CHAPTER ELEVEN

Learning and Innovation in the Chemical Industry

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Introduction

Technological and organizational learning in firms has received a great deal of attention in the innovation literature. Today, next to the analysis of the economic impact of innovations, and the strong efforts made to create models of the growth patterns by including technological change, the processes by which firms build their learning capabilities are an issue in themselves. Technological performance and innovation are largely the result of these processes. But at the same time, a debate has been opened about the origins and importance of the internal learning capabilities of firms and the influence of external factor, such as the macroeconomic conditions, the level of development of material infrastructure, the educational levels of the population and the institutional framework. All these have been wrongly opposed to the internal learning of a specific company. Indeed, the whole issue of the national system of innovation can be seen as an interrogation about the relations between these internal capabilities and the environment of the firms. Our study tackles the issue by looking at the specific case of the chemical industry.

After a brief overview of the trends in the chemical sector worldwide and a presentation of the general characteristics of this industry in Mexico, we focus our analysis on the technological behaviour of firms. Based on the research we carried out on several chemical firms in Mexico, we can conclude that the industry has shown undeniable learning capabilities, accumulated mainly in the past thirty years. Our approach stresses the fact that the answers given by firms have not been uniform. The learning experiences should ideally be seen as unique to a particular firm: all firms differ in their technological behaviour and consequently in their performances. The important fact here is that even when belonging to the same industrial sector, sharing the same market and institutional environment, firms can behave differently. What, then, makes such a strong difference? All sorts of answers can be given depending on the resources that one sees as more important, which shrinks down to looking at how these resources are channelled to the productive units as well as how the companies view their environment, their limits and advantages. The way companies diffuse knowledge among departments and organizational divisions, the way this knowledge is managed, the way 'knowledge channels' such as suppliers' or clients' needs are managed, contribute to the particular behaviour of a firm. The whole universe of chemical companies is examined in terms of technological regime differences where three large clusters are defined. As is noted in Chapter 10, each cluster can be characterized by its differences in terms of opportunity, appropriability, cumulativity, knowledge base composition and the technological linkages that firms establish.

Overview of the chemical innovation system worldwide

The chemical market is a very large one, representing one trillion US dollars in 1990, 1991, p. 104), dominated by very large companies. The largest one, Höescht, announced sales of 36,408 million dollars. European companies, which are the more important ones, tend to be multiproduct firms, including a pharmaceutical division, whereas American companies tend to be more specialized. By and large, the typical expansion policies until the early 1980s were based upon vertical integration. Nowadays, a turn has been made and most of the expansion strategies focus on specific markets through mergers and buying smaller specialized companies.

In the 1980s and until 1995, the world market prices for commodities fell regularly. After these sharp decreases in prices, the industry has been obliged to go through a thorough restructuring process that ended in more efficient plants, with firms looking at focusing on their 'core competencies' instead of diversifying their production. The sector has also been marked by numerous alliances and cooperative agreements on both commercial and technological grounds. The restructuring of the chemical industry world wide has been particularly important for the large European companies, such as Höescht, Bayer, Akzo and ICI.

The role of national state policies has been crucial in this period. In all industrialized countries, the state has been active in implementing all sorts of instruments, including subsidies and direct intervention (OECD, 1992a). But in most cases, the policies have been implemented through indirect action: strengthening public research and technologies programmes, procurement programmes, policies for human capital formation and mediation in salary negotiations with trade unions and active interventions in financial and fiscal matters (OECD, 1992b). Probably a quite efficient means of action, although difficult to measure, has been that of concertation, networking and the gathering of distinct actors from a variety of different social and economic contexts. The existence of cooperative and technological alliances has fostered a more rapid communication between the public and the private sectors in Europe, the USA and Japan. But some evidence indicates this to be true even in large developing countries. These types of cooperative technological agreements, joint ventures and similar technological alliances are particularly active in new technological markets such as combined polymers, new materials and biotechnological developments applied to chemical processing.

Companies, and not only state policies, have been protagonists of these networking efforts. Although it is known that large companies in the chemical sector have historically been active promoters of technological development in cooperation with university research centres, they now assist in the expansion of cooperative technological agreements (Hounshell and Smith, 1988). These take many forms and may combine distinct types of competencies and up to a certain point are learning experiences (Bruno, 1995). It is also important to remember that the chemical sector has been historically largely based upon a great ability to promote large investments, reduce costs by scale economies and distribute products on large global markets. After the profound restructuring of the 1980s, the sector has been more geared to innovation of processes rather than products, designing more flexible and efficient productive schemes (Arvanitis and Mercado, 1996).

Technology in the chemical sector is complex and cannot be reduced to a unique and simplistic view. One way to differentiate within the industry is to distinguish a more traditional industrial sector, linking basic chemical 'commodities' to products directly dependent upon them, and a second sector that relies upon the finer products with high value added and satisfies a demand for differentiated products. Recently some authors have introduced the notion of 'performance products' which can be both pseudo-commodities (high production of low cost products for specific uses) and specialities. The sector is a science-based sector according to Pavitt (1984), owing to the central role played by R&D and academic science. A more in-depth view of the sector would create a more complex image, with the coexistence of at least three divisions: traditional scale-intensive industries (mainly commodities and pseudo-commodities); firms which act as specialized suppliers tailoring products with traditional technological content to the needs of their clients; and science-based firms in advanced technological areas and markets. Most large firms typically belong to all three of them.

The chemical industry seems to be moving along the following lines worldwide: (a) increased market globalization; (b) a growing importance of 'clean' products or environmentally friendly products and processes; (c) products – and thus production – seem to meet clients' expectations more closely. These general lines imply a strong pressure towards efficient quality programmes, efficient production and 'just-in-time' or similar no-stock schemes, as competitive advantages. Thus knowledge on production processing is essential, as well as R&D product knowledge. Conversely, a large portion of production depends on low prices of inputs, which in petroleum producing countries such as Mexico is a competitive advantage. Traditionally, science and technology have been closely linked to the chemical sector; chemical engineering is one of the outcomes of this close link. Nowadays, the chemical sciences and engineering are undergoing large changes in order to address future challenges: (a) new synthesis techniques for combining molecules; (b) new catalysers and reactive systems that allow for shorter life-cycle products, more efficient and environmentally friendly processes; (c) alternative uses of traditional raw materials; (d) new materials with better performances and shorter production routes, or routes that allow new combinations of materials in the process; (e) the introduction of bioprocesses in traditional chemical industries (ACS, 1996; Arvanitis and Mercado 1996).

These trends are not uniformly applied to all companies and all industrial plants. However, they reveal the importance of functions inside firms that become vital: the ability to have a prospective view of the market and devise new strategies and the growing role of R&D and engineering clearly indicate these new trends. Problem-solving activities are to become increasingly complex, thus demanding a closer articulation of these productive functions, different knowledge and different types of actors. Innovation seems to be the product of an articulate network of institutions more than the sole product of the internal R&D effort of a firm. Table 11.1

Table 11.1 Comparison of General Characteristics of the Chemical Industry in Industrialized Countries and Mexico

	Industrialized countries	Mexico
Firms' characteristics	Large firms dominate the market; great number of small and medium-sized companies specialized in specific products in high-tech 'niche' markets. Firms growth mainly by mergers.	Large firms are medium-sized by international standards; few high-tech small companies. Firms growth by exports and to limited extent by mergers.
Production characteristics	High scale of production. High diversification of products. Multiproduct companies. High costs of inputs, mainly petrochemicals. Vertical integration from basic petrochemicals to final finished consumer market and semi-finished products (industrial markets).	Small scale of production. Limited diversification. Low product scope. Low cost of petrochemicals. Limited vertical integration due to the state monopoly on basic petrochemicals.
Strategies	Continuous introduction of innovative products. Numerous technological alliances between firms (large and small). Concentration to 'core activities'. More efficient production. Flexible schemes of production. Environmentally oriented strategies are dominating the R&D and innovation process: strong incentive for pollution prevention rather than 'end-of-pipe' pollution abatement.	Improvement of the quality of products, few innovative products. Very few technological alliances. More efficient production. 'End-of-pipe' pollution abatement, environmental behaviour responds to 'command-and-control' governmental strategies. Feeble voluntary environmental strategies.
R&D	High basic research intensity in firms, strong links with academic science and numerous independent R&D consultant firms.	Low R&D oriented towards basic processes and components in firms, few links with academia, no independent R&D.
Innovation	Highly intensive innovation process, in both products and processes.	Low innovation, mainly oriented towards adaptation of products to local markets and efficient production processes.
Markets	Large commodities markets, strong competition in 'global' markets. Very diversified markets for a large variety of specific types of products, with high value-added ('pseudo-commodities', 'performance' products and specialities).	Small commodities domestic markets; need to export in order to sustain large-scale production costs. Extremely small and rare markets for specialities, performance products and pseudo-commodities. Niche markets for products tailored to the needs of clients.

summarizes the main characteristics of the chemical industry in industrialized countries and compares them to those of the Mexican industry.

Some general characteristics of the chemical industry[1]

The coverage of what is broadly identified as the chemical industry varies according to the different products and subsectors considered. For the purposes of this section, by chemical industry we mean basic petrochemicals (other than the most basic products controlled by Petróleos Mexicanos, PEMEX), intermediate chemical products (including agrochemicals) and final products excepting pharmaceuticals. Rubber and plastic products are also excluded.[2] The share of the chemical industry thus defined in total manufacturing GDP averaged 8 per cent in the period 1970–93, increasing slightly over the last few years; for instance, for 1993 its share was 10 per cent (see Table 11.1). The evolution of the GDP illustrates the fact that the chemical industry on the whole has had a rather smooth and rapid growth since 1970. Petrochemical goods are growing more slowly and even experience a decrease after 1993. Specialities, which are included in the 'other chemical products' category, and are more oriented towards the national market, experience more heavily the depression of the national market that is generated by devaluations. Major multinational companies have also increased significantly their capacities in Mexico, which explains the rapid growth of sectors such as detergents and cosmetics and the large 'other chemical products' category.

The chemical sector includes industries that are essentially capital-intensive. But there is also a large population of medium and small companies that are labour-intensive. Overall, the industry is a low employer: it represents only 4.5 per cent of the workforce (as compared to 5.7 per cent of the US industry), and as ANIQ's Anuarios Estadísticos shows, the employment level decreased in 1995 with respect to 1994.[3] However, the sector's productivity has risen notably, up to three times the average labour productivity of the manufacturing industry in 1993. According to the industrial census, in 1993 there were 2,269 industrial chemical plants with an average of 81 employees per plant. Such an average might be misleading because of the great differences in industry's structure: large firms with more than 250 employees, while making up only 7 per cent of the total number of firms, account for 53 per cent of the labour force, whereas medium-sized firms represent 32 per cent of the labour force.

The chemical industry in Mexico has been concentrating production in larger firms, and shows a clear focus, both in these large firms and in successful SMEs, on exports as domestic demand diminishes. It thus profits from the industry's comparative advantages, mainly cheap inputs from the petrochemical sector and labour, advantages which apply for petrochemical basic products, pseudo-commodities and some special markets. Investment increased considerably around the early 1970s and at the beginning of the 1990s. Foreign direct investment from large foreign firms, and joint ventures between these and domestic firms, have also been significant. It should be noted none the less that the majority of investments are concentrated in large groups of firms. The industry's GDP is distributed in the following way: final products, 46 per cent (soaps, detergents, cosmetics, lubricants, paints, varnishes and so on); intermediate goods, 20 per cent (polymers and fibres); basic chemical products, 15.4 per cent, basic petrochemicals, 15.5 per cent.

Intra-industrial trade grew from 24 per cent in 1980 to 57 per cent in 1990, with more chemical firms catering for firms within the same industry. Finally, it must be recorded that the chemical industry is highly concentrated. The degree of concentration in each branch does not seem to depend upon the type of products, scale of production, orientation of sales or other productive characteristics; thus the degree of concentration is most certainly the product of the firms' strategies.

With the North American Free Trade Agreement (NAFTA) a new framework seemed to be put in place, although the opening of the sector to international trade took place even earlier, between 1985 and 1987.[4] Since the NAFTA opened the US market to Canadian and Mexican products, up to 92 per cent of Mexican chemical exports consist of products with no tariff barriers in the USA.

Both exports and imports have increased at a remarkably high rate since 1987, growing at an average rate of 15 per cent from 1993 to 1996. Mexico is strongly specialized in inorganic chemical products (e.g. petroleum derivatives) although it is a petroleum producing country. Exports have focused on dynamic international markets, though even with large shares Mexican exports grow at a lower rate than world commerce. The degree of specialization is rather low, and is mostly concentrated in markets which are relatively small, as measured by their 'sectoral contribution' (the share of a market in OECD imports). Thus, on the whole, export behaviour seems satisfactory but fragile. Nevertheless, this overall pattern hides the fact that exports are very concentrated in a few companies and that the absolute figures for exports are quite low. Moreover, the trade deficit is a structural problem throughout Mexican manufacturing industry whose explanation is beyond the scope of this chapter. It should be noted, however, that in general, large exporters are also large importers; this is also the case in this industry.[5]

While larger companies tend to export, they are generally more exposed to competition and also more keen on attending to efficiency and productivity on a more permanent basis, rather than supplying a market at whatever cost. Thus changes in the economic environment that resulted from the NAFTA have translated into changing strategies of large firms (Unger, 1994). SMEs, on the other hand, are faced with harsher financial shortcomings and principally serve domestic markets that are rather small and less competitive by nature, since their behaviour is more tightly linked to clients and they have greater dependence on external technologies. SMEs also have a more cautious attitude towards growth and external sources of growth (Villavicencio *et al.*, 1995; CEPAL, 1996).

Employment in the chemical industry has a large share of skilled workers, technicians and engineers, who have traditionally been developed within the firms themselves. In addition to this, the growth of graduates in chemical engineering and similar careers has been quite regular over the years. Thus the industry, and also the state and academic institutions, could rely on a regular flow of high level human resources.

As far as research in chemistry is concerned, it is interesting to note that chemical disciplines account for 8.9 per cent of all scientific publications in Mexico. However, the dominant areas of research – synthesis of natural products, analytical chemistry – are not oriented towards applied science. This clearly indicates how far the

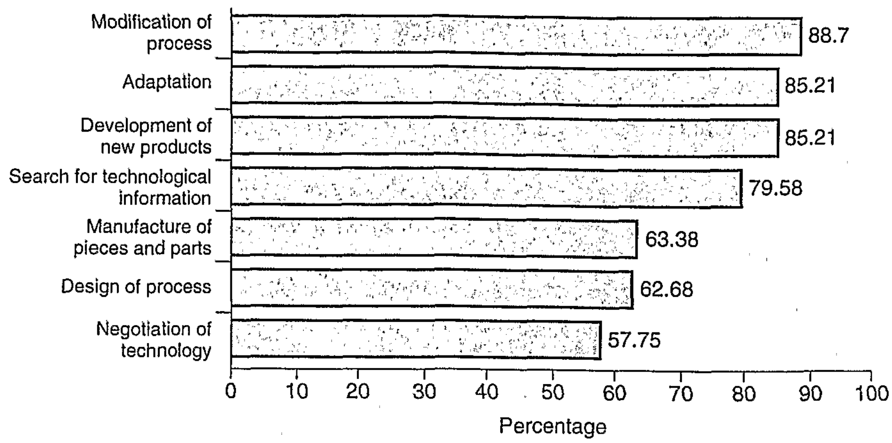

Figure 11.1 Internal Technological Learning Activities.
Source: ORSTOM-UAMX, Survey of the chemical sector, 1995.

Mexican research system is from the productive world, since even research on catalysis, a field with internationally recognized researchers, important publications and evident strategic interest for a petroleum-producing country, is mainly basic research (Arvanitis *et al.*, 1995, 1996). Recent efforts to link the academic world with the productive sector are few and very restricted.

Regarding patenting activities, the chemical field is the single most important field in Mexico: core chemical fields (organic and inorganic chemistry, agricultural chemistry, processes and petrochemicals) represented 23.6 per cent of the granted patents between 1980 and 1992, and 13,994 patents in the core chemical fields between 1980 and 1996, 15.21 per cent of the total registered patents.[6] The domestic firms' utilization of the patent system and industrial property is extremely poor, none the less. They applied for only 5 per cent of the total number of patent applications in Mexico, averaging between 400 and 600 patents per year since 1994, the year in which the new law of industrial property came into effect, which has mainly benefited foreign firms.

The learning capabilities in chemical firms

In Mexico, firms in the chemical industry have two important technological competencies. First, they are capable of modifying or improving production processes, adapting machinery and equipment according to their needs, by means of empirical activities based on the production and engineering personnel, activities that are often referred to when speaking of 'learning by doing'. Relatively few companies have experience in the design of new processes, which is a more complex activity indicative of a real design capacity. Second, they have capacities for developing new products, which constitutes the main orientation of innovative efforts. These new products may be the modification of chemical formulations, the copy of products or formulations and original formulations and products (see Figure 11.1).

It is difficult to assess the degree of novelty of new products. In most cases, novelty refers to the fact that the company introduces some product which is new to the Mexican market but usually exists in foreign markets. It appears that, although companies in the chemical sector have developed an important human resource base and effective technological capacities, they seem not to proceed to a more innovative behaviour. More than half the companies registered fewer than ten innovations in five years in products and processes. Only 12 per cent of surveyed companies introduced some new product not existing elsewhere. Thus the vast majority of chemical companies are moderate innovators looking mainly at copies or adaptations of already known products.

Most of the innovative firms developed their own R&D and engineering activities, and only few firms maintain cooperation agreements with external agents and institutions. In general, the main reasons for innovating are related to satisfying client's needs, increasing the quality of products, productivity and exports, in that order. The R&D activities of the firms are more important than is usually assumed from the official figures on R&D expenditure by the productive sector. We polled 87 companies out of the 1994 sample for whom we had verified data on R&D and sales. These 87 companies allotted a total of 176.7 million new pesos in 1994 for R&D activities. That represents an average of 2.76 million new pesos by company and 4.17 per cent of sales. If we include companies with no R&D expenses, the average R&D expenses amounts to an average of 2.24 per cent of sales. Furthermore, we have observed that almost a quarter of the companies do not have any serious R&D capacity. Effective R&D represents 45 per cent of our sample. The number of R&D personnel for the sample of 87 companies is 447, which represents 2.7 per cent of the total personnel in the sample.

Finally, if we observe the proportion of R&D expenses on sales, 18 per cent of the companies do not spend anything, 39 per cent spend less than 2 per cent of their sales and more than 40 per cent of the companies spend more than 2 per cent of their sales on R&D. Given the quite low innovative activities that we have mentioned above, it seems that R&D figures are quite high. In fact, a thorough examination of the content of R&D activities in most companies indicates that research organized by projects with medium-term objectives is very rare. Most R&D is dedicated to complementary activities: intensive search for information on technologies; service to production and marketing functions of the company, including the definition of client 'needs'. Additionally, and more importantly, compared to an homologous company of an industrialized country, the typical Mexican company will devote larger resources to developing its own research, information and training programme, all things that are rather difficult to find 'out there' in the vicinity of the company. Thus, the content of R&D activities is probably different in Mexican chemical companies than in, say, a German or a US company. What is different is the proportion of research 'projects' in Mexican companies. Probably, information search, technical support to production and marketing and other peripheral technical labours to the productive processes tend to be the bulk of the work in a typical R&D unit in Mexico. Furthermore, since most Mexican companies are buyers of foreign technology, the installation processes might be longer than in a country native to the technology. Distance, language, cultural differences and references all need to be digested by the local firm. This installation process might be a lot more important, and the R&D personnel will be typically engaged in this assimilation process.

The chemical companies usually adopt an 'autarchic' behaviour. Links with other institutions, public services, universities, research centres and so on are very weak. Links are strong with clients and foreign technology suppliers. They are moderate with universities as far as highly skilled engineers are concerned. The vast majority of companies never rely on outside sources of information when adopting strategic decisions. Our data show that companies have used their own developments for the productive technology improvements, as their own R&D capacities are the principal source of improvements in products and processes. Only half of the companies have narrow links with national companies for product and process developments and even fewer engage in links with universities and research centres.

Companies feel that when they wish to engage in an active development policy, even at a rather moderate level by adapting equipment or processes, or by engaging in minor innovations on products, there is nothing outside the company that might serve its information and knowledge purposes. Companies have to generate their own information and their own knowledge, and thus have shown to a large extent experience in searching for technological alternatives but a low negotiation capacity for foreign technologies (see Figure 11.1). Moreover, even for financial support public institutions are very little used by companies. So larger companies have more facility to grow because of larger in-house financial resources than SMEs.

Based on the above-mentioned survey, we can illustrate the external technological linkages of the firms (see Figure 11.2). The chemical industry prefers foreign suppliers of technology independently of size, origin of capital or market. Very few companies have approached universities or research centres for technological developments. The weakness of the relationships with universities is not related to the nature of the linkages with universities but to the difficulty companies have in establishing linkages with any type of suppliers or technical associates.

Foreign producers of equipment are largely preferred to local producers or commercial suppliers: 23 per cent of the surveyed companies had an exclusive contract with a foreign producer of equipment and 22 per cent had exclusive contacts with a commercial company that usually represented a foreign supplier. Only 9 per cent of the companies relied exclusively on a local equipment producer. The local supplier is usually a combined supplier with some foreign equipment producer. These figures illustrate both a preference of companies for foreign suppliers and a 'missing link' in industrial development. There are practically no reliable local producers of large equipment for industry. The capital goods industry is lagging behind in Mexico and the figures for preferences of suppliers translate this missing type of industry.

Links with clients are also very strong: 56 per cent of the companies sell more than 40 per cent of their production to their three more important clients. This proportion goes up to 30 per cent for those selling more than 60 per cent of their product to their principal clients. In the majority of cases the relations are on a long-term basis. The intensity of these links has to do with their markets: links are more intense with industrial clients.

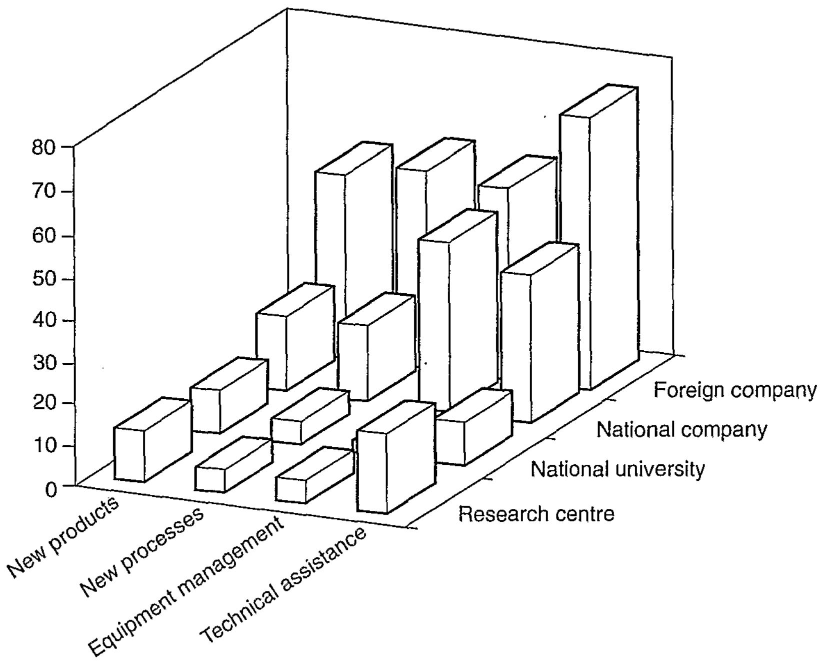

Figure 11.2 External Technological Linkages of Companies.
Source: ORSTOM-UAMX, Survey of the chemical sector, 1995.

Clusters of companies in the chemical industry

With regard to the chemical sector, it is easily seen that large firms within this industry, often backed up by foreign capital or large financial corporations, have kept up with the pace of international competition. They became more efficient, producing better quality products, reducing production costs and raising productivity, implementing lay-off schemes and investing in modernization. SMEs have endured a great deal more economic pressure and consequently are more reluctant to implement programmes requiring significant investments. Massive lay-offs as well as the closure of many SMEs were the trademark of the 1980s and 1990s; thus their figures for productivity and production should be carefully considered.

From the above discussion, it seems that firms with active development strategies favour an 'outward' pattern of behaviour, whereas smaller firms or less technologically active firms adhere to more traditional markets with a more 'inward' pattern. The first type of firms favours joint ventures and alliances and will, obviously, include subsidiaries of multinational firms. The second type is more idiosyncratic and favours local adaptation of technologies and in-house development.

There seems to be a second divide, probably more interesting to policy-makers, which might indicate some route for novel technological development policies, and which accompanies this first large cleavage. There seems to be some opposition in behaviour between companies that deal principally and quasi-exclusively with their foreign technical partners and those that have a preference for local developments.

This cleavage really covers a different priority as far as efficient process development is viewed, as opposed to new product development. One can thus identify a type of company that attends clearly to process development as an obligatory search for efficiency: 'be good or be dead' is their motto and to some extent they dominate the discourse on industrial development. Quality is the buzzword here. These companies look mainly at foreign technical partners and have exports in mind.

The other type includes companies also definitely interested in this expansion through exports, but with a more intense search for product development, adaptation and copy. These companies have a real internal R&D and engineering capacity, but are not only interested in processes. They favour product development mainly because of their types of markets. A typical case might be a company that produces intermediate polymers; that is, performance products. If the company wants to keep its market, the necessity is to find novel materials and new uses for their products. They need to do that based on both a grounded technological design capacity and a good prospective capacity. In a very unstable economic situation, like the one depicted in the preceding section, one dares to enter these activities only because there is the absolute certainty of not being challenged seriously by competition. This is also the great difference with similar companies in the other more industrialized countries of the OECD, which will deal more permanently with competitive uncertainty as well as the inherent uncertainty of technological development. But the comparison with European or US companies is of little help because of huge differences in the size of companies and markets.

In fact, the whole of this industry acts mostly as a market-based cluster, where firms rely heavily on themselves, often guided by the needs of their clients and an idiosyncratic development strategy which to a certain extent has kept firms isolated. It should be borne in mind, however, that the process of opening up the economy might alter the pattern described so far since it has modified the population – size and distribution – of chemical firms. Such a process will undoubtedly accentuate the differences between 'inward' based – promoting mainly internal technological learning – and 'outward' based strategies – relying principally on foreign technical sources of development – as well. It is expected that markets will play a key role together with those macroeconomic policies affecting them in the future development of the chemical sector. Moreover, in taking into account differences among types of firms we obtain three clusters that show similar characteristics (see Table 11.2) and belong to the same brand of 'technological regimes'.

Cluster I contains large corporations usually backed up by a financial consortium. These are usually leaders in their branch, and are mainly oriented towards export competition. They fear no competition and adopt international standards. The subsidiaries of multinationals usually belong to this type. But one also finds many nationally owned large companies, which usually belong to a large financial or industrial corporation.

One such case is CelQuim, a very large and old Mexican company, founded as the by-product of the vertical integration effort of a large industrial group in the north of the country. CelQuim is a complex industrial group producing polymeric material for the textile industry as well as for other industries. It was certified to ISO 9000 shortly after the norm was issued. It is a very dynamic producing group and has been driven by a tendency towards industrial excellence. The managers are among the

Table 11.2 Firms, Markets and Technological Regimes of the Clusters in the Chemical Industry

	Cluster I	Cluster II	Cluster III
Characteristics of firms	Large corporations, backed up by financial consortia including banks.	Large corporations, backed up by financial consortia including banks.	SMEs with little financial support.
Type of products	Commodities and specialities, mainly for industrial clients.	Commodities and specialities, mainly for industrial clients.	Common consumer products.
Markets	Export leaders. High competition.	Market leaders (domestic or foreign). Low competition and monopolistic positions.	Domestic markets (niche markets).
Sources of technology	Higher education (engineering). Alliances with foreign firms. Importance of clients and suppliers, especially PEMEX.	Higher education (engineering). Equipment suppliers. Input suppliers (PEMEX).	Higher education (engineering). Equipment suppliers. Clients.
Opportunity conditions	Low level of innovative activities, but strong learning patterns. Technology flows mainly through foreign partners and technology suppliers. Limited vertical integration R&D limited to production support.	Technology mainly based on internal R&D, product and process design. Limited vertical integration.	Dependence on suppliers of technology, mainly foreign. No integration.
Appropriability conditions	Complex technologies. Protection mainly through secrecy for national firms, and patenting for foreign subsidiaries.	Complex productive technologies. Difficult to imitate products. Low patenting; secrecy.	Easy to copy products (being themselves many times copied), simple processes. Secrecy; little incentive for protection of innovation.
Cumulativeness of technological knowledge	Assimilation of technologies through strong engineering. Efficient in seeking patterns of production. Strong quality programmes.	Development of new products and more efficient processes through R&D and engineering. Permanent R&D and development seeking. Strong internal learning.	Low development capacity. Adaptation and copying of products. Internal learning-by-doing based on use of technology. Old equipment and high gap with competitors.
Nature of the knowledge base	Complex, similar to foreign companies, without R&D capabilities but interaction of engineering and quality programmes.	Complex, science-based and linked to strong design and R&D capabilities	Simple, mainly based on strengthening productive capabilities.
Nature of linkages	Economic and information back-up by financial consortia. Few contacts with universities.	Economic and information back-up by financial consortia. Strong links to university research through R&D departments. Government support.	No contacts with universities. No government support.

best in the country, proud of the level, which they like to compare to similar North American companies. Technology is one of its basic assets and has been largely acquired or modernized through joint ventures with foreign companies. The associations with the foreign technology provider are an exchange on the basis of 'my market–your technology'. The company has given serious thought to opening a corporate R&D laboratory and has even hired a person who would fit the profile of an R&D manager. But after some exchange, the idea of setting up the laboratory was abandoned. The interesting fact about the company is that it maintains very thorough and strong links with universities in the country. It has been the driving force of a biotechnology project which now may be seen as one of the most accomplished technological developments in environmental technology. But excepting this very particular case, the group has been reticent on the idea of developing its own technology. So cluster I would include this type of company, where high quality production, high degrees of competitiveness and efficient management do not necessarily lead to more internal technology development, by choice or strategy.

Cluster II also gathers large companies, but of the more inward pattern type. They also are leaders but usually fight to keep exclusive markets and monopolistic positions. A good case is Pegado, a company that, although it now belongs to a large financial holding group, has been one of the most famous Mexican chemical companies. While its older business unit, the one that is oriented towards consumer products (mainly glue) is a brand known by all Mexicans, it is more the newer business units – the polymer and the intermediates producing units – that are dynamic and highly efficient companies. A common feature has been, historically, the need felt by the company to develop its own technologies. This has been accentuated by the fact that its principal foreign technology provider has broken its link to Pegado. Thus the company which had already created a corporate R&D unit increased its research activities, initially in an effort to provide support to the productive units. In fact, the R&D unit was quite strong and has been an active research unit even at academic levels, employing doctoral candidates and PhDs. Interestingly enough, its highly innovative activities are not the direct product of visible projects; they are the product of intense relations with producing units in some very select areas. In many cases, chief executive officers of the group have been threatening to close the corporate R&D unit if benefits are not directly linked to its status. It can also be said that the fruitful development of R&D – that is, R&D producing value for the company – has been possible only in these business units with a quasi-monopoly of the market. For the discussion here, we should mention that Pegado has not always been in a good financial situation and that it has suffered a lot from the restructuring of the chemical sector.

Many such companies can be found in Mexico. But the majority have probably not been as effective in overcoming the difficulties that are posed by the process of opening the economy to foreign competitors. Apart form the monopoly ingredient and the commitment to R&D, these companies share a strategic point of view of the chemical sector: they choose to enter markets where technologies are complex, needs are more niche-like and markets are less oriented towards commodities and more towards specialities; that is, high priced products.[7]

Cluster III gathers all SMEs that mainly ship in domestic markets. One good example is PETROPROD. It is a medium-sized company that specializes in intermediate petrochemical products. It has chosen to enter this market because 'raw petrochemicals', as they call it, is not paying sufficiently. It has a large array of R&D activities and its R&D department employs five persons on a regular basis, of which two are highly specialized engineers. The head of the company, the son of its founder, is also a chemical engineer and has always been interested in the technical part of his business, although he no longer directly intervenes in the productive operation of the company. The knowledge developed in the R&D unit has been so good that it developed a continuous-line process instead of its batch process. But it installed the process in a Korean chemical company in Korea rather than in its own production plants, because the size of its market would not permit it to absorb the production of a continuous line. Most companies that belong to Cluster III are usually interested in developing very strong links with their clients, up to a point where in some cases they depend too much on them. This is a way of avoiding large market changes. It should also be mentioned that most companies in this cluster are positioned in consumer products rather than intermediate chemical products.

Of course, this heuristic clustering of the chemical industry does not account for companies that are too small or too inefficient in their use of technology (but see Arvanitis and Villavicencio, 1998, for an effort to create a more comprehensive taxonomy). In fact, we can say that clusters of companies show differences in the technological regimes in terms of opportunity, appropriability, cumulativity and knowledge base and the linkages they have (see Table 11.2).

Opportunity conditions can be differentiated across sectors and reflect the likelihood of innovating for any given effort associated with different sources. The first type of firms (cluster I), exporters and quality oriented, are not as interested in innovation. They do have R&D and engineering, and could develop these capacities even more. But the R&D effort is mainly oriented towards production support and peripheral activities, as we have already pointed out. Technology flows mainly from their foreign partners, with whom they have strong links either through alliances (the foreign partner offers the technology and the Mexican counterpart offers the market) or because they act as subsidiaries of a foreign company. The second type is much more based on its own R&D effort. Usually these companies prefer not to deal with a foreign partner. Historically they have developed a strong R&D and engineering base. These appear to be more innovative companies and produce rather complex technological products. They use their internal capacities more fully than firms from cluster I. This is totally different from most SMEs belonging to cluster III, which depend on their technology supplier. Most companies in cluster III have to keep their production capacity alive and occupy their engineering personnel to strengthen their technology base. The very rare cases of innovative SMEs share common characteristics with the larger firms from cluster II: they have some R&D oriented towards innovative projects; they also try to avoid foreign sources of technology. But since these SMEs have little financial support, most projects are doomed or limited in scale.

Appropriability conditions are also very different in the three clusters. Cluster I firms use patents when foreign capital is in. Nationally owned firms are less oriented towards patents because they have little to patent. This is not the case for cluster II companies, which should be the natural clients of the patenting system. For reasons that are still not known, they avoid the use of patents and prefer secrecy or rely on the fact that most national competitors are unable to follow them. Cluster III companies are themselves strong copiers and low innovators and thus do not seek patenting. Even the more innovative SMEs avoid patenting, mainly for reasons of the high costs of this practice.

Cumulativeness is linked to past experiences and abilities to develop new technologies. Cumulative conditions, however, are not easily applied to the concept of sectors, as they are endogenously determined within the firms. Most of the elements in this category result from the above analysis of the learning pattern in each group of firms. The pattern for each category is defined as follows: cluster I, assimilation of technologies through strong engineering, efficient seeking patterns of production, strong quality programmes; cluster II, development of new products and more efficient processes through R&D and engineering, permanent R&D and development seeking, strong internal learning; cluster III, low development capacity, adaptation and copy of products, internal learning by doing based on use of technology, old equipment and a high gap with competitors.

Of course the net result of these differing patterns is a different knowledge base which also cumulates differently. Cluster I companies are producing good quality products that can be exported through efficient internal learning procedures based on foreign technological bases. Cluster II will be rather producers of novel products and will compete mainly because of a strong engineering and R&D capacity. The low technological development effort of cluster III companies restricts their production to adaptations of simple products using an empirical knowledge base.

For many firms, accessing scientific and technological information, competitor's achievements, and economic data, entails costs they are not always able to afford. Many of them get the information they need by creating and enhancing *external linkages* with other economic organizations and institutions like technology suppliers, universities and research centres, as well as promotional and financial development public agencies. In the chemical industry, technology support and equipment maintenance linkages are very strong, generally with foreign suppliers (see Figure 11.2). However, the linkage pattern is different in each of our three clusters.

In cluster I, firms usually have no difficulty in getting the necessary technical and scientific information. They do this through the channels that are instituted when setting up their alliances or technological linkages with an external – usually foreign – provider. Since firms belonging to this cluster usually do not run their own R&D centre, they have to rely heavily on the R&D facilities of a 'mother' company (this will be the casc for a subsidiary) or of the foreign partner (usually the case for the Mexican owned companies). Linkages for the development of new products or adaptation of processes will rarely be with universities or public national research and technical centres.

Firms in cluster II rely heavily on their own R&D facilities. They will try to develop their own research links with external R&D centres and universities. They will get involved in government-supported innovation programmes that will provide them with financial support, human resources training or long-term joint ventures with public research centres.

Finally, cluster III firms will rely or not on external linkages with universities or research centres based mainly on very short-term benefits. But mostly these companies will tend to have as few external linkages as possible, except with their basic equipment provider. Most of these companies, being SMEs with strong financial limitations, will tend to avoid any involvement in cooperation they tend to consider as costly. These 'autarchic' companies, as we proposed naming them (Arvanitis and Villavicencio, 1998), will develop most of their processes by themselves. The fragility of such a strategy appears clearly under financial pressure. None the less, most of these companies will avoid getting involved in publicly supported programmes.

Conclusions

We have shown that different patterns of technological learning in firms can be identified. These are based upon differences in the way companies obtain knowledge from the environment, the way this knowledge is managed and diffused into the organization, as well as the way knowledge coming from the suppliers or the clients is processed and transformed into new capabilities. It should be stressed that the economic behaviour of a company seems to be strongly linked to the rough changes in the economic environment experienced in Mexico. But instead of sweeping it away, one observes that the industry has shown a real capacity to anticipate these changes. This was possible because of the strong learning capabilities accumulated by their former experience in a rapidly changing economic environment. By developing R&D or getting tied to a foreign technology provider, Mexican chemical companies have been able to manage adequately the announced crisis that followed the NAFTA treaty.

At the same time, one can observe the lack of direct state intervention in the chemical industry (with the very notable exception of the state owned company, PEMEX). Companies have influenced the NAFTA negotiations, and have typically found resources for their projects outside the public sphere. Thus all the changes in the industry can be easily qualified as 'market-driven'. This is true not only when assuming that, in the absence of strong public policy, the market is dominant, but also by observing the fact that changes affecting the provision of raw material or of technical inputs have been dealt with quite efficiently by the chemical companies themselves. This ability to precede changes is a fundamental aspect of technological and organizational learning. It is the result of a constant effort to improve the technology, although the motives and the patterns might be different across different clusters of companies.

Most of the discussion in economics of innovation insists upon the importance of sectoral characteristics and the size of companies. These are quite easily observable dimensions, and can be examined at an aggregated or a firm level. We do believe these factors to be essential, but not unique. In this chapter we have defined three clusters of companies. Two clusters are groups of mainly large firms and the third one groups of SMEs. This third cluster could be divided into many sub-clusters, based upon the types of markets or the technical linkage patterns. The purpose of such an analysis would be to redefine the criteria that permit identification of a specific pattern of learning and a specific type of management of technology. But it would obscure the fact that these companies have had to deal with considerable financial pressure due to changes in the overall economic pattern of Mexico. Most of these companies are SMEs and the key to their resolution of difficulties has been their extremely strong links to their clients. This is not to say that larger companies have been less favourable to listening to client needs; instead it allows them to demonstrate that they are more committed to a type of market, and by way of consequence to a type of technology, than to a specific client. If our interpretation is correct then one would need to be cautious about the benefits of flexibility. Larger firms have been less flexible than knowledgeable; smaller firms have been less flexible than cautious. And all of them have devised adequate technological strategies that permitted them to face these changes.

Notes

1. All data on technological activities, R&D, engineering and technical linkages of the Mexican chemical companies are drawn from a representative survey in 142 companies that was done between October and November 1994 in a joint research project between IRD (formerly ORSTOM) and UAM-X. See main results in Villavicencio *et al.* (1995); elaboration on the technological behaviour of companies can be found in Arvanitis and Villavicencio (1998).
2. This *stricto sensu* corresponds to the definition managed by the large manufacturers' associations like the Chemical Manufacturing Association (CMA) in the USA or the *Asociación Nacional de la Industria Química* (ANIQ) in Mexico.
3. It should be kept in mind that we are talking of rather low figures of employment in absolute terms (around 150 thousand workers) as compared to employment in the chemical industry worldwide (for example, 1,045 thousands workers in the US chemical industry) (see Arvanitis and Villavicencio, 1998).
4. The degree of protection of national chemical production fell from 86.8 to 18 per cent between 1985 and 1987. This drastic lowering of barriers to imports went further: by 1988 domestic production protected by import permits was minimal (2.5 per cent) and the protection of local production by the regulation of import prices disappeared totally. In 1988, the average tariff level was almost 13 per cent. This change is very important and probably prepared the industry for the further abatement of legal protections. Furthermore, most of the suggestions made by the chemical trade association (ANIQ) have been included in the final agreements of the NAFTA. See CEPAL (1996). Additionally, 70 per cent of the clauses of the NAFTA that were negotiated concerned the exchange of products between Canada and the USA that are not produced in Mexico.
5. In 1996, exports were above US$4 thousand million, while imports were US$3 thousand million. But 1996 was a most exceptional year, since the previous year's exports were almost $6.7 thousand million in 1995. This diminution explains the positive trade balance of 1996, which is generally negative in this industry.
6. General data on patenting by Aboites and Soria (1997). We use a different definition of 'chemical fields' through the international patent classification from these authors, who are restricted to chemical processes in the chemical industries ('Core chemical fields') and extract a more limited database from the Aboites and Soria general patent database. Thanks to Manuel Soria for allowing the use of data.
7. See Mercado (1995) for a similar analysis for Brazil, and Mercado (1996) for Venezuela.

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