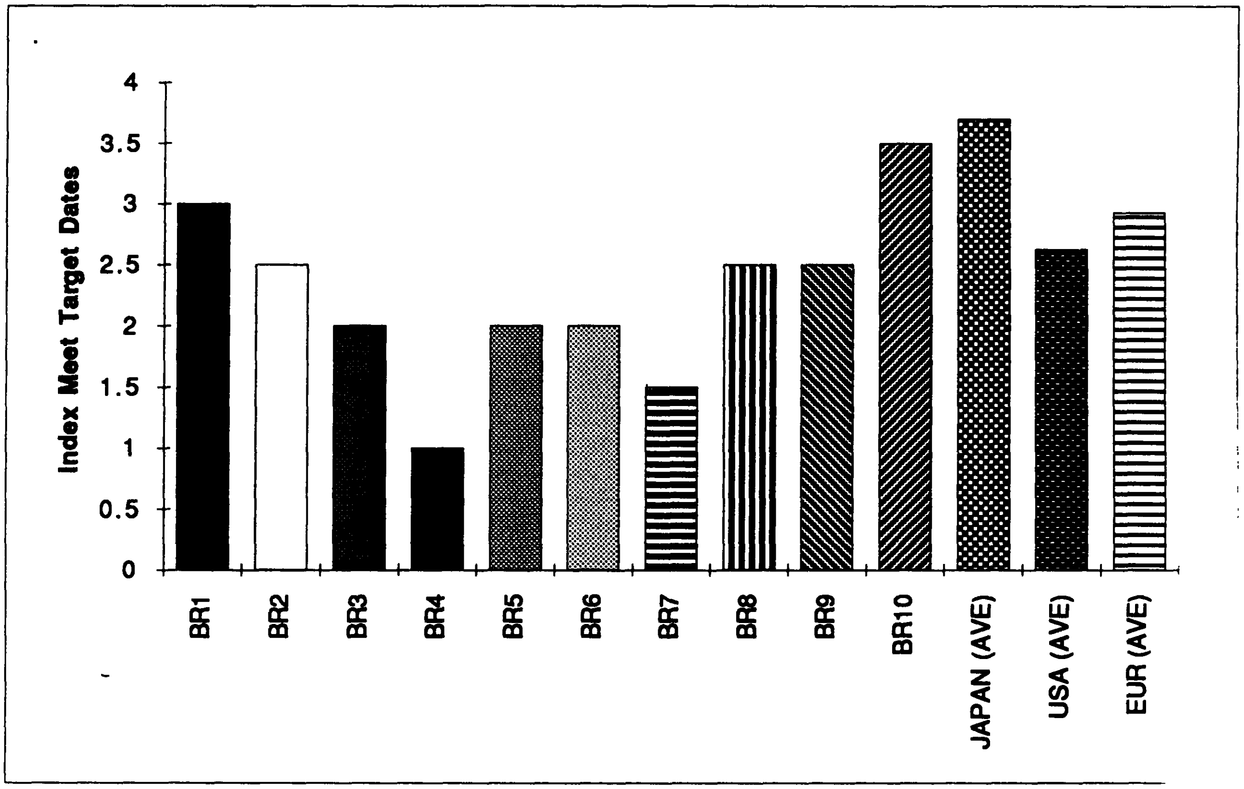


Figure 5.3.2.20: Meeting target dates on prod/proc innovations in Brazil

5.3.3) Adjustment Processes

Adjustment processes are aimed at identifying industry's threats and opportunities and firm's strengths and weaknesses. It involves technology monitoring and assessing; analysis of competition; and answers to global technological issues, like the internationalization of R&D and external sources of technology. For the purposes of this thesis, which focuses in policy recommendations for the Brazilian industry, only monitoring activities and the relationship industry/university are explored.

Starting with monitoring activities, figure 5.3.3.1 depicts the most used mechanisms for all survey respondents[64]. Internal steering groups is the most used mechanism, followed by industry consortia and customer input. Although venture capital is the lowest used mechanisms, it nevertheless is not far from the other region's indexes.

The use of monitoring activities at the regional level is shown in figure 5.3.3.2. The figure illustrates the percentage of companies in a specific region that have a moderate to high use of monitoring activities as part of their R&D processes. Whereas almost 60% of Japanese respondents and near 50% of American respondents use monitoring activities importantly in their R&D process, only 20% of Brazilian respondents and no European respondents use these activities significantly to improve their R&D processes.

The index used to segment firms in figure 5.3.3.2 is an aggregated value among all different types of monitoring activities. In table 5.3.3.1, the monitoring index is illustrated for each specific activity. Brazilian companies have the lowest indexes across all monitoring activities, besides customer input and venture capital.

Brazilian respondents have very few links with universities. Indeed, figure 5.3.3.3 illustrates the percentage of companies that indicate a high use of university programs. Importantly, as depicted in figure 5.3.3.4, universities

---

64 The intensity of the monitoring activity (monitoring index) is calculated by averaging the answers to question E.1/part I.

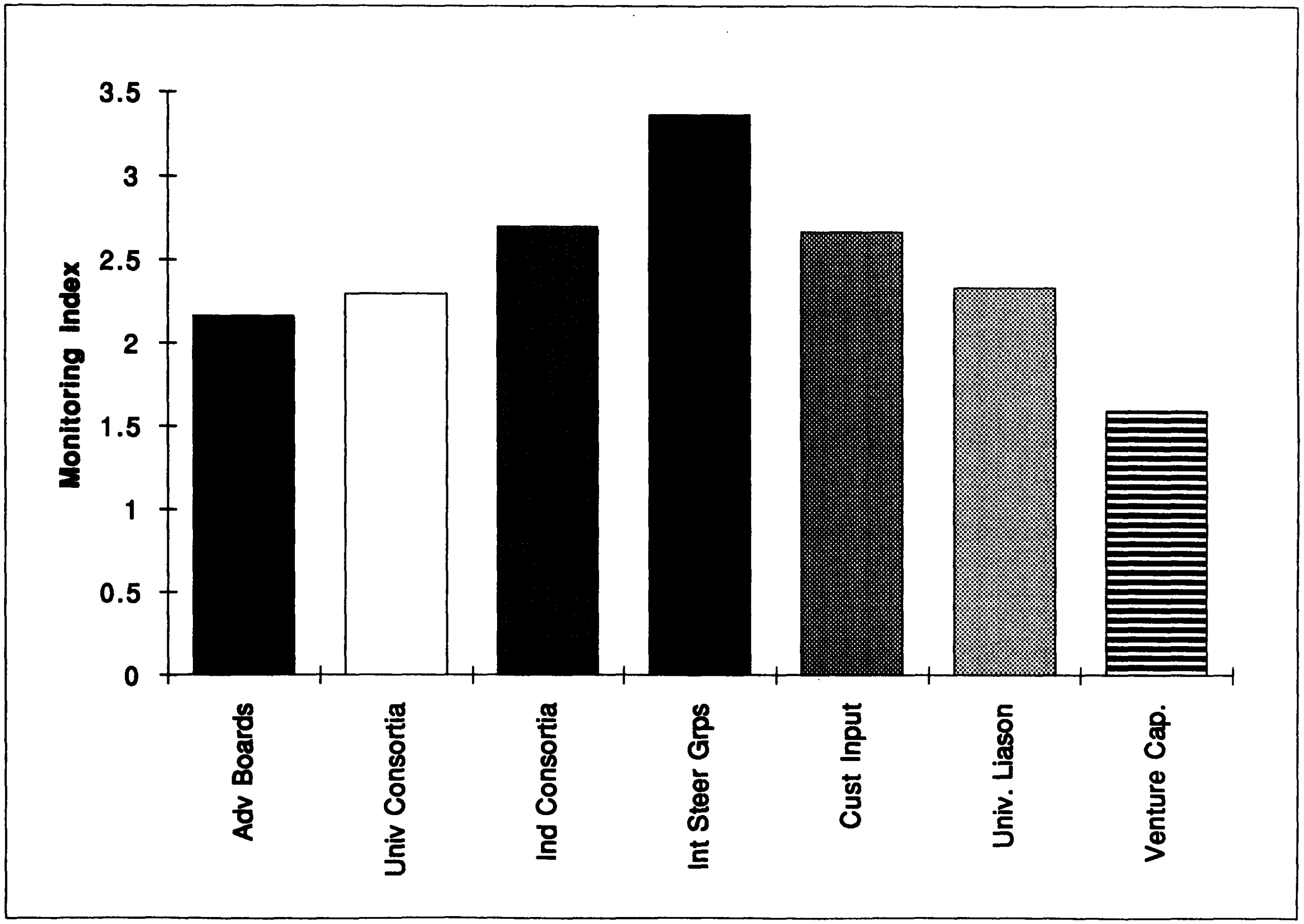


Figure 5.3.3.1: Mechanisms of technology monitoring

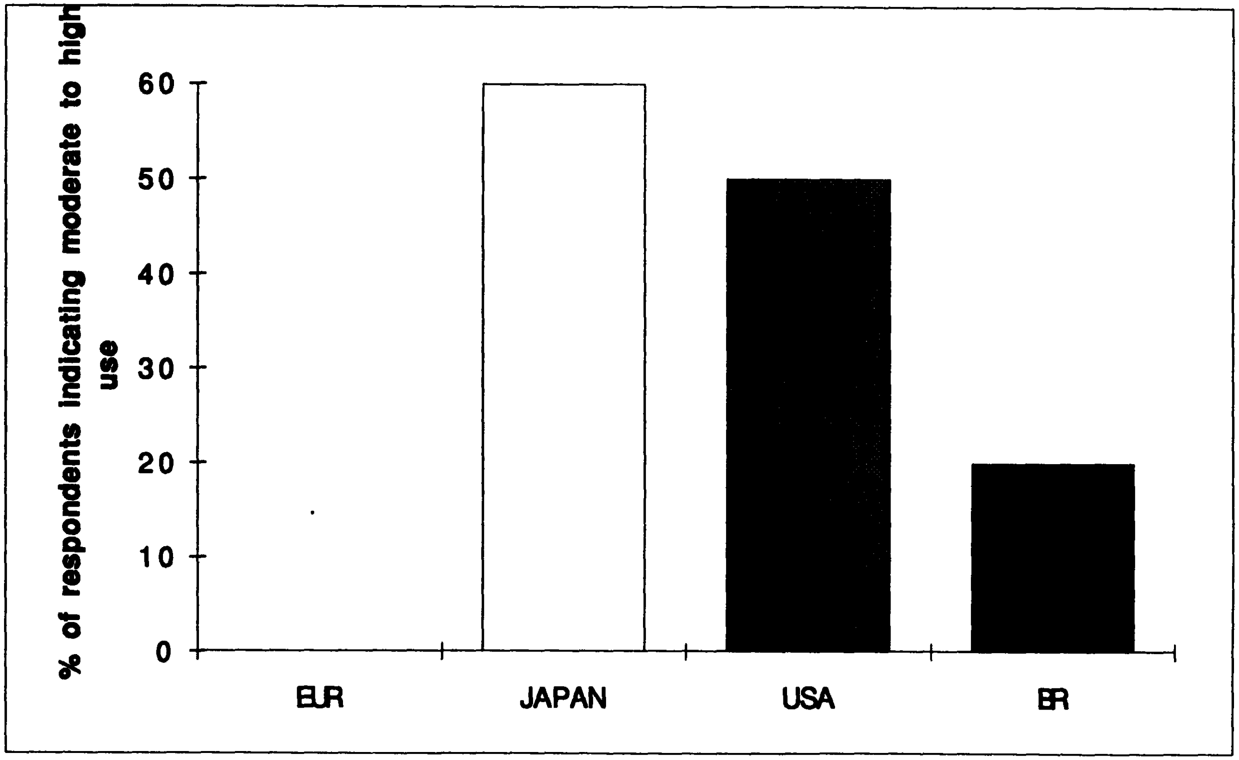


Figure 5.3.3.2: Companies using technology monitoring activities in each region

Table 5.3.3.1: Monitoring activities across regions

Region	Monitoring (Compounded index of activities)						
	Adv Boards	Univ Consortia	Ind Consortia	Int Steer Groups	Cust. Input	Univ. Liaison	Venture Cap.
EUR	1.86	2.43	2.43	3.43	1.43	2.29	1.29
JAPAN	3.00	2.60	3.20	3.80	3.40	2.60	2.60
USA	2.38	3.13	3.50	3.50	3.25	3.25	1.50
BR	1.80	1.40	2.00	3.00	2.70	1.50	1.40

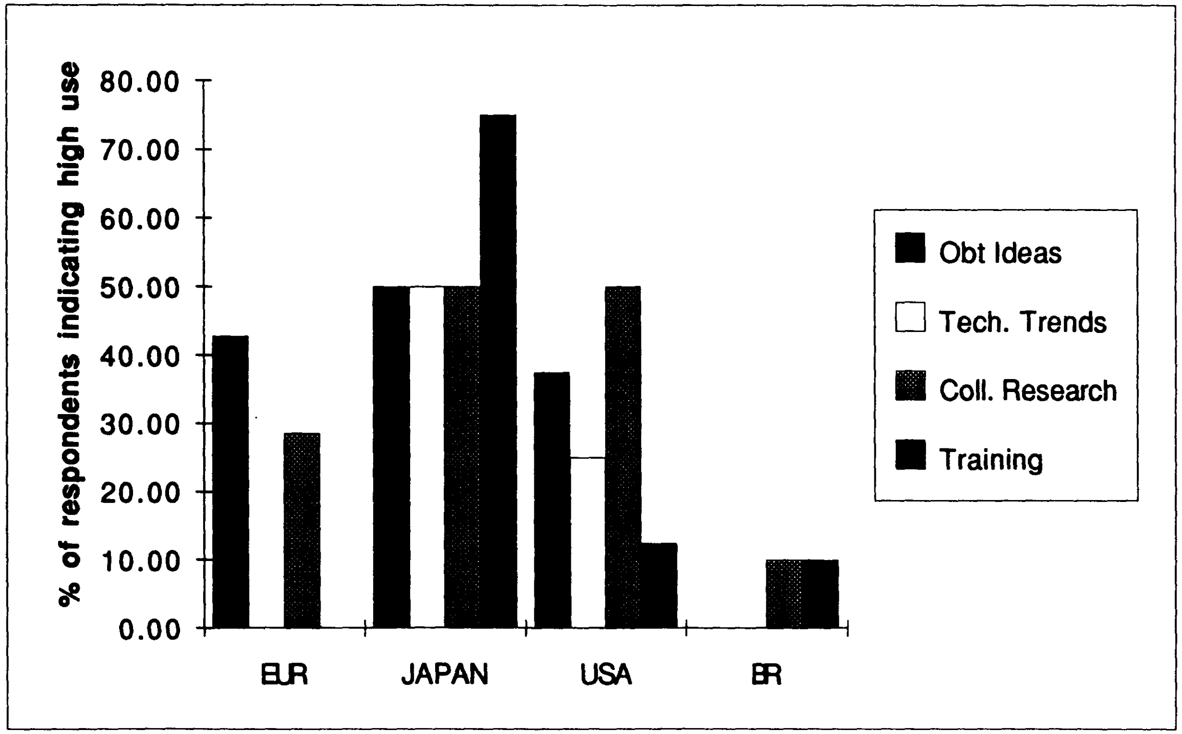


Figure 5.3.3.3: Use of university programs in each region

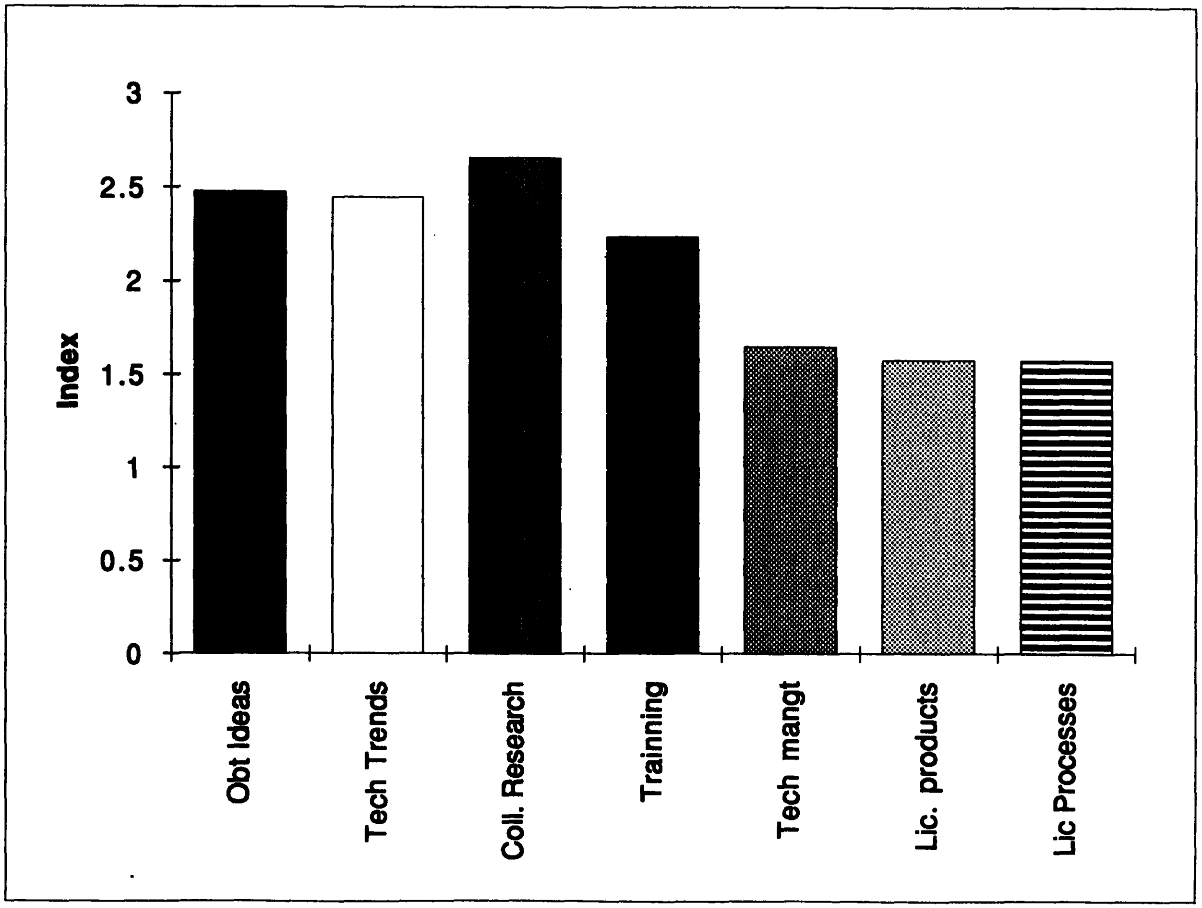


Figure 5.3.3.4: Use of university programs

are mostly used for collaborative research, training, assessment of technological trends, and to obtain innovative ideas.

Looking at figure 5.3.3.5, one sees that technology is mostly acquired through licensing and joint-venture in Brazil. This is exactly the point in which universities do not contribute significantly for the private sector as a whole (as seen in figure 5.3.3.4). On the other hand, figure 5.3.3.5 also tells that research, development through industry consortia, and development through university consortia are still important for some respondents in Brazil. In this context, one could expect a higher participation in university programs, mainly collaborative research and training, as it is demonstrated by table 5.3.3.2.

Training would be even more fostered as technical employees need more and more business skills to contribute more effectively for the R&D process (see figure 5.3.3.6). In addition, industry consortia and university consortia also become more important as companies increase their reliance on external sources of technology, as depicted by figure 5.3.3.7. We believe that this increase is closely associated with the increase in risks and costs of innovations in the chemicals/materials industry. In this context, association would be very interesting since it helps to spread costs and risks of the innovation process.

5.4) Summary

This chapter presented a regional analysis of management of technology practices in the chemicals/materials industry. The framework developed by Adler (1992) was used to determine performance and practice benchmarks in all regions.

Japanese respondents have an impressive record of having the highest utilization indexes of many of the important policies that contribute to R&D performance at the firm level. American respondents follow close, but opportunities seem to exist in some areas, namely: linkage between technology

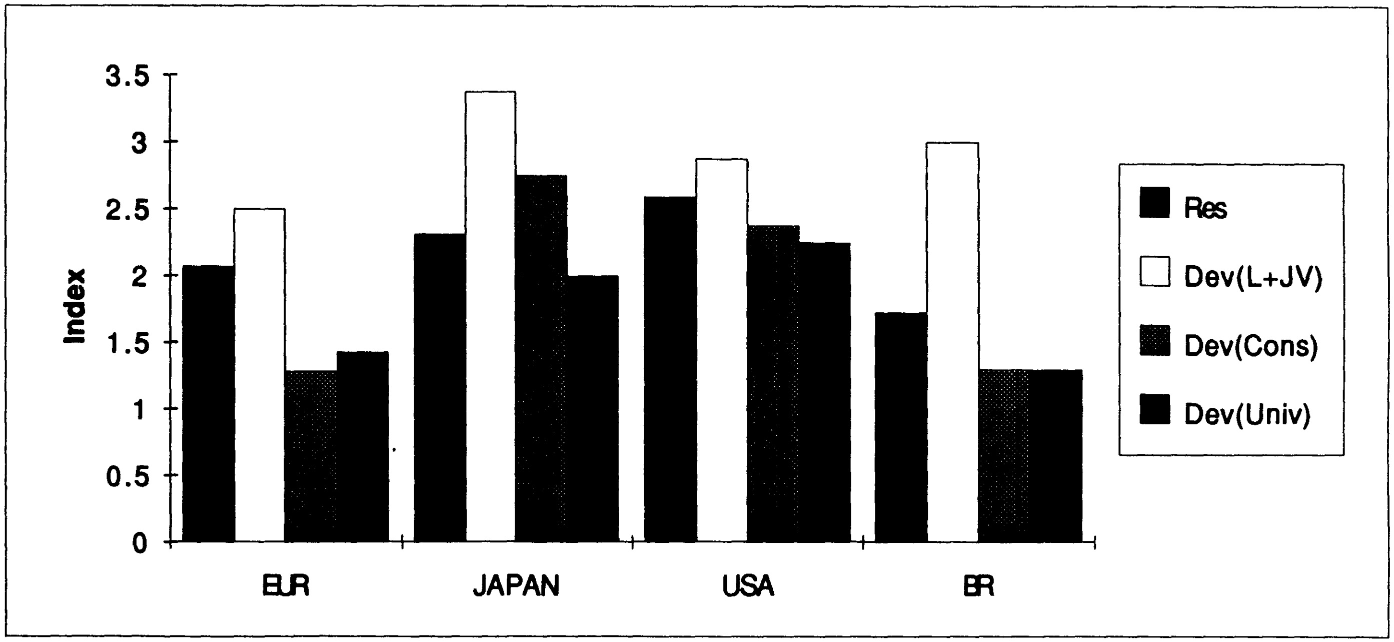


Figure 5.3.3.5: Mechanisms to obtain technology

Table 5.3.3.2: Use of university programs per activity

Region	University Use (%of respondents with high)			
	Obt Ideas	Tech. Trends	Coll. Research	Training
EUR	42.86	0.00	28.57	0.00
JAPAN	50.00	50.00	50.00	75.00
USA	37.50	25.00	50.00	12.50
BR	0.00	0.00	10.00	10.00

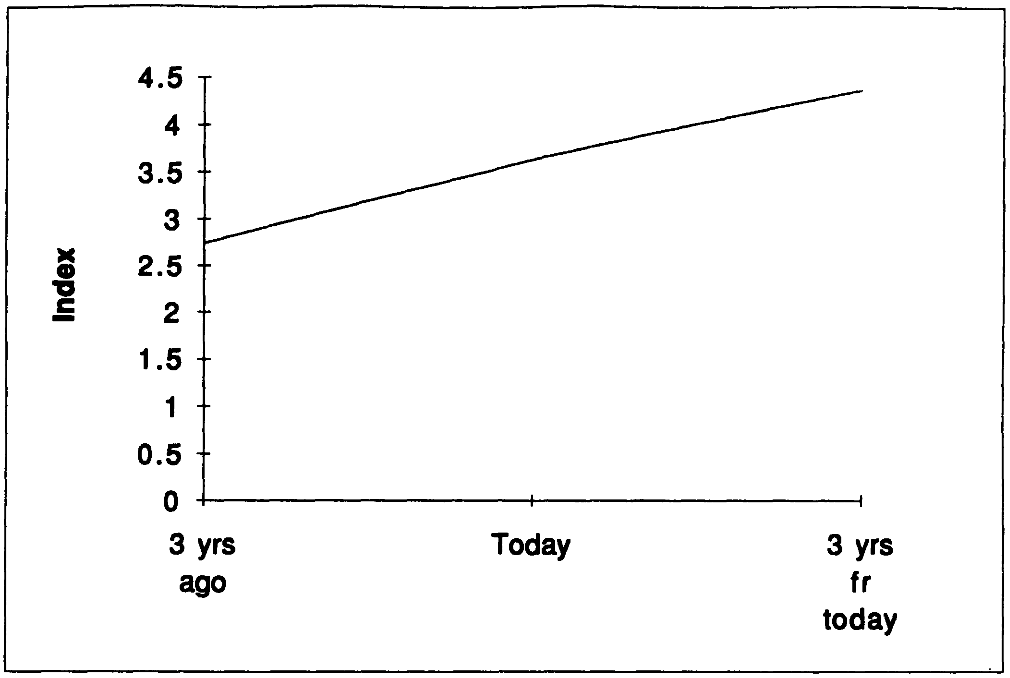


Figure 5.3.3.6: Changes in skills of technical employees - business skills

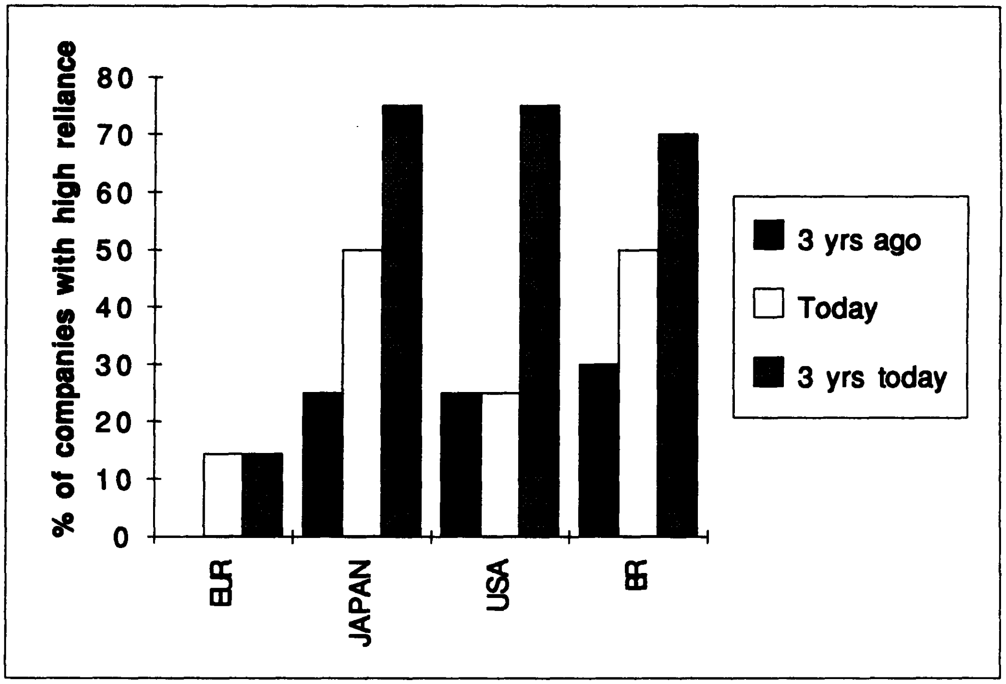


Figure 5.3.3.7: Reliance on external technologies

strategy and corporate strategy; and the involvement of the CEO in the R&D process.

It was somewhat surprising to see the use of diverse management practices in European respondents. Opportunities for improvement exist n many policy areas. To start, one may suggest: improve formulation, communication, and acceptance of technology strategy; increase the participation of CEOs in the R&D process; and increase the use of multi-functional teams in the process of innovation.

This thesis does not address the issues involved with improving R&D performance in those regions however. Rather, the focus is on the Brazilian chemicals/materials industry and how organizational capabilities can be created to improve the innovation process in the industry.

The analysis of this chapter indicates that significant opportunities for R&D process improvement seem to exist in the Brazilian chemicals/materials industry. Table 5.4.1 illustrates them. Importantly, one can not tell yet if those policies are a product of actual differences between management of technology practices or if they are a result of mere data variability among a common overall sample mean. The next chapter address this question and try to formalize explicit policy opportunities for the Brazilian industry and its firms.

Table 5.4.1: Possible Policy Options

Elements	Policy Option
Posture and Direction	Formulation, Communication, and Acceptance of Technology Strategy
	Linkage Technology and Corporate Strategy
Roles	CEO involvement
Systems	Multi-functional teams
	Policy time to market
Linkages	Customer Input
Adjustment Processes	Monitoring

Chapter Six: Policy Options

6.1) Introduction

The objective of this chapter is to identify policy opportunities that would improve the innovation process in the Brazilian chemicals/materials industry. Two levels of analysis are explored. First, policies that contribute to R&D performance are outlined. Second, policies that diminish the time required to move innovations from concept to implementation are assessed.

The chapter builds upon the regional analysis conducted in chapter five to identify policy opportunities in the three dimensions of strategic management of technology -- posture and direction; systems; and adjustment processes. As a benchmark, the analysis use Japanese practices. An analysis of variance (anova) test is conducted to identify the level of statistical significance that management practices at the industry level in Brazil differ from management practices at the industry level in Japan and, sometimes, North America. The results of those tests are used in the formulation of policy opportunities, both at the industry and the firm level, for the Brazilian chemicals/materials sector.

6.2) A Brief Word on the Brazilian Context

As described in chapter 5, Brazilian respondents differ considerably from European, Japanese, and American respondents. In terms of sales, Brazilian respondents are seventeen times smaller than their Japanese and European counterparts and 25 times smaller than the North American respondents. If one takes sales per product line, which we suppose is a more reasonable measurement of comparison, Latin American respondents are, on average, 20 times smaller that Japanese, European, and American respondents.

One cannot expect Brazilian companies to follow the same technology strategies of the other firms in the sample. Indeed, Brazilian respondents are generally late technology followers, have a technology portfolio more focused on short-term projects and on familiar technologies, and obtain technology mainly through external licensing or joint-venture.

It is not the purpose of this thesis to suggest a particular technology strategy to the Brazilian chemicals/materials industry. Indeed, the firms operating in this industry are much more equipped to developed their own strategies considering specific threats and opportunities and internal capabilities. We do can, however, suggest management of technology practices that would improve the R&D process regardless of the firms' technology strategy or size, as was determined in chapter 4 of this thesis. One would expect some of this practices, or policy options, to be important to the Brazilian industry as a whole, others, as is described later, would be important for Brazilian firms on an individual basis.

One still can argue that the market characteristics in Brazil are very different from the markets in Europe, Japan, and North America. Following that reasoning, one can argue that the markets in developed countries are much more homogeneous for the commodities segment and present a broader array of opportunities for product development in the specialty sectors. In Brazil, however, markets are less sophisticated and are not in the forefront of innovation. In this context, Brazilian firms do not really need to implement policy changes, since their markets do not require them to do so.

I would respond to this argument in two ways: research methodology; and institutional and industry changes. First, from a methodological perspective, the multiple linear regression analysis determined significant correlations between management practices and R&D performance regardless of origin and market characteristics. This means that Brazilian companies that have a high degree of use of certain policy options have better indices of R&D performance when compared with other Brazilian companies, regardless of the differences that do exist between Brazilian and developed regions' markets. Figure 6.2.1 illustrates this point. The figure depicts a qualitative relationship, for eight Brazilian respondents, between a policy index regarding use of the most important policy options[65] and their reported R&D performance index. Despite firms 3 and 7, a higher adoption of the suggested policy options increases R&D performance.

At the institutional and industry level, moreover, important changes are occurring both in Brazil and in the world at large. As developed in chapter 2, institutional changes in Brazil (lower trade barriers, privatization, better macroeconomic policy coordination) coupled with industry changes at the world level (overcapacity, world recession and unemployment, integration of the EC, fall of the communist block, etc.) will increase rivalry and bargaining power of buyers in Brazil, diminishing industry profitability in the long run. Firms that are not well equipped to develop new products to tap emerging marketing opportunities or to acquire or develop new processes to reduce cost or increase product differentiation will be more affected by these institutional and industry changes. In this context, it is suggested that the policy options develop below can be an important instrument for Brazilian firms in the years ahead.

6.3) Research Methodology

The identification of policy options followed two steps. First, a benchmark of strategic management of technology practices was established. In establishing the benchmark, the regions that are best positioned in terms of the policy approaches that are most important for R&D performance and time to market were selected. As pointed out in chapter 5, specially Japanese and, to a lesser extent, American respondents are better positioned than European respondents in those management practices. Japanese indexes were establish as a benchmark for the Brazilian chemicals/materials industry. Sometimes,

---

[65] As pointed in chapter four, those policy options are: formulation, communication, and acceptance of technology strategy; linkage between technology strategy and corporate-level strategy; CEO involvement; and use of multi-functional teams. The index is calculated by weighting each policy option to their respective t-Student statistics.

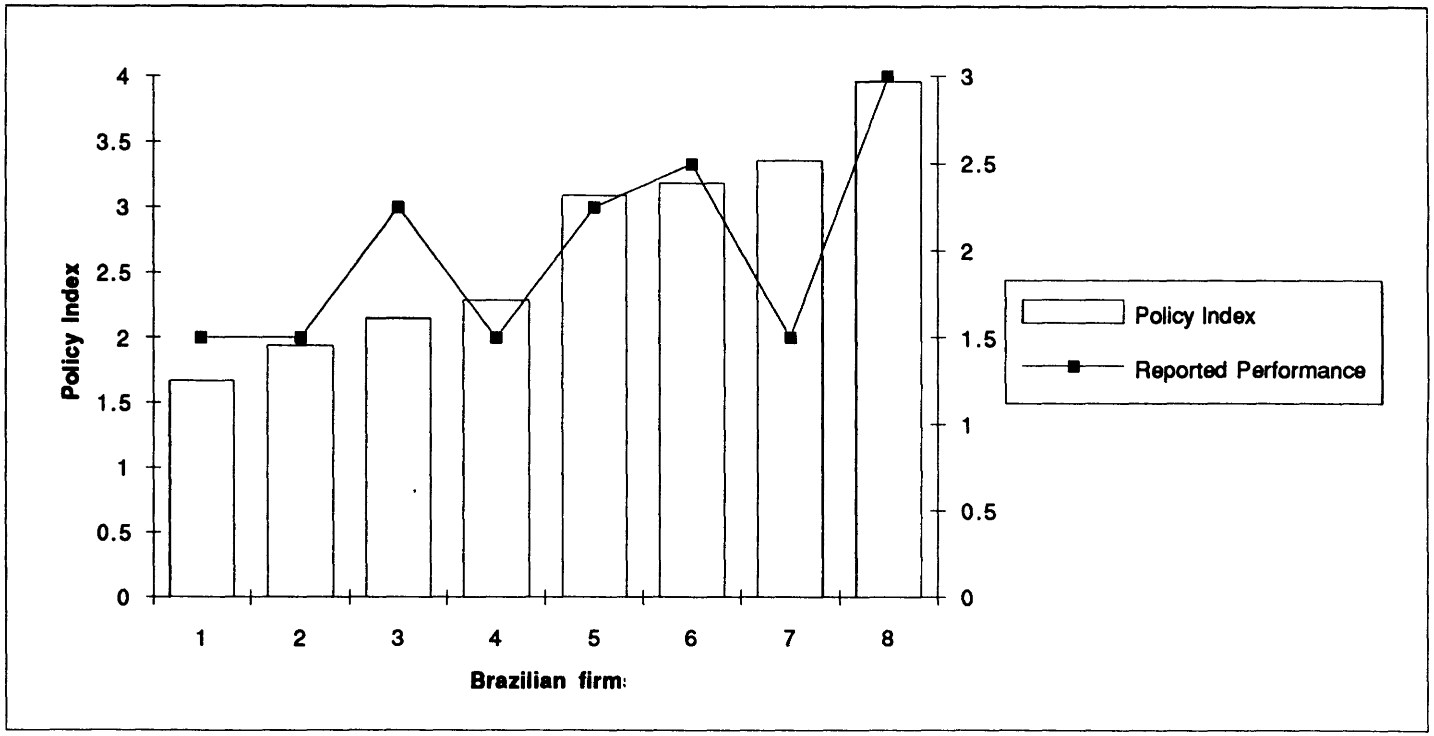


Figure 6.2.1: Policy options and reported R&D performance for Brazilian firms

however, a mix between Japanese and American indexes are used as a benchmark.

Having established the benchmark, statistical tests were conducted to determine the extent that Brazilian practices were different from Japanese practices. This is done through a single-factor analysis of variance test (anova), which determines whether means from two or more samples are drawn from populations with the same mean[66]. If the confidence level obtained in those tests is greater than 90% (p-value lower or equal to 0.1), the policy under assessment can be considered as a policy option to the whole Brazilian industry. If the confidence level is lower than 90% (p-value higher than 0.1), industry level recommendations cannot be developed but firm level suggestions can still be formulated.

6.4) Policy Options

As described above, the assessment of policy opportunities follows the framework develop in chapter 3. According to this framework, strategic management of technology can be viewed through three lenses: posture and direction; systems; and adjustment processes. The discussion below follows this rationale.

6.4.1) Posture and Direction

As pointed out in chapter 4, direction and posture have a very important impact in R&D performance. For instance, a strong link between technology strategy and overall corporate-level strategy is an important policy approach to increase R&D performance (p=0.0218). In addition, a well formulated, communicated, and accepted technology strategy also increases R&D performance (p=0.0057).

A compounded index of formulation, communication, and acceptance of technology strategy was developed through averaging the answers to question

---

[66] Appendix II gives more details about the Anova test.

A.1. Figure 5.3.1.1 (page 77) illustrates those indexes for Europe, Japan, North America, and Brazil. The Anova tests do not tell us with enough confidence that the Brazilian index is different from the Japanese/American index (p=0.28). On the other hand, Brazilian respondents have a lower degree of technology formulation, communication, and acceptance than Japanese respondents (p=0.10).

Suggestions can be formulated in two levels. First, at the industry level, Brazilian industry should improve the level of formulation, communication, and acceptance of technology strategy as a whole[67]. Second, at the firm level, individual firms that score low on this index should work to improve it.

In terms of formulation, table 5.3.1.1 (page 80) can be a guide to the identification of an agenda. In general, Brazilian respondents should increase the extent in which their corporate-level technology strategies include: a technology mission statement; competitive technology position; internal customer requirements; definition of core technical strengths and competencies; and evaluation of alternative technologies competing against theirs. In general, firms in Brazil have a well formulated strategy considering external customers requirements and criteria for internal development vs. external access of technologies. Communication and acceptance, however, are the most critical issues regarding technology strategy, since they involve an organization-wide effort.

In terms of the link between technology strategy and corporate-level strategy, it is not possible to assert that Brazilian respondents have a lower average index (p=0.17 with Japan and p=0.80 with Japan/USA index). There are opportunities, however, for individual firms. We believe that the link can be improved by strengthening the role of the CEO and by bringing other areas into the technology strategy process, like, for example, the VP of marketing. As pointed out in chapter 4, although the most important issue in technology strategy is the fulfillment of market needs (even for Brazil), the VP of marketing has an insignificant participation in the technology strategy process. Regarding the role of the CEO, she/he can be an important element in

[67] We basically used the Japanese benchmark for this recommendation, given the importance of the policy to R&D performance.

the linkage between technology strategy and corporate-level strategy. This issue is explored in the next section.

6.4.2) Systems

Chapter four identified that a high involvement of the CEO in the innovation process and the use of multi-functional teams have an important effect in R&D performance (p=0.041 and p=0.10, respectively). In this context, it would be important to determine how the Brazilian respondents fare relative to the Japanese and American respondents.

Figure 5.3.2.11 (page 93) depicts an involvement index that is calculated by averaging the answers to question B.9. Table 5.3.2.1, on the same page, breaks down the main activities of the CEO in the R&D process and show the percentage of CEOs in each region that are highly involved in the R&D process.

To determine the extent to which Brazilian CEOs are involved in the innovation process relative to Japanese and Japanese/American CEOs two anova tests were conducted. One cannot tell with enough confidence (p=0.28) that Brazilian CEOs are less involved in the R&D process than our benchmark CEO, who is an hybrid of Japanese and American CEOs. On the other hand, Japanese CEOs are more involved than Brazilian CEOs with 93% confidence level (p=0.07). Again, because of the importance of this policy to the R&D process, the Japanese benchmark is used.

In general, the CEO involvement index for Brazilian respondents is high mainly because of their high involvement in the selection of outside technological investments. This may be mainly a reflection of the technology strategy adopted by Brazilian firms up to now, which is based mostly on the acquisition of external technologies (see figure 5.2.3 on page 62). On the other hand, important gains in R&D performance could be achieved if Brazilian CEOs have a more active involvement in: technology strategy development; project selection/prioritization; establishment of overall R&D budget; and internal technology resource allocation. In doing so, moreover, the CEOs would be also fostering a stronger link between technology strategy and corporate-level strategy, which, as discussed above, is also extremely important for R&D performance.

Multi-functional teams are also important for the R&D process. As depicted in figure 5.3.2.9 (page 91), Brazilian respondents have a low use of multi-functional teams in their R&D process. Indeed, the use of multi-functional teams is lower than in Japan and in the US with 90% confidence level (p=0.10).

Figure 5.3.2.10 (page 91) depicts the use of multi-functional teams per activity at a regional level. Opportunities exist for improvement of use of multi-functional teams in development and research. In technology planning and development, Brazilian firms have usually a higher index of use of multi-functional teams. In those activities, however, the involvement of the CEO is lower than it is for Japanese respondents (see table 5.3.2.1 on page 93). The challenge, therefore, is to increase the participation of the CEO in technology planning and development without diminishing multi-functional team approach to the activity. This task involves considerable organizational effort and it will be addressed later on chapter 7.

The use of multi-functional teams in development activities also requires organizational and cultural changes. To work well, those teams need much more than certain types of organizational architecture. They need support from the entire firm, they need to communicate well inside and outside the team, they must be supported by correct incentive systems, and so on.

Adequate systems can also have an important impact in the process of moving products to market. In chapter 3, we identified four policy approaches that have an important effect in reducing time from concept to implementation (they are summarized in table 4.4.3 on page 57).

Table 5.3.2.4 (page 102) illustrates the percentage of respondents that indicate a high use of these four policy approaches at a regional level. An anova test was conducted to examine the extent to which Brazilian respondents have a lower use of these policy approaches. The benchmark was constructed as being an average between American and Japanese companies. The test indicate that Brazilian respondents have a lower use of those policy mechanisms at a 99% confidence level.

As policy options, therefore, the Brazilian industry would improve its capability to meet target dates for product commercialization and process implementation if it increases the use of: multi-functional teams; accountability of project managers; adopt procedures of early market test; and total quality management approaches.

6.4.3) Linkages

In this section, we explore how Brazilian respondents fare in terms of their use of customer input in the R&D process when compared with the established Japanese and American benchmark. Although the correlation between customer input and R&D performance is not significant at a 90% level or higher, we believe that the importance of the customer will be higher as rivalry in the industry increases and as companies try to move to more high value added segments of the markets. In this context, an increase in customer input or perhaps a better idea of what companies are doing in Japan and North America may be beneficial to the Brazilian industry.

Figure 5.3.2.14 (page 98) depicts the percentage of respondents that indicate a high use of customer input across the R&D process. An anova test determined that Brazilian companies have a lower index of use of customer input relative to Japanese/American firms with 92% confidence level. Table 5.3.2.3 (page 98) illustrates the percentage of respondents that indicate a high use of customer input at different phases of the R&D process. An analysis of that table indicate that the Brazilian industry may consider higher customer input in the following phases of the R&D process: setting program objectives; concept development; prototype development; testing; and product refinement and commercialization.

The process to obtain customer input involves many organizational entities inside the firm. Although the process can be informal or highly structured, there isn't much difference between regions in the way customer input is obtained. On the other hand, opportunities exist in the Brazilian industry for the improvement of the links between marketing and R&D entities, mainly when the comparison is made with the Japanese respondents. The process to obtain better linkages between different organizational entities is not easy tough.

6.4.4) Adjustment Processes

Monitoring activities are not significantly correlated with R&D performance (p=0.30). On the other hand, those activities may be more important in the future if one considers the increase of reliance on external sources of technology and, specifically in the Brazilian case, the technology strategy of Brazilian firms, which is based mostly on the external acquisition of technological resources. In this context, we conducted an evaluation to determine how Brazilian respondents fare relative to Japanese and American respondents.

As seen in figure 5.3.3.2 (page 106), few Brazilian companies have a high use of monitoring activities relative to Japanese and American respondents. What is striking is that one would expect Brazilian companies to have a high level of monitoring since external acquisition of technologies is their main form of technology strategy. An Anova test confirmed this finding with 99% confidence level (p=0.0028). Table 5.3.3.1 depicts a monitoring index, which is calculated by averaging the answers to question E.1, for each activity at a regional level. Opportunities exist for improvement in all dimensions of monitoring: advisory boards; university consortia; industry consortia; internal steering groups; customer input; university liaison; and venture capital. It is acceptable that Brazilian companies fare low in venture capital because of their scarcer resources relative to other firms in the sample.

Another issue is the low involvement with universities. Regarding the use of university programs, figure 5.3.3.3 (page 108) illustrates that few respondents in Brazil use university programs. Comparing with Japanese and American respondents, we can assert with more than 99% confidence (p=0.000587) that industry-university links in Brazil are weaker. One reason that might explain that is that, in fact, universities are not mostly used for licensing activities, which is the main strategy of the Brazilian industry, but for collaborative research, monitoring, and training. In the other hand, opportunities do exist in the areas of training and collaborative research.

6.5) Summary

This chapter identified policy opportunities that would improve the innovation process in either the Brazilian chemicals/materials industry or the individual firms operating in that industry. Table 6.6.1 illustrates them. Chapter 7 assesses the changes that are involved at the firm level in the implementation of these policies.

Table 6.6.1: Policy options for the Brazilian chemicals/materials sector

Elements	Policy Option	Innovation Process (p-value)	Anova Test Jap/Ame bmark	Anova Test Jap bmark	Importance to
Posture and Direction	For., Com., Accept. of TS	0.0057	0.8	0.17	Firms
	Linkage TS and CS	0.0218	0.28	0.1	Industry
Roles	CEO involvement	0.0407	0.28	0.07	Industry
Systems	Multi-functional teams	0.1	0.1	---	Industry
	Policies time to market	0.06 (ave)	0.01	---	Industry
Linkages	Customer Input	0.415	0.08	---	Industry
Adjustment Processes	Monitoring	0.3	0.0006	---	Industry

Chapter Seven: Implementation Strategy

7.1) Introduction

Chapter 6 presented the main policy options for improving the innovation process in the Brazilian chemicals/materials industry. As mentioned earlier, the implementation of those policies involves considerable organizational-wide efforts. This chapter is aimed at exploring the changes required for building the institutional capabilities that would improve the innovation process in Brazilian chemicals/materials firms.

7.2) An Organizational Approach

Table 7.2.1 reviews the policy options that contribute to the process of building innovation capabilities in the Brazilian chemicals/materials industry. Those policy options - like formulation and acceptance of technology strategy, use of multi-functional teams, and improved linkage between technology and corporate strategies - impose considerable difficulties to managers, since they involve more than mere changes in structures and responsibilities within an organization. Although difficult, we urge Brazilian managers to focus on them, since they can have a more beneficial impact on the R&D process than other policies, like the implementation of CAD/CAM, for example.

A more holistic understanding of organizations may be insightful to managers who plan to implement the policies suggested herein. In this context, the framework developed by Bartlett and Ghoshal (1992)[68] is used to assess the necessary changes that the organization might consider in building its institutional capabilities.

---

[68] Bartlett, C. A., and Ghoshal, S., "Transnational Management: Text, Cases, and Readings in Cross-Border Management", Irwin, 1992, pp. 442-462.

Table 7.2.1: Policy Options

Elements	Policy Option
Posture and Direction	Formulation, Communication, and Acceptance of Technology Strategy
	Linkage betweenTechnology and Corporate Strategy
Roles	CEO involvement
Systems	Multi-functional teams
	Policy time to market
Linkages	Customer Input
Adjustment Processes	Monitoring

Bartlett and Ghoshal (1992) suggest an organizational model that has three distinct levels: (i) anatomy, which comprises the formal structures of assets, resources, and responsibilities of an organization; (ii) physiology, which embeds the organizations' systems and decision processes; and (iii) psychology, which includes the organization's culture and management mentality.

Anatomy

Changes in anatomy involve changes in structures and responsibilities, which define new lines of relationships within the organization. There might be a tendency of managers to focus on anatomic changes, perhaps because they can be performed by executive orders in a relatively short period of time. In fact, managers throughout the organization are largely responsible for coordination and information flow. As pointed out by Bartlett and Ghoshal, by adapting the various administrative systems, hierarchical channels and informal relationships to different situations, managers can exert a more significant control over information flows. The authors refer to this type of arrangements as part of the organization's physiology.

Physiology

Changes in physiology comprise changes in interpersonal relationships and processes. The aim is to promote a more efficient flow of information within the firm and its partners.

It is our belief that an organization will not achieve a target state of institutional development if it manages the process of change only at the anatomy and physiology levels. Indeed, it would be an error to assume that full policy effects are achieved by changes in the formal and informal structures alone. Although these changes can have an impact on the way managers think and interact, mainly in times of crisis, it is simplistic to assume that they would force changes in the organizational culture. Cultural changes are ultimately the most potent form of transformation, since cultural patterns determine both the quality of informal and formal communications and the caliber of decision-making processes. Quite the contrary, modifications in the anatomy and physiology levels can be an important source of conflict if the culture and the values of managers are not changed accordingly.

Psychology

Changes in psychology involve the very culture and mentality of the organization. The objective of change should be to create a "learning environment". A learning environment is one where a common sense of purpose sustained by shared systemic models of reality is pervasive. Those two characteristics will enhance synergistic thinking and interaction among the different members of the organization (managers, workers, engineers, etc.) and provide the means for the implementation of multi-functional teams, for the improvement of acceptance of technology strategy within the organization, and for the betterment of the linkage between corporate and technology strategies.

It is important to emphasize the potential effect of changes in the organization's psychology. Normally, policy analysts focus their attention on building institutions that would be able to reconcile the different interests that exist in a specific environment (an organization, for example). Although this is a very important task in the implementation process, it does not consider the fact that interests may not be possible to be reconciled. Changes in psychology attempt to modify interests by creating shared mental models and common sense of purpose among the members of that environment.

The development of common sense of purpose and shared mental models involves the modification of individual and collective perceived facts about the world. Those facts, or underlying assumptions, should be surfaced, challenged and changed. To understand how one can do this, one must first understand how the different mental models that exist between the members of an organization arise.

Bohm and Peat (1987)[69] explore how mental models are formed and why they tend to induce to fragmentation. According to those authors, the cause of

---

[69] Bohm, D., Peat, F.D., "Science, Order, and Creativity", Bantam Books, 1987, pp. 16-25.

fragmentation involves what they call the "tacit infrastructure of ideas". Most of the ideas and skills that one uses in her/his professional activities exist in the form of such tacit infrastructure of knowledge. This knowledge, like the knowledge of riding a bicycle for example, takes a subliminal and mainly unconscious form. Most professionals, for example, carry out their activities by using theoretical frameworks or techniques that were first picked a long time ago. In this way a professional may spend years working in a subject without ever needing to question her/his tacit knowledge in any basic way.

But an organization, as well as the world around it, is in a constant process of evolution and change. In this process, the changes produced in one area (e.g. the marketing department detects a new product concept) have serious consequences for the foundations of theories and practices in other areas (e.g. the R&D and manufacturing entities are not familiar with this new product concept). The result of this change is that the underlying tacit infrastructure of concepts and ideas may gradually become inappropriate or even irrelevant. But because managers (of R&D and manufacturing) are accustomed to using their tacit skills and knowledge in subliminal and unconscious ways, individuals tend to hold on to them and try to go on working in old ways within new contexts. But why should this be? According to Bohm and Peat,

> ... [the answer is related to] the mind's strong tendency to cling to what it finds familiar and to defend itself against what threatens seriously to disturb its overall balance and equilibrium. Unless the perceived rewards are very great, the mind will not willingly explore its unconscious infrastructure of ideas but will prefer to continue in more familiar ways.

The mind's tendency to hold on to what is familiar, i.e., on what diminishes uncertainty, can generate three outcomes. One is the denial of the relevance to explore the new concepts and ideas. Another is to overemphasize the separation between a particular problem and other areas. In this way the problem can be studied in a limited context and without the need to question related concepts. The result is the fragmentation of mental models and poor thinking and interaction between the different entities of an organization.

The third outcome is the formulation of institutions that limit the exposure of individuals to unfamiliar practices and theories. Once those institutions are built, for example R&D and Engineering departments, it is even more difficult to converge individuals' mental models , since they have now anatomic barriers among them. A policy change like the use of multi-functional teams may represent an unfamiliar practice and, although formally implemented by executive orders, can in practice be a total disaster.

Some tools and procedures can be implemented to improve thinking and interaction inside organizations. Those tools and procedures can help in the identification of issues, in problem-solving activities, and in bringing tacit knowledge to the surface making them able of being challenged. They are explored below.

7.3) An Implementation Strategy

According to the discussion above, we believe that a map containing relevant issues in policy implementation can be developed. Importantly, however, this map has to adapted to the specific cultural characteristics of different organizations, and only a specific knowledge of the firm in question can allow one to do that. An appreciation of the issues involved, however, can be grasped through the following suggested implementation strategy.

7.3.1) Changes in Organization's Psychology: Common Interests?

We believe that this is the most important step in the process of change. Unfortunately, it is often forgotten or overlooked. Although some success could be achieved by only changing an organization's anatomy and physiology, full improvement in the R&D process can only be achieved if changes occur in the dynamics of thinking and interaction among the people within an organization. Furthermore, we believe that by starting at this level, most of the anxiety and conflicts involved with change can be diminished.

Changes toward the creation of a learning organization will serve as a means for the effective implementation of the policy options developed so far. Most important are the effects that those changes can bring on: (i) formulation, communication, and acceptance of technology strategy; (ii) the linkage between technology and corporate strategies; and (iii) the use of multi-functional teams.

As described earlier, changes in organization's psychology comprise the surfacing of underlying assumptions, modifications of some of them, and achievement of a shared vision and a sense of new purpose.

Training and education of managers, workers, and engineers can be a powerful way of surfacing, challenging, and changing mental models. It is important to create an environment of mutual learning. We suggest that organizations create courses on group dynamics, problem-solving methods, theory of innovation, industry analysis, systems thinking, etc.

The topics of those courses should address directly the issues faced by the organization in diverse areas and not only in the technological dimension. In addition, those courses should be coupled with the activities described in the next section, so that changes in psychology can be implemented.

7.3.2) Changes in Organization's Physiology

The next step - changes in organization's physiology - should begin either during or after the first step -- education and training. Done in this way, changes in decision making processes and interpersonal relationships can both reinforce and be reinforced by changes in organizations' psychology. Diverse mechanisms can be used to foster changes in physiology. Among these, we identified the following: management committees (product profiling, integrated strategic planning); multi-functional teams; and job rotation and personal transfer. These mechanisms are described below.

Management Committees

Management committees serve as a forum where managers can interact more informally to address company-wide issues and respond to diverse changes in the firm's competitive environment. In this context, management committees work as an informal setting for communication, information exchange, and decision-making activities. Two activities can be conducted by those management committees:

- **Integrated Strategic Planning.** Integrated planning systems can be developed as a conscious process of bringing managers' mental models to the surface. This concept has been implemented by tools like scenario planning. Through the use of scenarios, planners can help managers to continually think through how they would manage under multiple possible futures and how their actions could influence others. Done in an integrated way, this can foster the learning process[70]. The strategy process should consider industry analysis, environmental scan, firm's competitive positioning, and firm's strengths and weaknesses.

- **Technology Strategy.** A team of managers which involves different entities of the organization (manufacturing, marketing, R&D, and even finance) should be assembled to develop a technology strategy for the organization. The committee should consider topics like: technology mission statement; product and process profiling against competitors; internal and external customers requirements; technology portfolio balance; definition of core technical competencies; life cycle stages of technologies; evaluation of alternative competing technologies; and criteria for internal development versus external acquisition of technologies. Done in this way, the committee is forced to consider trade offs between each stakeholder's interests.

Multi-functional Teams

Team building can be used as a leverage to achieve physiological changes in organizations. Teams convey a learning environment where information is shared more openly and decisions are made based on a more holistic view of the organization. The formation of teams is indeed a policy that improves the

[70] Notice that this planning system denies the traditional procedures of strategic planning in most organizations, i.e., the top thinks and plan whereas the local executes. Integrated strategic planning should involve line managers and individuals who have potential of becoming leaders in the organization in the future.

innovation process[71]. As an initial approach, teams could be formed to develop a technology strategy for the organization, as described before. As the whole process of change evolves, teams could be formed to conduct specific innovation activities.

Job Rotation and Transfer of Personnel

Job rotation and transfer of personnel can be used for training purposes but also to promote the development of friendship-type relationships and personal contacts across the entire corporation. Two considerations substantiate this approach. First, people who know each other through service on projects often maintain channels of communication open for some time after the effort ends. And second, the acquaintance between individuals frequently facilitates the communication process and helps ease tensions in areas of conflict. It is possible to create a large number of communication paths and to improve coordination significantly with only a few number of transfers.

Job rotations for training could begin as soon as the change process starts. Job transfers for specific projects, however, should only be implemented after changes in anatomy are also developed. Those are discussed in the following section.

7.3.3) Changes in Organization's Anatomy

Changes in psychology and physiology will not take effect if the organization's anatomy does not support the final objectives of collective thinking and interaction. Whereas a better linkage between technology and corporate strategy and better acceptance of technology strategy are by products of steps 1 and 2, other policy options involve specific changes in responsibilities, structures and processes within the organization. Those policies are:

- Stronger accountability
- Higher involvement of the CEO

[71] As demonstrated in chapter 4.

- Use of multi-functional teams
- Early market test

Neither those anatomic nor the psychological nor the physiological changes will actually work, however, if the incentive systems embedded in the organization are not changed. For this reason, an implementation strategy should consider the definition of the constituency of the change process.

7.3.4) Definition of Constituency and Incentive Systems

A firm has to establish incentive systems that are aligned with the objectives of interaction and collective thinking. If a company wants to improve the innovation process, it has to promote incentives that favor inter divisional activities and collaborative efforts, and not incentives that promote sectarianism. An incentive system should try to realign the diverse interests of the stakeholders of the innovation process. The first step, therefore, should be towards the definition of constituency.

Constituency

The purpose of this section is to present a brief analysis of the interests of the different stakeholders that are involved in the innovation process. The stakeholders are: workers; scientists and engineers; middle management, specifically manufacturing, R&D, and marketing managers; top management; company shareholders; and customers. Table 7.3.4.1 summarizes the stakeholders' main interests and the conflicts that may arise among those different interests.

Workers are basically interested in policies that would increase compensation, diminish uncertainty (both related to employment and safety), and increase satisfaction on the job. Conflicts arise with projects that are aimed at labor saving, or reducing compensation or job satisfaction.

Scientists and engineers are interested in activities that would increase compensation, job satisfaction, and their chances of achieving career objectives (either management or more senior research positions).

Table 7.3.4.1: Constituency of the innovation process

Parts Involved		Interests	Conflicts
Workers		Higher Compensation Diminished Uncertainty Job Satisfaction	projects that are labor-saving, alienating, and safety threatening
Scientists and Engineers		Higher Compensation Diminished Uncertainty Job Satisfaction Career Opportunities	labor managers engineers
Middle Management	**R&D**	Higher Compensation Diminished Uncertainty Job Satisfaction Career Opportunities	labor not always tuned with manufacturing or marketing unfamiliar projects
	Manufacturing	Higher Compensation Diminished Uncertainty (employment) Job Satisfaction Career Opportunities	labor unfamiliar projects long-term projects product projects
	Marketing	Higher Compensation Diminished Uncertainty (employment) Job Satisfaction Career Opportunities	labor process projects unfamiliar projects
Top Management		Maximize Shareholder's value Diminish Uncertainty Compensation	labor, engineers, managers
Shareholders		Maximize Value	projects that do not maximize value
Customers		Affordability Quality and Reliability Environmentally Safe	

Importantly, scientists and engineers are also be interested in diminishing uncertainty in their job activities. This not only means job security but favoring familiar projects. Conflicts may arise with labor, managers, and among engineers themselves, depending on their technical focus and on their career objectives.

Middle managers try to diminish uncertainty in their activities, mainly relative to employment and type of activity. In addition, they are interested in higher compensation, increased satisfaction, and activities that improve their chance of rising on the corporate ladder. These interests assume different dimensions according to the specialty of each manager. R&D managers, for example, tend to favor projects that are in her/his knowledge domain. Manufacturing managers favor projects that involve innovations that foster cost reduction, i.e. that do not compromise their ability to appropriate dynamic scale economies (learning curve), and projects that are familiar. Marketing managers, on the other hand, favor projects focused on product development and on familiar areas. Conflicts may arise with labor and among managers themselves, regarding their preferences in technology portfolio selection and career objectives.

Top management is interested in continuing to serve as high level executives, in increasing compensation and job satisfaction, and in decreasing uncertainty. Moreover, top managers should be working to increase shareholders' value. Conflicts may arise between labor, middle managers' interest, and engineers' objectives.

Shareholders favor projects that increase stock value. Issues of communication between shareholders and managers can complicate the financing of long-term or unfamiliar projects. Managers may have incentives to undercut these kinds of projects to increase the short-term value of the firm[72]. Conflicts may arise between workers, middle managers, and top managers.

---

72 In this cases, the assumption of perfect capital markets is not valid.

Finally, customers perform an important role in disciplining the firm by requiring high quality, affordable and environmentally sound products and processes.

These groups constitute the constituency of the firm. Any policy implementation should consider the characteristics of this constituency if it aims to achieve its original objectives. The next section presents some suggestions that may accommodate those diverse interests.

Incentive Systems

As a suggestion, three elements are listed to improve the capability of incentive systems in accommodating diverse interests. They are:

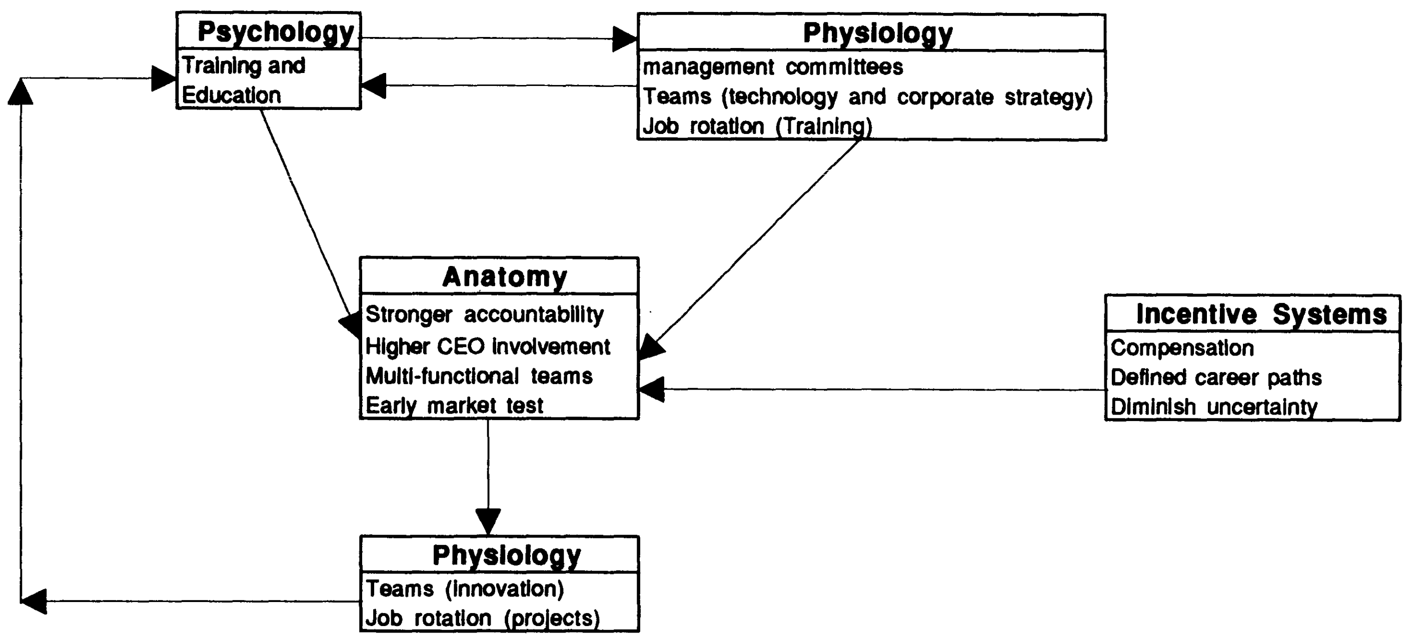
- **Compensation.** Create compensation schemes that are tied with product and process innovations. For example, one can establish that 30% of the annual bonus of workers, engineers, and managers (R&D, manufacturing, and marketing) is dependent on the successful implementation of process innovations and commercialization of product innovations. Importantly, compensation systems should also consider the interests of shareholders, i.e., value maximization.

- **Career Paths.** Team participation and the coordination of multi-functional teams should be viewed as important steps for growth in the corporate ladder. In this context, a top level manager should have in his curriculum a successful history in team management.

- **Uncertainty.** Uncertainty has two dimensions. First, there is uncertainty regarding the effects of a particular innovation on employment. Front-line workers are the ones who are most concerned with this dimension. Some companies in the chemicals/materials industry have been adopting specific employment policies to deal with this issue. In some cases, there is a formal guarantee by management that no dismissals will occur due to the implementation of specific technologies inside the company. Although one would argue that this limits cost reduction possibilities, this policy may generate higher cost savings by fostering the implementation of a higher number of innovations. A second dimension of uncertainty is related with the tacit models that professionals carry with themselves. A way of dealing with this is through specific programs of education and training, as described above.

7.4) Summary

This chapter discussed the different levels of analysis that should be consider in the implementation of the policy options developed in chapter 6. In addition, an implementation strategy was suggested using the presented framework. It is summarized in figure 7.4.1.



Outcomes

- Formulation, Communication, and Acceptance of Technology Strategy
- Stronger linkage between technology strategy and corporate strategy
- Higher involvement of CEO in the Innovation Process
- Higher use of multi-functional teams
- Stronger accountability of R&D and project managers
- Early market test of product innovations
- Total Quality Management approach

Figure 7.4.1: Implementation strategy

Chapter 8: Conclusions

This thesis focused on strategic management of technology in the chemicals/materials industry. After a brief industry analysis, an investigation of firm level policies was conducted in four different regions of the world, i.e., Europe, Japan, North America, and Latin America. A global analysis was performed to identify specific policies that positively impact R&D performance across different firms. Then, a benchmarking of policies presented opportunities for improvement either at the firm or at regional industry levels, emphasis was placed on the Brazilian current situation. Finally, implementation issues were addressed from an organizational perspective.

The work supports the elaboration of three general conclusions: sound policies for improving R&D performance; policy opportunities for the Brazilian industry; and implementation strategy.

8.1) Sound Policies for Improving R&D Performance

Firms that adopt specific management of technology policies consistently have higher R&D performance and higher capability of meeting target dates for product commercialization or process implementation. Importantly, this thesis argued that these policies form organizational systems that improve the innovation process in the chemicals/materials industry regardless of regional/national or a firm's strategy characteristics. The policies that were found to improve R&D performance are[73]:

- Higher formulation, communication, and acceptance of technology strategy (p=0.0057);

---

[73] The lower the p-value, the higher is the significance of the statistical test.

- Stronger linkage between overall-corporate strategy and technology strategy (p=0.0218);
- Higher involvement of the Chief Executive Officer in the innovation process (p=0.0407); and
- Higher use of multi-functional teams in the innovation process (p=0.10).

The policies that were found to diminish time from concept to product or process implementation are:

- Stronger accountability of the R&D and project managers (p=0.0285);
- Use of multi-functional teams (p=0.04);
- Early market test of product innovations (p=0.069); and
- Total Quality Management approach (p=0.101).

Importantly, some of those policies are not directly controlled. Rather, they are a reflection of a set of organizational capabilities. This is the case, for example, of technology strategy acceptance and the efficient use of multi-functional teams.

8.2) Policy Opportunities for the Brazilian Industry

There are significant opportunities for creating innovation capabilities in the Brazilian chemicals/materials industry. These opportunities, or policy options, are given below in order of importance to the R&D process.

Improve Formulation, Communication, and Acceptance of Technology Strategy.

Formulation, communication and acceptance of technology strategy among Brazilian respondents is lower than among Japanese, American, and European respondents. In terms of formulation, Brazilian firms should target issues like: technology mission statement; competitive technology position; internal customers' requirements; core technical strengths and competencies; and evaluation of alternative competing technologies. The improvement of communication and acceptance involve organizational-wide efforts. They are improved by changes in the culture, values, and interaction among the diverse members of an organization.

Improve Linkage between Corporate and Technology Strategies

Although not applicable at the industry level, opportunities do exist for individual firms. Strengthening the role of the CEO in the innovation process and assembling multi-functional teams of high ranking executives (mainly with the marketing area), is an important step to reinforce the link between overall-corporate strategy and technology strategy. Linkage is also a by-product of a good learning organizational environment.

Increase the CEO Participation in the R&D Process

Brazilian CEOs should increase their participation in: technology strategy development; project selection/prioritization; formulation of the overall R&D budget; and in decisions involving internal technology resource allocation. Importantly, this increase in participation should not diminish the team approach that is recommended in the entire R&D process.

Increase the Use of Multi-functional Teams

Brazilian respondents have a low index of use of multi-functional teams. The should be used more actively in development and research activities. The increase in the role of the CEO in the innovation process should not limit the participation of multi-functional teams in the technology planning process. Importantly, the effective use of multi-functional teams also requires organizational and cultural changes.

Increase Use of Policies that Diminish Time from Concept to Implementation

Brazilians have a very low index of use of policies that diminish time from concept to implementation. The capability of meeting target dates for either product commercialization or process implementation will certainly improve if the Brazilian industry makes more use of: multi-functional teams; stronger

R&D and project manager accountability; early market tests procedures; and total quality management approaches.

Other Policies Worth Implementing

Considering both the technology strategies followed by Brazilian respondents and the changes that are likely to occur in the patterns of competition of the industry, other policies are worth some consideration. In this context, the Brazilian industry would benefit if it increases the use of technology monitoring activities[74] and the use of customer input, mainly in the later phases of the R&D process.

8.3) Implementation Strategy

The implementation of those policy options involves considerable organizational-wide efforts. Implementation should consider three distinct organizational dimensions: anatomy, which includes structures and responsibilities; physiology, which comprehends interpersonal relationships and processes; and psychology, which is the very culture and values of the organization. Policies should be implemented in each one of those levels to create an environment which is able to accept the policy options suggested above. The implementation plan should then consider:

- training and education;
- implementation of management committees, teams, and job rotation programs; and
- changes in the incentive systems, mainly targeting issues of compensation, career paths and uncertainty relative to employment and knowledge skills.

[74] Considerable opportunities exist for closer ties with universities.

8.4) A Final Word

We believe that these policy options form a sound basis for the improvement of the innovation process in the Brazilian chemicals/materials industry. We urge managers in Brazil who are interested in improving industry sustainability and competitiveness to start implementing these policies.

Appendix I: Questionnaire

Global Survey on the Strategic Management of Technology

This questionnaire aims at establishing a series of global benchmarks on Strategic Management of Technology in the Chemicals/Materials industry. The questionnaire was sent to leading companies in the U.S., Europe, and Japan last year. Now, we are extending the survey to companies in Latin America.

In completing this survey, we request that the corporate Chief Executive Officer or Chief Technology Officer (or his/her designate) answer the questions from his/her personal knowledge and experience. Seldom should there be a requirement to consult detailed company records, or other officers of the firm. In answering questions relating to division or business unit activities, please answer with respect to the one largest or most representative unit in the company, using your best judgment or estimate in cases of uncertainty. Done in this matter, this questionnaire will require 30 to 45 minutes of your time.

Although no proprietary information is sought in this study, we assure that total privacy of your responses will be maintained. All data analyses will be carried out in multi-company aggregates. No identification of your company will be made in any presentation of survey results.

We deeply appreciate your timely cooperation and your sharing of your insights in this research for practice and performance benchmarks for global technology management. We will send all survey respondents a copy of the study results, expected in January, 1994, which will integrate this data with the information gathered in the regions previously stated.

Paulo R. Bellotti
Master of Science Candidate
Technology and Policy Program, MIT

Dr. Edward B. Roberts
Chairman, MIT Management of
Technology and Innovation Group

Part I: Benchmarking

A. Mission, Objectives and Strategy

We want to understand the nature of your firm's technology strategy, and how it is linked to both your overall corporate-level strategy and your business unit strategy.

1. In each column on the right, please check the single phrase that best describes: (i) your corporate-level technology strategy; (ii) the technology strategy of *your typical* business unit:

	Corporate Technology Strategy	Business-Unit Technology Strategy
a. The technology strategy is vague or virtually non-existent.	( )	( )
b. A technology strategy exists and is communicated to the organization, but it is not well understood or accepted.	( )	( )
c. The technology strategy is understood, but is generally not accepted.	( )	( )
d. The technology strategy is communicated to and accepted by the organization as a whole.	( )	( )

2. In each line please circle the extent that your corporate-level technology strategy specifically includes the indicated element: **(1=Not very much; 5=Extensively)**

Technology mission statement

1 2 3 4 5

Competitive technology position

1 2 3 4 5

Internal customer requirement (timing, budget, specifications)

1 2 3 4 5

External customer requirements (performance/cost)

1 2 3 4 5

Defining core technical strengths/competencies

1 2 3 4 5

Life cycle stages of technologies

1 2 3 4 5

Evaluation of alternative technologies competing against ours

1 2 3 4 5

Internal development vs. external access (e.g., acquisition, license, joint venture, etc.)

1 2 3 4 5

The balance in our portfolio of technologies

1 2 3 4 5

Other strategy elements: ____________________

1 2 3 4 5

3. How would you rate the following issues in terms of their importance to your company's technology management strategy and processes? **(1=Not very important; 5=Extremely important)**

Total Quality methods in R&D

1 2 3 4 5

Matching R&D to market needs

1 2 3 4 5

Decreasing time to market for new products

1 2 3 4 5

Managing R&D with constrained resources

1 2 3 4 5

4. How strong is your corporate-level technology strategy linked to your overall corporate strategy? **(1=Not very much; 5=Extensively)**

1 2 3 4 5

5. How frequent do you:

	About 1/year	Less often than 1/year
a. Develop new corporate technology strategy	( )	( )
b. Review corporate technology strategy	( )	( )
c. Adjust corporate technology strategy	( )	( )

6. Which three roles or positions are most critical in your firm to achieving linkage between corporate technology strategy and overall corporate strategy? and business-level strategy?

In each of the two columns please rank these three positions in order of importance **(1=Most important)**

Linkages:	Corporate Strategy	Business-level Strategy
Chief Executive Off. (CEO)	___	___
Chief Operating Off. (COO)	___	___
Chief Technical Off. (CTO)	___	___
R&D VP/Director	___	___
Marketing VP/Director	___	___
Finance VP/Director	___	___
Business unit managers	___	___
Other ____________	___	___

The CTO typically oversees all areas of a company's technology, including but not limited to R&D. Not all companies have such a position.

7. In considering how to link technology to overall corporate strategy, we want to understand the practices used in your company. Please rate the importance of each of the possible next steps that you use to provide that linkage. **(1=Not very important; 5=Very important)**

a. Assess customer opinions

1 2 3 4 5

b. Use predetermined external forces to define priorities (environmental regulations, macroeconomic factors, etc.)

1 2 3 4 5

c. Assemble teams of R&D, marketing, finance, commercialization, and manufacturing to carry out further work on R&D ideas and present selection to top management committee with CEO's participation

1 2 3 4 5

d. Evaluate R&D ideas in regard to your core R&D competencies and determine what you should do internal to your company, what technology to acquire outside, and on what projects to seek collaborators

1 2 3 4 5

e. Develop scenarios, balancing risks, costs, and other uncertainties

1 2 3 4 5

B. Organizing for Technology Development and Use

What structures and roles support the development and use of technology in your organization?

1. Indicate which statement best reflects changes in the control of technology resources for research and development in your company today vs. 3 years ago:

Research	Development	
( )	( )	more corporate-level control today
( )	( )	about the same corporate-level control today as 3 years ago
( )	( )	less corporate-level control today

2. For those technology resources controlled at the corporate level, how are they primarily organized? Check one area each for research and for development.

Research	Development	
( )	( )	organized around products/markets
( )	( )	organized around business units
( )	( )	organized around technical disciplines
( )	( )	organized around projects
( )	( )	other____________________
( )	( )	there is no corporate-level control

3. For those technology resources controlled by business units, how are they typically organized? Check one area each for research and for development.

Research	Development	
( )	( )	organized around products/markets
( )	( )	organized around technical disciplines
( )	( )	organized around projects
( )	( )	other ____________
( )	( )	there is no business unit control

4. Roughly speaking, about what percentage of funds is allocated to each of the following activities within your corporate-level Research, Development & Engineering budget? in your typical business unit R, D & E budget?

	Corporate RD&E	Business Unit RD&E
Research	____	____
Development	____	____
Product technical support	____	____
Process technical support	____	____
	100%	100%
There is no specific allocation	____	____

5. If you have a Corporate-level R&D function, how is it funded? Please rank order the following options from **1(most) to 4(least)** in terms of the amount each contributes:

Corporate	____
Business Unit as fixed % (overhead "tax")	____
Business Units on direct by project basis	____
Outside of the company	____
Do not have corporate-level R&D function	____

6. We would like to understand the role of your company's Chief Technology Officer (CTO) or equivalent, whether that person is you or someone else. What is her or his title?

____

Does he or she sit on the Board of Directors/Main Board of the company? ( ) Yes ( ) No

Please indicate how true each of the following statements is regarding this individual *and* check off the three which best characterize his (her) job:
(1=Not very true; 5=Completely true)

( ) a. Participates in overall corporate strategy development

1 2 3 4 5

( ) b. Directs corporate technology strategy development

1 2 3 4 5

( ) c. Reviews corporate technology strategy

1 2 3 4 5

( ) d. Controls resource allocation between Corporate and Business Unit R&D

1 2 3 4 5

( ) e. Controls R&D resource allocation across Business Units

1 2 3 4 5

( ) f. Directs Business Unit technology strategy development

1 2 3 4 5

( ) g. Reviews Business Unit technology strategy development

1 2 3 4 5

( ) h. Participates in Business Unit technology strategy development

1 2 3 4 5

( ) i. Directs the Corporate R&D organization

1 2 3 4 5

( ) j. Monitors and assesses external technology

1 2 3 4 5

( ) k. Determines company's investment in outside technologies, and assesses technical strengths of external partners.

1 2 3 4 5

( ) l. Serves as liaison to outside organizations (e.g., universities, technical associations, etc.)

1 2 3 4 5

7. List other functions, besides R&D, for which the CTO has responsibility (e.g., Information Systems, Manufacturing):

____
____
____

8. At your company, how much are multi-functional teams used for: **(1=Not very much; 5=Extensively)**

Technology planning and strategy development

1 2 3 4 5

Research projects

1 2 3 4 5

Development projects

1 2 3 4 5

Technology monitoring

1 2 3 4 5

9. Please indicate how your company's CEO is involved in each of these areas; circle a response for each activity that applies: **(1=Not very involved; 2=Reviews; 3=Participates; 4=Directs).**

Technology strategy development

1 2 3 4

Project selection/prioritization

1 2 3 4

Establishment of overall R&D budget

1 2 3 4

Internal technology resource allocation

1 2 3 4

Selection of outside technology investments

1 2 3 4

C. Responding to Global Technological Issues

Please describe what technology activities your company is undertaking in other countries. If your company is not involved in such activities in other countries, please skip to section D.

1. Please circle each non-domestic region (those outside of your home base country) in which you carry out each technology activity listed below.

Regions

NA= North America
LA= Latin America
WE= Western Europe
EE= Eastern Europe
AP= Asia/Pacific

License of technology from other countries

NA LA WE EE AP None

Joint technology development with companies from other countries

NA LA WE EE AP None

Acquisition of technology through the acquisition of non-domestic companies or products

NA LA WE EE AP None

Our own labs in non-domestic countries

NA LA WE EE AP None

2. Please indicate the level of non-domestic activity for each technology activity listed below, where **1=very little non-domestic activity; and 5=significant non-domestic activity.**

License of technology from other countries

1 2 3 4 5

Joint technology development with companies from other countries

1 2 3 4 5

Acquisition of technology through the acquisition of non-domestic companies or products

1 2 3 4 5

Our own labs in non-domestic countries

1 2 3 4 5

3. Please indicate the approximate percentage of your company's total R&D activity which is based in foreign countries:

today	____%
3 years ago	____%
3 years from now	____%

4. Which statement best describes the function of your non-domestic R&D facilities?

( ) They perform the same activities as domestic R&D facilities (e.g., same type of projects, but adapted to the local market).

( ) They represent worldwide "centers of excellence" for a particular technology, discipline, etc.

( ) They focus on a particular phase of the R&D process (e.g., basic research, applied research, development, technical support).

5. How independent of corporate control are your non-domestic R&D activities in terms of what they do? in terms of how they do it? **(1=Not very independent; 5=Totally independent).**

what they do:

1 2 3 4 5

how they do it:

1 2 3 4 5

6. In your firm, how is technology transferred from the originating country to other locations? Please check *up to three* most commonly used approaches.

( ) Relocation of internal technical experts to recipient countries
( ) Training programs in the recipient countries
( ) Documentation
( ) Reports
( ) Conferences
( ) Planning sessions
( ) Other ______________________

7. To what extent do you use each of the following to monitor technology developments in other countries? **(1=Not very much; 5=Extensively)**

Our own labs in other countries

1 2 3 4 5

Our company's staff liaison in other countries

1 2 3 4 5

Formal technical panels of outsiders

1 2 3 4 5

Newsletters, reports

1 2 3 4 5

Consultants from other countries

1 2 3 4 5

Participation in international consortia

1 2 3 4 5

Sponsored research at foreign universities

1 2 3 4 5

Liaison/affiliate programs at foreign universities

1 2 3 4 5

Other ______________________

1 2 3 4 5

8. Please indicate the significance of each of the following criteria in deciding to utilize some form of non-domestic R&D: **(1=Not very significant; 5=Extremely significant)**

To support local manufacturing capability

1 2 3 4 5

To keep abreast of foreign technologies

1 2 3 4 5

To adapt products to local requirements, regulations, ingredients, etc.

1 2 3 4 5

To take advantage of technology development by foreign organizations

1 2 3 4 5

Other ______________________________

1 2 3 4 5

D. Relating Technology to Markets and Customers

This section deals with how you utilize input from external customers and the marketplace in the R&D process.

1. For each of the following technology activities, please indicate how much you use direct customer input: **(1=Not very much; 5=Extensively)**

Technology strategy development

1 2 3 4 5

Setting program objectives

1 2 3 4 5

Obtaining innovative ideas

1 2 3 4 5

Concept development

1 2 3 4 5

Prototype development

1 2 3 4 5

Testing

1 2 3 4 5

Product refinement and commercialization

1 2 3 4 5

Product improvement

1 2 3 4 5

Are there any other activities for which you solicit/use customer input? If so, please list:

____

____

____

2. How would you describe your process for obtaining customer input? **(1=Ad Hoc, Informal; 5=Highly structured, formalized)**

1 2 3 4 5

3. Please indicate which *single* statement best reflects how you obtain external customer input: in research activities; in development activities:

Research	Development	
( )	( )	R&D determines what customers inputs it needs, and obtain them.
( )	( )	R&D identifies what customer inputs it requires, but another organizational entity, e.g., marketing, obtains them.
( )	( )	Other organizational entities, such as marketing, have the responsibility to determine customer inputs, they obtain them, and they do an adequate job of transferring the information to R&D.
( )	( )	Other organizational entities, such as marketing, have the responsibility to determine customer inputs, but do an inadequate job in obtaining and transferring the information.

E. Monitoring and Assessing Technology

We are interested in how your company monitors technology and acquires the requisite technologies and skills to ensure success in the markets in which you compete.

1. To what extent do you rely on each of the following mechanisms to *monitor* technology?**(1=Not very much; 5=Extensively)**

Science/technology advisory boards

1 2 3 4 5

University research consortia

1 2 3 4 5

Industry-based consortia

1 2 3 4 5

Internal technology steering groups

1 2 3 4 5

Customer panels or input

1 2 3 4 5

University liaison/affiliate programs

1 2 3 4 5

Venture capital funds

1 2 3 4 5

Industry Suppliers

1 2 3 4 5

Informal Contacts

1 2 3 4 5

Other ____________________

1 2 3 4 5

2. To what extent do you rely on each of the following mechanisms to *obtain* technology, for each area of R&D? **(1=Not very much; 5=Extensively)**

	Research Work	Development Work
Internal		
Central Corporate Research	1 2 3 4 5	1 2 3 4 5
Internal R&D within divisions	1 2 3 4 5	1 2 3 4 5
External		
Licensing	1 2 3 4 5	1 2 3 4 5
Joint venture or alliance with other company	1 2 3 4 5	1 2 3 4 5
Consortia	1 2 3 4 5	1 2 3 4 5
Sponsored university research	1 2 3 4 5	1 2 3 4 5
University liaison/affiliate program	1 2 3 4 5	1 2 3 4 5
Continuing education	1 2 3 4 5	1 2 3 4 5
Recruiting students	1 2 3 4 5	1 2 3 4 5
Equity investments in smaller firms	1 2 3 4 5	1 2 3 4 5
Consultants/Contract R&D	1 2 3 4 5	1 2 3 4 5
Acquisition of:		
Technologies	1 2 3 4 5	1 2 3 4 5
Products	1 2 3 4 5	1 2 3 4 5
Companies	1 2 3 4 5	1 2 3 4 5
Incorporation of supplier's technology	1 2 3 4 5	1 2 3 4 5
Incorporation of innovative customer's technology	1 2 3 4 5	1 2 3 4 5
Other (please state)		
____________	1 2 3 4 5	1 2 3 4 5
____________	1 2 3 4 5	1 2 3 4 5

3. Please indicate the extent of your actual and expected reliance on external sources for technology acquisition for each time period indicated below: **(1=Not very much; 5=Extensively)**

Today

1 2 3 4 5

3 years ago

1 2 3 4 5

3 years from now

1 2 3 4 5

4. How important are each of the following criteria in choosing between internal and external mechanisms for acquiring technology: **(1=Not very important; 5=Extremely important)**

a. Cost

1 2 3 4 5

b. Time and sense of urgency

1 2 3 4 5

c. Our own familiarity

1 2 3 4 5

d. Availability

1 2 3 4 5

e. Competence/ability

1 2 3 4 5

f. Intellectual property ownership

1 2 3 4 5

g. Industry fit/standards

1 2 3 4 5

h. Other ___________________________

1 2 3 4 5

5. Please indicate how much you use university programs for each of the following technology monitoring and acquisition activities: **(1=Not very much; 5=Extensively)**

Obtaining innovative ideas

1 2 3 4 5

Determining technology trends

1 2 3 4 5

Collaborative research efforts

1 2 3 4 5

Training company personnel

1 2 3 4 5

Modifying technology management practices

1 2 3 4 5

Licensing product innovations

1 2 3 4 5

Licensing process innovations

1 2 3 4 5

6. How much have the skills you require of your technical staff changed over the past 3 years? **(1=Not very much; 5=Extensively)**

1 2 3 4 5

7. Please rank the importance of the following for your company's acquisition of new technological skills: **(1=Most important)**

_____ hire new people directly from universities
_____ hire experienced people from competitors
_____ train/retrain existing people

8. How important is it that technical employees also possess business skills? **(1=Not very important; 5=Extremely important)**

Today

1 2 3 4 5

3 years ago?

1 2 3 4 5

3 years from now?

1 2 3 4 5

F. Evaluating Technological Effectiveness and R&D Performance

In this section, we are interested in gaining your assessment of the overall performance of your R&D organization. The several specific corporate measures will help us understand the possible relationship between your technology management practices and your company's effectiveness.

1. In your perception, which are the top 3 companies worldwide in R&D performance in the chemicals/ materials industry? (Your own company may be included).

1. ______________________________

2. ______________________________

3. ______________________________

2. Please rate your company relative to your perceptions of your most serious competitor on each of the following dimensions:

	Worse than Competitor	About the Same	Better than Competitor
a. Degree to which your R&D successfully satisfies the current needs of:			
End-use customers	( )	( )	( )
Corporate strategy	( )	( )	( )
Manufacturing	( )	( )	( )
b. Overall performance of your R&D organization in terms of:			
Effective use of R&D resources	( )	( )	( )
Efficient use of R&D resources	( )	( )	( )
R&D's timeliness (delivering on schedule)	( )	( )	( )
Percentage of company's revenues derived from products/processes/services not existing 5 years ago	( )	( )	( )
Success in reducing company's cost of production over the past 5 years	( )	( )	( )
c. Ability of your R&D organization to adjust to major external changes	( )	( )	( )

3. What is the average maturity of your company's key technologies? (1=Extremely new; 5=Extremely mature).

1 2 3 4 5

4. Thinking about your key core technologies, how do you evaluate your company overall, relative to your perception of your most serious competitors? And to the leading companies in the industry? Check only one:

	Serious Comp.	Industry Leaders
Typically, we are a technology leader.	( )	( )
We are on par with our competition.	( )	( )
Typically, we are a fast follower.	( )	( )
Typically, we are technology follower.	( )	( )

5. Please provide an overall value for your company for each of the following. *In addition*, please indicate whether this value is higher than, lower than, or about the same as it was three years ago.

	Current	3 years ago this number was: (check one) Higher	Same	Lower
a. Average break-even time of new products from date of first market release	____mos.	( )	( )	( )
b. Percentage of R&D projects over preceding 5 years which met or exceed internal objectives vis a vis:				
Time to market	____%	( )	( )	( )
Budgeted development cost	____%	( )	( )	( )
Technical specifications	____%	( )	( )	( )

6. Please indicate the extent to which you agree with each of the following statements:(1=Strongly disagree; 5=Strongly agree)

a. R&D typically gets the amount of money it requests for its budget.

1 2 3 4 5

b. Top management's attitude toward R&D is highly supportive.

1 2 3 4 5

7. How well-balanced do you consider your portfolio of technologies to be in terms of:

	Well-balance	Not well-balanced not enough emphasis on:
Short-term (<3 years) vs. medium-term (3-7 years) vs. long term (>7 years)	( )	( ) ______
Familiar to us vs. unfamiliar to us (but familiar to others)	( )	( ) ______
Product vs. process orientation	( )	( ) ______

8. Company Background Information

If the following information is readily available, we would appreciate your providing it to us here. It will be useful in helping us to cluster responses. Please omit any responses which you consider to be of a sensitive or proprietary nature.

a. Approximate annual sales volume - most recent completed years (US$ millions) ______

b. 5-year average annual sales growth of company (%) ______

c. Approximate net income after tax (US$ millions) ______

d. Annual R&D spending (US$ millions) ______

e. Increase (decrease) in R&D spending from previous year (%) ______

f. Percentage of revenues from non-domestic operations (%) ______

g. Average market share of top three business in your company ______

9. In which country is your Corporate Headquarters located?

____

10. How diversified is your company in terms of numbers of lines of business? (check one)

( ) 1-2 ( ) 3-5 ( ) 6-10 ( ) >10

11. Please identify the approximate breakdown of your company sales for the most representative business area and fill in a percentage figure; indicate the remaining sales as "other."

	Approx. % of total sales
Basic chemicals	______
Minerals	______
Industrial organic chemicals	______
Synthetic materials	______
Chemical products	______
Agricultural chemicals	______
Petroleum products	______
Rubber and plastic products	______
Other	______
	100%

12. Please identify the approximate geographical breakdown of your company sales and production activities:

	Approx % of Sales	Approx. % of production
Europe	______	______
Asia	______	______
Africa	______	______
North America	______	______
South America	______	______
Rest of World	______	______
	100%	100%

13. Please check the box that corresponds to the total number of employees in your company.

( ) 0-1000 ( ) 1000-5000 ( ) 5000-10000

( ) 10000-20000 ( ) >20000

14. Please provide the following information to enable us to track who our respondents are. Your name and your company's name will not be directly associated with your responses to the survey.

Company name ______________________

Respondent name ______________________

Respondent title ______________________

Telephone number ______________________

Fax number ______________________

G. Moving Products to Market

We want to understand the practices used in your company to move a product or process from concept to implementation.

1. Please check each of the following approaches that you use in moving products to market. Then, rate the impact of each *that you use* on moving your products to market. **(1=Very little impact; 5=Very high impact)**

( ) a. Early formation of multi-functional teams, e.g. involvement of marketing, manufacturing, and finance functions

1 2 3 4 5

( ) b. Specially-designated idea generators

1 2 3 4 5

( ) c. Formal product champions

1 2 3 4 5

( ) d. Senior management sponsors

1 2 3 4 5

( ) e. Accountability of assigned project managers

1 2 3 4 5

( ) f. Permanent project management function

1 2 3 4 5

( ) g. "State-Gate" product development process

1 2 3 4 5

( ) h. Simultaneous engineering product development process

1 2 3 4 5

( ) i. Total quality management approach

1 2 3 4 5

( ) j. Flexible manufacturing systems

1 2 3 4 5

( ) k. Rapid prototyping techniques

1 2 3 4 5

( ) l. Computer-aided design/engineering

1 2 3 4 5

( ) m. Computer-aided manufacturing

1 2 3 4 5

( ) n. Quality Functional Deployment techniques

1 2 3 4 5

( ) o. Early freezing of design specifications

1 2 3 4 5

( ) p. Early market testing

1 2 3 4 5

( ) q. Reduction in number of parts

1 2 3 4 5

( ) r. More use of outside vendors

1 2 3 4 5

2. Please indicate the three approaches listed in question (1) above which you have found most effective in shortening the time it takes to move a product to market.

a. ______________________________

b. ______________________________

c. ______________________________

Any other not listed above which you have found especially effective?

____

____

3. Do you typically transfer key individuals with a project as it moves from development into manufacturing?

( ) Yes ( ) No

If yes, which individuals (title, role, or function) are most likely to be transferred?

____

____

4. About how often do you roughly meet or exceed your target date for: **(1=Not very often; 5=Almost always)**

Product commercialization:

1 2 3 4 5

Process implementation:

1 2 3 4 5

5. What measure do you use most commonly to evaluate your timeliness in moving products to market? (Please check one)

( ) Time from idea to commercialization
( ) Time from development to commercialization
( ) Time to achieve break-even

Other _______________________________

Part II: Special Research Topic: Technology with Constrained Resources

We would like to understand your company's overall experience with the current economic climate.

A. Assessing the Problem

1. Please indicate your best estimate of your company's actual and expected changes in each area listed below, for the three time periods indicated: **(D=decrease; S=the same; I=increase)**

	Actual Change '87 to '89 D S I	Actual Change '89 to '92 D S I	Expected Change '92 to '94 D S I
a. Total R&D expenditures	( ) ( ) ( )	( ) ( ) ( )	( ) ( ) ( )
b. R&D capital investment	( ) ( ) ( )	( ) ( ) ( )	( ) ( ) ( )
c. Size of R&D staff:			
professional	( ) ( ) ( )	( ) ( ) ( )	( ) ( ) ( )
non-professional	( ) ( ) ( )	( ) ( ) ( )	( ) ( ) ( )

2. Roughly speaking, for each of these four categories of R&D activity, please indicate the % breakdown of R&D expenditures for 1989, 1991 and estimated for 1994:

	1989	1991	1994
a. Product/process maintenance (impact within 1 year)	___	___	___
b. Short-term development projects(<3 years)	___	___	___
c. Longer-term development projects (3-5+ years)	___	___	___
d. Research activity	___	___	___
	100%	100%	100%

3. Please indicate the degree of involvement of each of the following in setting business unit R&D budgets today compared to 2 years ago: **(1=More involved today; 3=About the same; 5=Less involved today)**

Board of Directors/Main Board

1 2 3 4 5

CEO

1 2 3 4 5

Business Unit general managers

1 2 3 4 5

Corporate VP of Technology (or equivalent)

1 2 3 4 5

Corporate VP of marketing (or equivalent)

1 2 3 4 5

Corporate VP of manufacturing (or equivalent)

1 2 3 4 5

Corporate VP of Finance (or equivalent)

1 2 3 4 5

4. Check all the following that have occurred in your R&D organization in the past two years:

( ) Early retirement programs
( ) Reduction of internal technical or managerial training programs
( ) Reduction of external education reimbursement
( ) Cutbacks in travel
( ) Reduction in the use of outside consultants
( ) Salary freeze
( ) Reduction in compensation incentives
( ) Hiring freeze
( ) Personnel lay offs
( ) Reduction of per diems (hotels, food)
( ) Reduction of company dinners, other social outings
( ) Reduction in equipment purchases
( ) Reduction in externally funded R&D
( ) Reduction in university affiliate memberships

5. Has your company instituted any other programs specifically to reduce R&D expenditures in the past two years? If so, please describe briefly.

____
____
____
____

B. Managing with Fewer Resources

1. Please indicate how important each of the following approaches has been as part of your company's response to managing technology in the current economic climate: **(1=Not very important; 5=Extremely important)**

Strategy Elements
Less ambitious strategic objectives for technology

1 2 3 4 5

Focus only on core technologies, whether for new markets or new products

1 2 3 4 5

Increased external acquisition of technology instead of internal investment

1 2 3 4 5

Increased attempts to exploit existing technologies

1 2 3 4 5

Programs
Stricter criteria for new program start-up

1 2 3 4 5

More stringent requirements for program continuation

1 2 3 4 5

Slowing the pace of some programs

1 2 3 4 5

Reduction in number of products/processes being supported

1 2 3 4 5

Productivity
Making existing technical organization more productive/efficient via:

tighter measurements
(e.g., head count, R&D $/employee)

1 2 3 4 5

stronger accountability

1 2 3 4 5

stronger identification of R&D contribution to profits

1 2 3 4 5

Increased use of automation and other non-human resources in R&D

1 2 3 4 5

Streamlined R&D organization, either corporate-wide or on division-by-division basis

1 2 3 4 5

Funding
Search for additional sources of external funding, e.g., government

1 2 3 4 5

2. Please indicate up to 3 most effective approaches your company is using (from the above list or otherwise), to manage technology with constrained resources during the current economic climate. (a=most effective)

a. ______________________________

b. ______________________________

c. ______________________________

Part III. The Role of Government

We would like your thoughts on whether the government has a legitimate role in establishing policies to foster commercial technology development and whether it can effectively perform that role.

1. It has been suggested that market failures, such as long-term pay-off, uncertainty, and loose appropriability, may limit firms' investment in certain R&D programs, reducing the rate of development of commercial technologies. In this context, please indicate the extent to which you agree with the following statements: (1=**strongly disagree; 5=Strongly agree**)

a. Governments have a legitimate role in supporting commercial technology development by reducing market failures.

1 2 3 4 5

b. Governments can effectively reduce market failures to support commercial technology development.

1 2 3 4 5

c. Governments do not have a legitimate role nor are effective enough to support commercial technology development

1 2 3 4 5

d. Governments should act to increase appropriability of R&D results (e.g., intellectual property rights)

1 2 3 4 5

e. Governments should invest in R&D to reduce uncertainty of a new technical field, (e.g., prove its feasibility).

1 2 3 4 5

f. Governments should act to reduce risk that firms face when investing in long term R&D programs through:

Procurement policy

1 2 3 4 5

Risk venture capital

1 2 3 4 5

Direct funding of R&D in the private sector

1 2 3 4 5

Setting standards

1 2 3 4 5

g. Governments should support commercial technology development in areas in which a country has comparative advantages (biomass; alternative forms of energy; etc.)

1 2 3 4 5

h. Governments should support commercial technology development in industries that:

Drive productivity in other industries (e.g., new materials, machine tools, semiconductors, etc.)

1 2 3 4 5

Are important for National defense

1 2 3 4 5

Provide social externalities that are relevant to society or other industries (employment; knowledge, etc.)

1 2 3 4 5

i. Governments should fund industry R&D consortia.

1 2 3 4 5

2. It has been suggested that individual firms may find expensive/difficult to acquire specific technologies that are beneficial to the entire industry. As a result, industries can benefit from programs aimed at diffusing/sharing technologies among players (diffusion-oriented technology programs). In this context, please indicate whether you agree or not with the following statements: **(1=strongly disagree; 5=Strongly agree)**

a. Governments should coordinate this diffusion-oriented programs.

1 2 3 4 5

b. Governments should help funding, but not coordinating this diffusion-oriented programs

1 2 3 4 5

c. Governments should not be involved. Industries should organize, fund, and coordinate diffusion-oriented programs by themselves.

1 2 3 4 5

d. Governments should adopt measures to facilitate the transfer of technology from abroad (e.g., tax incentives, subsidies, etc.)

1 2 3 4 5

e. Governments should provide educational/training programs to support technological diffusion.

1 2 3 4 5

3. It has been suggested that governments do not effectively correct market failures and/or select strategic industries in its goal to foster commercial technology development. Do you agree? **(1=Not at all; 5=Strongly agree).**

1 2 3 4 5

If you believe that governments are not well-suited to direct commercial technology development, what do you think are the main reasons that would explain such institutional failure? **(1=strongly disagree; 5=Strongly agree)**

a. Policy-makers are not usually sensitive to the realities of the market.

1 2 3 4 5

b. National laboratories are away from market realities, i.e., they have a low commitment to commercial success.

1 2 3 4 5

c. Policy makers are usually too enthusiastic about high-technology, giving technology policy a strong technology-push instead of a market-pull prospective.

1 2 3 4 5

d. Research institutes are reluctant to work on subjects that have not been part of their traditional research activities.

1 2 3 4 5

e. Universities and national laboratories do not take into consideration the social and economic needs of society at large.

1 2 3 4 5

f. Technology policies usually reflect political manipulation of resources that benefit few interested parties, instead of benefiting the public interest at large.

1 2 3 4 5

4. Please indicate if and to what extent other government policies should support a technology policy aimed at increasing innovation and competitiveness in the chemicals/materials industry. **(1=Not very much; 5=Extensively):**

( ) a. Tariff protection of selected sectors (specify ____________________).

1 2 3 4 5

( ) b. Development of anti-dumping legislation.

1 2 3 4 5

( ) c. Elimination of trade barriers.

1 2 3 4 5

( ) d. Institution of technology-forcing legislation to achieve specific environmental standards.

1 2 3 4 5

( ) e. Waive selected sectors from environmental regulation (specify ____________________).

1 2 3 4 5

( ) f. Active public procurement programs to foster development of specific technologies (e.g., new materials, biotechnology products, energy-efficient process/products).

1 2 3 4 5

( ) g. Investment tax break programs

1 2 3 4 5

( ) h. Provide high quality basic education

1 2 3 4 5

( ) i. Provide vocational educational programs

1 2 3 4 5

( ) j. Provide training and educational programs for adults and unemployed.

1 2 3 4 5

( ) k. other ______________________________

1 2 3 4 5

We deeply appreciate your time and your cooperation in completing this comprehensive survey.

If you have any questions, please contact Paulo Bellotti at FAX# (617) 253-7140.

Please mail the completed questionnaire to:

Paulo Bellotti
Technology and Policy Program
MIT-Room 242, Build. E-40
Cambridge, MA 02139,
USA

Appendix II: Statistical Methods

t-Test

Recall that the underlying regression equation is assumed to be

$$E(y) = Bo + Bi\ x$$

If there really exists a relationship of this form between x and y, Bi would have to differ from O. Thus a conclusion regarding the significance of the regression relationship can be tested using the following hypotheses:

$$Ho: Bi = 0$$

$$Hi: Bi >= 0 \text{ or } Bi <= 0$$

An *F test* can also be used for determining whether or not the relationship between x and y is statistically significant.

Anova test

The analysis of variance (anova) test is designed to test the following hypotheses:

Ho: xi = xj = xk = ...

Hi: not all xs are equal.

where x is the estimated mean of the population. More details about the *t-test* or the *Anova test* can be found in any basic statistics textbook.

Bibliography

Adler, P. S., McDonald, D. W., and MacDonald, F., "Strategic Management of Technical Functions", *Sloan Management Review*, Winter 1992, pp. 19-37.

Bartlett, C. A., and Ghoshal, S., "Transnational Management: Text, Cases, and Readings in Cross-Border Management", Irwin, 1992, pp. 442-462.

Bohm, D., Peat, F.D., "Science, Order, and Creativity", Bantam Books, 1987, pp. 16-25.

Hollander, S., "The Sources of Increased Efficiency: A Study of Du Pont Rayon Plants", The MIT Press, Cambridge, Massachusetts, 1965.

Katz, R., "Time and Work: Toward and Integrative Perspective", *Res. Org. Behav.*, 2, 1980, 81-127.

Katz, R., "The Effects of Group Longevity on Project Communication and Performance", *Admin. Sci. Q.*, 27, 1982, 81-104.

Martinez, N., "Management of Technology and Corporate Strategy in the Chemical Industry", Unpublished Master Thesis, Sloan School of Management, Massachusetts Institute of Technology, June, 1993.

Porter, M, "Competitive Strategy: Techniques for Analyzing Industries and Competitors", Free Press, 1980.

Roberts, E. B., "Stimulating Technological Innovation - Organizational Approaches", *Research Management*, November, 1979.

Stobaugh, R., "Innovation and Competition: The Global Management of Petrochemical Products", *HBS Press*, 1988.

United Nations, "Annual Review of the Chemical Industry", 1992.

Von Hippel, E., "The Sources of Innovation", Oxford University Press, 1988.