Abstract

The chemical industry is one of the largest and most R&D-intensive manufacturing sectors in all advanced economies, and its innovative patterns and productivity growth processes can have profound impacts on economic growth as a whole. Within this context, the European chemical industry is internationally very competitive, even if there are some indications suggesting that the industry is loosing grounds vis-à-vis the other advanced regions, especially in the high-tech segments. Hence, the main objective of this project was to develop a comprehensive analysis of the European chemical industry by studying the development and shaping of the industry, and its impact on other industries, different regions and SMEs, while comparing its performance with the cases of Japan and the U.S. An important background for this project was the *Green Paper on Innovation* and the important questions that it opened up about innovation in Europe.

The project has explored two main issues: (i) the science & technology base and the dynamic performance of the European "system of innovation" in the chemical industry, with particular attention to its contribution to economic growth through innovation and competitiveness, and to the ability to translate its research into commercially useful products; (ii) the forces that encourage the diffusion of chemical innovations on downstream user industries, across regions, and on SMEs, with particular attention to the diffusion processes (user-producer interactions) and spillovers to other industries, regions and Small-Medium Enterprises (SMEs).

Each of these two main themes was analysed by looking at specific issues, and different studies have been promoted within each of them. The results of these studies give a fairly complete description and understanding of the European chemical industry, the existing division of labour between small and large firms, its technological base, and its competitive position. The results of the studies have also been used to define innovation-related sources of competitive advantage and address specific suggestions for policy interventions and actions.

1. Executive summary.

This project aimed at developing a comprehensive report on innovation processes and policies in the chemical industry, following the example of the *Green Paper on Innovation*. The main purpose was to analyse the strategic aspects of innovation and related technological policy, taking into account the idiosyncratic characteristics of the European chemical industry.

The project had three main objectives:

a) Analyse the science & technology base and the dynamic performance of the European "system of innovation" in the chemical industry, with particular attention to its contribution to economic growth through innovation and competitiveness, and to the ability to translate its research into commercially useful products.

b) Analyse the forces that encourage the diffusion of chemical innovations on downstream user industries, across regions, and on SMEs, with particular attention to the diffusion processes (user-producer interactions) and spillovers to other industries, regions and SMEs.

c) Discuss policy implications and actions, based on a comprehensive study of the factors and the conditions enlisted in the previous two points.

Each of the first two themes was subdivided in more specific tasks, which have been afforded by different research units by using various methodological approaches and specific theoretical backgrounds. In the following, we present a synthesis of the main issues addressed by each task.

Theme 1 – The science and technology base and the dynamic performance of the European "system of innovation" in the chemical industry, and their relationships to innovation and market development, competitiveness and economic growth

Task 1.1 – Evolution of industry structure in the US, European and Japanese chemical industries: A historical approach

In this task, we discussed similarities and differences in the evolution of industry structure and innovation processes in the US, European and Japanese chemical industries. The understanding of this issue has clearly an introductory purpose, and aims at defining the importance of historical factors. Some of these factors have preserved and accentuated initial differences in industry structure and innovation processes in the three regions, while others have induced greater similarity and convergence across the three areas. For instance, the rise of scientific capabilities and the increasing role of users have been of the first type, while international trade in goods and technologies have been of the second type.

One of the main findings that we obtained is that two factors that have arguably been the motive force for the growth of the chemical industry in the last half century lie on the technological domain: polymer chemistry, and chemical engineering. *Polymer science* has been the source of a large number of major product innovations, and is the basis for very many of the sectors regarded as the heart of the chemical industry. The other, *chemical engineering*, has been responsible for making possible the production of these polymer based products (and polymer building blocks) at a cost low enough to ensure their success.

Task 1.2 – Market structure and innovation in the US, European and Japanese chemical industries: Empirical analyses

In this task we tested specific hypotheses about the relationship between innovation processes and market structure in the chemical industry. Based on a novel theoretical framework, the objective of this contribution was to analyse the relationship between market size, the existence of alternative technological trajectories in R&D intensive industries, and concentration. In particular, we tested two main hypotheses:

- as market size grows, industries with endogenous sunk costs, such as advertising and R&D expenditures, may not evolve in equilibrium towards fragmented market structures;
- high R&D intensity industries' minimum concentration levels are affected by consumers' heterogeneity of preferences, since the latter fosters the existence of alternative technological trajectories. In that context, the heterogeneity in research trajectories yields more fragmented structures.

Task 1.3 – Publicly-funded scientific research in chemicals, and its effect on commercially useful innovations

This task analysed the “transmission mechanisms” between publicly funded chemical research in Europe – particularly the research performed by universities and other non-profit institutions – and commercial innovations. The purpose was to assess whether and to which extent the European chemical industry suffers from the so-called “European paradox”, also by comparing the nature and the characteristics of the existing transmission mechanisms in Europe with those of the US and Japan.

In order to analyse this issue, the task has been divided into three studies, focussing on different levels of the problem. By doing so, it was possible to provide an assessment of the existing linkages between science and technology, both developing theoretically and implementing empirically new research methodologies. Furthermore, we were able to perform country comparisons, with particular attention devoted to the differences between Europe, US and Japan.

The three studies focused on the following issues:

1) Persistence and integration. The knowledge base of the pharmaceutical industry;
2) The Evolution of Specialisation. Public Research in the Chemical and Pharmaceutical Industries;
3) Science-Technology Linkages. The case of Combinatorial Chemistry.

Task 1.4 – Changes in the “geography” of industrial research and innovation in the chemical industry

In this task we assessed whether the location of industrial research in chemicals – or in specific sub-fields like biotechnology, new materials or environmental technologies – has concentrated in specialised areas or locations worldwide. The issue can be read from the viewpoint of chemical firms. From this perspective, it seemed to be interesting to evaluate whether European chemical firms are locating their “generic” R&D in regions outside Europe (and particularly the US), through different means such as mergers & acquisitions, strategic alliances, or foreign direct investments.

The study has been conducted in two different steps. In the first, we gave a look at the international flows of chemical plants investments, in order to assess whether the European industry is moving abroad, and in order to compare the “geographical” evolution of the European chemical industry with US and Japan. This was an introductory study on the issue of geography of innovation and R&D, not directly focused on innovation and R&D, but aiming at understanding whether the chemical industry is going to become a global industry, or whether all firms of developed countries are moving their investments to emerging or developing countries. The second step has been to enter directly in the issue of geographical distribution of R&D activities in Europe, according to the purposes already expressed.

The first important result of this analysis is that the European chemical companies perform most of their research in their home-country, and that patenting activity clusters in few regions. Other results indicate that, compared to the geographical cluster, the multinational company is a better mechanism for creating larger networks, for enhancing collaborations amongst de-localised inventors, and for producing interdisciplinary patents. In short, this confirms that the firm, and particularly the large companies, typically promote larger research networks, and they produce rather general sort of research, at least in the chemical business.

Task 1.5 – The new high value added “specialty” chemical market: Is Europe loosing grounds?

This task aimed at examining the relative position of the European chemical industry in these high quality R&D-intensive industries, and compare its competitiveness with the US and Japan. Indeed, the position of European chemical producers was not completely clear. In some sectors, the US or Japan appeared to be the leaders. For instance, it is well recognised that in biotechnology-based products Europe was loosing grounds vis-à-vis the US. Similarly, Japan appeared to be much more effective than Europe and the US in high-tech fields like chemical applications for electronics or advanced fibres.

We took into account four specific fields of specialty chemicals – agrochemicals, new materials, paints and coatings, and pharmaceuticals – where the relative position of European chemical firms is different in each field. We used specific research methodologies for each field which allowed us to reach a deep understanding of the specific features of the speciality chemicals sectors, and of the relative position of the European chemical industry within this sectors.

Task 1.6 – The effects of different financial systems on competitiveness and innovation performance in the chemical industry

This task provided a comparison of how different financial systems – in the US, Japan and different European countries – constrain and support the innovation policy of chemical firms. A related objective was to compare the ownership structure of European leading firms with their US and Japanese competitors. Compared to Japan and the US, the European situation appears less favourable to investments in R&D. European companies lack the close interconnections of Japanese rivals, and are not subject to strict discipline of financial markets as in the US.

We looked at *restructuring* and its effects on firms' R&D decisions. Restructuring at the firm level entails changes in the composition of both capital and labour, and in particular the divestiture and acquisition of productive assets. Restructuring at the level of the industry entails the entry and exit of firms through takeovers, mergers and acquisitions, i.e. sales and purchases of whole businesses. It is then important to understand what effect restructuring has on R&D. Hence, the purpose of this study was to provide some insights on how firms change their R&D investment as a result of changes in their business portfolios.

Theme 2 – The forces that encourage the diffusion of chemical innovations on downstream user industries, across regions, and on SMEs.

Task 2.1 – The effects of different forms of government interventions on the incentives of firms to undertake R&D, especially R&D characterised by significant spillovers

In this task we studied the effects of different government interventions on the R&D process of the chemical industry, and explicitly, we studied the effects of government interventions in the development of the environmental technologies in the chemical industry.

Government intervention in this field is mainly based on two instruments: i) the "command and control" approach, based on direct regulation; ii) the use of economic instruments and voluntary programmes. The first solution is characterised by a reduced flexibility, because it consists of measures aimed at directly influencing the environmental behaviour of social actors, since it determines limits, restrictions and rules related to specific product and processes. On the contrary, the second solution is comparatively more flexible, because it consists of instruments such as taxes, tradable quotas, subsidies, covenants and so on. The effects of these different government interventions have been analysed.

Task 2.2 – The "world" market for chemical process technologies: Their diffusion and the beneficial effects of division of labour on other firms and users

This task discussed in detail the nature and characteristics of the market for process technologies in chemicals. The chemical industry is a leading example of the effects produced by the creation of a market for technology. While technology transfers are not uncommon in other industries, few have witnessed the rise of a market for new technologies disembodied from capital goods and equipment. In the chemical industry, licensing, especially of new process technologies, has been a widespread practice for many years. Moreover, this practice has given rise to an efficient division of labour between companies that have specialised in the design and engineering of chemical plants (the so-called "Specialised Engineering Firms"), and downstream producers that acquire the services of these upstream suppliers.

The study was conducted in four different steps. In the first, we provided an empirical assessment of the size of the market for technology in chemicals. In the second, we discussed the theoretical insights, trying to understand why firms have incentives to license their technologies and to promote the expansion of the international market for technologies. In the third, we discussed the advantages coming from the existence of such a market in terms of international spillovers and economic growth processes. Finally, the fourth step looked at the issue from a managerial viewpoint, and compared two entry modes that multinational enterprises can use to invest in new markets, namely wholly owned subsidiaries and technology licensing.

The issue of division of innovative labour in chemicals has been explored also by focussing in the pharmaceutical sector of the industry. We analysed the formation or R&D networks as organisational devices for the coordination of heterogeneous learning processes by agents endowed by different skills, competencies, and access to information and assets. We tried to establish a closer connection between the structure and evolution of knowledge and the structure and evolution of organisational forms in innovative activities.

Task 2.3 – The new challenge: Environmental technologies. Is the chemical industry "spilling over" to other sectors, to other European regions, and to SMEs?

In this task we examined the present efforts of the chemical firms in the field of environmental technologies, and discussed how the latter have become an important source of industrial competitiveness of the industry. Relatedly, we examined how the European firms are coping with this problem and their competitive position in this technological field as compared to the US and Japanese firms.

The study has been conducted in two different steps. In the first, we focussed on Europe by performing three different analyses, aimed at a better understanding of the processes of development and diffusion of environmental technologies. By using patent information we investigated the innovative rate of the chemical industry in the environmental field. By using case studies we examined the reasons that would push or dampen the development and the diffusion of environmental technologies. Finally, by means of an Internet analysis we analysed the environmental industry, i.e., the sector specialised in the supply of environmental products, services and technologies.

In the second step we focused on the case of Germany, and in particular on the efforts which German chemical firms are making to reduce water waste resulting from manufacturing processes. This issue has been explored by analysing two specific objectives. First, the patterns of process innovations of West German chemical firms to reduce water waste. Second, the firms' reasons for carrying out or refraining from process innovations to reduce water pollution. Understanding the firms' innovative behaviour is a precondition for an effective support of public policy towards an environmentally safer development.

Policy implications

The analyses performed in each task, allowed us to have a complete picture of position of the European chemical industry compared with the US and Japan, from the point of view of the sources for competitive advantage. From this picture, we were able to define a set of policy implications and policy interventions that the European authorities could promote in order to strengthen the competitiveness of the European chemical firms. Hence, the level of policy that we discussed is primarily European. However, this is an industry with a clear international dimension. It is therefore hard to think of local policies for this industry. Moreover, its increasing globalisation suggests that even national policies may be confined to a fairly narrow territorial level. The European dimension is, therefore, in many respects the right dimension for innovation policies in this sector.

We started by discussing the sources of competitive advantages for the European chemical industry, by focussing on the innovation-related sources of competitive advantages, and distinguishing amongst the different types of firms or realms to which such sources of competitive advantages would most specifically apply.

1) Sources of competitive advantage: Public research

One the possible sources for competitive advantage is based on the knowledge base from which firms in Europe may draw for innovation. The project has looked at this issue from different perspectives. On the one hand, some of the research tasks has looked at the publicly funded research and tried to assess the performance of European public research institutions. This has been done by looking at publications and patents and by trying to develop performance indicators. On the other hand, the importance of the knowledge base for specific subsectors has been analysed.

Overall, the results of our project indicate that, despite the fact that in terms of number of publications and patents the European chemical innovation sector is performing well, according to other indicators, such as specialization and persistence, the US may be outperforming the EU.

Different studies highlight this point. In sum, these studies have assessed the performance of European public and private actors in the development of the knowledge base for various subsectors of the chemical industry. One of the main questions of the project was if the European chemical industry is able to translate its knowledge base into commercially successful products. These studies yield initial evidence to tackle this question. First, with respect to some indicators such as specialization and persistence, the knowledge base of the European innovation system does not perform as well as previously thought, so in some sense there may be fewer discoveries to push commercial applications than what is needed. Second, from the evidence gathered from the pharmaceutical industry, it seems that some European firms are successful in translating scientific discoveries into products, but these discoveries are not based in Europe but mainly in the US.

2) Innovation policies and the large chemical firms

Some of the key findings of this project about large firms can be summarised as follows.

- Market structure

The structure of the European chemical industry conforms quite well with the predictions that in R&D-intensive segments the industry is concentrated. This suggests that one is unlikely to observe major shake-outs or relevant changes in most segments of the European chemical industry in the near future. As far as policy is concerned, this suggests that no particular action should be undertaken, or one is expected to undertake in this domain. Also, major crises in the industry (e.g. business failures, significant competitive threats, etc.) are unlikely to occur, with implied no anticipation of strong policies in this and related areas of intervention.

- The organisation of R&D in the large chemical firms

The European chemical companies perform most of their research in their home-country, and that patenting activity clusters in few regions. This confirms that the globalisation of R&D by multinational enterprises is at best a quite incomplete process. Other results indicate that, compared to the geographical cluster, the multinational company is a better mechanism for creating larger networks, for enhancing collaborations amongst de-localised inventors, and for producing interdisciplinary patents. In short, this confirms that the firm, and particularly the large companies, typically promote larger research networks, and they produce a rather general type of research, at least in the chemical business.

But this also suggests that, as far as the large European chemical firms are concerned, there is no urgent policy intervention for promoting the generation of R&D and related activities. The large European chemical firms do engage in these activities, and as a matter of fact they do give rise to large networks of inventors and they do produce patents with wide potential applicability.

- International Investments

The studies conducted in this project point out two major facts: a) that the chemical industry has become more global, with a lower share of plants belonging to a particular company from one region located in the same region, and a higher share of plants from one region in the other regions; b) that the European companies have proved to be particularly active in this globalisation process, as they have typically increased their share of plants abroad. Moreover, this happens both in advanced markets like the US and Japan, and in the open market of the developing countries, and particularly in Asia.

Hence, the competitiveness of the major European chemical firms has not declined in the past decade or so. In turn, this confirms that no major policies are needed today for enhancing the ability of these companies to internationalise. It appears that they are continuing a long standing tradition of internationalisation, and there is no need for investing major policy resources in promoting patterns that are mastered quite effectively by these companies without any particular policy support.

- R&D, innovation and restructuring in the chemical industry

The major policy implications from this analysis is that policy should encourage restructuring processes in Europe, especially because – as this study finds – they ultimate produce an increase in the R&D intensity of firms. Related to this is the fact that restructuring often involves serious costs as it implies changes in the structure of firms and this entails short-run costs, both private and social (e.g. layoffs, reduced profits). These have often restrained restructuring processes. We suggest that important policy interventions are necessary in order to: a) reduce the social costs involved; b) separate them from the restructuring and other private costs of the companies.

In short, we suggest that governments should take up the short run social costs of restructuring that are often borne by individuals who are less capable of smoothing out incomes and losses over time (particularly in the short-run), or who would not be the same people that will benefit from the positive outcomes of company restructuring in the longer period. The private cost of restructuring should instead be borne by the shareholders, or whoever will benefit from the restructuring in the longer run. This separation is central to enable the restructuring especially in Europe were vested interests and political economy considerations are often involved in processes like this. In this respect, by separating social and private costs, and relatedly by attributing the costs to those who enjoy the longer run benefits of restructuring, we believe that restructuring processes will be easier to accomplish.

At the same time, governments should avoid intervening in the restructuring process, and on how it is carried out. The European experience of restructuring in the chemical as well as in other industries during the 1980s is that governments managed the restructuring process to a good extent, especially in France and Italy. The restructuring process should be governed by market forces. Moreover, the results of this study suggest that business swaps (e.g. exchange of divisions) by established firms through mergers and acquisitions, divestures, and the like, which have been often observed in recent years amongst the largest European chemical firms, should be encouraged.

3) Integration between large firms and public R&D (university)

The main conclusions from our analysis of public research and large firms indicate that large European chemical have little difficulty in obtaining technology. The differences in performance between European and US firms, or between different firms in Europe, should be sought not in differences in the ability of firms to obtain technology but in differences within firms in how they manage very similar technology. As a consequences the key to understanding the competitive position of the European industry is understanding the differences between firms in how they manage technology, as it is this that determines relative economic performance.

4) Innovation policies and the small firms

The role of the smaller companies is linked to the opportunities for the development of a full fledged markets for technology in Europe, and more generally for the participation of the European firms in the global market for chemical technologies. The rise and development of markets for technology in the chemical industry was the subject of an entire research task of this project (task 2.2).

We highlight the importance of adequate policy interventions that would remove the barriers to the creation of these markets. In some sense, one might say that the large chemical companies have a long standing tradition and competitiveness, which we confirmed with the various studies of this project. This implies that no major policy action is needed for enhancing their competitiveness. By contrast, European markets for technology are far from being developed, and this requires policy support for their formation. In particular, this calls for policy actions to encourage the rise and growth of smaller firms specialised in the development of technologies.

Specifically, we envisage the following policy actions for enhancing the markets for technology in the European chemical industry, and particularly in its engineering and technological sub-sectors:

- *Development of proper forms of Intellectual Property Rights (IPRs) to support the activities of smaller technology-based companies.*

- *Development of adequate forms of financing for new technology-based companies.*

- *Development of new forms of technology diffusion by universities, and the scientific institutions more generally.*

Finally, the results of this part of the project, and the related policy implication, are also important for the vertical structure of the chemical industry. Most notably, the rise of markets for technology implies a division of labour which in turn benefits the downstream producers. The classical advantages of a division of labour are indeed that the downstream producers can take advantage of the input at lower costs than if such input had to be produced in-house.

Apart from efficiency gains in the downstream industries, this implies greater diffusion of the technology downstream, greater entry of new competitors in final markets, etc..

These advantage of vertical specialisation suggests some further policy actions, and particularly:

- Policies that would encourage the external monitoring of new technologies by existing producers in final markets, and more generally policies that would reduce the transaction costs for technology exchange that may exist in such markets. Transaction cost reducing mechanisms may range from the establishment of proper standards for reducing the potential segmentation of technologies that are in fact used for similar purposes, to the creation of proper institutions for technological exchange (e.g. standard contract), etc..

- Policies that would reduce the search costs for new technologies, by creating new forums, electronics exchange markets, and the like for the exchange of technologies. In this respect, we welcome for instance initiatives like *Cordis*, the on-line data bases of technologies promoted by the Commission.

- Policies that would discourage the so-called “not invented here” syndrome, which affects many firms and even countries. The NIH syndrome is the one in which firms disregard technologies not developed internally, and it has been widely documented in the managerial literature, as we also noted in our research. As markets for technology develops, the problem with such a syndrome is that firms may loose important opportunities for acquiring technologies at lower costs, with implied benefits on their demand for technology, and ultimately on their profitability, competitiveness, and on their ability to increase employment. At the same time, such a syndrome may even prevent the markets for technology to arise in the first place, because the general business climate does not encourage the exchange of technologies amongst different parties.

2. Background and objectives of the project.

The main objective of this project was to develop a comprehensive analysis of the European chemical industry by studying the development and shaping of the industry, and its impact on other industries, different regions and SMEs, while comparing its performance with the cases of Japan and the U.S. An important background for this project has been the *Green Paper on Innovation*. Indeed, The *Green Paper on Innovation* opened up many important issues about innovation in Europe. One of its limitations however is that it provides a very general view of the problems of innovation. In fact, the nature of technology and the problems of innovation differ considerably across industries. Moreover, within each industry many of the issues raised by the *Green Paper* have to be articulated in more detailed ways to reflect their special needs and characteristics. Hence, we followed the example of the *Green Paper on Innovation,* but we took into account the idiosyncratic characteristics of the European chemical industry.

This general research theme was translated into three interrelated objectives:

1. Analyse the science & technology base and the dynamic performance of the European "system of innovation" in the chemical industry, and understand how it relates to innovation and market development, competitiveness, and more generally economic growth. Particular attention was devoted to the ability of the chemical industry in Europe to translate its research into commercially useful products, and the problems thereof. While the research activity is clearly of European dimension, whenever relevant and useful we provided comparisons with the US and Japan. In pursuing this objective, we focused on issues like: The importance of historical factors in affecting the dynamics of this industry in the three advanced regions; the effects of differences in market structure on their performance; the nature of the "transmission mechanism" from upstream scientific and technological research on commercially useful new products and processes; the localisation of chemical research worldwide and the role of strategic alliances and mergers and acquisitions in shaping the present dynamics of the industry; the European competitiveness in the new R&D-intensive specialty chemical sectors; the effects of different financial systems on innovation performance.

2. Analyse the forces that encourage the diffusion of chemical innovations on downstream user industries, across regions, and on SME. Particular attention has been devoted to the nature of this diffusion process (e.g. user involvement, user-producer interactions), and

more generally to the factors that encourage greater spillovers from chemical research and innovation on other industries, regions, and SME (e.g. in fields like biotechnology, environmental technologies, specialty chemicals). In particular, we discussed issues such as: the effects of different forms of government interventions on the incentives of chemical firms to undertake research characterised by extensive spillovers; the effects of licenses and of the rise of a market for chemical technologies on the growth of other firms or industries; the potential benefits produced by the development of new technologies by the chemical industry (like environmental technologies) on other firms, and particularly on firms like the SME which cannot develop these technologies in-house.

3. Discuss policy implications and actions, which were based on a comprehensive study of the factors and the conditions enlisted in the previous two points. Ultimately, our goal was to deal with the critical issues about innovation and competitiveness of the European chemical industry, which had been highlighted in the *Green Paper on Innovation*. The third objective highlights the corresponding policy implications. Particularly, we tried to distinguish between policy implications for the European chemical industry (first objective), and policy implications for enhancing the diffusion of chemical innovations and the spillovers from the chemical sector to other sectors, regions or to SME (second objective).

3. Scientific description of the project results and methodology.

The general scheme of the project was translated into two subsequent objectives. The first aimed at analysing the science and technology base and the dynamic performance of the European "system of innovation" in the chemical industry, and at understanding how it relates to innovation and market development, competitiveness and economic growth. Special attention was posed to the ability of the European chemical industry to translate its research activity into commercially useful products. While the research activity is clearly of European dimension, comparisons with the US and Japan were provided whenever useful and relevant.

The second objective aimed at analysing the forces that encouraged the diffusion of chemical innovations on downstream user industries, across regions, and on SMEs. The nature of this diffusion process was particularly studied – in terms of user involvement, user-supplier interactions, and so on – and the factors that encourage greater spillovers from chemical research activities and innovation on other industries, regions, and SMEs was highlighted. In particular, we analysed fields like biotechnology, environmental technologies and specialty chemicals.

Each of these two themes was subdivided in more specific issues, which have been afforded by different research units by using various methodological approaches and specific theoretical backgrounds. In the following, we present a synthetic description of the methodology used and of the results obtained in each task.

Theme 1 – The science and technology base and the dynamic performance of the European "system of innovation" in the chemical industry, and their relationships to innovation and market development, competitiveness and economic growth

Task 1.1 – Evolution of industry structure in the US, European and Japanese chemical industries: A historical approach

The objective of this task was to discuss similarities and differences in the evolution of industry structure and innovation processes in the US, European and Japanese chemical industries. The understanding of this issue has clearly an introductory purpose, and aims at defining the importance of historical factors. Some of such factors have preserved and accentuated initial differences in industry structure and innovation processes in the three regions, while others have induced greater similarity and convergence across the three areas. For instance, the rise of scientific capabilities and the increasing role of users have been of the first type, while international trade in goods and technologies have been of the second. This Task was conducted by Arora and Gambardella (1998).

As far as methodology is concerned, the analysis of this task was performed mainly by using historical analyses, comparative analyses of markets and institutions, and industry case studies. Data on recent trends in industry dynamics have been drawn from databases (e.g. *Chemical Economic Handbook*, Stanford Research Institute, Palo Alto CA), which are specialised on the chemical industry and on specific chemical companies.

The evolution of the chemical industry has been driven by advances in technology and by the institutions that have facilitated the growth of new markets. In addition to the conventional market growth in the form of demand from developing countries, the evolution of the chemical industry has also been profoundly affected by the growth of a market for technology, and a market for capital. When technology becomes widely available, albeit at a price, it ceases to be a decisive source of competitive advantage, be it for firms or for countries. Instead, competitive advantage must be sought elsewhere, in cheaper inputs or closeness to markets. Similarly, a global market for capital gives shareholders the opportunity to look for the best returns, putting managements under pressure to cut costs and improve shareholder value.

In some sense, the evolution of the industry has been characterised both by the presence of a series of big *discontinuities* at the industry-level, and by a big *continuity* in companies' life. On the one hand, the dyestuff model, the development of polymer chemistry (i.e., the science of chemical products), and the chemical engineering (i.e., the science of chemical processes) were major changes in the knowledge sphere. The shift from coal to petrochemicals in the years before the Second World War had strong consequences on regional leadership in chemicals, and allowed the American chemical industry to catch up with Europe. The emergence of specialised engineering firms (SEFs) made it easier the outsourcing of process technologies and allowed a growing division of labour at the industry level between SEFs and chemical companies. The world demand decrease during the 1980s induced a process of industry restructuring.

On the other hand, chemical firms were able to evolve and compete over time. BASF, Bayer, Dow Chemical, Agfa, ICI, Du Pont, i.e. some of the leading chemical companies nowadays, have more than one hundred years history and have been top chemical producers during all this period. This means that between small and large companies, markets, research institutions and other organisations there has been a process of co-evolution, with firms playing the central role within the chemical system.

Two factors that have arguably been the motive force for the growth of the chemical industry in the last half century lie on the technological domain: polymer chemistry, and chemical engineering.[1] *Polymer science* has been the source of a large number of major product innovations, and is the basis for very many of the sectors regarded as the heart of the chemical industry, including synthetic fibers, plastics, resins, adhesives and paints and coatings. The other, *chemical engineering*, has been responsible for making possible the production of these polymer based products (and polymer building blocks) at a cost low enough to ensure their success. The rate and direction of technical advance in these domains has changed in the last twenty years, and with it, the identities of the main actors have changed as well. These changes, which have taken place against a backdrop of slower economic growth in most of the developed world, have also contributed to significant changes in the strategies of many of the leading firms in the industry, and to the dramatic shifts in industry structure in recent years.

The rise of petrochemicals in the post-World War II period laid the basis for the *technological convergence* of the oil-refining and chemical sectors. Indeed, polymer chemistry showed how petroleum and gas-based feedstocks could be used to make very useful products. In addition, chemical engineering provided the basis for the design of both refineries and chemical plants for products such as polyethylene and nylon. The impact of this convergence in the oil and chemical sectors was asymmetric. While oil firms moved downstream into chemicals, chemical firms were much less successful in moving upstream into oil refining. Furthermore, oil firms retained control of crude-oil supplies, and had existing distribution channels and networks for by-products of oil-refining which were difficult for chemical producers to try to

[1] Catalysis is another important class of technological innovations, which is complementary to innovations in polymer chemistry and chemical engineering. Indeed, many of the new products required advances in all three areas. See Landau (1988) for a discussion of these issues.

duplicate. As a consequence, chemical companies tried to react to their inability to move upstream by moving further downstream into differentiated products.

Following the big technology push in the industry during the 1950s and 60s, technology diffused more widely than it ever had before. Specialized engineering firms played a key role in creating a global market for process technologies for a large number of basic and intermediate chemicals. The maturing technology, along with increasing competition and slower demand growth, lowered the payoffs to traditional types of innovations. Commercialisation became more expensive and required ever more sophisticated knowledge of customers and the market. Faced with over-capacity, the industry restructured, beginning in the 1980s in the US, and a few years later in Western Europe. The drive to reduce cost dominated the initial restructuring phase, driven in part by the relentless pressure from shareholders and their representatives. Major realignments of the product portfolios of many firms followed, with many mergers and acquisitions and the rise of entirely new firms in the industry.

During this phase, many firms cut down on R&D and refocused R&D expenditures on short term projects and away from more fundamental research. In the past couple of years, there are some indications that the industry may be entering a new phase of technological change and R&D spending appears to be picking up as well. Nonetheless, the restructured firm portfolios beg the question of who will perform the basic research that continues to be very important for the future of the industry. The current situation points to the possible need for increased government support for R&D in an industry that has hitherto largely financed its research by itself.

Task 1.2 – Market structure and innovation in the US, European and Japanese chemical industries: Empirical analyses

While Task 1.1 represented an introductory stage of our project, in this Task we wanted to test specific hypotheses about the relationship between innovation processes and market structure in the chemical industry. This Task was conducted by Marin and Siotis (2000). Based on the novel theoretical framework developed by Sutton (1991, 1998), the objective of this contribution was to analyse the relationship between market size, the existence of alternative technological trajectories in R&D intensive industries, and concentration. In particular, according to Sutton predictions, Marin and Siotis tested two main hypotheses:

- as market size grows, industries with endogenous sunk costs, such as advertising and R&D expenditures, may not evolve in equilibrium towards fragmented market structures;
- high R&D intensity industries' minimum concentration levels are affected by consumers' heterogeneity of preferences, since the latter fosters the existence of alternative technological trajectories. In that context, the heterogeneity in research trajectories yields more fragmented structures.

These two hypotheses can be correctly tested in the case of the chemical industry. Indeed, the chemical industry is formed by many sectors where different firms are operating. Each sector is characterised by a different R&D intensity and a different number of product classes, and presents a different market structure. In none of these sectors advertising expenditures are particularly relevant since most of their products are sold as intermediate outputs.

A large effort in conducting this Task was spent in building a useful and large enough database. Different data sources were used and combined. The "central" database was *Chem-Intell* (1998), which provides detailed information on 36,343 chemical plants world-wide. Of crucial importance for the purpose of this study, the data collected in *Chem-Intell* pertains to chemical *substances* rather than final products. The database contains plants producing 2,279 different chemical substances that are grouped into 14 broad categories such as petrochemicals, organic chemicals, inorganic chemicals, and the like. Obviously, this aggregation is of no use for the purpose of the study. To properly test the theory, it was particularly importance to define markets adequately. Indeed, demand side substitutability is a key parameter at the time of constructing markets. While each product may embody distinct technologies, what matters is the degree to which a given product is perceived as a substitute for other products in the same market.

So Marin and Siotis used a second data source. The relevant information was retrieved from the *RISC* database that provides a detailed input/output table for the chemical sector at a very low level of disaggregation.[2] The authors were thus able to identify downstream users for about 200 substances. For the substances that could not be classified using *RISC*, Marin and Siotis relied on specialised publications, the Web, and trade journals. At the end of this process, they were able to identify 52 specific markets – i.e., distinct group of end-users.

Before constructing the variables measuring concentration, they had to aggregate plant-level information into firm-level data. These data were drawn from *Chem-Intell*. The database contains data on ownership, which were used to construct firm level aggregate capacity for each group of substances. This information was crossed checked with the *Amadeus* database which contains balance sheet and ownership data for more than 200,000 European firms. With this information in hand, Marin and Siotis were able to compute two measures of concentration, the one-firm (C_1) and four-firm (C_4) concentration ratios.

The last step in the construction of the data source pertained to the partitioning of sectors according the R&D intensity. Unfortunately, *Chem-Intell* does not contain data on R&D expenditures. To alleviate this problem, Marin and Siotis made use of *Worldscope*, a database that provides information on the 1,500 largest R&D spenders in Europe. They retrieved the R&D of all the firms that appear both in *Worldscope* and *Chem-Intell*. They then examined the product portfolio for each firm that appeared in *Worldscope*, using the information provided by *Chem-Intell* and assigned the firm level R&D intensities retrieved from *Worlscope* to each of the substances manufactured by these firms.

By using these data it was possible to test the two hypotheses. All the empirical results provide strong support to the underlying theory. One of the key result suggests that greater fragmentation of the industry implies that research efforts devoted to single product lines generate fewer spillovers for products in other lines. In turn, in R&D intensive industries, the degree of fragmentation reduces the degree of concentration. Indeed, when investing in one research trajectory, one firm may reach a high market share only when some conditions are met. This occurs when there is a high substitutability among varieties of the product and all consumers start buying the superior quality variety. Alternatively, there are strong scope economies and innovations can be applied to all product varieties made by the firm. In R&D

[2] RISC also contains legislation applicable to the chemical sector in fields such as technical standards, consumer protection, and environmental hazards. This provided useful information when we had to define geographical markets.

intensive industries substitutability among varieties plays its role. Firms in the industry produce several groups of products that are imperfect substitutes in consumption and on the supply side, since they embody different technologies. In this case, R&D expenditures devoted to one group of product have limited spillovers on another group of products. Firms can develop many different technologies, each one related to a different group of products and must choose either to spend all their money on one trajectory or to distribute it among several trajectories. This represents the choice between an *escalation versus proliferation strategy*. Clearly, the choice between these two strategies will depend on the existence of economies of scope and substituability among product varieties. As a consequence, it is possible to observe higher concentration in industries with greater substituability among product varieties.

Task 1.3 – Publicly-founded scientific research in chemicals, and its effects on commercially useful innovations

The objective of this Task was to analyse the "transmission mechanisms" between publicly funded chemical research in Europe – particularly the research performed by universities and other non-profit institutions – and commercial innovations. The purpose was to assess whether and to which extent the European chemical industry suffers from the so-called "European paradox", also by comparing the nature and the characteristics of the existing transmission mechanisms in Europe with those of the US and Japan.

In order to analyse this issue, the Task was divided into three studies, focussing on different levels of the problem. It was so possible to provide an assessment of the existing linkages between science and technology, both developing theoretically and implementing empirically new research methodologies. Furthermore, we were able to perform country comparisons, with particular attention devoted to the differences between Europe, US and Japan.

1) Persistence and integration. The knowledge base of the pharmaceutical industry

At the macro-level, the study was conducted by Geuna and Brusoni (2000) by comparing the concepts of *integration* and *persistence* in the pharmaceutical industry. The problem can be defined by the following question: what are the key dimensions along which we can meaningfully compare the knowledge base of different countries? It is well known that recent research has challenged the relevance of the national dimension. In particular, it is stressed that firms and researchers are entangled in thick networks of international relationships that cut across national boundaries. National systems of innovations are under increasing strain, as large firms R&D activities are progressively internationalised. Such internationalisation would be caused by emerging imbalances between what a country science base has to offer and the knowledge requirements of innovative processes. However, despite the undeniable increase in R&D linkages, such linkages have not developed on a global scale, but rather involve mainly US, EU and, to a lesser extent, Japanese firms (Patel and Pavitt, 1998).

If R&D activities are increasingly internationalised, but not ‘globalised’, it becomes vital to understand why specific countries lay at the core of such international networks. Standard explanations refer to a number of factors considered key determinants of ‘national competitiveness’. Indeed, a country’s ‘specialisation’ pattern in specific scientific and technological fields plays a key role: firms establish R&D facilities where they perceive there are relevant capabilities.

However, most of the studies that empirically explore specialisation patterns at country level focus on a rather narrowly defined concept of ‘specialisation’. The emphasis falls squarely on the fields in which countries and/or firms patent. Classic specialisation studies focus on the cumulative evolution of countries’ technological capabilities. In most of the cases scientific specialisation is not analysed. Moreover, the stability of specialisation patterns over time (what can be called knowledge persistence) is a well-established result, but persistence and cumulativity are not the only dimensions relevant to a study of knowledge bases.

It is well known that design and development activities capture a relevant share of the R&D funded by companies (Rosenberg, 1994). A country knowledge base may have a strong science base but lack the engineering capabilities to embody scientific results into profitable products. Or it can have strong development capabilities not sufficiently supported by a robust basic scientific knowledge. Different typologies of knowledge are complementary and interrelated. A strong standing in each typology of research induces an easier multidirectional flow of knowledge that can facilitate the production of successful innovation. Therefore, what type of research (e.g. basic vs. engineering oriented) is carried out in each field becomes a key issue.

Hence, the objective of this study was to develop a framework to analyse knowledge specialisation that includes measurement of both "science" and "technology" specialisation. In so doing, Geuna and Brusoni identified the relevant dimensions that make the comparison of different countries' knowledge bases a meaningful exercise. Therefore, particular attention was devoted not only to examining whether each country specialisation is stable over time (*knowledge persistence*), but also whether specialisation by field is similar across different typologies of research (*knowledge integration*).

The empirical analysis was carried out by using two distinct data sets. First, the results of the PACE questionnaire (Arundel, van de Paal, and Soete, 1995) pinpoint the pharmaceutical industry as a highly internationalised industry. PACE shows not only that EU pharmaceutical R&D managers value the results of public research, but also that they rely upon international research much more than the chemical sector and the other manufacturing industries do. Also, PACE stresses that the pharmaceutical industry relies on North American research to a greater extent than on EU research. The question that demands an explanation is why EU pharmaceutical firms rely to such a great extent on North American research. What makes that attractive to EU firms? In order to answer this question, Geuna and Brusoni compared the knowledge base of different countries by developing a grid designed along the two dimensions identified above: integration and persistence.

The operationalisation of these two dimensions was based upon the design of a comprehensive data set of peer reviewed papers obtained combining the standard ISI classification by science field with the CHI classification by type of research (i.e. Applied Technology & Engineering, Applied Research and Basic Research). In so doing, the authors obtained an original data set encompassing some 630,000 papers published in eleven different sub-fields of chemistry and pharmacology between 1989 and 1996. This data set allowed for a quantitative analysis of the evolution of the scientific specialisation of the four largest European countries (the UK, Germany, France and Italy), the EU as a whole, the US and Japan.

The results of the analysis provides a taxonomy of country level knowledge specialisation by countries. Furthermore, the analysis of the relationships between core positive and negative specialisation, and the typology of research (applied technology & engineering, applied research and basic research) has shown that the countries considered have different degrees of knowledge integration and knowledge persistence. EU R&D managers have stressed that public research developed in countries that exhibit high degrees of both persistence and integration (e.g. the US in pharmacology) are the most likely source of useful results to their innovative efforts.

These results suggest some policy implications. First, the data set does not identify any 'European paradox' in Pharmacology. EU countries exhibit capabilities in terms of applied and engineering research, but not in basic research. Instead, the US only increases its specialisation in basic research in Pharmacology and Medical chemistry. No clear pattern is discernible for EU countries with the exception of the UK, which is despecialising in such research fields. Such lack of basic research capabilities may well explain the frequency with which EU R&D managers in pharmaceuticals approach the US knowledge base. As for chemicals, the pattern of sourcing is different. As their home country knowledge bases seem more capable of providing a more integrated pattern of research capabilities, EU chemical firms rely chiefly on their home country knowledge base and then approach the EU one. At least for Pharmacology and Medical Chemistry, Geuna and Brusoni have found no evidence of paradoxes.

Second, this approach hints at the possibility that government can actually influence the rate of technical change by fostering the development of an *'integrated' specialisation profile*. In fact, despite the enormous resources devoted by policy makers to the exploration of emerging technologies, picking the winner remains a rather hazardous activity. The greatest successes of recent years are the unintended consequences of policies aimed at fostering other paths of research. What specific scientific field is about to deliver the next revolution remains very difficult to say. Geuna and Brusoni argue that their approach would allow governments not to pick the winners in advance, but to support the development of an integrated knowledge base *once that a new path has emerged.*

2) The Evolution of Specialisation. Public Research in the Chemical and Pharmaceutical Industries

This study was conducted by Geuna and Malo (2000). The purpose of this study was twofold. On the one hand, it aims to contribute to the debate over the relationship between public scientific research and industrial innovation, analysing, in particular, the importance of distance in the process of knowledge transfer from public research to industrial innovation. On the other hand, given the importance played by publications and technical reports in the process of knowledge transfer, it examines the evolution of scientific specialisation of the four largest European countries (the UK, Germany, France and Italy), the EU as a whole, the US and Japan in the chemical and pharmaceutical fields. With regards to the first purpose, two main issues were analysed. First, whether the knowledge produced by public research institutes and universities is viewed by industrialists as important to the process of innovation in the chemical and pharmaceutical industries. Second, given the fact that public research is valued, analysis was made of how the distance from the public research institute or university affects this perception and the use that is made of the research.

As far as methodology is concerned, the study was conducted by using two sources of data. Firstly, Geuna and Malo used data from the PACE survey. The PACE questionnaire surveyed the largest R&D performing industrial firms in the twelve EU countries in 1993. These data have been used to analyse the importance given to public scientific research by chemical and pharmaceutical firms. Secondly, the publication profiles of different countries in the fields of Chemistry and Pharmacology & Pharmacy allowed distinctions to be drawn between countries and industries. The Science Citation Index database of the Institute for Scientific Information was used to analyse the publication output of the four largest European countries, the EU, Japan and the US in the period 1989-1996. Eleven scientific fields relevant to the chemical and pharmaceutical industries have been identified. Each publication in these fields is classified in a typology of research using the CHI journal classification: Applied Technology, Engineering and Technological Sciences, Applied Research, and Basic Research. On the basis of these data the Symmetric Relative Specialisation Indexes have been calculated, and core positive and negative specialisation and the evolution of the country specialisation in the eight-year period have been analysed. Particular attention was devoted to examining whether the country scientific specialisation is similar in different typologies of research and if it is stable over time. In the course of this examination the concepts of knowledge integration and knowledge persistence have been used.

The results of the analysis carried out in this study highlight the fact that there are significant differences in the degree of importance assigned by industrialists to university and publicly funded research, and that localisation matters both in this regard and in relation to the channels through which its results are obtained. For example, about two-thirds of the respondents from the pharmaceutical sector considered technical knowledge obtained from public research institutes and universities as important to their innovative activity, while this was the case for less than one-third of respondents in the chemical sector. In each case, publications and technical reports are the most important (and most often used) methods for learning about public research.

The analysis of the scientific publication profiles has provided a first detailed description of the characteristics and evolution of the scientific publication output in chemistry of the four largest European countries, the EU, the US and Japan during the period 1989-1996. The relationships between core positive and negative scientific specialisation, and the typology of research (Applied Technology & Engineering, Applied Research and Basic Research) has shown that the countries considered have different degrees of knowledge integration and knowledge persistence.

Preliminary results indicate that the US has a much clearer specialisation profile, both in terms of positive and negative specialisation and in the area of research, indicating a much higher degree of knowledge integration than in the EU. Also, the evolution of country scientific specialisation in the eight-year period was analysed and this showed that the US has the most stable publication profile; compared to the other countries it has the highest level of knowledge persistence. In general, when a country has a specialisation in a scientific field in the area of basic research one can expect high persistency in that specialisation.

Finally, the results of the PACE questionnaire, indicating that public research carried out in North America was valued and used extensively by the largest R&D firms in the pharmaceutical sector in the EU, are consistent with the fact that the US has a persistent specialisation in Medical Chemistry and Pharmacy & Pharmacology both in applied and in basic research. This conclusion points to a direction for further research that will aim to test the existence of a correlation between knowledge integration and knowledge persistence in certain scientific fields and technological and economic performances of firms and countries.

3) Science-Technology Linkages. The case of Combinatorial Chemistry

Combinatorial chemistry and biology is an emerging research platform that spans a broad spectrum of applications from drug to new materials discoveries. Embedded in a large network of firms, universities and research centres, combinatorial synthesis methods, albeit still in their infancy, are bound to be a spawning grounds for a stream of new products. For this reason, a quantitative assessment of the science-technology linkages characterising combinatorial chemistry and biology appears especially interesting, in particular the role of public research and its contribution to combinatorial innovations. Hence, the purpose of this Task was to provide such an assessment and to answer questions like: What are the institutional characteristics of this new research field? Does location matter in this context? This analysis was promoted by Geuna (2000).

In order to empirically answer these questions, Geuna mainly used information drawn from patent data and the linkages between patent data and scientific journals. Indeed, patent data contain references to existing patents and mainstream literature. This means that the citations in patents to journal papers of specific technologies or industrial sectors can be extracted from the patent database for further analysis. In particular, one can learn more about the underlying research science base of a particular technology or industry by categorising citations in patents to literature according to a classification produced by CHI Research Inc., which breaks down several thousand journals covered by the Science Citation Index into four different levels:

- Level 1: Applied technology (e.g. Journal of Urology);
- Level 2: Engineering and technological sciences (e.g. Chemical & Engineering News);
- Level 3: Applied research (e.g. Journal of Chromatography);
- Level 4: Basic research (e.g. Nature, Journal of the Chemical Society).

Once citations are classified along these lines, science and technology linkages may be traced by looking at the extent to which basic research journals are being cited as prior art for a given technology/industry. Underlying this reasoning is that patents granted in science-based industries ought to cite basic research journals more frequently than patents in other industrial sectors. In this context, Geuna examined whether combinatorial patents include a high level of scientific content, i.e. a high proportion of citations to patents in basic research journals.

By using this methodological approach, Geuna collected information on 220 small combinatorial chemistry and biology start-ups, 1165 patent applications, which spanned the period 1985-1997, as well as 2,570 scientific publications that were released between 1984 and 1996. Not surprisingly, the Commonwealth Serum Laboratories, the Australian company where Mario Geysen originally worked, was one of the first to enter the field 1) by establishing in 1988 the first combinatorial chemistry and biology company, a subsidiary named Coselco Mimotopes; 2) by patenting Geysen's new synthesis method in 1986; and 3) by publishing a paper in the well-established Proceedings of the National Academy of Sciences in the USA in 1984.

The results of the empirical analysis provide evidence that supports the following conclusions. First, the predominance of patent citations to basic research journals supports the view that technological invention in combinatorial synthesis is characterised by an extremely high scientific content. In particular, biomedical research is the most significant knowledge base of reference for combinatorial chemistry and biology patents, although chemical literature has been increasing in relevance since the early 1990s. Of the cited papers, 80.7% belong to level 4 (i.e. basic research), 17.6 % were in level 3 (i.e. applied research/clinical investigation) and the rest (1.7%) in levels 1 and 2 journals (i.e.. applied technology and engineering and technological sciences/clinical mix). Breaking down the patent data and the citations in scientific journals by type of innovations, the role played by science in the creation of process innovations (86.0%) appears to be even more predominant than product innovation (77.8%). Furthermore, the distribution of citations is extremely skewed in favour of the top institutions. The 30 top research organisations receive about 36% of citations. Of these institutions, 26 are from the US, 18 are universities (mainly the most prestigious US universities), and the Public Research Centres are the second most important institution type.

Second, as in the case of biotechnology and computational chemistry, the US lead in firm formation is paralleled by the dominant role played by US universities and research centres. Geuna found some evidence that the EU countries are catching up in terms of university publishing, while the number of new combinatorial synthesis firms in Europe remain very small.

Third, the inventive capacity of a country heavily depends upon the strength of the underlying universities and public research institutes. The innovation process of firms relies to a great deal upon research carried out by universities and by public research centres of their own country. By comparing the country share of publications in the Science Citation Index (SCI) with own country citations, the results confirm a bias in favour of “local” literature. This is true for the US and particularly for European countries, whose bias in favour of local literature is even more accentuate. Hence, the current analysis confirms that science-technology linkages in combinatorial synthesis, as measured by the citations to the literature in patents, are affected by the location of the organisations. The technological inventions of a country rely heavily on the scientific discoveries made in that same country, especially in the universities and public research centres.

Finally, the analysis of patent applications and patent citations underlines the importance of small firms in the development of the combinatorial synthesis research platform. Not only are they patenting in a significant way, but they also are producing important publications that are cited in other patents.

The preliminary results of this study emphasise the significance of the contribution of basic research – from universities and other public research centres – to industrial innovation. This overall conclusion must be qualified given the shortcomings inherent in the methodology adopted, such as the fact that citations are not only inserted by the inventor but also by the examiner of the patents. Further detailed analysis of the institutional network in combinatorial synthesis is required to develop a better understanding of the micro mechanisms by which knowledge created in universities and public research centres spills over into the knowledge creation processes of firms and other institutions.

Task 1.4 – Changes in the “geography” of industrial research and innovation in the chemical industry

Recent economic research has shown that there is a growing trend towards specialisation of individual countries and regions in specific R&D activities. Hence, the objective of this Task was to assess whether the location of industrial research in chemicals – or in specific sub-fields like biotechnology, new materials or environmental technologies – has concentrated in specialised areas or locations worldwide. The issue is quite important. In the case of specialisation in R&D activities there would be greater opportunities for agglomeration advantages and “external” economies. To examine the position of European countries appears interesting in this context. The issue can also be read from the viewpoint of chemical firms. From this perspective, it may be interesting to evaluate whether European chemical firms are locating their “generic” R&D in regions outside Europe (and particularly the US), through different means such as mergers & acquisitions, strategic alliances, or foreign direct investments.

The study was conducted in two different steps. In the first, Arora, Gambardella and Garcia-Fontes gave a look at the international flows of chemical plants investments, in order to assess whether the European industry is moving abroad, and in order to compare the “geographical” evolution of the European chemical industry with US and Japan. This is an introductory study of the issue of geography of innovation and R&D, not directly focused on innovation and R&D, but aiming at understanding whether the chemical industry is going to become a global industry, or whether all firms of developed countries are moving their investments to emerging or developing countries. Once made this “introduction,” the second step was to enter directly in the issue of geographical distribution of R&D activities in Europe, according to the purposes already expressed.

1) Investment flows of large European chemical firms

The European chemical industry ranks first in the world in terms of turnover, but there is a considerable concern the European industry is loosing ground. The smaller and more fragmented European market have encouraged European firms to invest abroad, while facing high labour cost in Europe. Hence, the main question the Arora, Gambardella and Garcia-Fontes (1998) tried to target with this study was: Is the European industry moving investments abroad? The question can only be answered by comparing the flows of investments not only in the European Union, but also in Japan and the United States. While it may be true that investments are moving abroad for the European industry, the same may be true for its counterparts in Japan and in the US, if the industry is becoming increasingly global or if all firms of developed countries are moving their investments to emerging or developing countries.

In general terms, the chemical industry has always been “global”, and for many years the industry has shown considerable flows on international investments, and systematic flows of engineering and process licenses. While up to the 1980s foreign investments were to a large extent confined to first world countries, in the recent decades there has been an increase in the flows towards the developing countries as well. As a matter of fact, chemical investments in these countries have become a critical strategy of the major multinational chemical firms from the advanced world, and to some extent the ability to invest in these countries has become a major factor in enhancing their competitiveness, and more generally an important element for competition in the industry. Moreover, apart form foreign direct investments in plants, the developing countries have become important areas for inflows of process licenses and engineering services. Again, the competitiveness of the chemical firms in advanced countries is often related to their ability to operate and invest in these markets, as well as on their ability to complement these investments with related technology flows through licenses or engineering services.

The empirical analysis was based on data obtained from the *Chem-Intell* (1998) database. This database collects information on about 36,000 chemical plants built world-wide since 1980, and belonging to about 18,000 different companies. For each plant, it reports information on the products been produced, the production capacity, the technology used, the owner, the contractor that provided the engineering services, the licensor, and the year of construction. Thus, *Chem-Intell* is a good source of data for process licenses and technology transactions embedded in engineering services. Among all the firms reported in the database, the authors selected the 150 biggest chemical firms and their plants, and analysed the flows of investments in five distinct regions: Western Europe, North America (US and Canada), Japan, Asia (all Asian countries except the Middle East and Japan), Rest of the World (Americans except the US and Canada, Africa, Eastern Europe and Middle East).

The results of the study show that, indeed, the European chemical industry has moved abroad its investments. However, the same can be said for the American and Japanese chemical industry. This means that there has been an increasing globalisation process for this industry, that can be translated into a significant increase in the number of chemical plants built in Asia, coupled with a decrease of the domestic share of Japanese of the domestic share of Japanese firms in Japan, American firms in the US and European firms in the European Union. In general, it can be said that there is a trend toward the location of plants near the customers and the fast-growing regions, where the demand and consumption may be stronger.

This trend might be related to an increase product differentiation and customisation of plants, together with an increased concern on reducing transport costs.

Having recognised this globalisation process, there is some evidence that the process is stronger for the chemical firms from the European Union. These firms have been major actors in the increase in investments in Asia, and in the reduction of shares for domestic firms in the US and Japan. Arora, Gambardella and Garcia-Fontes also obtained evidence through econometric analysis that the trend for the location of European firms in North America, Japan and Asia is stronger than the trend of American and Japanese firms locating in Europe.

In terms of products, the main products for the shift of investments to Asia have been Organic Chemicals Refining, Petrochemicals and Plastics & Rubber. In general, during the 1980s, the largest share of plants belonged to Organic Chemicals Refining, while during the 1990s, it shifted to Plastics & Rubber and Petrochemicals.

2) The location of R&D and the networks of inventors in the European chemical and pharmaceutical sectors

The study conducted within this Task (conducted by Mariani, 2000) examines the geographical distribution of R&D activities in Europe in the chemical and pharmaceutical industry, and examines R&D collaborations that lead to a patent. More specifically, it studies the role of the geographical proximity among inventors (i.e. *physical proximity*) as a coordination mechanism for fostering research collaborations, and compares it to the effectiveness of the affiliation of the inventors to the same firm (i.e. *organisational proximity*).

The empirical analysis was carried out by using patent statistics (a random sample of 10,000 chemical patents in 1987-1996) and other data drawn from the *European R&D database* and from *Eurostat Regio*. For each of the 10,000 patents Mariani collected information about the name of the applicant/grantee and its nationality, the address of the inventor and his country of residence and the year of filing. Other sources of information are also used – i.e. *Who Owns Whom* and *Fortune 500*. The geographical unit of analysis is the country and the European regions according to the NUTS classification (Nomenclature des Unités

Territoriales Statistiques) at the second and third level of disaggregation. To map the location of R&D Mariani used the actual location of the inventors listed in the patents. Each patent was also allocated to a specific branch of the chemical industry by using information on the technological class assigned by the EPO (3-digit, IPC classes).

The analysis is composed of two parts. The first one describes the spatial distribution of research in the chemical industry. It examines whether research in chemicals clusters geographically, and whether this happens for some technologies more than for others (i.e., biotechnology *vs.* organic chemistry). It also explores the location and the degree of internationalisation of chemical R&D. The second part examines the role of the location characteristics – i.e. being in a technological cluster or not – over the formation of networks of inventors for producing chemical patents. Hence, the *geographical proximity* in a technological cluster was compared to the affiliation of the inventors to the large chemical companies (*organisational proximity*).

The results on the spatial distribution of patents over the period 1987-96 show that inventive activity concentrates geographically. The top 20 regions account for 77.5% of the total number of patents invented in Europe. The top 10 regions invent 58.7% of these patents. Most of the regions in the top positions are German. There are also a few French, British, Italian and Dutch regions. The Spanish and South Italian regions are at the bottom of the list. Moreover, although there are significant differences among sectors, innovative activity clusters geographically in all chemical sectors. Most of the top 20 regions in which the largest shares of innovations are invented are the same across 4 or 5 sectors. Others show up only in one or two sectors. Biotechnology in particular seems have great potentialities for regions that are not traditionally specialised in developing innovations in chemicals.

Second, the extent to which chemical companies perform research outside their home country is limited. The overall average of overseas research ratio is 11.6%. European companies locate in Europe 86.0% of their research activity in chemicals. The share of US patents developed in the US is 87.7%. It increases to 96.5% for Japanese companies. In Europe, however, there are inter-country and inter-sectoral differences in the propensity to locate research abroad. Companies from Italy (87.6%), France (84.9%), and Germany (84.0%) develop more patents in the home-country than companies from Belgium (55.8%), Switzerland (47.7%) and the Netherlands (41.4%). As far as the sectors are concerned, European companies invent in the US a share of patents similar to the share of patents invented in Europe by American companies in materials, organic chemistry, polymers and pharmaceuticals. Only in biotechnology European companies localise 17% of research in the US *vs.* 7.5% of American biotechnological patents invented in Europe.

The final part of the analysis compared the effectiveness of two alternative coordination modes for fostering and managing the innovation process: the *organisational proximity* and the *geographical proximity* among inventors. First of all, the results show that unlike co-patenting, networks are a common practice among individuals in R&D activities. Less than one-fourth of chemical patents feature one inventor. All other patents feature two or more inventors, and a good fraction is made by 4 or more inventors. Moreover, patents with a larger number of inventors are more interdisciplinary, as shown by the positive correlation between the number of inventors and the number of supplementary technological classes assigned to the patent. In other words, more inventors seem to be necessary in order to produce innovations that relate to more technological classes and disciplines.

The comparison between the large firm and geographical cluster as mechanisms for inducing collaborations among inventors shows that the larger the firm is: a) the lower is the probability that inventors are co-localised, in the sense that a lower percentage of patents is produced by inventors located in the same place; b) the larger is the network of inventors that collaborate to produce a patent; c) the higher is the number of supplementary classes listed in the patent. By contrast, the technological characteristics of the regions positively affect the probability of the inventors to be co-localised, but they show not to be correlated with the breadth of the networks and with the level of interdisciplinarity of the innovations. Hence, compared to the *geographical proximity* in a technological cluster, *organisational proximity* in large companies enhance international networks of inventors, induce a greater number of inventors to collaborate and produce more interdisciplinary or “general” patents.

However, the co-ordination mode provided by the firm is subtle to understand. Although large companies perform a higher share of de-localised patents compared to the “other” companies, they still perform a high percentage of co-localised patents (58.2% over the total number of patents assigned to the “Fortune 500” companies). This suggests that only a few firms have the capabilities to coordinate R&D projects across distances. This also rises questions concerning the R&D strategies of European multinational companies. There are quite a few empirical studies on the globalisation of research, but the results are controversial. Some of them show that there is a pattern towards the location of research on global basis, and that large internationalised firms are increasingly organising research activities as they were global innovation networks (see, for example, Cantwell, 1991). By contrast, other authors emphasise the non-global nature of innovative activities (see, for example, Patel and Pavitt, 1990).

The results obtained by this study suggest that the latter view prevails, and that the vast majority of large multinational companies might not behave as most studies suggest. The higher co-localisation of the inventors of a larger firm suggests that either larger companies create subsidiaries which also feature a number of complementary capabilities for invention, or that these subsidiaries take advantage of locating in a cluster. In other words, it might be that the subsidiaries of large chemical multinationals also tend to be a natural locus of specialised and complementary competencies. Or, as these results suggest, the subsidiaries of these global firms are more probably located in the clusters, and here they develop entirely their research projects. However, when these large multinational companies act as networks that harness the needed expertise in different and distant places, and link them together through internal coordination mechanisms, the innovations they produce are different in terms of generality and size of the networks of inventors that they coordinate.

Second, another important question concerns the comparative advantage of being in a technological cluster for smaller firms compared to large multinationals. The technological cluster, like the large company, typically features a good deal of different and complementary competencies inside the territorial area. Therefore, firms localised in a technological cluster have limited need for finding these competencies outside the region. But, who benefits more from being in such a conducive environment? The results of this study suggest that co-localisation is comparatively more important for smaller firms. Hence, although both small and large firms take advantage from being in a technological cluster, smaller companies rely on the external scientific and technological environment more heavily than large multinationals. *Geographical proximity* in a technological intensive region plays a more important coordination function for companies that lack the internal scientific competencies and the organisation capabilities needed to coordinate the collaborations. In this sense, *geographical proximity* is a good substitute for the *organisational proximity*.

Task 1.5 – The new high value added “specialty” chemical market: Is Europe loosing grounds?

The production of “high quality compounds” which are customised for special markets and uses has represented in recent years a new profitable opportunity for chemical producers, which, on the contrary, were facing a dramatic decrease in growth rates of bulk chemical compounds. Based on this assumption, this Task aimed at examining the relative position of the European chemical industry in these high quality R&D-intensive industries, and compare its competitiveness with the US and Japan. Indeed, the position of European chemical producers was not completely clear. In some sectors, the US or Japan appeared to be the leaders. For instance, it is well recognised that in biotechnology-based products Europe was loosing grounds vis-à-vis the US. Similarly, Japan appeared to be much more effective than Europe and the US in high-tech fields like chemical applications for electronics or advanced fibres.

This issue is particularly important also for reasons related to the nature of the innovation process. Unlike bulk chemical compounds, which are sold to tons, effective user-producer interactions are critical for innovation and economic performance in the specialty markets. Hence, an important subject of this Task was the analysis of user-producer interactions. In particular, the role of the users in encouraging greater innovation performance by chemical firms, and the difficulties that the lack of such interactions may create on the development of new specialty products by European chemical firms have been examined.

In order to better explore these issues, we took into account four specific fields of specialty chemicals – agrochemicals, new materials, paints and coatings, and pharmaceuticals. Each field presents specific features which make its analysis particularly interesting, and the relative position of European chemical firms is different in different fields. Furthermore, we used specific research methodologies for each field.

In the following, we report a brief description of methodological aspects and main results obtained in each of the four fields, and then a summary and discussion of main conclusions.

1) Agrochemicals

The study of Mahdi (2000) tried to assess the current position of European research-based agrochemical firms in order to answer these questions, by adapting Porter's model of the external business environment, which focuses on the science base and financial capability assessment in the supply side; market condition and various negative demand factors in the demand side, as well as industry characteristics, structure and firms' strategy.

The study has found that European research-based agrochemical firms are among the leaders in the agrochemical industry. Europe has a long tradition of a strong science base in subjects related to agrochemicals, for example organic chemistry. European agrochemical firms do not seem to have any difficulty in raising funds for their increasing research costs. This is due to the favourable conditions (e.g., no anti-trust laws) that allow firms to collaborate to raise money. Finally, new EC directives on the harmonisation of agrochemical registration and the Supplementary Protection Certificate favour European research-based agrochemical firms.

However, this study has also found some factors that may hinder the competitive performance of European research-based agrochemical firms. One of these is that European countries lag behind the US in some important science bases such as new discovery strategies for IT-related science. European countries are also able to issue policies, adopted by all the members, which can have a negative influence on the demand for agrochemicals in Europe. Moreover, European legislation procedures are likely to be more complicated than in the US. This creates a lengthy process of agrochemical patent and registration. Finally, the European public is more hostile towards agrochemical and biotechnology products. This may cause under-investment by agrochemical companies to the potentially important sector of the future: agricultural biotechnology.

Policy for the competitiveness of European research-based agrochemical firms should centre then on the following aspects:

- development of an IT-related science base competence in Europe to supply future demand in industry;
- the involvement of research-based agrochemical firms in European policy-making related to the agrochemical sector;
- simplification of patenting and registration procedures for new active ingredients;
- greater transparency concerning agrochemical registration to raise public confidence.

2) New materials

The study of Hopkins and Sharp (2000) concentrated on the European chemical industry's activities in the fields of polymeric materials, specifically plastics and polymer matrix composites. There were high hopes in the 1980s that breakthroughs in technology in this sector would make new materials one of the driving forces across innovation in a large number of sectors. This proved not to be the case. Instead the trend has been towards steady, incremental innovation in mainstream technologies, with the drivers being on the one hand energy/environmental factors and on the other the search for new higher-value added market opportunities for companies caught in increasingly tough global competition.

Economies of scale mean that the large traditional chemical and petrochemical companies still dominate mainstream production, but they are increasingly working in partnership with users (e.g., automobile companies) and/or small companies to develop specialist users. Across the many industries that use plastics the demand is for cheaper materials, faster manufacturing processes, and 'greener' life cycles. Recent pressures, especially the collapse of Asian markets, have put pressure on profit margins and led a number of companies to retreat from exposure, indeed in many respects the market place currently resembles a game of Monopoly with the players desperately swapping assets in an attempt to maintain profitability and answer the demands of the user. Europe's core strength in this remains, but US firms and US science are challenging this traditional position.

3) Paints, coatings and printing inks

The study by Brusoni (2000) aimed at reviewing the state of the paints, coatings and inks industries by providing an empirical contribution, and a tentative comparison of the EU and US coating industries with respect to a specific case of environmental innovation: the adoption of waterborne formulations. The relationship between the diffusion of low solvents or solvent-free paints and the introduction of regulation limiting the emissions of Volatile Organic Compounds (VOCs) was analysed. Two case studies were designed that focused on the two largest segments of the coatings industry: decorative paints and vehicles paints.

Particular attention was paid to the relationship between technical change and the opportunities and constraints posed by environmental regulation.

The results of the analyses show that, from a technological point of view, the industry seem to be perfectly capable of coping with the diffusion of new, solvent free formulations. In this respect, the fieldwork has hardly spotted any difference between US and EU firms, as they all market waterborne products alongside traditional solvent based paints. The diffusion of waterborne is then unlikely to generate an industry shake out. Incumbents seem to be well equipped with the R&D, manufacturing and marketing capabilities to pre-empt any challenge from potential entrants. Indeed, the capability to manage the interdependencies between R&D, manufacturing and marketing is the key factor that makes the paint market hardly contestable by new entrants.

Rather than a lack of technological capabilities, customer demand is the key to understand some of the problems related to the diffusion of waterborne products, particularly in the decorative business. In both the cases analysed, the role of demand is paramount. Whether 'naturally' different, or regulation induced, customers have played a fundamental role in driving (or constraining) the diffusion process of alternative formulations. Given the relative stability of the industry knowledge base, it is hard to consider technical capabilities as the key issue that set apart EU and US producers. The relevant factors have probably to be sought in the external environment, in the characteristics of demand and customer preferences, in the different role played by process and product regulation. Further, different financial settings may have facilitated the rationalisation efforts of US companies, in the sense that US financial investors have given a premium to the rationalisation and refocusing efforts greater than that granted by European investors.

From a policy-oriented perspective, one has to wonder as to the appropriate object and level of regulations, in the sense that process-oriented legislation should be accompanied by product-level legislation. Other considerations are worth mentioning. First, most of the VOC-related US regulations occur at state-level. It remains then debatable whether stringent, product-level legislation should be a competence of the EU, rather than of national authorities, closer to the 'sticky information' embedded in the their markets. Second, despite much of current legislation impinges upon producers only, distributors play a fundamental role in determining the market viability of alternative products. Particularly in those countries where retail and trade paints are sold via large retail chains (e.g. the UK), legislation may involve also these latter in an effort to promote the diffusion of clean technologies.

4) Pharmaceuticals

The study by Nightingale (2000) has explored the competitive position of the European Pharmaceutical industry, by means of a case studies analysis. It has found that the European industry is in good shape and is adapting well to changes in its economic and technological environment. Currently, three of the top five and six of the top ten firms are European. The US industry tends to perform more strongly, while the Japanese industry performs poorly. European success is concentrated in the UK, Sweden, Switzerland, Germany, and France. However, the competitive position of the European industry is a difficult concept to incorporate into any policy analysis because of the international nature of the industry. US firms conduct large amounts of research and development in Europe and European firms conduct large amounts of research and development in the US. As a consequence, a narrow ‘national champion’ or techno-nationalist policy perspective is likely to be damaging.

The processes of drug discovery are currently being transformed by new genetics technologies. Pharmaceutical R&D is moving from a craft based process to an increasingly automated mass production process. While it is not possible to predict future performance at present due to the high levels of uncertainty involved, interviews suggest that some European firms are in a good position to take advantage of these new technologies. The ability of firms to exploit these new technologies over the next 5-10 years will determine the strength of their new product pipelines. Firms that are successful will be able to fund the on-going changes in the industry. Firms that do not may be forced to merge. Firms that fail may become potential take-over targets.

The industry is under pressure from a number of different sources: (i) the rising cost of drug development and marketing, (ii) changes in the scientific basis and the technology platforms of drug discovery, (iii) genomics & informatics, (iv) high throughput screening, and (v) changes in the marketplace with tighter control on drug spending. In response to these pressures the industry has invested in new platform technologies, globalised its research, engaged in mergers, and increased the use of collaborative agreements between firms.

European firms have generally been slower than American firms to change, but this is not considered a major source of competitive weakness by the industry. Firms do not seem to be having difficulty accessing the technologies they need for this transformation. The major source of competitive weakness among European firms is found *internally* within their management structures.

As a policy suggestion, the competitive situation of the European industry could be supported by continued investment in basic research and policies that encourage more effective organisational adaptation to changing technologies and markets. The industry will consolidate further and a number of large global research intensive firms will emerge linked into a complex network of smaller biotechnology companies, and academic and medical research units. Since some of these research networks will be trans-Atlantic, policy should concentrate on promoting innovation rather than on the competitiveness of the European industry.

5) Specialty chemicals. General themes emerging from the four case studies

The analysis of the “specialty chemicals” sector started by seeking to identify what might be called ‘speciality chemicals’ and rapidly realised that this term in itself covered a whole range of different segments of the industry – from dyes and inks, to plastic composites, to food additives. Amongst all of these the choice of sector proved in the end somewhat arbitrary. We had been asked to undertake a study of the pharmaceutical industry and in particular to consider the impact on the drug discovery process of the new genetic technologies. We chose to look additionally at the agro-chemical industry because in many respects it shares the same characteristics as pharmaceuticals. While long in the vanguard of globalisation, this sector has now become a focal point in the restructuring of the wider chemical industry. Increasingly, the conglomerate chemical company, which dominated the industry for much of the last century, is disappearing, to be replaced by narrower, more specialist firms. The knock-on effect of this restructuring had major impact on the third sector we chose to study – new materials. Here again we were looking for a sector with a strong record on innovation. Finally, we decided to take a traditional, but now mature, sector of the industry – paints and inks – and ask here, too, what’s new and what is driving innovation.

5.1) Radical versus incremental innovation

The key question underlying this project has been that of how innovation takes place. How do new developments in science translate themselves into new products? The answer is, of course, that it is not a one-way street. The linear model operates at best during brief phases of time when science is advancing at so fast a pace that all else falls in behind it. Arguably this is the current situation with the genetic technologies – so many potential new developments are tumbling out of leading edge developments that it is difficult not to be carried along on a tide of optimism. It is important, however, to stress that in the translation of science to products, radical breakthroughs are rare. It is happening today in the genetic technologies and affecting the pharmaceutical and agrochemical industries (or more accurately, the plant-science industry). For the vast bulk of the chemical industry, innovation is incremental, not radical, and driven by demand-pull as much as technology push. This is aptly illustrated in the new materials sectors where developments in new polymeric materials is being driven by the demands of the aerospace and motor car producers, often working together with specialist suppliers such as Hexel. In the paints and inks sector, demand in turn is being driven by regulation and we are confronted by the somewhat bizarre circumstances of the dominant companies (now ICI, DuPont, BASF) actually asking for EU regulations to be made more stringent (and closer to the US model), because this helps to reinforce their position vis-à-vis local specialist firms.

The paints and inks example also illustrates the need, when innovation is gradual and incremental, to forge new sales by capturing new markets either geographically, or by establishing new uses for established products. In mature markets, innovation comes from the search for new uses from established products. Here the interface between science and technology is also important, but reactive rather than pro-active. It is interesting how companies resist too pro-active a role in these circumstances.

5.2) Industrial restructuring – the fault line of technology

Radical breakthroughs, leading to a new alignment of science and technology, have come from the life sciences area and at present affect only a small part of the chemicals industry. They have, however, led to a significant restructuring of the industry with many (but not all companies) moving away from being large conglomerate chemical companies, with interests in all major areas, to a narrower, most specialist companies. ICI set the trend. The demerger in 1993 of the life-sciences divisions to form Zeneca (subsequently in 1998 to merge with Astra of Sweden to form Astra-Zeneca) left the 'new' ICI as a broad-based firm in (largely) organic chemicals. This new ICI has subsequently traded divisions via acquisitions and mergers, selling off its bulk chemicals, fibres, fertilisers and plastics interests and buying up Unilever's speciality chemicals, so as to transform itself from any semblance of a conglomerate into a fairly narrowly defined speciality company with interests in food additives, colourings, paints, inks and dyes. Other companies have followed suit. Ciba Geigy and Sandoz (having merged to form Novartis), Astra and Zeneca, Hoechst and Rhône Poulenc Rorer (have created the new life science company Aventis). Generally, the pattern that has emerged is of companies narrowing interests and increasing specialisation and geographical coverage within that specialisation. A few companies – Dow, DuPont, BASF – have bucked the trend and remained conglomerates, but they are the exceptions.

5.3) Restructuring and globalisation – from national to global oligopoly?

This restructuring reflects two coincident trends. One is technology – in most cases companies have split down the fault line of technology – life sciences versus synthetic organic chemistry. The other is globalisation. What were *national* companies competing as oligopolists in predominantly national or regional (e.g., European) markets have become international companies competing against each other in the global market place. This has important implications. The process of specialisation via merger and acquisition has essentially meant that what was national or regional oligopoly has been transformed into global oligopoly. In each sector, competition is still, in most cases, a matter of intense competition between six and twelve large firms that dominate the market, but that market place is now global. New entrants need to compete both in terms of scale and marketing, and it is often at the marketing end – knowing the specialist middlemen – that new entrants find it most difficult to penetrate. This means that, in spite of intense global competition, it is still possible for one or two firms to dominate in each national market place (because they effectively control access to consumers) which in turn means that competition authorities need to be forever vigilant.

The implications of the emergence of global oligopoly have yet to be explored. Even in home markets, competition authorities have had problems controlling oligopolistic behaviour. What appears to be collusion emerges from the need to be ever vigilant in relation to competitors, to anticipate and counter immediately any moves they make to gain market share. In a global market place, the threat of entry from other global competitors should keep those involved in any specific national market alert and prevent the establishment of monopoly positions. But the fragmentation of competition responsibilities between national players exposes national markets to international collusive practices – for example, an agreed division of markets with, implicitly, the agreement between players not to compete against each other in certain geographically defined markets. Some of the agreements concluded between pharmaceutical companies come close to such international collusion, as indeed, do so-called voluntary export constraints in consumer electronics or car markets.

5.4) Competitiveness – what does it mean?

If, in the process of merger, acquisition and restructuring, firms are becoming more international (in the sense of producing, selling and doing R&D in more countries), what does competitiveness mean? Krugman (1994) has rightly reminded us that it is firms, not countries, that compete. Porter (1990), however, pointed to the advantage seemingly gained by an economy housing two or three firms competing in similar areas. Thus the presence of Hoechst, Bayer and BASF, together with the close competition from Sandoz, Ciba Geigy and Hoffman la Roche in Switzerland, was seen to provide the basis for the comparative (competitive) advantage of Germany and Switzerland in chemicals and pharmaceuticals. Britain's support for a 'cluster' of pharmaceutical firms was likewise seen to have brought the UK competitive advantage in this sector.

The tendency on the part of most companies to specialise more narrowly within the chemical industry does not affect the concept of competitiveness based on the clustering of MNE plants. Cartagena, in Southern Spain, for example, is rapidly establishing itself as a centre for the European polymer industry; Munich, as a centre for biotechnology. Given the international mobility of capital and (much) technology, the key issue becomes that identified by Reich (1991) namely to ensure that the investment brings with it high value added jobs. In this respect, and only in this respect, *national* policies matter. A country which, like Ireland, invests heavily in training its workforce and providing a high quality infrastructure to support high tech production and research, ends up by attracting more MNE investment and better quality jobs than those without such assets. National competitiveness can be seen, therefore, not so much in the performance of nationally-based MNEs, as in the degree to which international companies are drawn to locate within national boundaries, and the quality of the jobs they bring with them and attract to them. The policy message is therefore that competitiveness is not the same as comparative advantage and cannot be measured in terms of trade balances or market shares of national companies, but can be measured in terms of the contribution to GDP of the divisions of international companies located on national soil. Education, training and an infrastructure supportive to science-based industries are all important factors contributing to this kind of competitiveness.

5.5) The Life Sciences – a dynamic area of development but can Europe compete?

The dynamic area of development amongst these companies is undoubtedly in the life sciences, where radical changes are taking place in the wake of new 'discoveries' in the genetic technologies. As with all such radical shake-ups, new players (specialist biotechnology firms) are entering the field, challenging the hegemony of established players who respond through a series of moves involving tapping new sources of knowledge via joint ventures, strategic alliances and university-industry link-ups. The two lead areas are pharmaceuticals and the plant sciences. In the former, as the case study on the pharmaceutical industry stresses, there is growing dependence upon developments not only in the genetics field but also in information technology and Europe's comparative disadvantage in the latter technologies, puts European companies at a disadvantage vis-à-vis their US counterparts. This helps to explain the increasing use by European-based companies of links with specialist US firms and their increasing emphasis on US-based R&D as an important constituent in new product development.

The combination of new firm entry and old firms shifting sideways and 'restructuring' themselves into the area makes pharmaceuticals currently an over-crowded sector where much pruning of company numbers is to be expected. This is not true of the plant sciences, where the costs and risks associated with the 'environmental release' of genetically manipulated species have played into the hands of large established companies. Here again, European-based companies have bought heavily into US science and capabilities, while the uncertainties of the regulatory and IPR situation in Europe have encouraged the expansion of US-based activities. Once again, the focus of leading-edge research and innovation has shifted to the US.

5.6) The impact of environmental regulation

The impact of the environment and environmental regulation is beginning to have a significant impact upon the industry. The paints and inks sector is an interesting illustration of the impact of regulation. Here the problems lie with the solvents used in oil-based paints, with water-based paints now favoured because they do not create toxic fumes. For historical reasons, water-based paints have been used more frequently in the US than Europe, and the European consumers have been reluctant to take them up. Moreover, whereas US regulations target the product itself, stressing the need for solvent-free products, European regulations concentrate on the manufacturing process and the health and safety of those producing paints and inks. Ironically, it is the manufacturers who are pressing governments to adopt the more stringent anti-solvent regulations in order to boost sales of water-based paints and thus provide a spur to innovation in the sector.

In general European regulations are stricter than US regulations. This has the effect, firstly, of concentrating research (e.g., on developing new, recyclable plastics) in Europe but, secondly, also of shifting production activities away from Europe to countries where regulations are less stringent. Europe may now have a 'clean' chemical industry, but how far is this at the expense of countries such as China, India or Brazil? Or, at the other end of the scale, how far is Europe's reluctance to embrace genetically-manipulated corn, or sunflowers inhibiting research in European laboratories to the benefit of the US?

5.7) Competition by regulation

One feature of the 1990s has been the increased use of 'competition by regulation' with countries using the regulatory framework (or lack thereof) as a positive factor in attracting footloose multinational investment. In biotechnology, the US approach to both patenting and regulation has seemingly been more ready to accept new approaches such as allowing the patenting of broad gene sequences, leaving the testing of such patents up to later court cases. Likewise, regulation by product (maize) rather than process (genetically manipulated) has meant a regulatory climate more conducive to experiment and commercialisation than the European 'precautionary' approach. That the two approaches do not match has been clear from the 'spats' in the WTO over the use of beef hormones and BST.

Overall, competition via regulation seems an unfortunate development. Just as it is wrong to clean up Europe's chemical industry at the cost of dumping dirty processes on third world countries, so it is futile for the US and the EU to go to war over genetically manipulated maize. Given globalisation, surely the answer is to shift towards global rules of the game. Competition through regulation is not satisfactory, because it encourages a 'race to the bottom'. Given the increasing acknowledgement of the global nature of the threat to the environment, it seems appropriate that there should be global standards set and adhered to in many of these areas.

5.8) What policy conclusions emerge from this overview?

National policies promoting *national* firms become increasingly irrelevant in a world peopled by multinational enterprises. The Reich (1991) approach, which looks to the value added, brought by firms to a country/region is more profitable. This stresses the provision (by the national state) of an infrastructure which attracts high value added jobs from MNEs. Furthermore, the science base is important both in its function as a trainer of highly qualified graduate staff and as a source of specialist knowledge and advice. Continuing investment in basic science and engineering is therefore an important element of policy.

Regulation can be an important driver of innovation but can also be a deterrent, encouraging R&D and exploitation to switch to less regulated environments. It is most unsatisfactory if regulation and IPR conditions become the focus for competition because of the tendency for such competition to become a "race to the bottom". This suggests that greater efforts need to be given to securing agreement at the global level on the broad content and approach of regulations and in moving towards the acceptance of a global portent.

Task 1.6 – The effects of different financial systems on competitiveness and innovation performance in the chemical industry

The objective of this Task was to provide a comparison of how different financial systems – in the US, Japan and different European countries – constrain and support the innovation policy of chemical firms. A related objective was to compare the ownership structure of European leading firms with their US and Japanese competitors. Indeed, it is well known that the Japanese industrial group structure (*keiretsu*) can overcome problems of trusts and limits to contracting so as to develop a deeper commitment to specific, irreversible, investments. This situation would be beneficial for R&D investments. On the contrary, the European situation appears less favourable to investments in R&D. European companies lack the close interconnections of Japanese rivals, and are not subject to strict discipline of financial markets as in the US.

Specifically, the study by Arora, Ceccagnoli and Da Rin (2000) looked at *restructuring* and its effects on firms' R&D decisions. Restructuring at the firm level entails changes in the composition of both capital and labour, and in particular the divestiture and acquisition of productive assets. Restructuring at the level of the industry entails the entry and exit of firms through takeovers, mergers and acquisitions, i.e. sales and purchases of whole businesses. It is then important to understand what effect restructuring has on R&D. Hence, the purpose of this study was to provide some insights on how firms change their R&D investment as a result of changes in their business portfolios.

This issue appears to be particularly important in the case of the chemical industry. Indeed, there are several important reasons to focus on chemicals:

- First, the chemical industry is capital and R&D intensive, so that changes in a firm's industrial portfolio may require large transactions in terms of plants, as well as in terms of R&D strategy. This makes this industry particularly suitable for the purpose of this study;
- Second, there have been some important and clearly identifiable shocks to the industry since the 1970s. The oil shock exposed overcapacity in petrochemicals; the rise of biotechnology severed the link between chemicals and pharmaceuticals, and created life sciences as a separate industry; the dissemination of maturing process technology worldwide made 'specialty' chemicals more lucrative than 'commodity' chemicals. The far reaching nature of these shocks has resulted in continued pressure for restructuring, giving a precious chance to study the effects of ongoing structural changes;
- Third, focussing on chemicals allows to identify several segments with distinct technological characteristics, and thus to assess precisely the nature of restructuring;
- Lastly, chemicals have been a truly global industry since long; Hence, looking at chemicals allows to grasp effects which go beyond national idiosyncrasies.

Unlike the bulk of the previous work in this area, Arora, Ceccagnoli and Da Rin analysed not only acquisitions, but also divestitures. Also, they considered not just acquisitions of entire firms, but also of single divisions and businesses. Since the bulk of industrial restructuring in chemicals – as well as many other industries with multi-business firms – involves assets sales and divestitures at the business or product level, their analysis provides further insights than the earlier literature on acquisitions. Moreover, the authors considered a sample of firms from the U.S., Europe, and Japan, so as to get a broader view of the dynamics of corporate restructuring, a view consistent with the global nature of the chemical industry. And they explored the effects of restructuring for the 1990s, which was an extremely intense period of restructuring in chemicals.

The empirical analysis was based on a unique database which covers the years 1987 to 1997, and which contains financial and company information for 535 North American, European and Japanese chemical firms for whose acquisitions and divestitures Arora, Ceccagnoli and Da Rin also gathered information. While the sample they used is biased towards North American firms, which constitute 58% of the sample, it nonetheless includes most of the large chemical companies from Europe and Japan. Explicitly, their sample is based on the publicly traded North American, European and Japanese manufacturing firms included in Compustat's *Global Vantag*e, a database which collects income and balance sheet information (including annual R&D expenditures) on thousands of firms worldwide. Of the 535 firms, 58% are North American companies, 21% are Japanese, 13% are European, and 8% are from the UK.

The authors then identified the restructuring deals in which the selected firms where involved by linking Compustat's *Global Vantage* with restructuring data coming from the Security Data Company's (SDC) *World-wide Mergers & Acquisitions* database, which covers almost 100,000 deals worldwide since 1985. They selected about 16,000 world-wide chemical related transactions, by including deals announced between 1987 and 1997. The 535 sample firms are responsible for about 30% of the selected worldwide chemical related deals.

Their main result is that restructuring does matter for R&D investment. Net acquisitions in R&D intensive industry segments have a positive and significant effect on R&D investment, a result robust to different specifications and samples. Arora, Ceccagnoli and Da Rin get further insights once they look into variations across industry segments: By looking into a single industry and at its segments, they have been able to get a finer appraisal of the effects of changes in portfolio composition on R&D. For example, they find that the significance of net acquisitions varies across specifications and samples. They also find that the elasticity of R&D with respect to sales is less than one, and varies widely across industry segments.

Financial variables like debt or cash flow do affect R&D, but not the effect that restructuring has on R&D. This result complements Hall's (1990) finding that the effect of leverage on

R&D intensity does not change whether a firm is an active acquirer or not. Finally, they find that the effect of restructuring on R&D and capital investments is markedly different, contrary to the findings of Hall (1994) for a large sample of U.S. manufacturing firms.

To get further insights into the impact of restructuring on industry R&D, they used their results to separate the impact on R&D through changing size distributions due to restructuring from the direct impact. In other words, the authors studied how much of the change in the average R&D intensity within industry segments is due to changes in scale distribution. They found restructuring to be an important component of the observed changes in R&D intensity. Moreover, the impact of restructuring differs across segments. For instance, in Life Sciences, most of the impact is through restructuring of firm portfolios rather than changes in the size distribution. In Other Chemicals, most of the impact is through changes in size distribution, with the size distribution becoming more equal after restructuring has had place. In Commodities, both matter, with an increase in size inequality as well as a direct increase in the inequality in R&D due to restructuring of the firm portfolios. These results provide a new, more composite, perspective on the effect of corporate restructuring on R&D.

Theme 2 – The forces that encourage the diffusion of chemical innovations on downstream user industries, across regions, and on SMEs.

Task 2.1 – The effects of different forms of government interventions on the incentives of firms to undertake R&D, especially R&D characterised by significant spillovers

In this Task we proposed to study the effects of different government interventions on the R&D process of the chemical industry. The papers by Cesaroni and Arduini (2000) and Becker and Englmann (2000) studied the effects of government interventions in the development of the environmental technologies in the chemical industry.

Government intervention is mainly based on two instruments: i) the "command and control" approach, based on direct regulation; ii) the use of economic instruments and voluntary programmes. The first solution is characterised by a reduced flexibility, because it consists of measures aimed at directly influencing the environmental behaviour of social actors, since it determines limits, restrictions and rules related to specific product and processes. On the contrary, the second solution is comparatively more flexible, because it consists of instruments such as taxes, tradable quotas, subsidies, covenants and so on.

Cesaroni and Arduni (2000) analyse the existing literature with the objective of providing a general overview of the environmental issue. They analyse as well some interventions promoted by specific countries, in particular to encourage the development and the diffusion of environmental technologies. Furthermore, they try to support some examples concerning this chemical industry.

At the firm-level, Cesaroni and Arduni show the ever growing importance that the environmental issues assume in the decision-making process, especially regarding the increasing pressure coming from the public opinion and authority. Such pressures vary among different countries, even if a growing convergence can be noticed, which pushes to bring near the different realities. In particular, it can be noticed that:

- there is a concentration of efforts and interventions towards prevention, rather than end-of-pipe intervention. Indeed, prevention is generally considered more efficient than end-of-pipe;
- there is a convergence in the levels established by the standards of the different countries;
- the instrument of “command and control” is ever more supported by economic instruments grounded on an incentive-based approach. Previous experiences demonstrated that the only direct regulation is not able to obtain sufficient outcomes. Nevertheless, it is not possible to easily individuate the most efficient instruments to realise a satisfactory environmental policy.

Cesaroni and Arduni proceed to analyse the ways in which European chemical industry contributes to the development and diffusion of environmental technologies. Two analyses are carried out: (1) a general patent overview, and (2) a specific case study analysis. The former gives information related to end-of-pipe and recycling technologies, and the latter to clean technologies.

Their main results are the following. First, innovative rates of the US, Japan and Europe in environmental technologies are similar to innovative rates in other types of technologies. The

US have shown a greater innovative rate in recycling, whose technologies are more effective and efficient than end-of-pipe technologies, both from an economic and ecological viewpoint. Among European countries, Germany shows the greatest innovative rate, both in the end-of-pipe and recycling sectors.

These results could bring to the consideration that rigid environmental standard and strong public pressure have a positive influence on the environmental innovative rate. As a matter of facts, the United States have faced environmental problems through very strict standards, and Germany has adopted the most rigid standards of Europe (see chapter 1). This could evidence the great influence that this type of regulation has on environmental innovation. However, it must be highlighted that both United States and Germany (compared to other European countries) are the more innovative countries, not only in the environmental sector, but also in general terms. This result shows that the environmental sector broadly follows the trend relative to innovation.

The influence of regulation on the innovative rate can be demonstrated from the clear US prevalence in the class of hazardous wastes. Neither Europe nor Japan patent in the United States in this sector, and in Europe the United States possess the 61% of patents. This result can be interpreted by considering that in the United States there is a wide regulation about hazardous wastes and an equally wide system of responsibilities do not exist neither in Japan nor in Europe (Esteghmat, 1998).

Another result of Cesaroni and Arduni study refers to the prevailing type of innovations. While the US realise most innovations in recycling, Europe seems more oriented towards end-of-pipe technologies. So, the US show a greater attention to prevention, because recycling technologies are more effective than end-of-pipe in solving environmental problems. On the contrary, in the past years European policy spent greater attention to the end-of-pipe sector, even if at a theoretical level, prevention was considered as mostly important.

Second, to better understand the innovative pattern of the chemical industry, Cesaroni and Arduni consider the patents realised by major chemical companies. They find that the chemical industry patents more than other industries in the environmental sector. Among environmental technologies, then, greater attention was paid to the recycling sector, both for

European and US companies. But American firms show a higher average number of domestic and foreign patents than European firms.

This result suggests the existence of an European delay in the development of environmental technologies, and US supremacy is confirmed in two other ways. Firstly, US patents have a greater average quality than European patents. Secondly, in some cases, European firms realise environmental patents in the United States. So, a greater market for environmental technologies exists in the US, and technological and research competencies are concentrated.

Third, Cesaroni and Arduini analyse a random sample of environmental patents in order to study innovating agents. They find important differences among countries. In the US most innovations are realised by independent firms, especially in the end-of-pipe sector. Japan is ever specialised in the end-of-pipe sector, where a high percentage of patents is realised by non-chemical groups. Chemical European and US groups realise high percentages of patents, and play an important role mainly in recycling, where they account for about 30-40% of total patents. Finally, universities, research institutes, and government agencies show very low percentages of patents. Interesting results appear only for American agents. Referring to multiple assignee patents, in Europe and the US they are almost rare, but in Japan they are not. So in Japan collaborative patterns in innovative activity are more likely.

Becker and Englmann (2000) study the effects of government interventions in the case of the development of environmental technologies in Germany. After reviewing the literature on the effects of environmental regulations on the innovative process of firms, they analyse the effects of direct and indirect (voluntary) regulations in Germany. They start first by carefully reviewing these regulations. Their main conclusions can be summarized as follows. First, the German approach of environmental protection primarily consists of two principles: On the one hand, it is based on *pollutant emissions*. The load capacity of the nature is seen to be an insufficient criterion for environmental protection because of the lack of knowledge about the environmental repercussions human that activities may cause. On the other hand, environmental protection means *technical protection* of the environment: According to the Water Management Act (Wasserhaushaltsgesetz [WHG]) a polluting firm only receives a permission for a water polluting production if it meets a certain technological standard which is associated with a limited amount and harmfulness of waste.

Besides emission standards, emission charges also are technology-related because the amount of the charge for a discharger depends on the compliance to the technology-related emission standards of the WHG. Second, the federal character of the German system produces a variety of systems of standards and charges for emissions into water. However, the Länder and municipalities are only allowed to set emission charges and emission standards within the frame of the law of the Federation. Third, the Water Management Act and the Waste Water Charges Act (which charges direct dischargers) are closely bound up. The same applies to emission standards and emission charges for indirect dischargers. Here, the charge will become zero if the indirect discharger meets the emission standards. Thus, careful interpretation is necessary when assessing the incentives of emission standards and emission charges to water benign process innovations. After this review of the German legislation, Becker and Englmann proceed to compare it to the European legislation.

After carefully analysing the reaction of firms to these regulations, they arrive to the following conclusions. First, there is suggestive evidence that the establishments´ reactions to environmental regulations were by far the most important reason for carrying out both end-of-pipe and production-integrated innovations. Second, successful compliance to actual emission standards are the most important reason for the establishments to refrain from (further) end-of-pipe innovations. In contrast to end-of-pipe technologies, the missing impulses due to non-tightening emission standards lost their outstanding role as innovation impediment in the case of integrated technologies. Here, the cost-efficiency of incumbent plants was as important as the missing impulses due to non-tightening standards as innovation impediment. The remaining innovation impediments could be divided into two groups. For about 17 to 34 percent of all establishments of the sample a long pay-back period, the focus on their core business, or the implementation of integrated technologies at the expense of end-of-pipe innovations were the most important reasons or belonged to the most important reasons for refraining from (end-of-pipe) innovations. In contrast, limited knowledge resources were almost never perceived as the most important innovation impediment. The importance of especially one innovation impediment systematically varied with the characteristics of the establishments. In contrast to establishments that do not participate in the “Responsible Care Initiative”, participating establishments turn to more sustainable technologies to reduce water pollution. Therefore, they refrain from (further) end-of-pipe innovations.

Task 2.2 – The "world" market for chemical process technologies: Their diffusion and the beneficial effects of division of labour on other firms and users

The objective of this Task was to discuss in detail the nature and characteristics of the market for process technologies in chemicals. Indeed, the chemical industry is a leading example of the effects produced by the creation of a market for technology. While technology transfer are not uncommon in other industries, few have witnessed the rise of a market for new technologies disembodied from capital goods and equipment. In the chemical industry, licensing, especially of new process technologies, has been a widespread practice for many years. Moreover, this practice has given rise to an efficient division of labour between companies that have specialised in the design and engineering of chemical plants (the so-called "Specialised Engineering Firms"), and downstream producers that acquire the services of these upstream suppliers.

Given this background, this Task aimed at discussing the conditions that gave rise to an independent market for technologies disembodied from capital goods, and to assess the potentials for efficiency and economic growth of the ensuing process of vertical specialisation and division of labour. Moreover, this Task aimed at analysing the world market of chemical technologies, and discuss the position of the European producers vis-à-vis US and Japanese firms.

The study was conducted in four different steps. In the first, Arora and Fosfuri (2000a) tried to provide an empirical evidence of the existence and dimension of the market for technology in chemicals. In the second, Arora and Fosfuri (1999) entered more specifically in the theoretical insights, trying to understand why firms have incentives to license their technologies and to promote the expansion of the international market for technologies. In the third, Arora, Fosfuri and Gambardella (2000) discussed the advantages coming from the existence of such a market in terms of international spillovers and economic growth processes. Finally, the fourth step (Arora and Fosfuri, 2000b) tried to look at the issue from a managerial viewpoint, and compared two entry modes that multinational enterprises can use to invest in new markets, namely wholly owned subsidiaries and technology licensing.

The issue of division of innovative labour in the chemical industry was explored also by using a different perspective. By focussing in the pharmaceutical industry, Baio, Pammolli and

Riccaboni (2000) analysed the formation or R&D networks as organisational devices for the coordination of heterogeneous learning processes by agents endowed by different skills, competencies, and access to information and assets. The objective of this work is to try to establish a closer connection between the structure and evolution of knowledge and the structure and evolution of organisational forms in innovative activities.

1) Evidence of the market for technology in the chemical industry. Causes and consequences

In order to understand the functioning of markets for technology, it is primarily important to discuss the role of patents in enhancing technology transfer, and not only as means to exclude others from the use of a proprietary technology. Simply put, patents can play a key role in facilitating the purchase and sale of technology, or in other words, the development and functioning of a market for technology. A market for technology helps diffuse existing technology more efficiently; it also enables firms to specialize in the generation of new technology. In turn, such specialization is likely to hasten the pace of technological change itself. The reason for focusing on the development and functioning of a market for technology is that it greatly reduces the transaction costs involved in buying and selling technology, implying that innovators have the option of appropriating the rents from their innovation by means of simple contracts, instead of having to exploit the technology in-house.

However, the development of a market for technology is not an automatic outcome. It depends not only on the efficacy of technology licensing contracts (and on the strength of patents that underpin these contracts), but also on the industry structure itself. This is an important issue – Whether firms contract for technology depends not only on the transaction costs, as commonly understood, but also on historical factors. Thus, in chemicals, the presence of specialized engineering firms that licensed technology, and in other cases, provided complementary know-how for technologies developed by chemical firms played a key role. The increasing competition has also fostered the willingness of even the largest chemical firms to license their technology, while globalisation and entry since World War II has meant that there exists a substantial number of chemical producers that are potential buyers of technology.

In general terms, technology licensing may be hindered either because licensing contracts are very inefficient or because it is not in the strategic interest of the technology holder to license the technology. Licensing contracts can be inefficient due to the need to transfer know-how and due to information asymmetries. Both are closely related to the strength of patent protection.

In the chemical industry, unlike most others, chemical processes can be effectively protected through patents. As a result, even the valuable unpatented know-how, needed to use the technology, can be licensed. Patents pertain to that part of the discovery that is codified. Therefore the effectiveness of patents depends on how cheaply and effectively new ideas and knowledge can be articulated in terms of universal categories. When innovations can not be described in terms of universal and general categories, sensible patent law can only provide narrow patent protection.

Arora and Gambardella (1994) pointed out that technological knowledge that is closely related to broad engineering principles and physical and chemical "laws" is more readily codifiable. Chemical engineering developed more general and abstract ways of conceptualising chemical processes, initially in the form of unit operations, and later in terms of concepts such as mass and energy transfer. A number of different processes could be conceived of in terms of these more elementary units. A chemical engineer could therefore see common elements across a number of processes that might appear very different and diverse to a chemist from an earlier generation. Chemical engineering (and the concomitant developments in polymer science and surface chemistry) thus provided the language for describing more precisely the innovations to be protected.

In other words, patents work well in the chemical industry because the object of discovery can be described clearly in terms of formulae, reaction pathways, operating conditions and the like. But it is not merely that the object of discovery is more discrete in the sense of being a particular compound. Rather, it is the ability to relate the "essential" structure of the compound to its function. This allows a patent to include within its ambit inessential variations in structure, as in minor modifications in side chains of a pesticide. The ability to explicate the underlying scientific basis of the innovation allows the scope of the patent to be delimited more clearly. The obvious extensions can be foreseen more easily and described more compactly.

While patents are necessary for a market for technology, they are by no means sufficient. Firms that specialize in the design, engineering and construction of chemical plants emerged and some developed proprietary technologies that they offered for license, at a time when many firms, all over the world, were looking to acquire chemical technologies. Specialised Engineering Firms (SEFs) induced chemical firms to license their technology as well. In addition, SEFs reduced transaction costs by acting as licensing agents for chemical firms and by bundling technology with complementary engineering, design and construction capabilities valuable to potential buyers of technology. The presence of SEFs, induced entry by a number of firms, increasing the number of potential technology buyers. The net result was a “thicker” and a more efficient market for technology.

2) Licensing the market for technology. Theoretical insights

This study was mainly focused around one specific question: Why do firms license their technologies? Indeed, the traditional answer is that they license if they are less efficient (or unable) at exploiting the invention than the potential licensee, or they attempt to establish their technology as a de-facto standard. Both of these motivations are well-known by the literature. Instead, in this study Arora and Fosfuri (1999) focus on the role of licensing in rapidly expanding the use of technology. Typically, there are significant firm level adjustment costs or other constraints that restrict how rapidly an innovator can expand output. Thus, a technology holder can turn to licensing as a way of exploiting the technology more aggressively.

In order to answer the question the authors developed a game theoretical model, focused on the case in which there are at least two technology holders in the market. The intuition of the model is simple. Suppose that two firms have independently developed their own technology suitable to produce a given (final or intermediate) product. What is the payoff of the licensing strategy? Arora and Fosfuri considered two effects. The first, the *revenue effect*, is given by the rents earned by the licensee which will accrue to the patent holder in the form of licensing payments. The second, the *rent dissipation effects*, is given by the erosion of profits due to another firm competing in the downstream market.

The answer to the question come s directly from the comparison of these two effects. Hence, if there is only one incumbent in the market, the rent dissipation effect dominates the revenue effect. Instead, when another incumbent exists and losses due to increased competition are shared with the other incumbent in the market so that the licensor does not fully internalise the rent dissipation effect. Thus, if the revenue effect is larger than the rent dissipation effect, the firms compete not only to supply the products but also to supply their technologies.

By using this model, the authors were able to demonstrate that:

- In the presence of competing technologies firms have incentives to license;
- The presence of high transaction costs decreases the incentives to licensing. On the contrary, stronger intellectual property rights enhance licensing;
- There are more incentives to licensing when the product market is homogenous;
- The presence of specialized engineering firms induces licensing (or more licensing) by chemical firms

Results confirm the important role of markets for technology. Indeed, markets for technology imply technology diffusion and increased entry, which improves the static efficiency of markets. However, by inducing entry, markets for technology may reduce the incentives to undertake R&D. Moreover, if licensing involves transaction costs, the presence of competitors in the market for technology might induce firms to an inefficiently high level of licensing. In general, policies aimed at stimulating licensing are likely to be welfare improving when there are few technology holders and products are differentiated.

3) The benefits of market for technology. International spillovers and investments

This study focused on how division of labour in one country has beneficial effects for other countries, in the sense that when division of labour in a country gives rise to upstream technology suppliers, other countries can benefit as well. The general framework can be so described: If technology suppliers develop in one country first, then, once the technology is developed, these technology suppliers can sell it to other countries at a small incremental cost (especially if compared with the cost of developing the technology in the first place). In this way, technology developed in leading countries can “spillover” to follower countries.

Indeed, the chemical industry provides an ideal test-bed of this framework. Beginning in the 1930s and continuing into the 1960s, the modern chemical industry in the developed countries grew rapidly. This stimulated the growth of firms that specialised in the design and engineering of the chemical processes, the so-called ‘specialized engineering firms’ (SEFs), which are similar to the software engineering and computer consultancy firms that are more visible in the American economy today. SEFs have been important reservoirs of expertise in chemical technologies, which they provide in the form of engineering services to chemical firms. In some cases SEFs have also developed radical process innovations but for the most part they supply improved versions of existing technologies packaged with engineering and design services. Other SEFs offered construction services in addition to engineering know-how. In the 1970s, and especially in the 1980s, as a modern chemical industry emerged in the developing countries, it benefited from the presence of these technology suppliers. Simply put, the growth of the chemical industry in the first world created an upstream sector, which later spurred the growth of the chemical industry in the developing countries.

To examine this issue Arora, Fosfuri and Gambardella (2000) studied investment in chemical plants in less developed countries during the 1980s. They developed a simple model. The model assumes that a larger number of technology suppliers increases the net surplus to buyers from investing in a chemical plant. This is a natural assumption since buyers should benefit from being able to choose from a larger pool of suppliers, and is consistent with a large set of economic explanations that variously emphasize reduced search costs, reduced bargaining power of sellers, and a better ‘match’ between the needs of buyers and the technology. The main result of the model is that if the existing SEFs in the first world are also potential suppliers of technology to developing countries, then the larger the number of first world SEFs in a given market for chemical process technology, the greater is the investment in that market in the developing countries.

The model also predicts that the larger is the number of first world SEFs, the greater is the number of plants in developing countries where engineering services are ‘bought’ from SEFs, and the smaller the number of plants whose engineering services are ‘made’ in-house by the chemical firms. Moreover, the impact of an increase in the supply of SEFs are more pronounced for companies that have higher cost of ‘making’ the technology in-house. This suggests that SEFs are more beneficial for local third world companies than for the multinational enterprises that may also invest in these markets. The authors tested these propositions using data on chemical plant investments in 136 leading chemical technologies and 38 developing countries. These are drawn from a novel and comprehensive data set of more than 20,000 chemical plants announced and constructed during the 1980s worldwide.

In order to test the model, the authors selected 139 chemical process technologies and 38 less developed countries during the period 1980-1990. Arora, Fosfuri and Gambardella looked at the amount of investment in a technology-country pair (as dependent variable), and they used the number of SEFs in the first world as main dependent variable. The main findings of the analysis show that:

- an additional SEF would have increased the investment by $109million;
- the increase of investment being larger for larger countries, for technology less diffused in the third world, and more mature;
- an increase in the number of SEFs is more beneficial for firms which lack technological capabilities and for more sophisticated investments.

Hence, the empirical results are consistent with the notion that the greater the number of technology suppliers, the more attractive the terms on which technology is supplied and, all else held constant, the more likely buyers are to invest. The authors do not mean to suggest that the observed rates of investment in chemical plants in developing countries are being fueled solely by specialist process technology suppliers from the first world and could not be achieved without them. Rather, they interpret those results as suggesting that that the investment is taking place earlier and more rapidly than if developing countries had to rely solely upon chemical producers in the first world to transfer the technology, or even worse, if they had to 're-invent the wheel' – i.e., develop process technologies and the broader engineering expertise required to design and construct chemical plants domestically. In short, the vertical organization of industry in the first world 'matters' not just for the growth of the first world but also for the growth of other nations.

4) Market for technology and international licensing. Wholly owned subsidiary vs. Technology Licensing

While the previous studies analysed the market for technology from a general perspective, in this study Arora and Fosfuri (2000b) looked at the problem from a managerial viewpoint, and analysed how the presence of the market for technology affects internationalisation strategies by large chemical companies. In particular, they focused specifically on whether technological competencies are exploited in foreign markets through licensing agreements or wholly owned subsidiaries. These two alternatives lie at the extremes of a continuum of governance structures ranging from a hierarchy to a market mechanism (Williamson, 1991).

This study was therefore an attempt to shed light on some outstanding questions in this area of research. Specifically: (1) Does cultural distance influence the choice between wholly owned subsidiary and technology licensing? (2) Do firms learn from previous business practices in foreign countries? And, which entry modes do provide more experiential learning to the investor? (3) How does the presence of other potential licensors influence the entry modal choice?

The empirical analysis was based on foreign direct investments, joint-ventures and licensing strategies promoted by 153 large chemical companies in the period 1986-1990. Arora and Fosfuri developed an econometric model in order to test why firms choose different internationalisation strategies, and looked explicitly at the number of potential licensors in the period 1980-1995, in a given technology class, as explanatory variable. Empirical data have been drawn from the *Chemical Age Project File* (CAPF) database, which covers all new chemical plants (over 20,000) announced all over the world during 1981-1991. The database provides the name of the company that operates the plant (or the names of the partners if the project is run under a joint venture) and that of the firm that has licensed the technology. This allowed the authors to identify whether, for a given project, the firm that ultimately possessed the technological capability, has chosen to set up a fully owned operation or to adopt a licensing strategy. In addition, the database reports for each plant the type of process technology that is used for production. So, for instance it is possible to identify all plants that produce “ammonia” or those that produce “acetic acid”.

The main results of the analysis show that:

- more potential licensors (i.e. larger MFT) imply higher probability of licensing strategy;
- the analysis controls for characteristics of technology such as complexity and codifiability.

This study offers some fresh evidence on a crucial strategic decision by firms involved in global competition: When is licensing better than a wholly owned subsidiary for exploiting technological competencies abroad? Although confined to one industry, the data set is rich and comprehensive. By focusing on an industry, Arora and Fosfuri can better control for differences in technology characteristics, such as codifiability and complexity, which is much more difficult in cross-industry studies. Furthermore, another contribution of this study is the analysis of the role of competition, especially in the market for technology, in conditioning the choice of the mode of entry.

The results of the analysis show that cultural barriers are an important limitation to the commitment of resources. Firms prefer to exploit their technological competencies through licensing when the target country is culturally far away from the home country. The results also support the idea that learning plays a crucial role in the design of internationalisation strategies. The authors find that prior experience in the host country increases the odds that the project is carried out through a wholly owned operation rather than licensing. Further, this experience is more valuable when it comes from prior projects that entail a greater degree of involvement with the foreign business environment such as joint ventures or wholly owned subsidiaries.

These results also shed light on a research question that has been little explored empirically. Although it is widely accepted that a firm's expansion strategy cannot be analysed in isolation, empirical studies on entry modes have typically ignored this point. Arora and Fosfuri find that the presence of other sources of technological competencies favours the use of licensing vis-à-vis wholly owned projects. This is consistent with the idea that when there are many sources of technological competencies, the lack of technology does not constitute a barrier to entry. Indeed, an entrant does not need necessarily to develop the technology in order to start production because it can acquire it from any of the potential licensors. In turn, this is likely to make competition in the product market more intense and favour the use of licensing as foreign entry mode, which is less demanding in terms of resources and commitment.

5) The evolution of the network of R&D strategic alliances in the pharmaceutical industry

The explicit focus of this study conducted by Baio, Pammolli and Riccaboni (2000) was on the dynamics of the network of collaborative agreements in R&D in the pharma/biotech industry after the "molecular biology revolution", in order to analyse the dynamics of the network over time.

The empirical analysis was performed by using a comprehensive database, built by the authors integrating several sources in the industry. The data base was built integrating, for the years between 1978 and 1993, the information drawn from *Bioscan*, a yearly directory published six times a year by *Oryx Press*, with data recovered on annual reports and specialized press.[3] The analysis was focused on the network of collaborative agreements in R&D and on license contracts relating to molecules under development drawn up among the firms of the sample still alive at the end of the period. On the contrary, direct reference to the numerous informal relationships with single researchers, to collaborations with Universities, research centres and other firms, and to formal agreements referring only to the production and/or marketing areas, was omitted.

Concerning network structure, it is found that, while the size of the network increases over time due to net flows of entry, its topological properties remain relatively unchanged. The evolution of the network has occurred without relevant deformations in the core-periphery profile. As far as age-dependent propensity to collaborate is concerned, the study found that the extent of inter-generation collaboration is much more significant than intra-generation collaboration. In addition, the propensity of firms of a given generation to enter into collaboration with firms of a different generation increases with the distance between the two, while the total number of intra-generation collaborations decreases over time and, moreover, tends to decrease for most recent generations. The study presented a unitary and coherent explanation of the evidence, coming to reveal the existence of a striking homology between structural properties of the dynamics of knowledge and of the evolution of network structure.

[3] *Bioscan* lists information on a firm's ownership, its current products, and its research in progress. All information about agreements and the characteristics of organizations reported here is drawn from the 1988 and 1993 volumes.

Next versions of this study will purport to define a more precise interpretation of the nature, structure and functions of the market for technology in the pharmaceutical industry, with an explicit focus on the dynamics of the division of innovative labour. The objective is to establish a closer connection between the structure and functions of the network of licensing agreements in R&D, its evolution over time, and the fundamental features of underlying knowledge bases and search activities.

Task 2.3 – The new challenge: Environmental technologies. Is the chemical industry "spilling over" to other sectors, to other European regions, and to SMEs?

The objective of this Task was to examine the present efforts of the chemical firms in the field of environmental technologies, and to discuss how the latter have become an important source of industrial competitiveness of the companies in the chemical industry. Relatedly, the Task examined how the European firms are coping with this problem and their competitive position in this technological field as compared to the US and Japanese firms.

The study was conducted in two different steps. In the first, Cesaroni and Arduini (2000) focussed on Europe by performing three different analyses, aimed at a better understanding of the processes of development and diffusion of environmental technologies. By using patent information they investigated the innovative rate of the chemical industry in the environmental field. By using case studies they examined the reasons that would push or dampen the development and the diffusion of environmental technologies. Finally, by means of an Internet analysis they analysed the environmental industry, i.e., the sector specialised in the supply of environmental products, services and technologies.

The second step conducted by Becker and Englmann (2000) focused on the case of Germany, and in particular on the efforts which German chemical firms and their establishments are making to reduce a specific waste which results from manufacturing chemicals: waste water. This issue was explored by analysing two specific objectives. First, the pattern of process innovations of West German chemical firms to reduce waste water. Second, the establishments´ reasons for carrying out or refraining from process innovations to reduce water pollution. Understanding the firms´ innovation behaviour is a precondition for an effective support of public policy towards an environmentally safer development.

1) Environmental technologies in the European chemical industry

This study analysed the way in which the European chemical industry contributes to the development and the diffusion of environmental technologies, and investigated the competitive position of the European chemical industry in the environmental field, compared with US and Japan. The analysis was performed both through a bibliographic research, patents analysis, case studies and via Internet analysis.

Patent analysis was conducted by using two different patent databases, i.e. the US and European databases. This opportunity has allowed Cesaroni and Arduini, firstly, to cover the international arena in a more extended and complete way. Secondly, and perhaps even more important, to make some cross comparison between the patenting behaviour of the companies in their origin and foreign countries. Indeed, the innovative behaviour of companies is related to their technological competencies, but the decision to patent in a foreign country depends also on the competitive importance of that country. Hence, this approach allowed the authors to evaluate the technological strength as well as the technological dimension of different countries.

The analysis was conducted with the following three steps. Firstly, Cesaroni and Arduini have considered the environmental sector as a whole. Secondly, they have analysed the patenting behaviour in this field by the largest chemical and petrochemical companies. And, finally, they have observed the characteristics of firms mostly responsible for environmental innovations.

Case studies have been used in order to define the forces that drive chemical companies to pursue R&D and innovations in clean technologies and green products. The authors have looked at the more relevant R&D projects of the five companies, and addressed the following questions: how does (public) financial support influence company innovative behaviour in this sector? How does policy regulation matter? Is public opinion pressure relevant in company decisions? Do companies consider research collaborations, both with research institutes, universities, and engineering firms, useful in innovation development processes? Do companies consider patents and/or licenses a useful tool for innovation diffusion?

Finally, the study analysed the “environmental industry” by collecting relevant information from the Internet. Cesaroni and Arduini have firstly looked for specialised Web-sites that were promoted to create a linkage between the environmental industry and other sectors. Then, they have analysed in depth some of the firms listed in those Web-sites, by implementing a specific questionnaire. A special attention was paid to engineering firms, because of their important catalytic role in fostering the technological change. The objective of the questionnaire was to understand whether the engineering firms offer end-of-pipe technologies, or whether they enlarged their supply portfolio, by including also clean technologies. They have then looked at the characteristics of such firms, in terms of size and diversification, and at the characteristics of the technologies supplied, in terms of degree of standardisation and diffusion. Furthermore, they have aimed to understand the role of chemical companies within the environmental industry.

Patent analysis have evidenced that innovative rates of the US, Japan and Europe in environmental technologies are similar to innovative rates in other types of technologies. This result shows that the environmental sector broadly follows the trend relative to innovation. United States generally patent in the environmental technologies more than Europe, and Germany patents more than all the European Countries.

The higher innovative rates found for Germany and the US in the environmental sector may be linked to the different government regulation and public pressure that they face. As a matter of fact, the United States have faced environmental problems through very strict standards, and Germany has adopted the most rigid standards of Europe. Moreover in these countries, the public opinion have played an important role in influencing the environmental policy and behaviour of firms. These results could bring about the consideration that rigid environmental standards and strong public pressure have a positive influence on the environmental innovative rate (as already explored in Task 2.1).

By looking at the patent analysis, another interesting result refers to the fact that the US have a greater innovative rate in the recycling technologies than Europe, while Europe is more oriented towards end-of-pipe technologies. Europe has a grater innovative rate in the recycling field only in the US database. This situation suggests that a larger market for such technologies does exist in the US, while European environmental innovative activities are still devoted to the development of *ex-post* solutions.

The chemical companies (both from the US and Europe) patent in the environmental sector more than firms from different industries. Furthermore, chemical companies patent more in clean technologies rather than end-of-pipe ones. Taken together, these results confirm the efforts made by the chemical industry in reducing pollution of chemical processes. According to this fact, the European chemical industry behaviour is similar to the US one, since European chemical companies are specialising in recycling technologies, both at home and in foreign countries.

So, the European chemical industry plays a relevant role especially in the recycling sector. This result emerges by the patent analysis, and is confirmed by the questionnaire survey. The share of environmental innovations held by the chemical industry in Europe is larger than that of any other innovative agent in the same region. This means that the chemical industry is proportionally more important in Europe than in the US, with regard to environmental innovations. If confirmed by other evidences, this result suggests that policy makers should focus their policies towards the chemical industry, thus allowing it to gain a higher competitivity in clean technologies. And a greater attention of policies in the chemical industry could also be suggested by the fact that this industry supplies many inputs to different production processes. So, an intervention in the chemical industry – in the sense of pollution reduction – has beneficial effects on the downstream sectors. As the patent analysis revealed, it is also to be noticed that the largest European chemical companies have an average number of environmental patents smaller than the US largest companies. And the same can be said with respect to the patent quality, as measured by means of patent citations, where the US patents are cited, on average, more than European patents.

As far as collaboration agreements are concerned, the growing complexity and globalisation of markets imposes firms to look for external relationships. The same can be said in the case of clean technologies, where the development of such agreements plays a relevant role. The reason for this results can be traced in the higher complexity of preventive solutions, whose development usually requires wider technological and scientific competencies. In this contexts, engineering firms represent an important partner, both in the case of radical and incremental innovation development.

As far as clean technologies are concerned, the small number of licenses related to technologies that case studies and the questionnaire has stated, highlights the problems of their diffusion. However, the presence of patents may represent an organisational instrument to ease up the diffusion processes. So, the thing that limits the transferability of clean technologies has to be related both to the demand-side, and to the competitive gains that clean technologies induce, and that push companies to pursue secrecy.

2) Process Innovations to reduce Waste Water: A Case Study of the German Chemical Industry during the 1990s

This study by Becker and Englmann (2000) focused on the efforts which German chemical firms and their establishments are making to reduce waste water. More particularly, the overall objective of the study was twofold. First the authors wanted to investigate the pattern of process innovations of West German chemical firms to reduce waste water. Here, process innovation meant the introduction of a water benign process technology which is improved or new from the viewpoint of the firm’s establishment. These technologies can be acquired externally or can be developed by internal resources. Here, Becker and Englmann explored the role of specialised engineering firms (SEFs) as external technology suppliers and analysed what kind of chemical firms are most likely to develop waste water reducing process technologies in-house. Second, the authors explored the establishments´ reasons for (i) carrying out or (ii) refraining from process innovations to reduce water pollution. In doing so the 1990s were especially interesting because in this time period chemical firms and their establishments increased activities to recycle valuable substance in polluting streams and to tackle pollution at source rather than to reduce pollution end-of-pipe.

This study followed an eclectic research approach. The *conceptual frame* of waste water reducing process innovation mainly consults theories and methodological input from economics and policy analysis. The *empirical information* was obtained by the examination of patent data and by the collection of direct information from chemical firms in order to get original data. Direct information was obtained by the evaluation of environmental reports from chemical companies, as well as the evaluation of questionnaires and interviews with representatives of chemical firms.

Some hypotheses could be tested statistically. With respect to the remaining hypotheses the authors could not provide information about how likely it is that the empirical results are due to chance of the particular data they used. In those cases the data provides “suggestive evidence” for certain conclusions.

The main results of the analysis show that between 1991 and 1998 about two thirds of the firms´ establishments of the sample introduced end-of-pipe and production-integrated technologies which were new or improved to them. In particular the very large firms and their establishments such as Bayer, Aventis (former Hoechst) and BASF had the technological strength to develop end-of-pipe and recycling technologies in-house. Outside suppliers such as Linde, Preussag and Envicon carried out R&D activities and applied for patents especially in the field of end-of-pipe technologies.

Furthermore, SEFs support “online” improvements of both waste water treatment and production plants. Hence, these firms are important external technology sources for chemical firms, in particularly with regard to end-of-pipe technologies. Among the reasons for both end-of-pipe and production-integrated innovations reaction to environmental regulations of the government and public authorities was the most important one. And consistent with the last findings is the result that missing impulses due to non-tightening emission standards (which are the predominant type of regulation in Germany) were an impediment to end-of-pipe innovations that the highest proportion of establishments perceived as most important. With regard to integrated innovations, missing impulses due to non-tightening standards lost their predominant role as innovation impediment. Here, the cost-efficiency of incumbent plants and missing impulses due to non-tightening emission standards were equally important impediments. Every second establishment the efficiency of incumbent plants was the most important innovation impediment or belonged to the most important innovation impediments. Additional integrated measures of these establishments would decrease their profits or increase prices or both. The innovation behaviour of establishments that participate in the voluntary “Responsible Care Programme” differed from non-participating establishments especially in the following way: Participating establishments refrained from (further) end-of-pipe innovations because they carry out integrated innovations, i.e. they tackle water pollution in such a way that preserves environmental resources.

4. Conclusions and policy implications.

4.1 Innovation-related sources of competitive advantages and innovation policy in the European chemical industry

This part of the Report will highlight the policy implications of our project. We start with two remarks.

First, we will focus on innovation and technology policy. The broader industrial policy in the chemical industry encompasses quite a few other issues, particularly regulation. Our goal in this project was to look specifically at the innovation- and research-based competitiveness of the industry. While this implies that we have missed some important areas for enhancing the competitiveness of the industry in Europe, we also believe that – as typical in high-tech industries today – innovation and technology play a key role for the dynamics of this sector. Innovation and technology policy will then cover some key aspects for encouraging its competitiveness.

Second, the chemical industry is a quite complex and differentiated realm. As a result, it is hard to focus on specific aspects, as the industry is composed of many different agents, market structures, technologies, etc., which makes it hard to discuss a unique set of policies or initiatives. Any discussion about policy issues then has to indicate the specific domain to which they have to be applied.

Third, the competitive position of the European industry is a difficult concept to incorporate into any policy analysis because of the international nature of the industry. US firms conduct large amounts of research and development in Europe and European firms conduct large amounts of research and development in the US. Nevertheless, different research tasks of this project have looked at the advantages or disadvantages of European firms vis à vis their US or Japanese counterparts.

Our approach in this section will be to start by discussing the sources of competitive advantages for the European chemical industry. In light of the points that have just been made, we will focus on the innovation-related sources of competitive advantages, and we will distinguish amongst the different types of firms or realms to which such sources of competitive advantages would most specifically apply. The sources of competitive advantages will be taken from the research papers of the project, which we have summarised in the earlier sections of this report. In other words, this section will present the most important results of this project in the form of key sources of innovation-related competitive advantages for the European chemical industry.

Finally, the level of policy that we will discuss will be primarily European. But as we said before this is an industry with a clear international dimension. It is therefore hard to think of local policies for this industry. Moreover, its increasing globalisation suggests that even national policies may be confined to a fairly narrow territorial level. The European dimension is in many respects the right dimension for innovation policies in this sector. Of course, this does not mean that we will not look at national or even regional policies when there are issues that may be better examined at this territorial level (e.g. clusters of SMEs).

4.2 Public research

One the possible sources for competitive advantage is based on the knowledge base from which firms in Europe may draw for innovation. The project has looked at this issue from different perspectives. On the one hand, some of the research tasks has looked at the publicly funded research and tried to assess the performance of European public research institutions. This was done by looking at publications and patents and by trying to develop performance indicators. On the other hand, the importance of the knowledge base for specific subsectors was analysed.

One way to look at the contribution of public research is to assess the importance played by publications and technical reports in the process of knowledge transfer. This analysis is presented in Geuna (2000), who examines the evolution of scientific specialization in the chemical and pharmaceutical fields in the four largest European countries (the UK, Germany, France and Italy), the EU as a whole, the US, and Japan. His results indicate that of the countries analysed the US has a much clearer specialization profile, both in terms of positive and negative specialization and in the area of research, indicating a much higher degree of knowledge integration than in the EU. The US has also the most stable publication profile; compared to the other countries and has the highest level of knowledge persistence. In general, when a country has a specialization in a scientific field in the area of basic research one can expect high persistency in that specialization. Geuna also uses the results of the PACE questionnaire, which indicate that public research carried out in North America is valued and used extensively by the largest R&D firms in the pharmaceutical sector in the EU. This is consistent with the fact that the US has a persistent specialization in Medical Chemistry and Pharmacy & Pharmacology both in applied and in basic research.

Malo and Geuna (1999) provide additional evidence based on the case of combinatorial and computational chemistry. In this particular sector, academic research has a significant contribution to industrial innovation. They show that, as in the case of biotechnology and computational chemistry (Orsenigo, 1989, Mahdi and Pavitt, 1997), the US leads in firm formation is paralleled by the dominant role played by US universities and research centres. They find some evidence that the EU countries are catching up in terms of university publishing, while the number of new combinatorial synthesis firms in Europe remain very small. Furthermore, the analysis of patent applications and patent citations underlines the importance of small firms in the development of the combinatorial synthesis research platform. Not only are they patenting in a significant way, but they also are producing important publications that are cited in other patents.

Overall, the results of our project indicate that, despite the fact that in terms of number of publications and patents the European chemical innovation sector is performing well, according to other indicators, such as specialization and persistence, the US may be outperforming the EU.

In various case studies, these general conclusions were tested against the knowledge base of different industries. One of the industries where the knowledge base is most important is the pharmaceutical industry, so a special attention was paid to this industry. Other scientifically active industries were analysed, such as new materials or agrochemicals. A more stable industry, the painting, coatings and printing inks industry, was also studies.

In Brusoni and Geuna (2000) study of the knowledge base of the pharmaceutical industry, it is highlighted that EU countries exhibit capabilities in terms of applied and engineering research, but not in basic research. Such lack of basic research capabilities may well explain the frequency with which EU R&D managers in pharmaceuticals approach the US knowledge base. As for chemicals, the pattern of sourcing is different. As their home country knowledge bases seem more capable of providing a more integrated pattern of research capabilities, EU chemical firms rely chiefly on their home country knowledge base and then approach the EU one. They hint at the possibility that governments can actually influence the rate of technical change by fostering the development of an 'integrated' specialisation profile.

Nightingale (2000) tends to confirm some of Geuna's and Geuna and Malo's findings. In the pharmaceutical industry, the European performance in science may be adequate in terms of quality but no in terms of quantity. In his case study of the European pharmaceutical industry he finds that, although firms differ little in their external environment, US firms have some advantage in having better access to public research than their European counterparts. Nevertheless, based on interview evidence, this advantage coupled with other advantages such as the closeness to a faster moving market and having more control of a transparent and efficient regulatory process is not enough to explain the better performance of US pharmaceutical firms. The main advantage would be, according to interviewees a better internal management.

In the agrochemical industry, Mahdi (2000) shows that the current discovery process of new agrochemicals requires the integration of various distinct scientific disciplines. He also finds that Europe has no shortage of trained manpower in the related disciplines demanded by the agrochemical industry. Furthermore, Europe shows a healthy publication level in fields necessary to the agrochemical sector. However, patent levels and the number of products introduced is low indicating that Europe has difficulty in bringing its research to market.

Brusoni (2000) analyses the case of a more stable industry, the paints, coatings and printing inks industries. Contrary to scientifically more dynamic industries, in this industry European firms seem in a better position. For instance, from a technological point of view, the industry seems to be perfectly capable of coping with the diffusion of new, solvent free formulations. Brusoni does not spot any difference between US and EU firms, as they all market waterborne products alongside traditional solvent based paints.

Hopkins and Sharp (2000) present additional evidence for the new materials subsector. The research effort in this sector is still very active but mainly public, as the private sector seems to wait for commercial potential, since the large firms that dominate this sector seem to see gestation periods as too long and too risky to commit substantial resources of their own.

However, these large firms have been the main source of incremental innovation with an important cumulative impact. These incremental developments are coming from the laboratories of these large firms, although frequently working in conjunction with users and/or outside specialists from academia or specialist firms such as Hexel or MERL.

In sum, the studies in this section have assessed the performance of European public and private actors in the development of the knowledge base for various subsectors of the chemical industry. One of the main questions of the project was if the European chemical industry is able to translate its knowledge base into commercially successful products. These studies yield initial evidence to tackle this question. First, with respect to some indicators such as specialization and persistence, the knowledge base of the European innovation system does not perform as well as previously thought, so in some sense there may be fewer discoveries to push commercial applications than what is needed. Second, from the evidence gathered from the pharmaceutical industry, it seems that some European firms are successful in translating scientific discoveries into products, but these discoveries are not based in Europe but mainly in the US.

4.3 Innovation policies and the large chemical firms

Large integrated firms play an important role in the European chemical industry. This emerged quite clearly from the studies produced by this project as well. It is therefore important to understand the extent to which such firms need specific policy interventions to enhance their competitiveness and their ability to promote innovation, employment, etc. We will start by highlighting some of the key findings about large firms in this project. We will then discuss related policy implications.

Some of the key findings of this project about large firms can be summarised as follows.

Market structure

The study by Marin and Siotis analysed the market structure of the chemical industry using the framework developed by John Sutton. The goal of this approach is to predict the concentration of an industry from its R&D intensity and the degree of homogeneity of its products. The theory says that in high R&D intensive industries, when the product differentiation of the goods is low, one will observe concentration. The rationale is that a single firm can internalise a fair amount of spillovers since R&D targeting a given product can produce results that can be employed for developing the other products as well. R&D opportunities in one area can then be used to move into related areas, thereby increasing the concentration of the industry. By contrast, when product differentiation is high, and the various sub-markets are fairly independent from one another, opportunities in one product segment will not translate into analogue opportunities in other segments which are close in product space. As a result, a given industry which encompasses fairly differentiated products, will be concentrated if it was concentrated to start with; it will not be concentrated if it was originally composed of independent firms in each of the independent sub-markets.

Marin and Siotis' study used data on several segments of the chemical industry. The goal was to estimate whether R&D intensive segments implied higher concentration when there was a high degree of homogeneity of the products within that segment. They cast their analysis in terms of a test of Sutton's theory. From a policy perspective, their analysis can also be interpreted as an attempt to understand whether we should expect major changes in the structure of the main segments of the European chemical industry in the near future. Suppose that they found that high R&D intensive segments with high degree of product homogeneity were not concentrated. By using Sutton's framework, one would expect that these segments may undergo notable changes in industry structure. This is because some firms in such low concentrated segments may make a discovery in their product domain that may in turn enable them to "escalate", as Sutton puts it, into related segments. Marin and Siotis use extensive data on chemical industry segments in Europe, which makes their analysis particularly apt and complete to address these issues.

They find that the structure of the European chemical industry conforms quite well with the predictions of Sutton's theory. Particularly, in R&D-intensive segments the industry is concentrated. This suggests that one is unlikely to observe major shake-outs or relevant changes in most segments of the European chemical industry in the near future. As far as policy is concerned, this suggests that no particular action should be undertaken, or one is expected to undertake in this domain. Also, major crises in the industry (e.g. business failures, significant competitive threats, etc.) are unlikely to occur, with implied no anticipation of strong policies in this and related areas of intervention.

The organisation of R&D in the large chemical firms

The study by Mariani focuses on the organisation of R&D in chemical companies. Particularly, the study compares the type of R&D and the research networks promoted by the large chemical firms in Europe, and compares them with the type of R&D and research networks observed in geographical clusters. In so doing, the analysis attempts to compare large firms and geographical clusters as alternative modes for conducting R&D.

The first important result of this analysis is that the European chemical companies perform most of their research in their home-country, and that patenting activity clusters in few regions. This confirms earlier study by Pavitt that the globalisation of R&D by multinational enterprises is at best a quite incomplete process. The second set of results explore research collaborations at the level of the individual inventors. Particularly, the analysis compares the firm and the geographical cluster as organisational modes for giving rise to larger networks of inventors and for producing more interdisciplinary patents. The results indicate that, compared to the geographical cluster, the multinational company is a better mechanism for creating larger networks, for enhancing collaborations amongst de-localised inventors, and for producing interdisciplinary patents. In short, this confirms that the firm, and particularly the large companies, typically promote larger research networks, and they produce rather general sort of research, at least in the chemical business.

But this also suggests that, as far as the large European chemical firms are concerned, there is no urgent policy intervention for promoting the generation of R&D and related activities. The large European chemical firms do engage in these activities, and as a matter of fact they do give rise to large networks of inventors and they do produce patents with wide potential applicability.

International Investments

Another critical area for the competitiveness of the European chemical industry is the degree of internationalisation of its firms. It is well known that globalisation is becoming a key strategy for the competitiveness of companies in many industries, and this is especially true of the chemical industry. The main players in this industry, and particularly the larger firms, typically operate on a global scale. As a result, the extent to which the European chemical firms are globalised, particularly in comparison with their US and Japanese competitors, is key for understanding their competitive position.

The study by Arora, Gambardella and Garcia-Fontes in this project employed a unique data base of the localisation of chemical plants worlwide. The Chem-Intell data base, which was described in the initial part of this Report, has provided information on an extremely large sample of chemical plants in the world, and it has enabled the authors to assess the extent to which the European chemical firms operate their production on a worldwide basis. It also enabled them to compare these patterns with firms in other geographical areas. The main results of this study can be summarised as follows:

- The number of plants built each year in the last two decades have decreased in the European Union, United States and Japan, while the number of plants built in Asia (except Japan and Middle East) have increased.

- In the Rest of the World (Latin America, Eastern Europe, Middle East and Africa) European and American firms are predominant, but there are more American than European plants planned for the future.

- In Western Europe there is a decrease in the number of plants built by European and American firms, with a predominant number of the former, and a small presence of Japanese plants. The share of European, American and Japanese plants seems to be stable within a general pattern of reduction of investments.

- In the United States and Canada the share of European firms has increased. While the number of plants built by American firms has decreased, the number of European plants has remained stable, increasing the share for European firms. The presence of Japanese firms is small.

- In Asia there is an increasing location of plants of the three regions, with an edge for European plants in terms of plants opened recently or planned to be opened in the future.

- Domestic investment have decreased for Japanese firms in Japan, European firm in Europe and American firms in the United States. This is part of the globalisation process the industry is experiencing over the last two decades.

- The probability that a domestically owned firm opens a plant in its own region is higher for Japanese firms, followed by American firms and last by European firms. This means that, despite the fact that there is a generalised globalisation process, it is stronger for European firms than for Japanese or American firms.

- In terms of comparing the probability of locating abroad, European firms show the highest probability of locating abroad in particular in North America, confirming that the globalisation process is stronger for European firms. There is also an increasing trend of European firms to locate in Japan.

In short, these findings point out two major facts: a) that the chemical industry has become more global, with a lower share of plants of companies from one region located in the same region, and a higher share of plants from one region in the other regions; b) that the European companies have proved to be particularly active in this globalisation process, as they have typically increased their share of plants abroad. Moreover, this happens both in advanced markets like the US and Japan, and in the open market of the developing countries, and particularly in Asia.

These results then suggest that the competitiveness of the major European chemical has not declined in the past decade or so. In turn, this confirms our previous remarks that no major policies are needed today for enhancing the ability of these companies to internationalise. It appears that they are continuing a long standing tradition of internationalisation, and there is no need for investing major policy resources in promoting patterns that are mastered quite effectively by these companies without any particular policy support.

R&D, innovation and restructuring in the chemical industry

The study by Arora, Ceccagnoli and Da Rin looked at how restructuring affects R&D, and they find that indeed restructuring does matter for R&D investment. Net acquisitions in R&D intensive industry segments have a positive and significant effect on R&D investment, a result robust to different specifications and samples. Amongst other things, they find that financial variables like debt or cash flow do affect R&D, but not the effect that restructuring has on R&D. They also separate the impact on R&D through changing size distributions due to restructuring from the direct impact. In other words, they study how much of the change in the average R&D intensity within industry segments is due to changes in scale distribution. The study finds restructuring to be an important component of the observed changes in R&D intensity. Moreover, the impact of restructuring differs across segments. For instance, in Life Sciences, most of the impact is through restructuring of firm portfolios rather than changes in the size distribution. In Other Chemicals, most of the impact is through changes in size distribution, with the size distribution becoming more equal after restructuring has had place. In Commodities, both matter, with an increase in size inequality as well as a direct increase in the inequality in R&D due to restructuring of the firm portfolios. These results provide a new, more composite, perspective on the effect of corporate restructuring on R&D.

The major policy implications from this analysis is that policy should encourage restructuring processes in Europe, especially because – as this study finds – they ultimate produce an increase in the R&D intensity of firms. Related to this is the fact that restructuring often involves serious costs as it implies changes in the structure of firms which entail short-run costs, both private and social (e.g. layoffs, reduced profits). These have often restrained restructuring processes. We suggest that important policy interventions are necessary in order to: a) reduce the social costs involved; b) separate them from the restructuring and other private costs of the companies.

In short, we suggest that governments should take up the short run social costs of restructuring that are often borne by individuals who are less capable of smoothing out incomes and losses over time (particularly in the short-run), or who would not be the same people that will benefit from the positive outcomes of company restructuring in the longer period. The private cost of restructuring should instead be borne by the shareholders, or whoever will benefit from the restructuring in the longer run. This separation is central to enable the restructuring especially in Europe were vested interests and political economy considerations are often involved in processes like this. In this respect, by separating social and private costs, and relatedly by attributing the costs to those who enjoy the longer run benefits of restructuring, we believe that restructuring processes will be easier to accomplish.

At the same time, governments should avoid intervening in the restructuring process, and on how it is carried out. The European experience of restructuring in the chemical as well as in other industries during the 1980s is that governments managed the restructuring process to a good extent, especially in France and Italy. The restructuring process should be governed by market forces. Moreover, the results of this study suggest that business swaps (e.g. exchange of divisions) by established firms through mergers and acquisitions, divestures, and the like, which have been often observed in recent years amongst the largest European chemical firms, should be encouraged.

On many occasions, these transactions have re-organised the underlying specialisations amongst leading firms by consolidating similar businesses that were in different firms. This improved the overall specialisation of the firms. The improved performance might provide one explanation why firms could employ new resources for additional investments in R&D, as the study by Arora, Ceccagnoli and Da Rin finds. Clearly, policy should also monitor these processes attentively to avoid that they create undesired monopolisations of certain industry segments. In short, policy should constantly check the balance between restructuring that consolidates and improves the specialisation of firms, and the coordination of certain businesses within one company, and the potential of these business swaps for anti-trust interventions.

4.4 Integration between large firms and public R&D (university)

For some industries, such as pharmaceuticals, large European firms have a less transparent access to public research than their US counterparts. This may be related to the fact that the intensity of R&D in some European industries is larger than the equivalent US industries (sales are relatively smaller with respect to R&D spending, see Nightingale, 2000).

Another important factor that has to be taken into account is that firms in the chemical industry increasingly draw from a globalised knowledge base, benefiting from public R&D done internationally. In some industries there is a lack of technological diversity in the upstream knowledge base between large firms producing similar products. This would indicate that differences in competitiveness are not due to differences in the ability to acquire the expertise to patent in a given set of technological fields.

Summing up, the main conclusions from our analysis of public research and large firms indicate that large European chemical have little difficulty in obtaining technology. The differences in performance between European and US firms, or between different firms in

Europe, should be sought not in differences in the ability of firms to obtain technology but in differences within firms in how they manage very similar technology. As a consequences the key to understanding the competitive position of the European industry is understanding the differences between firms in how they manage technology, as it is this that determines relative economic performance (See Nightingale, 2000 and Hopkins and Sharp, 2000).

4.5 Innovation policies and the small firms

Apart from leading world wide chemical firms, smaller companies play an important role in the chemical industry as well. We have seen in the earlier part of this report that many analyses conducted in this project focused on small firms. We also noted in the previous section that the large European chemical companies need limited policy support. They have been able to invest in R&D, and to compete internationally. By contrast, we shall see here that smaller firms need greater policy support, at least in terms of the creation of suitable conditions for their growth, and for enhancing the potential that their growth may have for the evolution of the industry (especially the new high-tech segments) and its effects on competitiveness and employment.

First and foremost, the role of the smaller companies is linked to the opportunities for the development of a full fledged markets for technology in Europe, and more generally for the participation of the European firms in the global market for chemical technologies. The rise and development of markets for technology in the chemical industry was the subject of an entire research task of this project (task 2.2).

The analyses in this task showed that the chemical industry pioneered the growth of a market for chemical processing technologies. Since world war II, specialised engineering firms (SEF) sold technologies through licenses to established chemical producers. This occurred from the US to other advanced countries (Europe and Japan) first, and in more recent years SEF from the US and Europe sold technologies to the developing countries. This project developed a thorough analysis of the market for chemical processing technologies in which the SEF played a predominate role. Since this appeared to be a quite well established market for technology, this enabled us to understand a number of features of these markets, which can be generalised beyond the SEF. In particular, the main features of these markets (which we documented using both empirical and theoretical analyses) are:

i) markets for technology allow for a significant diffusion of technology, which increases the investments of the companies operating in the final markets. Amongst other things, they reduce barriers to entry, as they make technologies available to companies with lower in-house technological assets, which in turn implies increased competition;

ii) these markets enable the formation of companies that specialise in the development of the technology even when they do not have the proper assets to develop and commercialise the final products. These companies are now formed because they realise that they can enjoy rents from selling the technology rather than having to gain such rents only through the sale of the final products in the much harder and competitive final markets;

iii) the formation of these companies has numerous advantages. First, they enhance the aforementioned process of technology diffusion, and they are the main vehicle for reducing technological barriers to entry, with implied increase in competition. Second, they induce other established producers to license because as technologies diffuse there is no advantage in trying to keep the technology secret; rather, the established producers themselves try to earn some rents in the market for technology, thereby enhancing the process of technology diffusion.

Apart from the SEF, the analysis conducted in this project found that similar technology specialists have developed today in the biotech industry, and in the environmental technology industry. Not only does this suggest that the phenomenon is more diffused than one could have originally thought, but also that many industries, and particularly many segments of the chemical industry are increasingly being organised in this fashion. Moreover, our analysis found that these technology specialists are less common in Europe than in the US, and that in Europe they deal with less advanced technologies (e.g. end-of-pipe rather than clean technologies in environment). In short, the market for technology appears to be less developed in Europe than in the US. While our analysis focused on the chemical industry, there are reasons to believe that the same applies to other industries as well. In turn, this suggests that the potential for technology diffusion and related economic benefits, are less pronounced in Europe.

This calls for adequate policy interventions that would remove the barriers to the creation of these markets. In some sense, one might say that the large chemical companies have a long standing tradition and competitiveness, which we confirmed with the various studies of this project. This implies that no major policy action is needed for enhancing their competitiveness, etc.. By contrast, European markets for technology are far from being developed, and this requires policy support for their formation. In particular, this calls for policy actions to encourage the rise and growth of smaller firms specialised in the development of technologies.

Specifically, we envisage the following policy actions for enhancing the markets for technology in the European chemical industry, and particularly in its engineering and technological sub-sectors:

- *Development of proper forms of Intellectual Property Rights (IPRs) to support the activities of smaller technology-based companies.* Our research found that IPRs can be an important factor for enabling such smaller companies to be founded and grow. This is because unlike the larger firms, they have no other means (e.g. downstream assets) for appropriating their innovations. As a result, IPRs can be the only form that they can employ to enjoy rents from their investments in research. The development of adequate, European wide forms of IPRs can then be critical for the growth of markets for technology in Europe.

- *Development of adequate forms of financing for new technology-based companies.* Apart from IPRs, markets for technology require new forms of financing for the small, technology-based firms to arise and grow. These include in particular forms that take into account the fact that these firms face a substantial technological risk compared to other activities. Hence, new forms of financing like venture capital should be strongly encouraged. While these issues have been emphasised on many occasions, here we provide a new perspective about why such forms of financing can be important – notably, they encourage the growth of markets for technology, which implies reduced barriers to entry, greater technological diffusion, and new patterns and opportunities for economic growth.

- *Development of new forms of technology diffusion by universities, and the scientific institutions more generally.* We have shown in our analysis that licensing by established producers increases when there are other agents that license. Moreover, we have seen that institutions with no stake in the downstream markets have the highest incentives to license because they have nothing to loose in the downstream markets if new competitors arise. Universities or other research centers are a quintessential example of such institutions. As a result, by encouraging the diffusion of technology by universities (either directly or through spin-offs) there is an additional effect beyond the very diffusion of these technologies – notably that established producers in that technological domain will also be encouraged to license.

Finally, we want to emphasise that the results of this part of the project, and the related policy implication, are also important for the vertical structure of the chemical industry. Most notably, the rise of markets for technology implies a division of labour which in turn benefits the downstream producers. The classical advantages of a division of labour are indeed that the downstream producers can take advantage of the input at lower costs than if such input had to be produced in-house. Apart from efficiency gains in the downstream industries, this implies greater diffusion of the technology downstream, greater entry of new competitors in final markets, etc..

We have noted these implications for the user industries on several occasions in our project. For example, we have shown that SEF imply efficiency gains, greater investments, and greater entry by chemical producers in downstream markets, and especially by producers that would not have been able to enter if they had to develop their technology in-house. Similarly, we have shown that specialised engineering firms can be quite important in diffusing new environmental technologies. These advantage of vertical specialisation suggests some further policy actions, and particularly:

- Policies that would encourage the external monitoring of new technologies by existing producers in final markets, and more generally policies that would reduce the transaction costs for technology exchange that may exist in such markets. Transaction cost reducing mechanisms may range from the establishment of proper standards for reducing the potential segmentation of technologies that are in fact used for similar purposes, to the creation of proper institutions for technology exchange (e.g. standard contract), etc..

- Policies that would reduce the search costs for new technologies, by creating new forums, electronics exchange markets, and the like for the exchange of technologies. In this respect, we welcome for instance initiatives like *Cordis*, the on-line data bases of technologies promoted by the Commission.

- Policies that would discourage the so-called “not invented here” syndrome, which affects many firms and even countries. The NIH syndrome is the one in which firms disregard technologies not developed internally, and it has been widely documented in the managerial literature, as we also noted in our research. As markets for technology develops, the problem with such a syndrome is that firms may loose important opportunities for acquiring technologies at lower costs, with implied benefits on their demand for technology, and ultimately on their profitability, competitiveness, and on their ability to increase employment. At the same time, such a syndrome may even prevent the markets for technology to arise in the first place, because the general business climate does not encourage the exchange of technologies amongst different parties.

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