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Mariana Rubim de Pinho Accioli Doria

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Advisors

Advisor:
Prof. Stefano Comino
Università degli Studi di Udine

Co-Advisor:
Prof. Christopher L. Gilbert
Università degli Studi di Trento

Referee Committee

Prof. Alfonso Gambardella
Università Commerciale Luigi Bocconi

Prof. Massimo Riccaboni
Università degli Studi di Trento

Doctoral Committee

Prof. Massimo Riccaboni
Università degli Studi di Trento

Prof. Howard Gospel
King's College London

Dr. Ornella Tarola
Università di Roma La Sapienza

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Lavoisier did not provide symbols for the elements, nor did he use chemical equations, but he provided the essential background to these, and I was thrilled by his notion of a balance sheet, this algebra of reality, for chemical reactions. It was like seeing language, or music, written down for the first time. Given this algebraic language, one might not need an actual afternoon at the lab – one could in effect do chemistry on a blackboard, or in one's head.

All Lavoisier's enterprises – the algebraic language, the nomenclature, the conservation of mass, the definition of an element, the formation of a true theory of combustion – were organically interlinked, formed a single marvelous structure, a revolutionary refounding of chemistry such as he had dreamed of, so ambitiously, in 1773. The path to his revolution was not easy or direct, even though he presents it as obvious in the Elements of Chemistry; it required fifteen years of genius time, fighting his way through labyrinths of presupposition, fighting his own blindnesses as he fought everyone else's.

There had been violent disputes and conflicts during the years in which Lavoisier was slowly gathering his ammunition, but when the Elements was finally published – in 1789, just three months before the French Revolution – it took the scientific world by storm. It was an architecture of thought of an entirely new sort, comparable only to Newton's Principia. There were a few holdouts – Cavendish and Priestley were the most eminent of these – but by 1791 Lavoisier could say, "all young chemists adopt the theory and from that I conclude that the revolution in chemistry has come to pass."

Three years later Lavoisier's life was ended, at the height of his powers, on the guillotine. The great mathematician Lagrange, lamenting the death of his colleague and friend, said: "It required only a moment to sever his head, and one hundred years, perhaps, may not suffice to produce another like it."

Oliver Sacks on *Uncle Tungsten: Memories of a Chemical Boyhood*, p.112-113, 2001.

To Margareth and Noêmia
in memoriam

Abstract

This thesis examines the relationship between environmental regulation, innovation, and competitiveness. Specifically, it investigates the impact of regulatory stringency on innovation in the chemical industry by analyzing the evolution of innovative activity in highly regulated technological areas in the European Union from 1976 to 2003.

A direct quantitative measure of regulatory impact on innovation was constructed by transforming the economic measurement problem into a technological classification issue. The specific regulation investigated was the EU Council Directive 76/769/EEC, which contains 986 restrictions imposed on the marketing and use of 939 chemical substances. These restrictions were linked to 17 technological fields in the International Patent Classification. The data on patent applications was extracted from the ESPACE Bulletin database maintained by the European Patent Office. Given the increasing regulatory stringency, four questions were investigated: Did regulation spur patenting activity? Has there been a change in the geographical origin of patents? Has there been an increase in patenting concentration? Has there been a change in the direction of the patenting trend? These issues were examined at the aggregated level using descriptive statistics, panel data regressions, and the study of technological trend. Four case studies were conducted to illustrate strategies utilized by European and non-European firms.

I found that most restrictions were imposed during the years of 1997 and 2003 and affected mainly technological areas associated with agrochemicals, polymers, and paints and dyes. In overall regulatory stringency impacted positively patenting activity. However, top players were impacted negatively. Consequently, there was a reduction in the concentration of innovative activity in highly regulated technological areas. Major changes occurred in areas in which the largest number of restrictions were imposed. There was an overall increase in innovations associated with new processes and formulations, indicating increased incremental innovation and a shift from patenting in regulated to non-regulated applications. Hence, there was increasing patenting activity in areas that did not depend on novel substances or did not have an opportunity to innovate in non-regulated uses. By contrast, there was a sharp fall in the number of applications in areas in which these conditions did not exist. Two explanations for these results are proposed: “new” technologies benefit from regulatory stringency while “old” technologies are discouraged; regulation spurs the development of substitutes better adapted to the actual regulatory framework.

Moreover, this thesis shows that the Porter hypothesis is supported for the chemical industry. Yet, this occurs not because firms innovate under more stringent regulation, but because it stimulates new entrants in the market of innovation.

Keywords Porter hypothesis; innovation; environment, health, and safety regulations; chemical industry; chemicals regulation; and environmental economics.

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Chapter 1

Introduction

This thesis addresses important topics that have been a priority on the world agenda since the UN Conference on Development and the Environment (Earth Summit, 1992). At that conference, delegations from 175 countries and 2,400 representatives from non-governmental organizations reached an agreement on the Climate Change Convention that later on led to the creation of the Kyoto Protocol. Even after being ratified by 162 countries, the biggest criticism of this international agreement is that it causes loss of competitiveness as it restricts emissions of Greenhouse Gases.

In February of 2001, the European Commission presented the White Paper on future chemicals policy to the European Parliament, European Council, and other bodies. This new chemicals policy called REACH (Registration, Evaluation, and Authorization for Chemicals) was intensely debated by European and non-European governments, industrial and non-governmental organizations. The main concern was the threat of loss of competitiveness by European industries in international markets, and extra costs for overseas industry in the European market.

More recently, in 2006 the Intergovernmental Panel on Climate Change (IPCC) disclosed the Fourth Assessment Report with new findings on the natural drivers of climate change. This document has strong suggestions for policy makers to restrict their regulations, due to the fear of climate chaos in the future. In December of 2009, the Fifteenth Conference of the Parties to the UN Framework Convention on Climate Change (COP15 – Copenhagen Climate Conference) failed to reach an agreement to update or even replace the Kyoto protocol. Still, developed and developing economies fear that any restriction on emissions of greenhouse gases will reduce their productivity and harm their firms already suffering with what is believed to be the biggest economic crisis since the Great Depression, in the 1930s.

These examples illustrate how important it is to clarify the relationship between environmental regulation, innovation, and competitiveness. These issues are of international concern, yet there is no common consensus on the topic. The difficulty of measuring regulatory stringency is one of the main problems faced by economists. Recently, researchers have been focussing on specific industrial sectors and analyzing different regulatory designs. These studies have a common theme, looking at how regulation should be designed in order to incentivise and not harm innovation.

This research initially displays a broad picture of the history of the chemical industry since the nineteenth century. Chapter 2 helps the reader to understand the importance of R&D and innovation in this industry.

The subsequent Chapter 3 describes the regulatory framework of the chemical industry. The regulations under concern are detailed, and also how the empirical economic literature has evolved on the debate on the relationship between environmental regulation and possible impacts over manufacturing firms (e.g. location choice, competitiveness, and innovation). The two main hypothesis that intensified the debate since the 1990s are described. This review enables a precise the analysis of the impact of social regulations over the chemical industry chain, and the identification of the most relevant controls imposed on chemical firms which must be investigated.

After this analysis Chapter 4 develops a quantitative measure of regulatory stringency over technological areas associated with the chemical industry in the European Union from 1976 to 2003. The methodology is exemplified for a better understanding. The main affected technological fields are highlighted, and these findings corroborate with previous studies supporting the methodology employed.

Chapter 5 consists of a deep analysis of the evolution of innovative activity in these highly regulated technological fields. Four research questions are investigated: has an increase or decrease in patenting occurred? Has there been a change in the country of origin of patents? Has there been any increase in patenting concentration? Has there been a change in the direction of patenting? New methodologies are employed to investigate the evolution of the technological path. The period investigated, from 1990 to 2006, was chosen because first most studies focus on the 1970s and 1980s, and second this period represents the highest increase of regulatory stringency in the European Union.

Four case studies were developed to better understand the strategies traced by European and non-European firms. Chapter 6 portrays a summary of these four firms which were leading the innovative activity in the investigated regulated areas in the beginning of the 1990s and have their history associated with the development of these technological fields.

Chapter 7 summarizes the results obtained by this research, the main contributions of this thesis to the literature, its originality, and possible directions and open questions for future research.

Chapter 2

The Chemical Industry

The history of the chemical industry can be characterized by three different technological cycles which spurred waves of innovation and development. These three major eras were stimulated by scientific developments on organic and inorganic chemistry starting from the 1700s.

The birth of the chemical industry in the nineteenth century was marked by the era of dyes. The growth of the textile industry and developments of the organic chemistry since the eighteenth century enabled the development of synthetic dyes. This era marked the initial development of the production of synthetic chemicals in large scale.

The production of synthetic dyes started simultaneously in five countries GB (1857), France (1858), Germany (1858), and Switzerland (1859). By 1878, the development of better processes for the production of azo-dyes propitiated a rise in variety of new dyes. By the beginning of the twentieth century, the majority of dyes sold in the market were azo-dyes. The growth of the dye industry came along with the large production of different chemical intermediates which started being applied in other industrial sectors (Murmann and Homburg, 2001).

A second technological cycle which characterizes the evolution of the chemical industry was the era of agrochemicals. The synthetic production of agrochemicals in industrial scale started over the 1940s. Up to the 1960s there was a continue growth in demand given the previously uncontrolled or poorly controlled crop problems. However, over the 1970s, the introduction of new agrochemicals started to decrease and new products were based on new formulations of existing substances.

Since the end of the 1980s companies which invested in R&D for the development of new substances started to face the competition of an increasing number of firms producing generic agrochemicals. Known by its heavy regulatory framework, this sector faces today the challenge of finding environmentally safer substances. Similar to the pharmaceutical industry, after the 1980s the number of new substances has been falling. Given the increasing rules to market new products the time needed to face all regulatory requirements has increased, leaving few years of patent protection to recover all investments (Hartnell, 1996).

The third major technological cycle was the era of polymers. Even though the first synthetic polymers were developed still over the nineteenth century and the synthetic rubber had a major role by the turn of the century, it was just during the II World War that this industry found major importance and started its fast development.

Up to today, 79% of all plastics belong to five families of polymeric resins: polyethylenes (PE), polypropylenes (PP), styrenics (PS), acrylics (PMMA), and vinyls (PVC). These portray the group of macromolecular commodities. Another group of polymers are the engineering which correspond to 11% of the volume and 34% of value of all plastic consumption. The last group of polymers are the specialties that together with the engineering polymers have special resistance in different ranges of temperatures and high mechanical performance. Today, the major developments in the macromolecular technology is on blendings of polymers (mix of substances), expanding the number of new materials with specific required characteristics by the market (Utracki, 2002).

Since the 1980s with major breakthroughs which propitiated the development of two new technological fields – nano and biotechnology – these three major groups which describe the evolution of the chemical industry received new vitality. Today, there are new fields of research and development in order to the development of new products that can substitute the use or need for certain dyes, agrochemicals, and materials.

The chemical industry today

The chemical industry is considered the first "high technology" industry and it is responsible for important changes in manufacturing since the late nineteenth century (Vithoontien, 2004). As a research-intensive industry, development and growth rely historically on the interaction between research institutes, firms and governments to create a highly innovative sector that serves as an important source of knowledge spillovers and technology diffusion (Cesaroni and Arduini, 2001).

As a highly diversified and complex sector, it now produces over 70,000 different chemicals (Lenz and Lafrance, 1996), which include chemicals derived from life sciences (pharmaceuticals, pesticides and products of modern biotechnology), products for consumer care, basic commodities, and specialities (OECD, 2001). These chemicals are produced in quantities that vary from less than a single ton to more than 10,000 tons per year. Basic chemicals are produced in the largest volumes - the majority of these are intermediate goods for other industries, mainly chemical, metal, glass, and electronics - while the rest are directly sold to consumers.

Supply chains in the industry are long, complex, and vertically and horizontally differentiated. In the 1980s and 1990s, mergers and acquisitions resulted in increasing concentration within the industry. Differences in environmental regulatory regimes are identified as one of the causes of concentration given that the relative cost of compliance with the regulation is higher for small firms than for larger firms (Mahdi, Nightingale, and Berkhout, 2002). The high concentration of large multinational firms is also a characteristic of the chemical industry, since firms have been obliged to increase in size so that they can more easily carry the high fixed costs of chemical plants, the high level of R&D investment, and the costs associated with a highly qualified work force, besides the need for marketing strategies to expand in geographically disperse markets (Cesaroni and Arduini, 2001). As a result, chemical firms in the United States (US), Europe and Japan have a similar structure.

Basic chemicals represent a mature market with few changes in the substances produced in the largest amounts over the last 50 years. Not only has the composition of this group remained largely unchanged, but there has been little variation in the rank order of production volume (Wittcoff and Reuben, 1996). Typically, plants use continuous operations with high energy consumption and low profit margins (OECD, 2001). This characterizes a higher investment in process innovation rather than product innovation, which are mainly incremental. Downstream firms have higher heterogeneity on firm sizes, as a result of more investment on riskier research and product innovation.

In the 1990s, 16 countries produced approximately 80% of the total world output of chemical products. In decreasing order, are US, Japan, Germany, China, France, UK, Italy, Korea, Brazil, Belgium and Luxembourg, Spain, the Netherlands, Taiwan, Switzerland and Russia (OECD, 2001).

In 1998, world sales of chemicals were estimated at US$ 1,500 billion. This represents more than twice the size of the world market for telecommunication services and equipment. In 2000, the chemical industry accounted for 7% of global income and 9% of international trade (OECD, 2001). In 2003, it was responsible for the consumption of 7% of world energy (Vithoontien, 2004).

The chemical industry employs over 10 million people worldwide, but employment decreased 7.5% over the last 10 years as the industry has become more capital intensive, with higher needs for qualified employees (OECD, 2001). In the EU, the chemical industry leads all the manufacturing sectors in terms of value added per employee (CEFIC, 2005). Large companies account for high production volumes, even though the majority of enterprises have less than 50 employees and are responsible for the large diversity of chemicals produced in small quantities (Vithoontien, 2004).

This innovative industry requires a range of human, technical and financial inputs. The availability of financial capital and highly educated people are the main issues which determine the location of chemical firms and their research centers (Mahdi, Nightingale, and Berkhout, 2002). The chemical industry is important because its products are significant for all manufacturing industries, maintaining agricultural production, and providing health care. Nevertheless, there is a lack of studies on significant aspects of the industry, most importantly the impact of regulation on innovation, since it is a highly regulated industry and innovation is critical for its maintenance.

What drives innovation?

Prices do not always reflect the true scarcity and social costs of all resources. Pure market forces emerging in a competitive non-regulated economy might not induce resource or pollution saving technological progress, and do not guarantee the desirable direction of innovation (Nelissen and Requate, 2004). Environmental policy can be an instrument to direct the technological progress, for example, driving toward new products that require less resources as input, or less energy in its consumption, or more efficient processes.

Horbach (2006) studied the drivers for environmental innovations. He points out that general innovation theory fails to analyze the influence of environmental policy, because it focuses solely on technology push (initial phase) and market pull (diffusion phase) factors as the driving forces of innovations. The former represents the physical and knowledge capital that a firm accumulates by investing in R&D, human capital, and equipment. The latter expresses the market influence given a change of preferences by consumers caused by social awareness and environmental consciousness, demanding more environmentally friendly products. Environmental regulation (for example, incentive based instruments or regulatory approaches) and institutional structure (for example, political opportunities of environmentally oriented groups, organization of information flow, existence of innovation networks) should have a major influence on the direction towards environmental innovation.

Firms' incentive to innovate is a quantifiable benefit that they enjoy from developing a new technology. Firm's strategies to reduce emissions may be either to reduce output (final products), or to keep it constant and employ an abatement technology. Abatement technology may be end-of-pipe technology (gross emissions remain unchanged and are subsequently decreased) or process integrated technologies, improving process efficiency and decreasing emissions (Nelissen and Requate, 2004). Less hierarchical organizations and participation in groups and networking activities are some management strategies which influence innovation positively, and prepare firms to give better and faster response to environmental regulation (Mazzanti and Zoboli, 2006b).

Investment on risky innovative activity depends on the expectation of future benefits. In the case of product innovation, given the high costs generally related for new chemicals, investments must be protected. That is the reason why the chemical industry is known by its propensity to patent innovations.

Chapter 3

Regulatory Framework

From the view point of the chemical industry itself, the ability to innovate by developing more efficient processes, and by introducing new and better products is what characterizes competition. Given that it is a science-based, the chemical industry uses its own resources to support R&D projects (Mahdi, Nightingale, and Berkhout, 2002). Consequently, a precise understanding of the impact of regulation on innovation is a fundamental issue for the strategic development of the chemical industry. The aim of this chapter is to present an overview of the regulation which impacts the chemical industry, and show how the economic literature has been exploring this issue.

Initially, it is addressed definitions regarding regulation theory and specifically environment, health, and safety regulations. More specifically, it will be examined in more detail the regulatory framework to which the chemical industry is subjected to in several countries, and how regulation may impact chemical firms and its industrial chain.

To illustrate how diverse the design of laws may be, it is provided a brief summary of the chemicals regulation in the European Union, US, and Japan. This overview shows how Nations may design in a distinct way their laws even with the same purpose, and this may influence differently firms.

Lastly, it is discussed empirical findings regarding the possible impacts of social regulations concerning human health and environmental protection on the manufacturing industry, with a main concern to high polluting industrial sectors and the chemical industry. This literature review shows the main findings of the economic literature concerning regulation, innovation, and competitiveness. First it is described the development of the main debated theories, followed by empirical papers which look at manufacturing industries in an aggregated form, and afterward specific studies on high polluting sectors.

Studies which analyzed the impact of chemicals regulation on chemical firms are highlighted, and a special attention is given to the relationship between regulatory stringency and innovation. Section five concludes this chapter.

This section initially discusses environment, health, and safety regulations within the context of regulation theory, some characteristics and definitions. In order to subsequently examine the possible impact of regulation over the chemical industry, it is described the main regulatory framework to which the chemical industry is subjected with respect to human health and environmental protection. Furthermore, an analysis of where the regulation acts over the industry chain is provided.

Two branches of laws are detached to better examine the impact of regulation on the chemical industry. The first is environmental legislation concerning the protection of air, water and soil from pollution. Its scope and structure is highly diversified, being unfeasible a full comparison between countries. The second regards specific regulations concerning the manufacture and commercialization of chemical substances. While this legislation also varies in different countries the scope is more delimited, making comparisons easier to carry out.

3.1 Environmental, health, and safety regulations

To define and subsequently measure regulation is a challenge. Besides, over the twentieth century different kinds of regulations arose together with the growth in complexity and diversity of economic activities. Specifically, environmental, health and safety regulations emerged in this scenario characterized by a set of instruments, combined and implemented in different ways, differing in each country. This makes a broader analysis of its stringency highly complex, as there are overlapping layers of different regulations ruling a single activity. Furthermore, the combination of different instruments will have a different result than the isolated performance of them, then they cannot be in principle analyzed separately and afterward the results will be their combination.

Regulations are commonly classified into three distinct groups: anti-trust, economic, and health, safety and environmental regulations. Anti-trust policies, are based on the premise that an efficient functioning of markets require conditions close to perfect competition paradigm. These policies therefore aim at impeding the formation and the abuse of market power. The presence of natural monopolies as in the cases of electricity and water supply industries are the basis of the second group of regulation. The aim here is to define policies that allow to obtain acceptable results in terms of efficiency and in terms of the distribution of the surplus between producers and consumers, also in the presence of firms with strong market power. The focus of this research is in a third group of regulations, which may act in different ways in order to mainly minimize the effect of externalities. This set of policies, also called "social regulations," include laws regarding the protection of the environment, the safety of the product for the consumers, and the health and safety of workers.

Market failures caused by the presence of externalities, imperfect information, and imperfect competition are motivations for the development of different laws and policies. In order to apply these rules there are several mechanisms. The imposition of taxes, for example, is a technique which gives the regulator the possibility of manipulating prices and making product more or less attractive, influencing economic behavior. The objective of the regulator shall be to balance the different interests between sellers and buyers, firms and consumers, or even to transfer welfare from one to another group.

Economic theory describes the objective of the regulator as to maximize public interest. However, several issues influence the design of a new policy. There are several theories which try to model the best political environment for the development of a regulation. One of the most well known is the "Capture Theory" by George Stigler, which states that the regulator will act in favor of the economic interest that it serves. As a matter of fact, there are competing private and public interests which influence the regulator. In order to design a new law in a market with diverse industries and different-size firms, there are several technical, economic, and political factors to which the regulator is influenced by (Viscusi, Vernon, and Jr., 1996).[1]

In the nineteenth century, the large scale production of soda ash, sulphuric acid, caustic soda, and dyes gave birth to the inorganic and organic chemical industry we know today. After 1850, with the advent of the industrial revolution the demand for more chemical substances as input for all other industries that were being developed increased. England, Germany, and the US were the precursors followed by Japan, and other western European countries. It took more than sixty years for environment and human health impacts of chemicals start to be considered and discussed widely by society.

The US Clean Air Act was the precursor of the environmental regulation. In 1970, the US Environmental Protection Agency (EPA) was created with the objective to monitor, establish standards, and enforce the new law. In the following years, a huge growth of regulations occurred in most industrialized countries. In 1976, Europe suffered the consequences of the Seveso disaster in Italy, and in 1982 developed the EU Directive 82/501/EEC for the control of major-accidents hazards caused by dangerous substances.

Regulations, interpreted as extra costs, are also accused of being responsible for market concentration in different sectors such the chemical industry. Nevertheless, if social regulations excludes inefficient firms from the market it will be a gain for more efficient firms which will have increased their place in the market. This will increase the productivity of the overall market, even if reducing the number of firms.

The decision to regulate or not raises several issues. Irrationality caused by a

[1]Each country has defined procedures to design a new policy. Section 3.3 provides a more detailed explanation on the mechanism for the development of European Union regulations, and details the US, Japan and EU chemicals regulation.

wrong perception of risk and uncertainty related to possibility of future harm, are some of these issues. For instance, a cost-benefit approach can be developed in order to evaluate the future policy. This is based on the principle that you can measure the costs of the regulation and the benefits which it will bring to society. Using water quality as an example, while it increases also the cost to increase water quality grows. There will be a moment where the the total cost of the policy will be higher than the value of the benefit obtained with water quality. Thus, the optimal policy would be the one which obtains the maximum net benefits-costs, or when the marginal benefits will be equal to the marginal costs.

Nonetheless, with new areas of technology emerging (e.g. biotech and nanotechnology) and high speed of a variety of new products reaching the market, the uncertainty related to future risks or benefits brings new challenges to the regulator. There will be the need to opt between a conservative and preventive policy and possibly harming the development of such technologies, or being aware but not regulating in a 'wait and see' attitude. In the case of new technological branches, it can take several decades for science to develop methods of research to assure the safety of a new product. As quoted before, in the case of the chemicals industry it took several decades for not only the general public and government, but also the industry to realize all harm those products could cause.

A cost-benefit analysis asks if a given industrial activity or product should or not be regulated in the present time. What is not traditionally employed is to evaluate the option of delaying the new policy. Financial economists have the concern with the optimal timing for the investment. Similarly, by having a risky policy which is costly and the benefits cannot be evaluated, the regulator aims that the present value of expected benefits of the new law today to be equal or exceed the present value of expected costs added to the value of the option to 'wait.'

The problem the regulator faces is to choose a plan for making these sequential and irreversible expenditures through time. New information might change the policy scenario originally designed, altering the initial choice of when to regulate. Thus, uncertainty is present when the future net benefits of regulating or not are not known at the time of the decision making.

Another issue which challenges economists devoted to this topic is how to measure non-monetary benefits such environmental preservation, or workers and consumers health and safety. How much society is willing to pay to diminish the probability for a negative effect on human health or environment? The present value of how much one will earn over its lifetime, or how much one will pay of taxes contributing to society are possible alternatives of measures (Viscusi, Vernon, and Jr., 1996). Nonetheless, each economic activity has different impacts and risks associated, as well as the consumption behavior of different groups in society. These heterogeneity highlights other issues that the regulator must face when defining a new policy.

Given the fact that the benefits sought by the regulator (e.g. air and water quality) do not directly result from market transactions, the regulator will then try to estimate the future social benefits to justify the real costs imposed by a new policy over the government, consumers, and firms.

3.2 Environmental regulation

Environmental regulation aims to protect the environment and human health from exposure to hazardous substances and pollutant releases from processes developed by a firm. The chemical industry is in particular affected given the complexity of its processes, and variety of chemical substances that are used as raw material, intermediates, and disclosed as products, byproducts, and waste.

As stated previously, the regulator acts in situations of market failure: incomplete markets, externalities, non-exclusion, non-rival consumption, non-convexities, and asymmetric information. On environmental economics the classic theory was proposed by Ronald H. Coase in 1960 concerning externalities.

Negative externalities occur when in a transaction a third party experiences costs although it is not compensated. This externality has no market price and it is an effect of the production or the consumption activity, affecting other producers and other consumers impeding the Pareto optimality. These externalities emerge as a result of common resources (or not privately owned, e.g. public goods) and negative effects of today's acts on future generations. In these situations the best for the consumer and the supplier (which are executing the transaction) is not necessarily the best for the society which will have to cope with other costs.

The Coase theorem postulates that economic efficiency is obtained when there is a full allocation of property rights, despite of to who they are initially allocated. The market will then determine the final allocations considering the value to the different parties and the freedom of individual choice, aiming zero transaction costs.

This theorem gave rise to intense debate. When dealing with one transaction a contract could be enough for allocating all costs. However, in a society there is a need for the imposition of regulation because it would be impossible to coordinate all actions and the incidence of free-riders (Viscusi, Vernon, and Jr., 1996).

How regulatory policy should be designed? Several policy instruments were designed in order to obtain maximum efficiency imposing minimum costs. These policy instruments are commonly described as follows (OECD, 1997b; Nelissen and Requate, 2004):

Command and Control Criticized by being not flexible, this instrument acts directly on the activity that affects the environment. It can impose technological and emission limits, forcing firms to adopt the 'best available technology,' or fuel quality standards. It may require firms to previously ask the regulator authorization for localization choice and installation of plants.

Economic A more flexible instrument, includes market-based tools which are intended to motivate firms to reduce emissions through prices, giving them the flexibility of deciding how much they want to emit or abate. It also includes emission taxes (where prices for emissions are administrated by a regulator), subsidies and grants on abatement emissions, and fines for non compliance.

Voluntary agreements Developed by private or public institutions, aim to improve a firm's environmental performance through commitment and disclosure of information.

A set of standards establishes a maximum acceptable behavior by the pollutant. Nevertheless, the choice of policy instruments is more complex and will depend on the nature of the pollution source and its consequences. For instance, command and control instruments might be more effective if there is the need for fast results or to eliminate a certain emissions or substances. Both economic and command and control instruments follows the "polluter pays principle" (also called "producer responsibility principle" – PRP). However, in the last decades the debate over he development of economic instruments such environmental taxes and emissions trading, preferred by economists, grew. Economic instruments operate balancing marginal abatement costs which cover all polluting sources.

Environmental (also called pollution) taxes provide a continuing incentive for firms to diminish pollution emissions over time, as it will always pay for all external costs in a dynamic efficiency environment. Taxes internalize external costs and the regulator has no need to obtain any information regarding individual abatement costs.

The market scheme is an economic instrument popular among economists. A certain number of permits (equivalent to a certain quantity of pollution) are allocated to each polluting agent per a defined period of time. After each period this number of permits will decline. The market for permits is then established and each agent will decide if will be better to sell its permits and reduce its pollution emissions, or to buy permits and be allowed to pollute more. This choice will depend on the price of the permit and the cost for each agent to reduce its pollution emissions.

This flexibility will enable the minimization of the abatement costs for each firm, and also the regulator will have no need of looking for information regarding each plant abatement costs. In a perfect market, the equilibrium will be reached when marginal abatement costs are equal to the permit price. This policy is in general limited to large polluters given its complexity and high transaction costs to establish the market. A significant number of large firms, that are able to deal with the trading scheme, would increase the possibility of success.

Under competitive conditions, market-based instruments are a guide to an equalization of marginal abatement costs across firms (Nelissen and Requate, 2004). A study on the impact of European policy on end-of-cycle vehicles, regulation imposed on 2000, shows that the dynamic efficiency of the economic instrument introduced in complex and systemic industrial settings will depend crucially on which sector of the industrial chain is directly regulated (Mazzanti and Zoboli, 2006a). The market power, relationship with other activities, position in the innovation process, and their technological and organizational capabilities are key issues for the success and efficiency of the regulation. Mazzanti and Zoboli suggest that these kind of regulations, economic instruments based on the "producer responsibility principle," should be considered when the target to be achieved depends highly on innovation.

More recently, research has been devoted to the involvement of industry in the regulatory development. Puller (2004) models the interaction between the regulator and an oligopoly in order to observe the equilibrium among innovation, regulation, and welfare. Because regulation is 'welfare improving' just when industry innovates enough to reduce the costs of greener products, the regulator may lower standards to not inflict socially expensive policy. He concludes that, in an oligopoly, the raise of competition will mitigate the low incentives of lax regulation. Consequently, regulatory commitment is not critical.

Environmental regulation may be described as an umbrella involving several laws regarding the protection of human health, safety, and the environment. It is designed in various ways in each country, with a broad scope. In general, it is not sector specific. This kind of regulation, which has emerged in US over the 1970s, has been disseminated all over the world. When analyzing competitiveness, it is not anymore a matter of regulated and unregulated countries, but different combinations of instruments being employed.

3.2.1 Regulation, competitiveness, and firm performance

The economic literature initially observed in a global perspective a world divided between regulated and non-regulated countries, and asked the questions: how firms behave in this situation, and which is the impact of this behavior on the country's economy, hence, on its competitiveness? Over the 1970s and 1980s, with the development of telecommunications, there was a fear that the production would move away from industrialized countries with increasingly regulation, and would raise the unemployment rates. "North-south" models were developed to look at what determines the location choice of firms and evaluate if environmental regulation was a significant issue.

Later on, but still in an aggregated level, researchers started to explore the impact of regulatory stringency on the manufacturing industry and its key factor of development: innovation. The increasingly complexity and stringency of regulation and the advent of different regulatory instruments, have possibly caused different impacts in each industry since the key factors of firms' development vary among them. Labor force, capital, raw material, product and process innovation, for example, have different levels of importance for each industrial sector. Consequently, the impact of regulatory stringency would be industry specific.

More recently, since results from the analyses on manufacturing industry suggested heterogeneous impacts among industrial sectors, economists focused their studies on highly pollutant sectors, therefore highly regulated, to determine the relationship between regulation and firm's performance: innovation, productivity, and profitability. A number of sectorial studies have been published making possible the development of more complex sector specific models and measures of regulatory stringency. Before entering on the different aggregation levels of empirical studies, this section will present the different theories which arose along with the growth of environmental concern, on the relationship of regulation and technological change.

Since the 1970s, a number of studies have claimed that environmental regulation impacts negatively on the innovative process of firms while others have argued the contrary. Eads (1980) has examined the possible influences that regulations on the environment, health and safety of workers, and safety of consumer products might have on technical change in firms. Four possible outcomes that these regulations might cause in the innovative activity of firms are defined:

1. Regulation may divert resources that otherwise might be used to fund research.
2. Regulation may change the firm's ability to calculate the payoffs to investments in research and developments.
3. Regulation may alter the proportion of benefits that are properly classifiable as "externalities", and this may change the nature of research the firm is likely to undertake.
4. Regulation may change the optimal institutional patterns for performing certain types of research. (Eads, 1980, pg. 51)

If regulation diverts resources that otherwise would be deployed to R&D, this would cause a major negative impact on innovation. As the perception of risk increases, firms would avoid investments on innovation given future uncertainties. Conversely, other scholars believe that this would be a temporary phenomenon.

Even though Eads (1980, pg. 54) states that regulation can affect *both the level and direction of innovative activity*, there are not sufficient studies to generate a convincing conclusion to this argument, and there should be greater efforts to make a better environment for innovative activities rather than changing the regulations that are suggested to be harmful.

For some authors (see Davies, 1983) a decrease in the number of players, given the raise on regulatory costs, means a decrease in the number of innovations. Firms defend the opposite idea, i.e. that larger firms innovate more than several small firms.

According to Mahdi, Nightingale, and Berkhout (2002, pg. 25), most studies which claim that regulation causes a negative impact on industrial innovation share three basic assumptions: first, *a decrease in the number of innovations is bad for an industry,* second, *that this is an irreversible process,* and third, *that increasing compliance costs are the main factor decreasing industrial innovation.*

Generally, these studies have suggested that the main consequence of restrictive regulation is an increase in production costs. This assumption justified the belief that the impact of environmental regulation causes loss of competitiveness and can induce firms to move to countries where the marginal social cost of production would be lower, as people in less regulated – usually poorer countries – would have a lower marginal valuation on the environment. This orthodox view has been called the "Pollution Havens Hypothesis" (Wu, 2000).

Nonetheless, another branch of research aims to demonstrate that restrictive regulation might incentivize innovation and, consequently, a competitive gain. In 1990, the economist Michael Porter argued in his book "The Competitive Advantage of Nations" that regulatory restrictions in specific firms gave them a competitive advantage with respect to firms from less regulated countries. His arguments, based on case studies and other causal evidence on international trade, show that nations with more restrictive regulation had a gain in competitiveness on the regulated products in the world market. Subsequently, in his essay published in Scientific American (Porter, 1991, pg 96), he stated that in other studies *the conflict between environmental protection and economic competitiveness is a false dichotomy. It stems from a narrow view of sources of prosperity and a static view of competition.* From his analysis he concludes that *strict product regulations can also prod companies into innovating to produce less polluting or more resource-efficient products that will be highly valued internationally.*

Porter and van der Linde (1995) list several arguments showing why regulation can bring competitive advantages to firms. As postulated by Nelson and Winter (1982), firms use rules of thumb with respect to their innovative behavior given huge uncertainties concerning the success of R&D. For Porter and van der Linde (1995), regulation would signal firms potential technological improvements on their processes in order to eliminate hazardous inputs and increase efficiency, to reduce uncertainties related to R&D investments on environmental innovation, and to create pressure for the development of innovative activity.

Innovation can occur to counterbalance environmental regulation. These innovation offsets arise because firms learn from pollution problems they might have. They act in order to reduce emissions, the amount of hazardous substances used, generated, and to improve efficiency. Or even environmental impacts are already incorporated during the research period, developing products and processes offsets. Nevertheless, non or relatively lax environmental regulation can favor the adoption of end-of-pipe technologies or secondary treatment solutions, and discourage investment on efficiency and cleaner products (Porter and van der Linde, 1995).

According to this view, such restrictions are a positive force driving firms to be more competitive in the world market. Other authors refer to this possibility as the "Porter Hypothesis." Over the last fifteen years, the most important debate on the relationship among environmental regulation, innovation, and competitiveness has centered upon the Porter Hypothesis.

Jaffe and Palmer (1997) identify three possible interpretations for the Porter Hypothesis. The first states that some kinds of environmental regulation – specifically the ones that focus in outcomes rather than processes – provide incentives for innovation. The second version states that environmental regulation stimulates some types of innovations, since it constrains a firm's profits and, as a result, the firm will rearrange their investments focusing in certain kinds of R&D. The third interpretation, identified as the 'strong' version, states that a new regulation induces firms to look for new products and processes that will obey the regulation and also be more profitable.

Regulation can be an opportunity promoting new areas, giving incentives to research on cleaner products and more efficient processes. It reduces risk and raises the value of "green" products. Since not all innovation is socially desirable, regulation can be an instrument to incentivize innovation, disincentivize it, or change its direction.

3.2.2 Regulation, country competitiveness, and location choice

Some studies use macroeconomic models to investigate differences of competitiveness in more or less regulated countries. Mainly, these studies use aggregated data on manufacturing industries, and they reach no consensus on whether there is a gain or loss of competitiveness. Future investments and location choice of each industry depend on many other factors and, in some cases, the restrictiveness of the regulation would be irrelevant on the choice for a country. These models consider factors such as intellectual property rights policy, law enforcement, differences between industries, possible future harmonization of regulation internationally, and the asymmetries that can arise. Most of these studies have used data from free trade areas, such as NAFTA[2] and APEC[3] (see Sturm and Ulph, 2002; Unteroberdoerster, 2003; Maria and Smulders, 2004; Taylor and Levinson, 2005; Mulatu, Florax, and Withagen, 2004).

In 1995 Jaffe, Peterson, Portney, and Stavins (1995) published a survey on the impact of environmental regulation on the competitiveness of the manufacturing industry in the US. They discuss which are possible indicators of competitiveness such as the efficiency of nations when producing manufactured goods. A country would export goods in which they are more efficient when producing, and would import

[2] North American Free Trade Agreement.
[3] Asia-Pacific Economic Cooperation.

those in which they are less efficient on producing. They propose alternative indicators of competitiveness such: the comparison between net exports of highly regulated goods and less regulated goods; the shift of production of pollution-intensive goods from highly regulated to less regulated countries; and the shift of investments of highly regulated industries from their own home country, to overseas less regulated economies.

Empirical studies point out that the difficulties on quantifying competitiveness and environmental regulation are main reasons for not reaching precise conclusions. Despite that, as Jaffe, Peterson, Portney, and Stavins (1995) also conclude, the impact of environmental regulation vary among industries, and foreign regulations may also affect national firms given that it may affect investment decisions. The authors observe that when a firm chooses a location it considers several factors such as its needs for the different kinds of labor force (high skilled or poorly qualified workers), the availability of raw materials, the political and economic risks, and the infrastructure. Thus, environmental regulation will be one more issue for managers and investors to deal with, and depending of the industry needs it might have a small impact on the final decision.

In addition, the reality of the world in 2000s is much different from the 1970s and 1980s. Emerging markets might attract industries given its increasing domestic demand with a higher potential than industrialized economies, with a lower rate of growth.

Even though recent empirical studies have been describing some statistically significant pollution haven effect, Brunnermeier and Levinson (2004) in their survey on the relationship between environmental regulation and industry location, conclude that there is not enough evidence to draw policy conclusions. Accordingly to the authors the measures of regulatory stringency normally employed in these studies have several important drawbacks. Moreover, also the selection of the industrial sample (pool of all industries or "dirty industries") may also hide other causal elements.

Most studies quoted by Brunnermeier and Levinson use data from the 1970s and 1980s. Over this period, there were financial incentives for firms from industrialized countries to move to developing economies. To obtain loans inside their home countries, firms faced newly imposed environmental rules on the installation of new industrial plants. At the same time, firms had access to funding, without environmental requirements, for the developments of their projects on developing economies. In the 1980s, this led to some criticism over the World Bank lending practices (Nielson and Tierney, 2003). International financing agents were also accused of financing "dirty" projects on developing economies, but requesting high environmental standards for projects on developed economies. This might have favored the creation of pollution havens.

Kirkpatrick and Shimamoto (2005) studied the effect of environmental regulation on the location choice of Japanese Foreign Direct Investment. To measure the restrictiveness of regulation in Japan in comparison to other countries, they used the number of environmental international treaties signed by each country. Data from foreign direct investment (FDI) in Japan was extracted from a survey on newly established and mergers and acquisitions of Japanese iron and steel, non-ferrous metals, industrial chemicals, pulp and paper, and non-metallic mineral products' firms, from 1992 to 1997. They found no support for the pollution havens hypothesis. Host countries' distance from Japan and market size were shown to be relevant to the location choice, while labor costs were not significant.

From their analysis environmental regulation is found to be a significant variable, illustrating that firms tend to move to countries with more stringent environmental regulations. This might be explained by the fact that "dirty" firms want to avoid future uncertainties, such as the imposition of new standards or being responsible for cleaning-up past pollution. Thus, regulatory stability is one of the main factors influencing location choice for foreign investment (Kirkpatrick and Shimamoto, 2005).

The results shown in Kirkpatrick and Shimamoto (2005) are partially confirmed by Co, List, and Qui (2004). These authors focus on US foreign direct investment (FDI) data, from 1982 to 1992, in two sectors: food and related products, and chemical and related products. These sectors were chosen because of their different pollution intensities. They show that capital flows in the chemical industry were more affected by environmental standards than in the food industry. As shown previously by Kirkpatrick and Shimamoto (2005), they found that for a group of firms stricter environmental standards are an important aspect in attracting foreign investment, however only for developed economies. In the case of developing countries stricter environmental standards may reduce FDI. Moreover, they also find that stringent intellectual property rights (IPR) is directly related to FDI (depending on how sensitive the industry is to IPR). This fact could then favor developing economies with higher IPR protection.

When analyzing previous empirical works on the impact of regulatory stringency on net exports over the 1970s and 1980s, Jaffe, Peterson, Portney, and Stavins (1995) found that most studies find no significant relationship, also for chemical, metals, mining, and pulp and paper sectors (pollution-intensive firms). Nonetheless, all these empirical studies while comparing environmental regulations of different countries fall on the same problem of qualitative or questionable proxies of regulatory stringency. Along with this drawback, given the complexity on defining and finding a proper indicator of competitiveness, most empirical studies focus on the impact of environmental regulation on innovation (as a proxy for competitiveness).

3.2.3 Regulation and innovation in the manufacturing industry

In this section I review the empirical literature that investigates the relationship between stringent health, safety, and environmental regulation and innovation of manufacturing firms. To better illustrate this review, two empirical studies on the US manufacturing firms over the 1970s and 1980s, believed to be particularly relevant, are carefully examined. The key variables in which I will focus are the proxies for regulatory stringency and innovation, given that a main issue is how economists have been measuring these variables to be able to capture empirically the relationship between them and their influences on firm performance and pollution reduction. Table 3.1 lists the two contributions and their main features.

Table 3.1: Empirical analyses on manufacturing industry: regulation and innovation.

Authors (Year)	Country	Period	Measure of innovation	Measure of regulation
Jaffe and Palmer (1997)	US	1975 – 1991	1. R&D expenditures 2. Patents (granted)	Pollution abatement costs and expenditures
Brunnermeier and Cohen (2003)	US	1983 – 1992	Environmental patents (granted)	1. Pollution abatement costs and expenditures 2. Number of pollution-related inspections

In the studies over the US manufacturing industry, the authors used as proxy for regulatory stringency the US census survey on pollution abatement cost and expenditure, so called "PACE survey." It consists of a questionnaire where firms declare abatement costs and expenditures related to compliance with governmental policy. The survey included answers from firms with more than twenty employees, from 1973 to 1994 (excluding 1987). Data on approximately 17,000 firms are available aggregated in 2, 3, and 4 digit SIC (Standard Industrial Classification) code levels.[4]

The survey intends to estimate a direct measure of costs of environmental policy. In spite of it all, the use of data extracted from the PACE survey has also its drawbacks. Firms might have interest on over estimating costs to signal to the regulator a higher stringency in order to obtain some advantage in a negotiation process of a future policy change. Also, it can under estimate the costs of the regulation given that it can be difficult to measure all costs related to the process control which will improve the quality of the product, save raw material and utilities (water and energy), and by consequence, reduce emissions and compliance costs with the regulation. For instance, the adoption costs of end-of-pipe technologies can be easily calculated, while the effect of other measures for guaranteeing less residues and less consumption of raw materials, such changes on the production process to obtain higher efficiency, can

[4]Unfortunately, the US Census Bureau stopped compiling the PACE survey in 1995. In 2001, a report on 1999 data was released but with a different methodology from the previous surveys, and was widely criticized (see Becker and Shadbegian, 2004).

be harder to be calculated. When the firm is improving the quality of its products reducing impurities it is by consequence consuming less raw materials and reducing emissions of pollutants. This provides environmental benefits but can be incentivized by economic motivations rather than by regulation.[5]

In order to overcome the drawbacks associated with the PACE survey, Brunnermeier and Cohen (2003) also used the number of water pollution-related and the number of air pollution-related inspections by state and federal agencies as alternative proxies for regulatory stringency. These measures can be interpreted as proxies of the level of law enforcement.

Turning now to the dependent variable of the analysis, three different proxies to measure firm innovation are commonly chosen: R&D expenditures, number of patents (applied or granted), and number of environmental patents (applied or granted). The choice of which proxy to use will determine the issues that can be studied and the interpretation of the results which are achieved.

Research and development expenditures are commonly used as a proxy for innovation, assuming that the amount of innovative activity is directly related to the amount invested by the firm in R&D. This is not necessarily true for all industrial sectors or in all periods of time. For example, the study by Thomas (1990) showed the continuos increase in R&D investments since 1955 by pharmaceutical firms in the US, but a sharp decrease of new marketed chemical entities after 1960 (the period analyzed went until 1980). However, an increase in R&D expenditures may suggest that firms noticed possible technological opportunities, demand for novel products and processes, but not necessarily that the number of innovations increased or decreased. Still, the theory states that regulation may divert resources which otherwise would be used in R&D, may alter the quantity of innovation, and may change the direction of the innovation (Eads, 1980). Regardless, in the case of industries which do not have the propensity to protect their innovations through patents, R&D can be a better proxy.

Another proxy commonly used to measure innovation is the number of patents, applied or granted, related to the industrial sector under investigation. There are two issues which might be problematic when using this proxy. First, patents are a direct measure of innovation but not all industrial sectors have the same tendency to patent their new products and processes. For instance, some firms might prefer industrial secrecy to protect their discoveries. Second, there are problems when relating the patents classification, based on technological areas, to industrial sectors. Despite this fact, the use of all patents as measure of innovative activity is able to capture overall

[5] For instance, Jaffe, Peterson, Portney, and Stavins (1995) cite other main issues that might cause problems on the interpretation associated with empirical analyses with this data. It has no baseline. Even non regulated firms might invest in cleaner technologies for other reasons such as more efficient processes, saving inputs, if a firm wants to keep a good relationship with the community close by or if they want to invest in its image as a greener brand.

innovation of a given sector.

For instance, Jaffe and Palmer (1997) discourse over the problematic classification of patents by industry. The industry of origin is not known by the patent office.[6] The patent classification by industry used by them was extracted in accordance with the US Patent Office concordance table. The two authors demonstrate two possible sources of misallocation of a patent. First, firms do not necessarily innovate on their core technologies. Second, pollution control capital goods can be equivocally assigned to the capital good using industry, and not supplying industry, which may or may not be the same. On highly aggregated studies, when evaluating the overall manufacturing industry for example, these drawbacks may be diminished.

Finally, when looking at the relationship among environmental regulation and innovation, the researcher may wish to focus not on the overall innovative activity, but just on environmentally friendly products and processes. Therefore, "environmental" or "green" patents (applied or granted) may be used to measure a specific kind of innovation. Still, available patent statistics do not explicitly classify patents as "environmental" or "green." Hence, if a researcher wishes to study the evolution of such technologies, s/he will have to develop first a sensible definition and an algorithm to extract them from the statistics available from the patent office databases. Less resource-consuming and more efficient processes will, as a consequence, reduce pollution. However, they are more difficult to be defined and extracted from a patents database.

As already discussed, innovations associated with more efficient processes can be motivated by regulatory reasons as well as by economic reasons. A higher rate of conversion (input/ raw material to output/ final product) will reduce costs with raw material, and an increase in productivity may convert in higher profits. Nevertheless, the use of environmental patents as dependent variable will show if regulatory stringency has incentivized the development of product innovations not associated with higher productivity and profitability. Parallel studies should investigate these other factors.

The literature regarding green technology grew in the last decade, but how to define environmentally friendly innovations and extract from patents database these products and processes still raises doubts. In a study on the dynamics of environmental innovations, Oltra and Jean define "clean technology" as *input substitution and savings, pollution control and prevention technologies, in-process recycling, and radically new cleaner production process* (2005, pg. 191).

In order to develop an empirical analysis on the development of environmental technologies by the European chemical firms, Arduini and Cesaroni (2004) classified these innovations into three categories: end-of-pipe, recycling, and clean technolo-

[6]The patent document contains the inventor, but not necessarily the firm or industry by which the inventor belongs to, or if s/he works for one.

gies. The first two focus on purification, decontamination, treatment of waste, and recycling, and had their data obtained from patent statistics following a keywords search. The third category, differently from the first two, cannot be extracted from a patents database because of its complexity as it is based on an ex-ante intervention in order to avoid pollution: a strategic decision regarding several aspects of the firm's production process. Clean technologies are based on prevention of pollution, and not purification and recovery. In order to obtain evidence on the development of such, Arduini and Cesaroni used case studies.

As noticed, the widespread definition used of environmental or green patents in economic studies are related to product innovations that focus on pollution reduction, mainly end-of-pipe technologies related to waste-water treatment, air pollutant filters, and recycling. For instance, Brunnermeier and Cohen obtained their data filtering patents related to *hazardous or toxic waste destruction or containment, recycling or reusing waste, acid rain prevention, solid waste disposal, alternative energy sources, air pollution prevention and water pollution prevention.*(2003, pg. 282).[7] A brief summary of the results of the two studies here discussed are shown in Table 3.2.

Table 3.2: Empirical analyses on manufacturing industry: results.

Authors (Year)	Dependent variable	Results
Jaffe and Palmer (1997)	1. R&D expenditures 2. Patents granted	1. Relationship between environmental regulation and innovation statistically significant but small in magnitude 2. Statistically not significant
Brunnermeier and Cohen (2003)	Environmental patents granted	Positive and statistically significant relationship between stricter environmental regulation and the number of environmental patents

Jaffe and Palmer (1997) used a panel data to see wether environmental regulation stimulated or not innovation. They estimated two models: first, using R&D expenditure by private manufacturing firms as a proxy for innovation, and the other using total successful patent applications.[8]

Jaffe and Palmer did not find any statistically significant relationship between regulatory compliance costs and general patenting activity, but they did establish a positive relationship for R&D expenditures, even if small in magnitude. They stated that this inconsistency occurs because of the highly aggregated nature of the data, the difficulty of classifying patents by industry of origin, and the limitation of using

[7]Extracted from the Office of Technology Assessment and Forecast of the United States Patent and Trademark Office.

[8]In the former, there were also as regressor government R&D expenditure within the industry, and, in the latter, they include a variable of successful patent applications by foreign corporations in the US Patent and Trademark Office (USPTO). This control variable was inserted for two motives: first, because there are differences in the number of patents from industry to industry; second, to check if there was a gain of competitiveness of US firms if compared to foreign firms.

the PACE survey as regulatory stringency.

The panel data estimated by Brunnermeier and Cohen investigated the relationship between environmental regulation and successful number of environmental patent applications of the US manufacturing industries. From the USPTO database they extracted $3,680$ of such patents related to environmental technologies. Other regressors used which were judge to affect environmental innovation were industry size and concentration, as indicators of market structure, among others.

Brunnermeier and Cohen found a statistically significant positive relationship between stricter environmental regulation and the number of environmental patents (although it did not imply larger profits), but with a very small correlation between the two variables. Both studies suggest that further research with less aggregated data is necessary to clarify the relationship between regulatory pressures, innovation, and competitiveness of manufacturing firms.

The investigation of the relationship between all patents produced and regulatory stringency may help identify if there was an increase in innovative activity given regulatory stringency. Even so, quantity of innovation does not mean quality of innovation (in a technological or environmental perspective).

Just a more detailed study would be able to identify if there was a change on the direction of the innovation which can happen in two ways: new technologies will be "cleaner" technologies (e.g.: more efficient processes and better products with less residues); or a technological area will be substituted by another. For example, if R&D expenditures and environmental patents are used in the same study, it can be measured if an increase on regulatory stringency made firms invest more on research to find solutions for the regulatory constrains; and if the same volume of R&D expenditures were diverted to find solutions for regulatory constrains. Regulation can raise costs or even withdraw certain products or processes from the market, becoming viable competing goods from another technological branch.

Some insights can be withdrawn from the results reached by this literature. Certainly, the effect of environmental regulation on innovation, if there is any, is not immediate. Furthermore, the difficulties of measuring the impact and confirming a hypothesis shows that there must be a large variation among manufacturing industries, and even between sub-sectors within a single industry. This high variability of costs of regulation and the different importance of innovation among different industrial sectors limit general conclusions.

3.2.4 High polluting industries

Jaffe, Peterson, Portney, and Stavins (1995) on their survey on environmental regulation and the US manufacturing industry, observed that the industrial sectors of pulp and paper, chemicals, petroleum and coal, and primary metals are the ones which show the highest pollution abatement expenditures in the PACE survey. Jaffe and Palmer (1997) also identified the sectors of metal products, pulp and paper, petroleum refining, and chemicals the ones which need to be more investigated.[9] As signalized by these and other studies on the manufacturing industry, sectorial studies have focused on industries with massive emissions of pollutants, or with high regulatory costs, or even with specific regulatory framework.

This section discourse over empirical analyses on industries considered to be highly polluting and, as consequence, highly regulated. The aim is to illustrate how the effect of health, safety, and environmental policies on firms' performance have been empirically studied over the years. Also, how regulation has been measured, and which are the main issues regarding the effect of regulation on these specific industrial sectors. First, are examined some empirical studies on the impact of stringent regulation on innovation, and later it is illustrated the literature on the impact of different policy instruments in innovative activity.

Innovation

Two papers which analyzed the impact of environmental regulation on the R&D expenditures of the Japanese industry are outlined in this section. First, Hamamoto (2006) studied high polluting manufacturing sectors over the 1960s and 1970s, and second, Hibiki, Arimura, and Takeba (2007) analyzed the automobiles industrial chain over the 1990s. Their key features are described in Table 3.3.

Table 3.3: Empirical analyses on Japanese high polluting sectors: key variables.

Authors (Year)	Industry	Period	Measure of innovation	Measure of regulation
Hamamoto (2006)	Pulp and paper; chemicals; petroleum and coal products; iron and steel; and nonferrous metals and products.	1. 1966 – 1976 2. 1972 – 1982	R&D expenditures	1. Pollution control expenditure. 2. Sum of pollution control expenditure with the change in charge payments required by the Japanese Compensation Law for Pollution-Related Health Damage.
Hibiki, Arimura, and Takeba (2007)	Auto-industry chain	1990 – 2002	R&D expenditures	Annual level of motor vehicle exhaust gas standards.

Hamamoto (2006) studied five sectors which had the highest pollution abatement control expenditures in Japan over the 1960s and 1970s: pulp and paper, chemicals, petroleum and coal products, iron and steel, and nonferrous metals and products. In order to evaluate the regulatory stringency he chose two measures: pollution control expenditure[10] and the sum of this value with a change in charge payments required

[9] Chemical and allied products sector represents 12.91% PACE as percentage of total capital expenditures, while rubber and miscellaneous plastic products sector represents 1.95%, showing the high heterogeneity along the industrial chain (data for 1991).

[10] Only abatement capital costs for complying with environmental regulation obtained from the Japanese

by the Japanese Compensation Law for Pollution-Related Health Damage. This law entered into force in 1973 and required firms that emit SO_2 to pay a compensation fee equivalent to their emissions. To develop his analysis, Hamamoto estimated two models: first looking at the effect of stringent regulation on R&D expenditures, and later on average age of capital stock.

The paper by Hibiki, Arimura, and Takeba (2007) estimated a panel data with 75 assembling, manufacturing, and body manufacturing firms, analyzing the impact of the exhaust gas regulation, established initially in 1966, in the different sectors of the Japanese auto-industry chain. At first, just carbon monoxide (CO) was regulated. In the late 1970s, nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM) emissions were also controlled first for gasoline and later for diesel-engine vehicles.[11] To build the proxy for regulatory stringency, the authors used the year of 1989 as a baseline, adjusted the level of emission standards to unit of each kind of automobile, and estimated the following years adding the relative value for each kind of automobile. There is an increasing trend of stringency of the exhaust gas emission standards. This data was compared with the evolution of R&D investments and firms' productivity in the auto-industry.

A summary of the results obtained by both studies on the impact of specific regulations in innovative activity of Japanese high polluting sectors are illustrated in Table 3.4.

Table 3.4: Empirical analyses on Japanese high polluting sectors: results.

Authors (Year)	Dependent variable	Result
Hamamoto (2006)	1. R&D expenditures 2. Average age of capital stock	1. Significant positive relationship between pollution control expenditures and R&D expenditures 2. Negative significant relationship between pollution control expenditures and average age of capital stock
Hibiki, Arimura, and Takeba (2007)	R&D expenditures	Regulation stimulates R&D expenditure of firms in the auto-industry

Results obtained by Hamamoto indicate that stringent regulation represented by pollution control expenditures of the Japanese high polluting sectors incentivized firms to increase R&D expenditures, from 1966 to 1976. It affected negatively the average age of capital stock possibly incentivizing the modernization of firms. In order to adapt to less polluting processes, firms might have changed the technology they were using.

The study by Hibiki, Arimura, and Takeba, found different impacts of regulatory stringency over the auto-industry chain. Their results suggest that regulation stimu-

report on Investment Plans in Major Industries, developed by the Ministry of International Trade and Industry.

[11] Motorbikes had to adapt to the regulation just after 1998.

lates R&D expenditure in a higher rate for assembling firms than in 'parts and body' manufacturing firms, and assembling firms suffer a direct effect of regulation on their productivity. This effect was not observed for the other firms from this industry.

The authors underline the highly innovative behavior of the auto-industry and the pressures which these firms have been facing. Mainly after the 1990s, different sectors of the society have been demanding "cleaner" cars given the major importance of everyday automobiles' emissions of greenhouse gases to the quality of the air in urban areas, and in the global warming. The burn of fossil fuels is responsible for emissions of several pollutants in the air, and it is controlled by not only the Japanese, but also other governments, in order to avoid the excess of pollutants which can cause harm to human health and the environment.

Both studies found a positive relationship between regulatory stringency and R&D investments on these high polluting sectors in different levels. However, the first study analyzed data over the 1960s and 1970s, which cannot be extrapolated to more recent years. Also, the second paper which investigated the 1990s, focus on the auto-industry chain, with particularities previously stated that impedes any extrapolation of results to other industrial sectors.

Different policy instruments

Another branch of research analyzes regulatory instruments and their effects on firms. Nelissen and Requate (2004) studied microeconomic models which investigate the relationship between different policy tools and the incentive for the development of environmental technologies, in different economic environments. Price mechanism instruments are shown to perform better than command and control policies just when the regulator is able to anticipate the technological development. However, under imperfect market conditions, the results are not clear. The authors conclude that emission taxes might be a better option in two situations: when there is a long term commitment to the levels of policy instruments; or, under "myopic" environmental policies, when the regulator cannot observe perfectly the technological level of firms.

Most research regarding the effect of different policy instruments in innovative activity of firms are theoretical studies (Popp, Newell, and Jaffe, 2009). Perhaps because there are still few market-based instruments implemented and not enough data to develop empirical comparison between different policies.

The market-based system created in 1990 by the US Clean Air Act (CAA) was studied by Popp (2003). He examined the impact of different policy instruments on the efficiency of "cleaner" technologies in the US energy production plants, in specific the flue gas desulfurization units technology (FGD). The key variables of his paper are illustrated in Table 3.5.

Popp investigated if the change in policy regimes, imposed by the CAA (1990), caused a change in the innovative behavior of the US energy production plants. He

Table 3.5: Empirical analysis on highly polluting industries: key variables.

Author (Year)	Industry	Period	Measure of innovation	Measure of regulation
Popp (2003)	Coal fired electric power plants	1985 – 1997	Stock of knowledge	Vector of dummy variables indicating the type of regulatory instrument: command and control or market-based.

analyzed the influence of the policy shift, from 'command and control' to 'market-based' system, on innovations associated with sulfur dioxide (SO_2) pollution control (end-of-pipe) technologies. Moreover, how these policy instruments impacted differently on environmental innovative activity.[12]

Previous to the CAA, the regulator required power plants to utilize the 'best available technology' in order to reduce SO_2 emissions. After 1990, the CAA established a market for SO_2 permits. Differently from command and control rules, in a market-based system firms have the choice of deciding for the most cost-effective method of emissions reduction. Two hypotheses were raised by Popp: innovation under command and control rules focus on lowering costs rather than increasing efficiency; and under market-based regimes, firms are free to choose between increasing efficiency or lowering costs.

Popp identified three different regulatory stages. In the first stage, emission rates of SO_2 were regulated for boilers built from 1971 to 1977. The second stage required higher emission control for plants built from 1978 to 1990. The third, imposed after 1990, allocated to firms tradable emissions allowances, creating a market with a national emissions limit.[13]

In a first regression, the author aimed to measure the effect of knowledge on removal efficiency of 186 plants that use coal and have flue gas desulfurization (FGD) units in the US, from 1985 to 1997. The dependent variable indicated the removal efficiency of the FGD unit, and the key explanatory variables the stock of knowledge before and after 1990.[14] In a second regression, Popp investigated if the real operating and maintenance costs varies with innovation. Thus, if the new technologies are more cost effective.[15] The summarized results are shown in Table 3.6.

[12]In a second paper, Popp (2006a) develops a similar analysis for regulatory regimes of NO_x in the US. In a third paper by Popp (2006b) examined the relationship among NO_x and SO_2 regulations and air pollution control technologies, innovation and diffusions in the US, Germany, and Japan. He investigated whether, through patent information, the regulatory pressure in one country influenced innovation in another country.

[13]Popp extracted patent data from nine different classification codes related to SO_2 pollution control to identify innovative activity along these different stages.

[14]Stock of knowledge was calculated assuming a decay rate and diffusion rate of 0.10 and 0.25, respectively. Other independent variables are the different regulatory stages which may affect each power plant, indicated by a vector of dummy variables (indicating 1 when defined policy affects the power plant), and the price of low-sulfur coal in the year the FGD unit started operating.

[15]The key explanatory variables are knowledge stocks, before and after 1990, calculated with the same

Table 3.6: Empirical analysis on highly polluting industries: results.

Author (Year)	Dependent variable	Results
Popp (2003)	Removal efficiency of the FGD unit	Command and control: Efficiency of FGD units fall as emissions limits increase; knowledge stock had no effect on removal efficiency. Market-based: New technology had a positive effect on removal efficiency.

Results demonstrate that efficiency of FGD units fall as emission limits increase. Before 1990, knowledge stock had no effect on removal efficiency, while after 1990, the new technologies had a statistically positive effect on removal efficiency. The imposition of standards, minimum efficiency goals of FGD units, lead to lower removal efficiencies. In addition, knowledge stock had a negative effect on operating costs in all three phases.

A similar study by Lange and Bellas (2005) also analyzed the change in regulatory regime imposed by the CAA in 1990. Their aim was to verify the effect of this change over scrubber costs. They found that scrubbers installed under the market-based regime became cheaper to purchase and operate in the short run, but the rate of diminishing costs did not perseverate in the following years. Summarizing, the authors state that the *adoption of policies that offer greater incentives for innovation provides for a great leap forward in cost reductions, but not necessarily subsequent ongoing progress* (2005, pg. 555). They also showed that in the long run, the market-based policy expanded the potential market of competing firms producing scrubbers.

Frondel, Horbach, Rennings, and Requate (2004) analyzed firm-level data with the objective of understanding the relevant variables which have incentivized the development of environmentally friendly innovations in German firms.[16] They showed that firms consider technology standards to be important or very important, but data demonstrates that market-based instruments have also grown in importance. Chemical, rubber, and plastics industries find that the maintenance of their corporate image is a strong incentive for environmental friendly management strategies. The survey also points that Environmental Management Systems (EMS) adopted by firms in order to improve firm's image, diminish costs with more efficient processes and waste management, and helped firms to comply with the regulation.

The existing empirical literature on the impact of different policy tools on tech-

decay and diffusion rates as before. Other independent variables are two vectors of FGD unit characteristics (one with time variant, and the other non-time variant characteristics) and a vector indicating policy regime.

[16] The data constituted of 899 facilities from the manufacturing industry. They had three main research questions. First, which are the responses of the industry, on their management, to different kinds of environmental policies? Second, how much does market forces or regulation influences firms' decision to innovate or improve their environmental performance? Third, how can the regulator influence on better firms' environmental performance?

nology and pollution reduction suggests better technological efficiency and pollution reduction under market-based instruments. However, the literature is still incipient to withdraw any conclusions, and results might differ in the short to the long run.

3.2.5 Remarks

The previous sections analyzed empirical studies concerning the impact of environmental regulation on different industrial sectors regarding two hypothesis: first, the orthodox view, which considers regulatory stringency as extra costs for firms; and second, the Porter's view, which considers regulatory stringency as an incentive for innovation.

The empirical studies regarding location choice of firms signalized that firms might give preference to already regulated countries, minimizing future regulatory uncertainty. Only for developing economies that Co, List, and Qui (2004) indicated a negative relationship between regulatory stringency and FDI investments.

When looking at the relationship between environmental regulation and innovation, most studies which used aggregated data on the manufacturing industry do not find any statistically significant relationship. Others find a positive, but small, relationship between these two variables.

In any case, these studies are not a strong support for the Porter's view. First, because of the highly aggregated nature of the data. There is a high heterogeneity among the manufacturing industries, and specifically with respect to the importance of environmental regulation and innovation. Second, as previously discussed, because of the drawbacks of the proxies employed. When analyzing the manufacturing industry, if choosing as proxy for innovation patents, it might be measuring properly some sectors and not others which do not have propensity to patent their innovation.[17] The proxy for environmental regulation used by the different empirical studies is even more complex to be evaluated.

When looking at specific industrial sectors, highly impacted by environmental regulation, most studies do find support for the Porter's view. However, a positive relationship between regulatory stringency and innovation, not necessarily will generate higher profits and competitive advantage for firms, as the Porter hypothesis states.

Furthermore, empirical studies regarding different policy instruments are not conclusive. It was found that under command and control or market-based tools, different kinds of innovation were developed. Nevertheless, this might occur just in the short-run. These results were based on the US CAA regulation and the impact on

[17] For instance, Bernauer, Engels, Kammerer, and Seijas (2006) gave some examples of how to better evaluate innovative activity proposing empirical researcher to examine analyze the number of environmental innovations within each field of innovation, distinguish product to process innovation, and measure the environmental relevance of such innovations. However, it is not clear if these suggestions are feasible.

power plants (which emitted SO_2). Still, there are few examples of market-based instruments in practice nowadays with enough data to reach better empirical results, and indicate the best policy tool to induce the desired environmental output.

Overall, empirical evidence here illustrated found a small or no correlation between environmental regulation and innovation, which does not mean support for the orthodox view.

3.3 Product regulation

In the first half of the twentieth century, environmental problems caused by the chemical industry were treated as localized phenomena. In the 1950s and 1960s, spurred on by disasters such as the Chisso-Minamata disease in Japan,[18] a wider mobilization occurred in industrialized countries to prevent future tragedies. Over this period, few substances had their risk fully identified, and regulatory controls over production and industrial waste were almost non-existent. There was also a lack of methodologies to study the impact of chemical substances on the environment and the human health. For example in the US, even though the US Food and Drug Administration (FDA) had already been created in 1906, it was only in 1938, with the introduction of the Food, Drug, and Cosmetic act, that firms started to be obliged to give evidence of safety prior to market a new substance. However, such legislation did not prevent the occurrence of important accidents; for instance it did not impede the use of thalidomide by pregnant women in the 1950s and 1960s, causing deficiencies in thousands of children around the world.

Product regulation that we are going to analyze with more detail targets the manufacture and market of chemical substances, and is part of the category of regulations regarding product safety to the human health and the environment. With an increasing number of product liability cases in the US, firms started to be considered responsible for all consequences of recurrent accidents due to lack of product safety, even though it is not always possible to prove the cause-effect relationship, linking a chemical substance to a certain disease.

Most product regulations consider that consumers do not have access to all relevant information about the product. Because of this asymmetry, the consumer is not able to evaluate the risks s/he is being exposed to, and to decide for the safer good. Firms can choose to disclose or not all information regarding safety and quality of their goods. However, increasingly Governments have been imposing specific forms of labeling to several products in order to indicate their hazards (e.g. cigarettes and alcoholic beverages). The regulator might wish to signal the consumer of a possible risk, even if not corroborated by all scientific community. In order to avoid labeling

[18]It was caused by a long period of industry discharges of methyl mercury on Minamata Bay, identified in the end of the 1950s.

firms might choose to change their formulation, substituting possible risky substances by others with verified safety (Viscusi, Vernon, and Jr., 1996).

Nowadays, several countries have rules for stock, production, and commercialization of chemical substances. The focus of these rules are mainly industrial chemicals which are produced in large scale, but not only. In each country this group of laws called "chemicals regulation" may vary in their scope, but usually they include a notification process, in order to request permission assuring safety to use or market a new substance, and a list of possibly toxic substances which are prohibited or limited in their manipulation and utilization.

In order to illustrate how diverse are these rules in different countries, a description of the existing rules regarding the notification and commercialization of chemical substances in the EU, US, and Japan is provided next. These three examples have rules for stock, production process, and commercialization of chemicals. The European Union and Japan also have a classification procedure and a list of dangerous substances, which imposes restrictions on their use. In the US, there are two important lists: first, a list of hazardous substances which must have an emergency plan for possible accidents; and second, a priority list of substances which should be removed from contaminated areas (it considers substances which were not properly disposed in the soil, lakes, and rivers until the 1960s). Finally, this section analyzes studies which investigated the relationship of the chemicals, drugs, or agrochemicals regulations and the technological development of the industry.

3.3.1 European Union

The European Union established recently a new chemicals regulation which is under implementation. Among the objectives of this new regulation – REACH – was to compile several directives into a single document, and eliminate asymmetries caused by regulations imposed on different periods. Next, the previous and actual chemicals regulation in the European Union are described.

- Council Directive 67/548/EEC: Deals with the classification, packaging and labeling of dangerous substances.
  - 6^{th} amendment: Directive 79/831/EEC, introduced a notification system for "new" substances (placed on the market after 18 September 1981).
  - 7^{th} amendment: Directive 92/32/EEC, added the Safety Data Sheet (SDS) as a tool for professional user.
  - Directive 2006/121/EC enters into force on 1 June 2008. It adapts the Directive to the new regulation REACH. It re-establishes the purpose of this regulation as classification, packaging and labeling of substances dangerous to man or the environment, excluding notification and risk assessment.
- Council Directive 76/769/EEC: Deals with marketing and use of dangerous substances and

preparations. Contains more than 900 substances with restrictions for use and market placement.

- Council Regulation 93/793/EEC: Deals with evaluation and control of existing substances. Requires a notification procedure to evaluate the risks of existing substances listed at EINECS (European inventory of existing commercial chemical substances).

  - Commission Regulation 94/1488/EC: Sets the principles for the assessment of risks to man and the environment of existing substances in accordance with council Regulation 93/793/EEC.

- Council Directive 99/45/EC: Deals with classification, packaging and labeling of dangerous preparations.

- European Parliament and Council Regulation 2006/1907/EC: It concerns the registration, evaluation, authorization and restriction of chemicals (REACH). It amends the Directive 99/45/EC, and repeals Council Regulation 93/793/EEC, Commission Regulation 94/1488/EC[19], Council Directive 76/769/EEC, and Commission Directives 91/155/EEC[20] , 93/67/EEC[21], 93/105/EC[22] and 2000/21/EC[23]. It also establishes the European Chemicals Agency (ECHA).

Directive 67/548/EEC and its 7th amendment, Council Directive 92/32/EEC (30 April 1992)

The objective of this Directive is to have a unique notification system, collection of information, classification and labeling, for the whole EU market. The main concern of the regulation is toward human health and the environment, through the safe use by workers, downstream firms, and final consumers.

Under the 6th amendment the substance to be notified should be “new” for the company. Even if a substance was already in the market or produced by another manufacturer, every new importer/ manufacturer is required to notify it. The 7th amendment changed this procedure, and a “new” substance is now defined as being new to the market. Notification is required by the first producer or importer of the substance.

There are two lists which contain all chemical substances commercialized in EU territory. EINECS (European INventory of Existing Commercial chemical Substances) contains 100,204 substances introduced in the market until 18 September 1981 and ELINCS (European List of Notified Chemical Substances) which contains

[19]Principles for the assessment of risks to man and the environment of existing substances in accordance with Council Regulation 93/79/EEC.

[20]Detailed arrangements for the system of specific information relating to dangerous preparations in implementation of Article 10 of Council Directive 88/379/EEC.

[21]Principles for assessment to risks to man an the environment of substances notified in accordance with Council Directive 67/548/EEC.

[22]Adds Annex VII D, containing information required for the technical dossier referred to in Article 12 of the 7th amendment of Council Directive 67/548/EEC.

[23]Concerns the list of Community legislation referred to in the fifth indent of Article 13(1) of Council Directive 67/548/EEC.

4,381 substances.[24], with different rules for its notification procedure Existing substances account for more than 99% of the volume of chemicals in the European market (Knight, 2007).

Exemptions

The Directive 67/548/EEC and its amendments deals with all chemical substances[25], which are not included on the EINECS, with exception to: medicinal products[26] (for human or veterinary use); cosmetics[27]; mixture of substances which, in the form of waste, are covered by specific regulation[28]; pesticides; radioactive substances covered by specific regulation[29]; food-stuffs; animal feeding stuffs; and other substances or preparations for which Community notification or approval procedures exists and for which requirements are equivalent to the Directive.

Polymers must be notified when it contains more than 2% of a new substance which is not on the EINECS.

Substances produced in small volumes (less than 10 kg per year per manufacturer), substances placed on the market on limited quantities (not exceeding 100 kg per manufacturer per year) for R&D purposes, or substances placed on the market also for R&D purposes (with a maximum period of one year) do not have to be notified for its use.

Substances placed on the market in quantities of less than one tonne per annum per manufacturer have a reduced notification procedure.

Procedure

The Directive 67/548/EEC requires the production of a standard set of data according to the tonnage which will be produced in the EU per year. The data is collected through specific tests following the Good Laboratory Practice (GLP). A notification dossier must be submitted to the competent authority in the Member State 45 days before its commercialization. The quantity of information requested will depend on the quantity produced per year by the manufacturer.

The first notifier can ask for a ten years period of confidentiality on part of the information on a chemical substance, if it is justifiable for intellectual property reasons. If this is the case, the second notifier will need to negotiate with the first notifier to obtain the information.

[24] More information can be obtained at `http://ecb.jrc.it/esis/`

[25] Defined by Council Directive 92/32/EEC as *chemical elements and their compounds in the natural state or obtained by any production process, including any additive necessary to preserve the stability of the products and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition.*

[26] Covered by Council Directive 65/65/EEC.

[27] Covered by Council Directive 76/768/EEC amended by Council Directive 86/199/EEC.

[28] Council Directives 75/442/EEC and 78/319/EEC.

[29] Council Directive 80/836/EEC.

The dossier contains technical information about the substance including proposals for classification, labeling and the safety data sheet. The regulator will then classify, label and prepare a summary of the dossier. If the substance is considered hazardous, the Member State competent authority will send the summary to the European Commission (Directorate-General for the Environment, Nuclear Safety and Civil Protection - DG XI) who will then send it to all the other competent authorities from each EU Member State. The competent authorities will have six months to make suggestions for labeling and classification of the substance. The European Commission is also responsible for adding the substances to the ELINCS. Hazardous substances are also added to the Annex I of the Directive.

Estimated costs

In 1998, Neven and Schubert published a detailed comparison of the regulatory requirements for the notification of new chemical substances in the EU, US, and Japan. There was criticism mainly from the industry, over asymmetry in the European regulation (giving different treatments to 'existing' and 'new' chemical substances), and on the high fixed costs required to market a new substance in the European Union. Criticism claimed that the regulatory framework in Europe was harming innovative activity of European chemical firms. As result of this debate and the issues it raised, a White Paper setting out proposals for a new regulation for the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH), was adopted by the European Commission in 2001.

The costs[30] are shown in Table 3.7 according to the number of tests required per volume produced/ imported[31]. In addition to the costs set out below, there is also a fee to file the notification dossier which varies in each Member State.

Table 3.7: Estimated costs of EU chemicals regulation

Tests requirements (Volume)	Laboratory Costs
Annex VII C (< 100 kg)	15,000 – 20,000
Annex VII B (100 kg – 500 kg)	25,000 – 30,000
Annex VII A (500 kg – 1 tonne)	75,000 – 85,000
Annex VIII Level 1	175,000 – 250,000
Annex VIII Level 2	275,000 – 325,000

[30]This data were extracted from the work by Neven and Schubert (1998), with values in ECU (European Currency Unit) for the year of 1998.

[31]Annex VIII Level 1 is applied when the substance placed in the market reaches 100 tons per year per manufacturer or 500 tons per manufacturer. And, Level 2 is applied when the substance placed in the market reaches 1,000 tons per year per manufacturer or 5,000tons per manufacturer.

REACH

Besides replacing a number of existing directives, which intends to simplify the extensive regulatory framework that has been created in the past decades, REACH has two main innovations. The regulation brings to an end the different treatments between "new" and "existing" substances. REACH requires that substances will be differentiated between phase-in (produced before the entry into force of REACH) and non-phase-in substances. REACH also transfers responsibility for carrying out the risk assessment from the Member State to the producers and importers of a chemical substance. Risk assessment will be 'use specific.' Each downstream user is required to declare how it uses the chemical substance, and the manufacturer is required to produce a risk assessment document with specific instructions for each situation. The regulation also creates the European Chemicals Agency (ECHA) which will be responsible for the scientific, technical and administrative management of the REACH system.

REACH will be fully implemented in eleven years time, starting from 2007. It will take a year to set up the Agency, while it will take ten years to fully register approximately 30, 000 substances, with priority given to chemicals produced or imported at larger tonnages and of high concern.

Exemptions

This regulation is not applied to radioactive substances[32]; waste[33]; substances used in medicinal products (for human or veterinary use)[34]; substances used in food or feeding stuffs[35], including the use as food additive[36], flavoring[37], as an additive in feeding stuffs[38], in animal nutrition[39]; preparations in the finished state intended for medicinal products[40], cosmetic products[41], medical devices[42], food or feeding stuffs[43].

There is a temporary exemption for the use of substance for R&D: producer or importer will have five years time to use a substance in the R&D purposes without having to register it.

Other exemptions of registration include basic elements, such as nitrogen, where

[32] Council Directive 96/29/Euratom.

[33] As defined by European Parliament and Council Directive 2006/12/EC.

[34] Scope of the European Parliament and Council Regulation 2004/726/EC, Directives 2001/82/EC and 2001/83/EC.

[35] In accordance to Regulation 2002/178/EC.

[36] Council Directive 89/107/EEC.

[37] Council Directive 88/388/EEC, Commission Decision 1999/217/EC, and European Parliament and Council Regulation 96/2232/EC.

[38] European Parliament and Council Regulation 2003/1831/EC.

[39] Council Directive 82/471/EEC.

[40] Regulation 2004/726/EC, Council Directives 2001/82/EC and 2001/83/EC.

[41] Council Directive 76/768/EEC.

[42] Council Directive 1999/45/EC.

[43] In accordance to Regulations 2002/178/EC and 2003/1831/EC, and Council Directives 89/107/EEC, 88/388/EEC (including Decision 1999/217/EC), and 82/471/EEC.

the hazards and risks are well known, naturally-occurring substance (which are not chemically modified), by-products (unless they are imported or placed in the market), and substances which result from an incidental chemical reaction.

Procedure

The procedure consists of four steps. The first step is registration, which requires the development of required tests and risk assessment reports by the manufacturer or importer of the chemical substance. Data-sharing on vertebrate animal tests is required in order to minimize the use of animals in vivo testing. The second step is the evaluation of the data by the European Chemicals Agency and perceived risks will be investigated. If the substance has properties of very high concern, it will be required to go through authorization. A list of substances of very high concern will be made available by the Agency. The manufacturer or importer will need to demonstrate that all risks will be properly controlled, what the socioeconomic benefits of using the substance are, or alternative procedures which will improve the safety and diminish the risks of the new substance. The authorization is awarded or rejected by the Commission. The fourth step consists of restrictions which may be imposed on certain substances, and that can include conditions or even prohibitions on use.

Estimated costs and possible impacts

Several studies have measured possible costs and mapped impacts of REACH. These were commissioned by a number of organizations including the European Commission, non-profit organizations, industry associations, and government.

Other studies investigated possible impacts on innovation, environment and health, the economics of large firms and SMEs, expected costs, and potential for using Q-SARs (Qualitative and Quantitative Structure-Activity Relationships). Case studies have also been developed looking at different chemical firms and other industries (RPA, 2006; KPMG, 2005; ISI, Foundation, Nordbeck, and IPTS, 2005; GmbH and Consulting, 2005).

The European Commission commissioned an impact assessment study, from KPMG. As part of this study, a table was published setting out estimates of testing costs agreed in 2004, and an updated registration costs (for 2005) for full testing of new substances by tonnage, in a minimum Q-SAR scenario. Table 3.8 illustrates the values in Euros, and the volumes in tons (KPMG, 2005, pg. 13).

3.3.2 The US

The US chemicals notification regulation is ruled by the Toxic Substances Control Act (TSCA), enacted in 1976, and its following amendments. The TSCA regulates the introduction of new chemicals in the US market with the aim of protecting human health and environment from unnecessary risks. It consists of four titles: provisions

Table 3.8: Estimated costs of REACH.

Tests requirements	Laboratory Costs	Registration Costs	Total
Annex V (1 – 10)	8,702	5,900	14,602
Annex VI (10 – 100)	151,573	11,150	162,723
Annex VII (100 – 1,000)	243,467	38,630	282,097
Annex VIII (> 1,000)	278,213	44,950	323,163

for the control of toxic substances, asbestos hazard emergency response, indoor random abatement, and lead exposure reduction.

The US Environmental Protection Agency (EPA) is the responsible for administering the regulation. It can solicit new tests, ban the manufacture or import of a highly hazard substance. It is also responsible for an inventory of commercial substances imported to, or produced in, the US market. The so called "TSCA inventory" is not easily available for reasons of commercial confidentiality. The EPA must be contacted if complete data or information on the number of notified substances is required. However it may not always be possible to disclose specific information on the substances.

Exemptions

This regulation excludes agrochemicals (pesticides), pharmaceutical products (for human and animal use), cosmetics, nuclear material, ammunitions, tobacco and tobacco products, food, food additives, and animal feeding stuffs.

In 2002, the minimum volume for reporting was raised. Substances produced in small volumes, i.e. 11,340 kg per year, are part of the 'Low Volume Exemption' (LVE). Substances for R&D use, or which are expected to have low releases and low exposure, or which are being imported for marketing tests and do not present risks, can also be exempted or very little information will be required.

Procedure

The firm must submit "all data available" to the US EPA. If necessary, the regulator will request more information. It is expected that the EPA pre-manufacture notice (PMN) dossier will contain technical data on the chemical substance and on the process, such as, volume produced, byproducts, use, environmental and human exposure. If EPA considers the substance as "high risk" it can prohibit its use. In the US there is no classification procedure as there is in the EU.

Estimated costs

Because the regulation does not require a specific list of information that must be delivered to the competent authority, Neven and Schubert (1998) did not estimate the costs of the procedure. However, there are minimum data on physical-chemical properties, human exposure information and environmental releases of the process that firms may already have for their internal research, and are delivered to the regulator.

A fee to submit costs US$ 2,500.00, but in the case of SMEs or intermediate substances being notified, the fee can fall to US$ 100.00.

3.3.3 Japan

The Chemical Substances Control Law (CSCL) was created in 1973 and had its most recent revision in 2003. It aims to protect the environment and human health from persistent and harmful chemical substances.

Exemptions

The CSCL excludes specified poisons, stimulants and narcotics which are ruled by specific regulations. It is different from the EU and the US in that it does not focus on industrial chemicals, it has few exemptions, and includes pharmaceutical products, food additives and cosmetics.

Substances produced in small volumes (1 tonne per year) do not have to be notified for use. Notification is also not required for intermediates, even if they are transported from one chemical plant to another of the same firm.

Polymers which show to be stable, and are insoluble in water and other specific organic solvents, are considered safe and therefore exempted. Otherwise, other chemical analysis will be required.

Byproducts can be exempted if they represent less than 1% of the total quantity of the product.

The 'Low Volume Exemption' (LVE) permits reduced requirements for a new substance produced or imported in quantities less than 1,000 kg per year, combining all producers and importers.

Procedure

A first defined set of data is initially submitted. Subject to the result of these tests, more information about the new chemical substance may be required. All data need to be submitted in accordance to the 'Good Laboratory Practice' (GLP) rules. The new substance will be classified by the regulator.

The first required test is on biodegradability. If the substance is biodegradable no more tests will be required. If it is poorly biodegradable, a bioaccumulation test will then be solicited. Q-SARs or analysis by analogy can be used in order to simulate the bioaccumulation result. The dossier must also contain physical-chemical and ecotoxicological data.

The classification is divided in three categories: class 1, class 2, and designated. Class 1 is a list of prohibited substances given their high bioaccumulative capacity, risk for human health, and low biodegradability. Class 2 corresponds to substances with low biodegradability, but also low bioaccumulation, and risk to human health. These two categories of substances will be labeled, have production and import controlled, and have defined guidelines for preventing pollution. Designated substances have low biodegradability, low bioaccumulation and low risk to human health. Labeling is not obligatory. However, the quantity of a substance produced and imported can be controlled.

The national authority will add the new substance to the Inventory of Chemical Substances (ENCS). Chemicals notified since 20 August 1974 are considered *new*, and the substances placed in the market before this date are considered *existing*.

Estimated costs

Neven and Schubert (1998) showed a range of estimated costs for the Japanese notification procedure, shown in Table 3.9 (Values in ECU for 1998). No fee is required by the national authorities.

Table 3.9: Estimated costs of the Japanese chemicals regulation.

Level of Requirements	Laboratory Costs
Advanced Report (AR)	$10,000 - 12,500$
Specified Class 1	AR +0
Designated	AR +($20,000$ to $25,000$)
Specified Class 2	AR +($50,000$ to $60,000$)

3.3.4 Remarks

There are sensitive differences between these regulatory frameworks. On the one hand, US environmental regulations are characterized by litigation and jurisprudence. On the other hand, in the EU regulations are used to bring detailed rules and standards already defined. The chemicals regulation are an example of these characteristics.

As described in this section, there are sensitive differences between all three regulatory frameworks. The EU and the US have adopted a regulation to deal with industrial chemicals, and Japan has designed a regulation for all chemicals entering the Japanese market. The European framework has a list of defined tests which must be submitted depending of the volume produced. The Japanese framework is built on a 'tree structure,' where further tests are required on the basis of the results of preliminary ones. Lastly, the US asks for 'all data available,' and depending of the analysis of the report provided by firm, more tests may be required.

Regarding costs, Fleischer, Kelm, and Palm (2000) illustrated a comparison with data supplied by Cytec, for the year of 1998. The company illustrated their costs for complying with the regulation in the EU, the US, and Japan. A summary of the data is shown in Table 3.10 in US $ (1998).

Table 3.10: Estimated costs of the different chemicals regulations in US$ (1998).

Tests	Costs of all tests	EU	Japan	USA
Toxicity	107, 220	97, 220	72, 500	8, 220
Environmental	166, 100	46, 100	120, 000	0
Physical/Chem Properties	33, 500	33, 500	10, 400	0
Total	306, 820	176, 820	202, 900	8, 220

For the EU and Japan, these costs may vary. The real costs for the former depend on the tonnage, and for the latter on the result of the bioccumulation test. If a firm has a worldwide market, the total cost of notifying a new product will not be the sum of the costs of the regulation on each country. For example, given that several tests are common to the different countries, a European firm decided to sell a new substance in the US market will add to the requested dossier by the US EPA just tests which are not demanded by the EU regulator. This may correspond to an advantage to firms that can expand their markets, being able to recover faster the regulatory cost compared to firms which act in just one market.

3.3.5 Product regulation and firm performance

The first two studies detailed in this section analyzed the US data on pharmaceutical and pesticide sectors, respectively. Thomas (1990) and Ollinger and Fernandez-Cornejo (1998) main concern was on the impact of regulatory stringency on firm size and market concentration. The key variables utilized by them are described in Table 3.11.

Thomas (1990) investigated the distribution of impacts of the US FDA regulations over US different-size pharmaceutical firms. It was an attempt to explain why occurred a drastic fall on the introduction of new chemical substances from pharmaceutical firms in the beginning of the 1960s (dropping by 90%) even with the continuous increase of R&D expenditures. In addition, why the lower innovative activity did not impede that the real market value of the larger pharmaceutical firms had doubled in the same period, from 1960 to 1970. Similarly, the aim of Ollinger and Fernandez-Cornejo (1998) was to study the impact of regulatory costs in mar-

Table 3.11: Empirical analyses of high polluting industries in the US: key variables.

Authors (Year)	Industry	Period	Measure of innovation	Measure of regulation
Thomas (1990)	Pharmaceutical	1960 – 1980	Stock of R&D expenditures.	Productivity trends on UK to isolate US regulatory effects.
Ollinger and Fernandez-Cornejo (1998)	Pesticide	1972 – 1989	Lagged research to sales ratio.	1. Environmental and health testing costs as a fraction of research expenditures. 2. Pollution compliance capital expenditures divided by sales (pollution abatement costs).

ket structure, through the analysis of key technological features of the US pesticides industry, from 1972 to 1989.

Both studies associated the impact of regulatory stringency over innovative activity, to a growth in competitive advantage for some firms, and disadvantage for others, in the US market. A group of firms would obtain higher profits with a lower number of innovations, causing changes in the industries' market structure.

In science-based industries, such as pharmaceuticals and agrochemicals, technical change depends highly on other issues such advances on scientific basic research. Because of that, Thomas (1990) chose to study the impact of regulatory stringency on firm size and not directly on technical change. The impact of a breakthrough innovations on basic chemistry is not easily perceived in an empirical model, and firms size is an easier variable to be evaluated. For this group of industries it is more complex to develop an empirical model with the proper variables to better explain innovative activity. To empirically investigate these effects, both studies identified the main regulations which impacted these sectors and drew different proxies to perceive these regulatory effects.

For Thomas (1990), the number of new drugs and their annual sales depend on R&D stock, factors of technical change, and regulatory effects.[44] In addition, annual profits[45] are determined by the number of new drugs and their annual sales. On his analysis, the ratio of annual profits by R&D stock should be constant with respect to R&D stock if firms with different dimensions of R&D investments experienced neither competitive advantage or disadvantage in R&D. He concluded that firms with a higher R&D investments (large firms) have a competitive advantage in comparison to firms with a lower capacity of R&D investments (smaller firms). This reasoning would explain the high stability of the ranking (by size) of pharmaceutical firms in the US, from 1960 to 1980.

Thomas (1990, pg. 500) analyzed the effect of the 1962 amendments to the 1938 US Food, Drug, and Cosmetic Act which included: *proof of effectiveness, clinical*

[44]Regulatory effects are abated by an annual depreciation rate of the R&D stock.

[45]Annual profits generated by R&D stock.

testing, good manufacturing practices and good laboratory practices, and "me-too" drugs.[46] In 1960, to market a new drug it was needed 3 years of testing, and by 1970 this period grew up to 10 years, and reached 12 years by 1980.

To be able to disentangle the effects of the regulation on US firms from other effects, Thomas chose an international comparison approach, using UK firms as a control group. Regulatory differences would be represented by an international residue (controlling for firm size). Even so, two problems were highlighted. First, the level os regulatory stringency has also increased in the UK, so this measure will depict the difference between the two regulations. Second, there were no controls for other factors which would also impact the development of new drugs and their sales. However, Thomas (1990) considered that these would not impact firm size.

Ollinger and Fernandez-Cornejo (1998) verified if a rise in regulatory costs would cause a concentration of the market. The reasoning is that the number of pesticide firms in the market decreases with a decrease in demand, or with an increase in R&D, regulatory costs, or competition. They used two variables to represent regulatory stringency: environment and health testing costs as a fraction of research expenditures, and pollution abatement costs (pollution compliance capital expenditures divided by sales). Both extracted from a survey on the US pesticide industry.

Conversely, Thomas (1990) argued that in the case of pharmaceutical firms, the use of drug testing costs for regulatory compliance would not be a good measure of regulatory stringency. Several other factors impacted positively and negatively these costs such technological developments of drug testing and the development of new therapies after 1960s. Differently from previous decades, there were new approaches on drug development which required new technical methodologies for testing. Table 3.12 shows a summary of the results obtained in both studies.

Table 3.12: Empirical analyses of high polluting industries in the US: results.

Authors (Year)	Dependent variable	Results
Thomas (1990)	1. Number of innovations. 2. Sales of innovations.	Larger firms were not affected by the regulatory restrictiveness, but benefited from the tendency that smaller ones had of leaving the market.
Ollinger and Fernandez-Cornejo (1998)	Number of innovative firms.	Pollution abatement costs and industry demand had no significant impact on the number of innovative firms. Product regulation and R&D have a negative effect on the number of innovative firms.

Using the productivity trends of UK-owned pharmaceutic firms as the net effects of the US-owned FDA regulation, Thomas (1990) estimated two models expressed in constant elasticity form. First, explaining the number of new chemical entities,

[46] Pre-market testing for safety and efficacy was then required for all new drugs in the market, even being 'generic" or "similar" products.

and second, explaining sales of pharmaceutical innovations in the period from 1960 to 1980, by firm per year.

An innovation released in a given year is linked to R&D expenditures of several previous years. In addition, firms might not introduce any new drug in certain years, while one or more new drugs in other years. Thomas cites two possible effects of the US FDA regulation on pharmaceutical firms: an increase on the required time to market a new product, and a reduction in productivity. Thus, with the same amount of R&D expenditure, firms will need more time to market less new drugs.

This study obtained mixed results. There was no relationship between innovation and firm size before 1962. However, in the following years (selecting certain intervals), large firms achieved higher sales for innovations. Although in the pooling of years, from 1963 to 1980, this effect was not significant.[47].

Thomas highlighted three main conclusions from his study. First, US large and small firms experienced different effects on their productivity after 1962. Second, comparing US to UK large firms after 1970, the innovative productivity was equivalent, inferring that there was no effect of US FDA regulation on US large firms. Third, there was a small decline on new substances developed by large US firms and an important growth on sales of these new substances. The same effect did not occur for small US firms or all-sizes UK firms, which experienced a small or any increase on sales of new drugs. This infers a reduction on the productivity of small US firms after 1962. Yet, large US firms experienced an advantage compared to their small counterparts. Large firms were not affected by the regulatory restrictiveness, but benefited from the tendency that smaller ones had of leaving the market.[48]

Ollinger and Fernandez-Cornejo (1998) developed different empirical models to analyze the impact of regulatory costs on market structure. The first explored the impact of product regulation (environmental and health testing costs) on the number of innovative firms in the US pesticide industry, and the other three models explored different combined effects. They defined innovative firms as agrochemical firms that conduct R&D and inserted new pesticides in the market over the period under study.[49]

Their results showed that product regulation had a negative effect on the number

[47]The competitiveness of firms were also evaluated given the sum of the elasticities associated with the number of innovations, and sales of innovations (in terms o R&D expenditures) In the US, this sum increased by five times, indicating a decrease on competitiveness of small firms. In the UK, there was a decrease in this sum of elasticities, indicating that smaller firms gained certain competitive advantage. It must be noticed that by 1960, UK large pharmaceutic firms (in R&D expenditures) were comparable to medium-size ones in the US.

[48]However, Thomas argues that in the 1980s innovation costs were more than doubled compared to 1962 and the market became more globalized. Consequently, the possible competitive advantage in 1962 would be less likely to happen in the 1980s, since these large firms would loose competitiveness internationally.

[49]Other explanatory variables were: fraction of research expenditures, pollution abatement costs (pollution compliance capital expenditures divided by sales), lagged research to sales ratio, farm sector demand, stage of the industry growth cycle (proxy for the toughness of competition).

of innovative firms. In addition, increasing product regulation costs affected more small than large firms, favoring the expansion of foreign-based firms in the US market. Higher sunk regulatory costs encouraged firms to exit the industry, and innovative firms were acquired by other innovative firms, affecting negatively the number of firms in the industry. Pollution abatement costs had no significant effect. In the period investigated, health and environment testing costs increased from 17% to 47% of total research costs.

The global results suggest that internationalized firms are shown to have a competitive advantage over firms which operate just locally. Since their products can be introduced in different markets, they can reduce R&D risks and recover regulatory costs (considering some common tests for different countries). Thus, product regulation may encourage foreign expansion.

The mixed results obtained by Thomas might be explained given the drawbacks of the measure of regulatory stringency. For that, Ollinger and Fernandez-Cornejo were benefitted by the survey data available on the US pesticide industry to extract the evolution of costs of the regulations (even though the survey also has its drawbacks, as previously discussed in this chapter).

Both studies analyzed industrial sectors which have specific product regulations, and have in innovation a key feature for their development and competitiveness. The period investigated depicts the first decades of the introduction of this kind of rules, and even though they cannot be generalized, these results already show the importance that product regulation has over science-based industries. Possibly, even more than pollution abatement expenditures, which are associated with more general environmental regulation.

Chemicals regulation

Much has been said about the different regulatory frameworks for chemicals adopted by the EU, the US and Japan, and how these differences could harm domestic firms. Specifically, two studies developed by the Institute for Prospective Technological Studies (IPTS) in Seville (Spain), a European Commission Joint Research Centre, were published in 1998 and in 2000, respectively. These describe and compare the regulatory framework of the European Union and its two major competitors: US and Japan. Both complemented the debate on the regulatory asymmetry in Europe, treating substances that were marketed until 1981 (existing) differently from substances that were marketed afterward (new). Today, in the European market, there are more than $100,000$ "existing" substances and less than $5,000$ "new" substances. This exigent and non-flexible regulatory framework has been accused of having harmed innovation of the European chemical industry.

More than the imposition of new tests (in 1981), the 6^{th} amendment[50] to the

[50]Directive 79/831/EEC.

Council Directive 67/548/EEC created a regulatory asymmetry, and gave firms no incentive for the development of substitutes for chemicals already in the market. The apparent lack of exigencies of the US regulation, and the 'simplified' Japanese framework might have driven, initially, more attention from the industry to those markets.

In aggregated numbers, Neven and Schubert (1998) showed that between 1979 and 1996 there were 25,545 notifications of new chemical substances in the US. From 1987 to 1996 there were 2,335 notifications in Japan. In the EU, from 1983 to 1996, there were 4,514. These numbers illustrate the large differences between new substances in the US market compared to the EU, and also suggest a certain advantage of new substances in the Japanese market compared to the EU. However, Mahdi, Nightingale, and Berkhout (2002) showed that the number of notifications of new substances in Europe grew since 1983 with a minor break in 1994. The notification of new substances in the US has been declining from 1994 down to 1999 (the last year investigated by the study). Specifically in this year, there were more notifications of new substances in the EU than in the US.

One possible explanation for this trend is that, in the 1990s, market globalization might have diminished the impact of the EU regulation. In a more globalized market, larger firms have a competitive advantage in contrast to smaller firms. Firms which commercialize their products in different markets have lower fix costs to comply with each country's regulation. Besides, companies might also have needed time to learn about the new regulatory framework, in order to be more efficient when submitting all requested information. Furthermore, over the 1980s firms operating in Europe might have exploited as much as possible their already marketed products.

Clearly, the debate over the 6^{th} amendment to the Council Directive 67/548/EEC is more complex. For highly toxic and persistent substances, the Japanese regulation can be more costly because for substances with these characteristics the required tests are more complex and expensive. In the US, the regulator can solicit more tests which will raise considerably the expenses of the notification procedure. Nonetheless, for low risk substances, the European regulatory framework has a higher fixed cost.

The initial fall of innovative activity after an increasing of regulatory costs might have signalized a redesigned of firms' strategy toward innovation. A focused approach may help the development of new products with higher aggregated value, which will be more valorized in the market by consumers, or even, will have competitive advantages in other highly regulated nations.

The second study by IPTS (Fleischer, Kelm, and Palm, 2000) developed a deeper analysis of the impact of the 6^{th} amendment to the Council Directive 67/548/EEC on innovation in European firms. Several proxies for innovation (e.g. innovation counts, R&D expenditures, patents, notification counts) and other economic performance indicators are examined in their research. They claimed that the difference in the regulatory regimes – fixed testing requirements in the EU in contrast to risk-contingent testing in US and Japan – were responsible for a lower innovative and economic performance of the EU chemical industry. The conclusions concerning the effect of the chemicals notification system on European firms might have been too strong. From a static view, they were considered a permanent outcome.

A higher regulatory cost will not necessarily lead to a higher expenditure on R&D to cope with the new rules. As previously discussed, the legislation can change the direction of innovative activity, and the same R&D investment can be concentrated on more environmentally friendly research.

Another assumption provided by this second study states that, with higher costs needed to market a new substance, the budget for R&D will be lower. Even if this is true, there is no valuation of the quality of the new substance in terms of profitability, health, and environmental safety. Quantity is not necessarily quality, or a decrease in the number of new substances is not necessarily bad for the industry.

Much of the importance given to the harm of the product regulation is based on the assumption that innovations in the chemical industry are *generally based on formerly new substances* (Fleischer, Kelm, and Palm, 2000, pg. 147). Product innovation is more important to downstream chemical firms, therefore the importance of this regulatory framework is not the same for all firms in the industrial chain. Furthermore, reasoning in the sense of technological cycles, new chemical substances are derived from the diffusion of innovative chemical processes which will allow, technologically and economically, the development of new substances in industrial scale. The importance of process innovation cannot be diminished in the chemical industry.

Fleischer, Kelm, and Palm (2000) collected extremely important data. However, the interpretation of these might have overestimated the effect of the EU chemicals regulation on the economic and innovation results of the EU chemical industry. Without a proper econometric analysis, it is not possible to verify if there is a positive or negative correlation between those variables and its size.

The high fix costs of the EU system in comparison with others can have caused an impact on the innovation and competitiveness of the European chemical sector. However, these claims are not well funded and there are contradictions on the indicators used. Comprehensively, the impact must be analyzed separately on the short run and on the long run.

3.4 Impact of regulation on the chemical industry

Different regulations can be compared according to their effectiveness and efficiency. Kahn (1988) analyses the degree to which regulation achieves its final purpose, and the cost and time spent imposing such regulatory policy. Another approach is to detach restrictiveness from flexibility of a regulation. Following Oates (1996), the stringency of a regulation is influenced by regulatory standards and enforcement. In addition, flexibility is influenced by the exceptions that regulation may allow. Regulation can be characterized by three factors: design, stringency, and efficiency (SQW, 2006). However, it is difficult to disentangle these factors, and the relationship among them is not linear.

Jaffe, Peterson, Portney, and Stavins (1995) proposed a taxonomy of all costs of environmental regulation. They summed Government costs on developing, monitoring, and enforcing the environmental regulations, with firm expenditure costs to comply with the regulation. They also add to this taxonomy possible negative effects which could cause transition costs and social impacts on unemployment rate and economic security. They map the chain of costs from the development of the regulation until the possible economic impacts on firms.

Conversely, in order to analyze the impact of regulation on specifically the chemical industry – and subsequently measure it – I chose a different path, evaluating the industrial chain and evidencing where and how the environmental, health, and safety regulations may affect chemical firms. This analysis focus on the perspective of the firm, allowing to detach the key impacts for firms in different sections of the industrial chain. Thus, knowing which kind of regulations are more relevant for firms in this industry (and its different sectors), it is easier to evaluate the possible costs and to search for relevant measures of regulatory stringency which can be used as proxy on empirical studies.

Figure 3.1 describes the structure of the chemical industry, from raw materials to the final consumers. Given the dependency in different levels of all other manufacturing and agro-industry on the chemical industry, regulation which directly impacts chemical firms will also indirectly have an effect over all other manufacturing firms which use chemicals. Not only is the impact perceived directly by firms having to deal with their own expenditures on pollution reduction, but also input prices of regulated raw material will be higher. However, production costs may also reduce as a consequence of the increase in productivity (more efficient processes), which in turn can be converted into lower product prices.

A chemical firm is mainly affected by altering the its costs of production and imposing constraints on the production process. Following the production flow, environmental, health, and safety regulations can:

Restrict input: it prohibits or restricts the use of certain substances, or utilities (water, air, and energy).

Impose controls over the production process: it may create emission standards, efficiency goals, or require the adoption of latest end-of-pipe technology.

Impose controls on the final product: new substances must be notified for its use and commercialization. Safety tests must be delivered to the regulator in

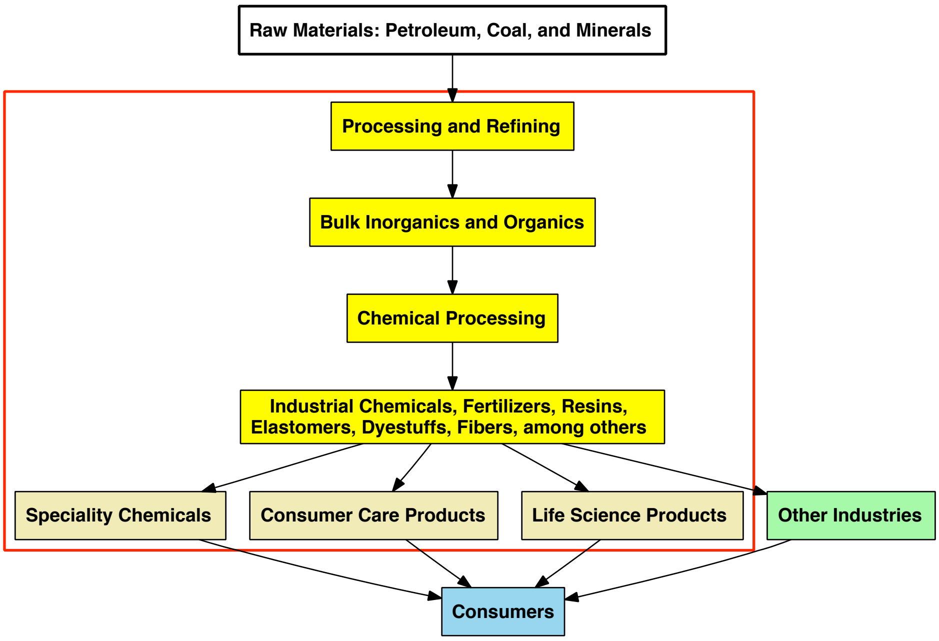

Figure 3.1: The structure of the chemical industry.

order to launch a new product.

Given this categorization, Figure 3.2 illustrates how industry-wide environmental regulation impacts the chemical industry. It may restrict the use of energy and water in a chemical plant or impose emission standards on an industrial area, limiting or prohibiting the release of hazardous substances resulting from chemical processes, or efficiency standards to firms. These kinds of regulations are usually imposed by a group of laws which focus the control over a certain area. For example, to control the concentration of CO_2 in the atmosphere of a metropolitan region, the regulator might limit traffic and industrial emissions, according to the hours of the day or weather forecast. The regulator will search for an equilibrium given the existing economic activities in the area.

When looking at the chemicals regulation, Figure 3.3 illustrates how it acts, imposing rules to the stock, transport, use, and disposal (to avoid future contamination) of chemicals. It may impact firms banning or restricting chemical substances which are inputs. Additionally, it may demand higher quality of the final product (minimizing residues). If the chemical process is not well regulated, the final product may carry other by-products or even not converted raw material. Furthermore, the chemicals regulation may require a higher control of the production process, and subsequently it restricts the output given that it requires pre-market safety and quality test for new products.

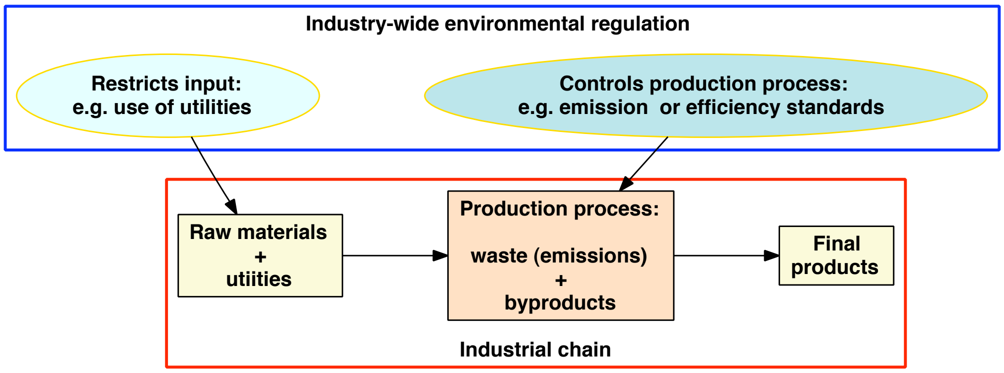

Figure 3.2: The different regulatory impacts on the production chain 1.

This kind of regulation might be more relevant to intermediate and downstream chemical firms that use a wider branch of chemicals as raw material, and manufacture products which are sold to individual consumers, subjected to higher health and safety controls. One must recall that the output of a chemical firm is the input of another chemical firm, propagating the impact all over the industrial chain.

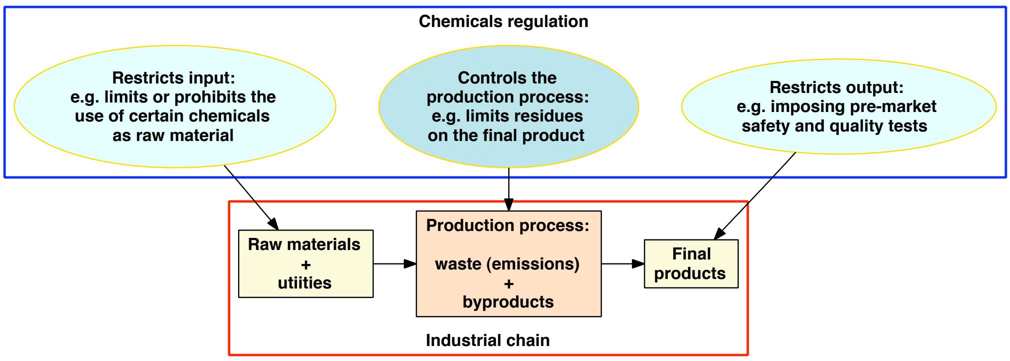

Figure 3.3: The different regulatory impacts on the production chain 2.

Chemical plants are idealized to be closed systems in mass and energy to reach the highest efficiency and minimize waste of raw material, utilities (air, water, and energy), and maximize the final product. Even so, the second law of thermodynamics states that even if no energy enters or leaves the system, the potential energy of the state will always be less than that of the initial state. This loss is called entropy. Generalizing this result to the chemical process, emissions and byproducts are loss of the system (entropy) and will always occur. But, it can be minimized with regulatory stimulus. Firms will be motivated to search for thermodynamic, and not economic, efficiency. More efficient processes will reduce pollution (entropy).

Basic chemicals producers have a higher interest on increasing their efficiency than downstream firms. Even though it is not possible to achieve a totally closed process, efficiency is a crucial factor of competitiveness for producers of commodities, not protected by intellectual property and by consequence less able to use prices to obtain higher profits.

In the last century, these two groups of regulations have been advancing together with the chemical industry. Knowledge diffusion is crucial to diminish the asymmetry of information existent between regulator and industry. The 'producer responsibility principle' is a way of conferring responsibility proportionally to the specialist knowledge (with respect to substances' hazard and possible technological improvements) held by the industry. However, given the speed of technological developments, there will always be a gap between innovation and knowledge of possible 'new' hazards.

Regulation is needed to optimize the system, to stimulate efficiency of the consumption of finite goods (inputs). It should aim to minimize pollution (entropy), and maximize the use of resources in a given time.

3.5 Conclusion

This chapter has defined the regulations regarding environment, health, and safety which arouse in the second half of the twentieth century. At the same time, the empirical literature concerning the relationship between these regulations and firm performance, with a specific focus on innovation, was exemplified in order to show the main hypothesis that economists have been investigating.

The review showed that initially economists focused their concern on the loss of competitiveness by firms from industrialized and regulated countries. Regulation would represent extra costs, incentivizing production plants to be transfered to less regulated countries, what was called the "Pollution Havens" hypothesis.

The debate orbited around studies which investigated the variables that affect the location choice of firms to studies on the impact of these regulations on firm performance. Specifically, the impact on innovation was stressed when Porter (1991) postulated that firms under more stringent regulation would be incentivized to innovate, thus would gain competitiveness in the foreign market. This was called the "Porter Hypothesis."

The objective of this review was to illustrate the evolution of the economic studies together with the development and diffusion of environmental regulations around the globe. At first, the studies focused on aggregated data on the manufacturing industries and with time moved to specific industrial sectors which are highly regulated. Still, even if some empirical results indicate that stringent regulation may have incentivized innovation on firms, results cannot be generalized mainly because of the difficulty on obtaining a proper measure of regulatory stringency.

Starting from the 1990s, researchers emphasized their studies on specific regulations, or regulatory instruments, in order to obtain more precise measures of stringency and thus more reliable conclusions. In the absence of good measures to evaluate all social regulations, the strategy has been to reveal some aspects of the impact of regulation in specific industries.

In order to better investigate the relationship between innovation and regulatory stringency in the chemical industry, the chemicals regulation was analyzed in three different markets: EU, US, and Japan. This overview illustrated different possibilities of establishing a control over the production and commercialization of chemicals. The relevance of the impact of this kind of product regulation over science-based sectors was illustrated with other two studies on the agrochemical and pharmaceutical sectors.

Finally, an analysis of the impact of environmental and product regulations over the chemical industry chain, provided a better understanding of how and where these controls might affect chemical firms. From this analysis was clarified the major role of the product regulation and the importance of developing a deeper study of the relationship between the chemicals regulation and innovation in the chemical industry.

Chapter 4

Measuring Regulatory Stringency

The effect of environmental regulation on innovation by firms and on competitiveness by countries has been a source of theorizing and debate for more than half a century. In particular, the chemical industry, that arose in Europe and the US at the end of the 19th century, has been prone to accidents that have impacted the environment. Indirectly, these accidents can be seen as responsible for the gradual growth of environmental consciousness and, beginning in the 1970s, the development of environmental regulation, first in the industrialized countries and later in the developing world.

Since the late 1980s, debates about the impact of health, safety, and environmental regulation on manufacturing industries have taken place. For governments and policy makers, the possible development of pollution havens in less regulated countries and the possible loss of innovative competitiveness in more regulated countries are the main issues. At the same time, consumers, workers, and environmental organizations have exerted pressure on governments to impose more extensive controls on pollution.

Among economists, there is still no consensus over whether innovation and competitiveness are impacted positively or negatively by increasingly stringent regulation. The critical issue is how to quantify regulatory restrictiveness in order to empirically determine the impact of regulation. Some proxies used by researchers – such as the number of international environmental agreements signed by a country or the number of visits of an environmental agency per year to firms – have been criticized for being too loose, only an indirect measure or for not being industry specific. Hence, these studies do not provide an adequate foundation for designing effective regulatory policies which will not harm industrial innovation.

From the view point of the chemical industry, as a science-based activity, the main form of competition is taken by innovating in developing more efficient processes and in introducing new and better products. This depends on its own resources to support R&D projects (Mahdi, Nightingale, and Berkhout, 2002). Consequently, a precise understanding of the impact of regulation on innovation is a fundamental issue for the chemical industry, given that innovation is a core competitiveness issue.

In order to study this questions, it is first necessary to examine the industry chain and related technological areas. The chemical industry can be initially divided between its organic and inorganic sectors. The former is characterized by the use of organic raw materials such as coal, petroleum, and natural gas, and its products are mainly petrochemicals. The latter uses inorganic raw materials such as phosphate rock, salt, sulfur, and sodium carbonate to produce, for example, fertilizers, sulphur acid, and caustic soda. From these two branches are derived intermediate and speciality chemicals which are sold to chemical firms, to other industrial sectors, or to the final consumer.

In terms of the International Patent Classification (IPC) the chemical industry, based on the ISIC codes from 23 to 25, which covers organic raw materials, productions of chemicals in general, rubber, and plastic products, is related to more than thirty technological areas (Schmoch, Laville, Patel, and Frietsch, 2003)[1]. Within these technological areas fourteen are specific to chemicals technology (from C01 to C14) while the others are mainly related to final products such as drugs, foodstuffs, and agrochemicals. The technological areas which were included in this research are detailed in the following section.

Health, safety, and environmental regulation impacts chemical firms in different ways depending upon the firms' position in the chain of production. First, regulations can restrict input, prohibiting or restricting the use of certain substances, or limiting the use of utilities (water, air and energy). Second, they impose controls on the production process with emission standards, efficiency goals, and the imposition of the latest end-of-pipe technology. Third, regulations imposes controls on the final product, such as safety tests that must be presented to regulators before marketing of a product can commence.

In the first two cases, general and industry-wide environmental regulations are the main responsible for restrictions. This is a group of laws, usually not industry specific, but applicable to all economic activities, which aims to protect the environment and human health from exposure to hazardous substances and pollutant releases from processes developed by firms, transport, and energy generation. General environmental regulation impacts a chemical firm by limiting or prohibiting the release of hazardous substances from chemical processes. The chemical industry is particularly affected by these regulations given the complexity of its processes and the variety of chemical substances which are used as raw materials, intermediates,

[1] The International Patent Classification (IPC) administered by the World Intellectual Property Organization (WIPO) is based on the Strasbourg Agreement Concerning the international Patent Classification, and entered into force in 1975. This research is based on the seventh edition, IPC-7, and considered two levels on the classification, for example, A01 or B27. The International Standard of Industrial Classification of All Economic Activities codes cited are: ISIC 23, on the manufacture of coke, refined petroleum products and nuclear fuel; ISIC 24, on the manufacture of chemicals and chemical products; and ISIC 25, on the manufacture of rubber and plastics products.

final products, byproducts, and waste.

This study focuses on those regulations that specifically regulate the manufacture and commercialization of chemicals, imposing costs and limiting applications. The chemical substances regulations involve two kinds of impact: the restriction or prohibition of chemical substances to manufacture specific products; and imposition of safety standards to market a new product in order to protect the final consumer from unnecessary exposure. Examples of chemicals regulation are the prohibition of the use of mercury in the production of toys and the imposition of tests to assure the safety to the environmental and human health of a new textile dye. Even if the impact may relate directly to the firm which uses the substance as an input, regulation will have an indirect impact on the entire industry chain. The supplier of the regulated substance and the buyer of the final product may also indirectly suffer.

The main motivation for focusing exclusively on chemicals regulation is the importance placed on it by industry, government, and non-governmental organizations in debates over the new chemicals policy of the European Union. In February 2001, the European Commission presented the White Paper on future chemicals policy to the European Parliament, European Council, and other bodies[2]. This new chemicals policy named REACH (Registration, Evaluation, and Authorization for Chemicals) was the source of intensive debates among governments, industry representatives, and non-governmental organizations for seven years. The main issue addressed was the threat of loss of competitiveness by European industries in international markets and possible additional costs for the foreign firms in the European market.

Another reason for focusing on chemicals regulation is that it is directed to users, producers, and commercializers of chemical substances. Thus, this regulation can be categorized as industry specific – even though it also impacts other industrial sectors – impacting all the links that make up the production chain of the chemical industry, from the choice of raw materials to the market of products. Moreover, this form of regulation has not yet been used by economists as a direct proxy to study the impact of regulation on the chemical industry.

This chapter is divided as follows. Section Two describes the methodology and data employed to the development of a measure of regulatory stringency illustrated with examples. Section Three discusses the results which can be derived from the final measure. And Section Four concludes this chapter with the advantages granted by this measure and an evaluation of possible future applications.

[2]The European Commission Enterprise and Industry has a specific website on the debate and historical background of the new chemicals policy, REACH. More information can be found at `http://ec.europa.eu/enterprise/reach/whitepaper/index_en.htm`, or historical background at `http://ec.europa.eu/enterprise/reach/whitepaper/background_en.htm`.

4.1 Measuring the level of regulatory stringency

Regulations regarding the market and use of chemical substances exist in many countries. In the European Union, the European Council is responsible for defining general political guidelines for the Member States, and it combines the President of the European Commission and the Heads of the Member States of the EU. The European Commission is responsible for presenting proposals for European law and by carrying out common policies. The operation of the common european market – as for the establishment of common rules for marketing, labeling, and commercialization of chemicals – are an important focus of the European Council (Commission, 2007).

Policies are developed after consultation of the main stakeholders involved, advisory bodies which will develop impact assessment studies and collect information with experts on the topics involved. The EU Directives define goals that must be achieved by every Member State with a predefined period of time, and it must be internalized by each Member State, adapting their laws in order to meet these objectives.

In 1976 the European Commission created a set of common rules for all EU member states, which applies to all firms who wish to use or commercialize chemical substances in the European market:

> Council Directive 76/769/EEC on the approximation of the laws, regulations and administrative provisions of the Member States relating to restrictions on the marketing and use of certain dangerous substances and preparations.

The Council Directive under study, the Council of the European Communities establish these rules with the aim of protecting the public and all that use such substances and preparations; contributing to the protection of the environment; restoring, preserving and improving the quality of human life; unifying different existing rules in the Member States that goes against the well functioning of the common market. The Council Directive EEC/76/769 also inserts restrictions imposed by the Council of the OECD on 13 February 1973 on polychlorinated biphenyls (PCB) which is dangerous for human health, and restricts polychlorinated terphenyls (PCT) which are shown to entail similar risks with the idea of gradually ban all PCBs and PCTs (Council, 2004).

In order to quantify the regulation, restrictions imposed by the Council Directive 76/769/EEC and its subsequent amendments were linked to seventeen technological areas in the IPC. These areas were chosen given the restrictions imposed on each substance and the importance they have to processes and products of the chemical industry.

Restrictions which affected technological areas related to other industries were not assigned. Thus, certain restrictions imposed on chemical substances were not linked to any technological area. Also, given that some restrictions may impact different products or processes, certain restrictions may have been linked to more than one technological areas. Table 4.1 shows the technological areas which had impacts assigned.

Table 4.1: IPC Code

A23	Foods or foodstuffs; their treatment, not covered by other classes.
A01	Agriculture; forestry; animal husbandry; hunting; trapping; fishing.
A61	Medical or veterinary science; hygiene.
B05	Spraying or atomising in general; applying liquids or other fluent materials to surfaces, in general.
B27	Working or preserving wood or similar material; nailing or stapling machines in general.
C01	Inorganic chemistry.
C02	Treatment of water, waste water, sewage, or sludge.
C03	Glass; mineral or slag wool.
C04	Cements; concrete; artificial stone; ceramics; refractories.
C05	Fertilizers; manufacture thereof.
C06	Explosives; matches.
C07	Organic chemistry.
C08	Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon.
C09	Dyes; paints; polishes; natural resins; adhesives; miscellaneous compositions; miscellaneous applications of materials.
C10	Petroleum, gas or coke industries; technical gases containing carbon monoxide; fuel; lubricants; peat.
C11	Animal and vegetable oils, fats, fatty substances and waxes; fatty acids therefrom; detergents; candles.
C14	Skins; hides; pelts; leather.

In the following subsections more details are provided on the link of regulatory restrictions to technological areas. First, it is described the content of the Council Directive and the sources of information used in order to link with a good precision each restriction to technological areas. Second, detailed examples clarify the methodology employed. And, third, the circumstances where restrictions were not linked to any technological area, judged to have had no impact on products or processes of the chemical industry, are explained.

4.1.1 Regulated substances and sources of industrial applications

The regulation under study was published in 1976 and amended 39 times up to 2003, having 28 amendments included restrictions to chemical substances. Restrictions are defined as constraints imposed on the use or commercialization of chemical substances. Some substances have been regulated more than once. Hence there are more restrictions than regulated chemical substances. For example, mercury was restricted twice, first in 1976 and later in 1998. In total, the Directive contains 986 restrictions imposed on the market and use of 939 chemical substances. Table 4.2 shows the number of amendments and the number of regulated substances for each year.

The majority of substances are classified into four categories which imposed the same restrictions on all the substances belonging to the given category. There are two

Table 4.2: Summary of the Council Directive 76/769/EEC

Year	# amendments	# regulated substances
1976	0	2
1979	1	1
1982	2	1
1983	2	15
1985	2	2
1989	2	11
1991	5	5
1994	3	1
1996	1	8
1997	4	796
1998	1	1
1999	3	26
2001	3	13
2002	3	2
2003	6	102
2004	1	0
Total	39	986

additional categories, flammability and danger, which have no substances restricted in the regulation under study, but related to Directive 67/548/EEC responsible for the classification, packaging, and labeling of dangerous substances have norms which must be applied by producers. These categories are shown in Table 4.3.

Substances classified on Annex I of the Directive 76/769/EEC as carcinogens, mutagens, and toxic for reproduction, have also been subdivided in category 1, which have their risk already scientifically confirmed, and category 2, when there are strong assumptions of risk. There are no differences between the restrictions imposed on both groups.

Nevertheless, until 1996 regulated substances in the Directive were not aggregated into classes. Initially, metals such as mercury and lead were regulated, followed by aromatics substances such as benzene. In total, there are seventy four restrictions imposed on a total of sixty nine substances which do not fit into the above classification. Table 4.4 shows the number of restrictions which were imposed individually on substances per year. Afterward, the majority of the restrictions imposed on the above categories excludes medicinal, cosmetic, and fuel products. This is shown clearly on Section Three, where the final result shows that the technological areas involved on these products are not shown to be heavily regulated.

In order to link the restrictions of a substance to technological areas, two main sources of industrial applications were used. The first was the European Chemical Substances Information System (ESIS) maintained by the Consumer Product Safety and Quality Unit (CPS&Q)[3]. The ESIS compiles information on chemicals

[3]Previously known as the European Chemicals Bureau (ECB), the CPS&Q is part of the Institute for

Table 4.3: Classification of the chemicals substances in the Appendix I of the Directive 67/548/EEC and conditions of restriction imposed on Annex I of the Directive 76/769/EEC

Year	Class	Summarized regulation	# restrictions
1994	Flammable, highly flammable or extremely flammable.	May not be used as such or in the form of preparations in aerosol generators marketed and intended for sale to the general public for entertainment and decorative purposes such as the following: metallic glitter intended mainly for decorations, artificial snow and frost, cushions, silly string, aerosols, imitation excrement, horn for parties, decorative flakes and foams, artificial cobwebs, stink bombs, etc.	0
1997	Dangerous	May not be used in ornamental objects, intended to produce light or color effects my means of different phases, tricks and jokes, or any object intended to be used as such, even with ornamental aspects.	0
1997	Carcinogen Category 1 or 2. Mutagen Category 1 or 2. Toxic to reproduction Category 1 or 2.	May not be used in substances and preparations placed on the market for sale to the general public in individual concentration equal to or greater than the concentration specified in Annex I to Council Directive 67/548/EEC or the concentration specified Annex I to Council Directive 88/379/EEC. The packaging of such substances and preparations must be marked legibly and indelibly as follows: 'Restricted to professional users.' By way of derogation, this provision shall not apply to: (a) medicinal or veterinary products; (b) cosmetic products; (c) motor fuels, mineral oil products intended for use as fuel in mobile or fixed combustion plants, fuels sold in closed systems; (d) artists' paints.	812 12 59
2003	Azocolourants.	Azodyes which may release one or more of the aromatic amines listed in the Appendix, in detectable concentrations, may not be used in textile and leather articles which may come into direct and prolonged contact with the human skin or oral cavity intended for use by the final consumer. Furthermore, the textile and leather Articles referred above may not be placed on the market unless they conform to the requirements set out in that point. Azodyes, which are contained in the List of azodyes that is here by added to the Appendix, may not be placed on the market or used for coloring textile and leather articles as a substance or constituent of preparations in concentrations higher than 0.1% by mass.	23

Table 4.4: Council Directive 76/769/EEC: Restrictions not imposed on groups of substances

Year	# restrictions
1976	2
1979	1
1982	1
1983	15
1985	2
1989	11
1991	5
1994	1
1996	8
1997	0
1998	1
1999	9
2001	10
2002	2
2003	6
Total	74

which are part of the European inventory of existing commercial chemical substances (EINECS), the European list of notified chemical substances (ELINCS), and other lists[4]. The search on ESIS can be undertaken with the substance name, its molecular formula or CAS number[5], and will show all information available for the substance under investigation.

Specifically, one of the documents present in the ESIS database is the chemical data-set from the International Uniform Chemical Information Database (IUCLID). Section one contains general information on the company that produces or imports the substance (name, country, contact information), the chemical name, type, classification, labeling, range of quantity produced or imported, source and occupation exposure limits, precautionary and emergency measures, information on water, air, and soil pollution caused by waste disposal and accident, and use pattern type (industrial or not) and category (for the production of which product, on R&D, or other uses). Section two contains data on physical-chemical characteristics such as melting and boiling point, density, vapor pressure, solubility, flammability, among others. Section three deals with the environmental fate and pathways, containing data on photo-degradation, biodegradation, bioaccumulation, chemical stability on soil and

Health and Consumer Protection (IHCP) a Joint Research Center (JRC) of the European Commission. The ESIS database ca be reached at `http://ecb.jrc.it/esis/`.

[4]No-longer polymers (NLP), biocidal products Directive (BPD), Persistent, bioccumulative and toxic (PBT), and very persistent and very bioccumulative substances (PBT and vPvB), Classification and Labeling substances or preparations, Export and import chemicals listed in Annex I of EEC 304/2003, High Production Volume chemicals (HPVCs) and Low production volume chemicals (LPVCs); IUCLID Chemical Data Sheets, IUCLID Export Files, OECD-IUCLID Export Files, EUSES Export Files, Priority Lists, Risk Assessment process and tracking system in relation to Council Regulation (EEC) 793/93.

[5]CAS: Chemical Abstracts Service provided by the American Chemistry Society.

water, and monitoring data of limits on air, water, soil, and food. Section four contains data on ecotoxicity of aquatic and terrestrial organisms. Section five details acute toxicity, oral, dermal, and inhalation toxicity, corrosiveness and irritability on eyes and skin, genetic toxicity, carcinogenicity, toxicity to reproduction. Section six lists all references to the document. Finally, Section seven details risk assessment of chemicals. Other remarks are quoted on the different sections and most of the information available are experimental results from firms on the effects of substances on animals and humans.

The information available at the IUCLID data-set is reported by firms and compiled by the CPS&Q in a document. In this study I extracted information on use pattern of each substance. The data-set lists use patterns and categories, for example, "industrial" and "used in synthesis in the chemical industry," respectively. The information provided is not detailed and, unfortunately, not all chemicals under investigation have a IUCLID data-set document and also not all substances which have it exhibit the use pattern. For these reasons other sources of information were needed in order to obtain more detailed data to properly assign chemicals to technological areas.

The second main source of information was the US Environmental Protection Agency (EPA) website, which has data on industrial applications of toxic substances[6]. A search was conducted with the chemical name or CAS number of regulated substances resulting on a list of information compiled by the EPA. In particular, the EPA has consumer fact-sheets which describe in some detail where and how dangerous chemicals are found and used, what are their trade names, and why they have been regulated in the US. For example, the use of benzene is described as *a building block for making plastics, rubber, resins and synthetic fabrics like nylon and polyester*, among other uses[7].

Other US governmental agencies were also used as source of information, mainly the National Institute for Occupational Safety and Health (NIOSH) and the National Toxicology Program (NTP)[8]. Chemical data-sheets provided by private companies were also consulted. However, the compilers of these documents do not always signal all applications of a substance. Moreover, most common information available about regulated substances are not industrial uses, but exposure limits in the work environment and symptoms of contamination. Patent documents and scientific papers were also consulted in the case of more rare substances for precise use information was unavailable from the preceding sources. Nevertheless, there remain restricted substances which have no industrial use, but which are produced as a consequence of the degradation or combustion of other substances.

[6]USEPA at `http://www.epa.gov/`.

[7]`http://www.epa.gov/safewater/dwh/c-voc/benzene.html`, visited on 28 July 2008.

[8]NIOSH at `http://www.cdc.gov/niosh/`, and NTP at `http://ntp.niehs.nih.gov/`.

4.1.2 Linking restricted substances to technological areas

This section provides some detailed examples to help better understand how the relationship between restricted substances and technological areas was traced.

Before entering the discussion of the examples it is important to stress few related matters. When linking regulated substances to technological areas restrictions assigned are only related to possible impacts on the chemical industry, even though they may also impact other industries. With respect to the Directive under consideration, most of the restrictions do not refer to pharmaceuticals, cosmetics, and fuels, which have each specific regulatory framework. Therefore, technological areas related to these final products do not appear as highly restricted in the data generated by this study.

The following examples were chosen in order to illustrate all kinds of substances and restrictions that are found in the Directive. This sample includes substances which were regulated several times over the years; classified in classes or regulated singularly; which impacted the basic chemicals or used on final products. The sample also contains substances used on other than the chemical industry, or with no commercial application, or not industrially produced.

Mercury

Mercury occurs naturally in the environment when released from volcanoes, or from the combustion of organic fuels and waste incineration, which may also liberate mercury. Human contamination generally occurs from contaminated food, contaminated air, or skin contact with the metal[9].

Environmental agencies are mainly worried on identifying where the pollutant is present in the environment, and most contamination has been shown to result from energy production and the ingestion of contaminated fish[10]. Little information is available on actual and past industrial applications of mercury.

Even though is a well known metal, it was only in the second half of the twentieth century that mercury was recognized as a dangerous substance and was banned from a number of applications. Actual information is based on current applications. However, a search for past industrial uses is needed to assign technological areas which were restricted at the time of the regulation.

Information on past uses and contamination sources may be found on the EPA webpage dedicated to mercury[11]. Combustion of coal is the major source of release of mercury into the environment, which occurs on coal-burning power plants, and

[9] National Toxicology Program (NTP) at `http://cerhr.niehs.nih.gov/common/mercury.html`, visited in 16 november 2007.

[10] The most famous case of contamination of mercury was on the population of Minamata Bay caused by Japanese Chisso Corporation (a fertilizer company and later on petrochemical), which for a long period discharged methyl mercury on the sea. The contamination was identified at the end of the 1950s.

[11] `http://www.epa.gov/mercury/`, visited in 13 November 2007.

on iron and steel production. In these cases, mercury release is a consequence of the production process, given that mercury is a contaminant in coal and not an input. In the case of chlor-alkali plants, mercury is used as an essential catalyst. Mercury and its compounds are also raw materials used in the production of pesticides, fungicides, latex paints, and explosives. Other sectors which use the metal are pharmaceuticals and cosmetics in the production of diuretics, antibiotics, dental amalgam, skin-lightening creams, and soaps[12]. Mercury is also commonly found in consumer products such as thermometers, switches, and fluorescent light bulbs. It is commonly used at the R&D phase, as a laboratory chemical, and as a reagent in inorganic and toxicology experiments[13]. The electronic industry also uses the metal in batteries and semiconductors.

Mercury was not classified in any of the listed categories. Hence, the Directive contains three separate set of regulations over mercury or compounds in 1976, 1989, and 1998. The restrictions imposed are shown next followed by the technological areas assigned as impacted by the regulation.

1976 Mercury *may not be used as substances and constituents of preparations intended for use: (a) to prevent the fouling by micro-organisms, plants or animals of: – the hulls of boats,– cages, floats, nets and any other appliances or equipment used for fish or shellfish farming, – any totally or partly submerged appliances or equipment; (b) in the preservation of wood; (c) in the impregnation of heavy-duty industrial textiles and yarn intended for their manufacture; (d) in the treatment of industrial waters, irrespective of their use.*

Technological areas assigned In 1976 regulation restricts the use of mercury as a fungicide in certain products. Technological areas B27, C02, and C09 were assigned as impacted. They refer first to the application of substances to preserve wood and other equipments which may contain fungicides with mercury; second, to formulas which deal with the treatment of industrial waters that may also contain mercury on the process and it is clearly prohibited by the regulation; and, third, to substances added to the formulas of dyes and paints with the purpose of creating a protective coat to different materials.

1989 Mercury compounds *may not be used as substances and constituents of preparations intended for use: (a) to prevent the fouling by micro-organisms, plants or animals of: – the hulls of boats, – cages, floats, nets and any other appliances or equipment used for fish or shellfish farming, – any totally or partly submerged appliances or equipment; (b) in the preservation of wood; (c) in the impregnation of heavy-duty industrial textiles and yarn intended for their manufacture; (d) in the treatment of industrial waters, irrespective of their use.*

Technological areas assigned In 1989 regulation expanded the previous rule to all mercury compounds. For the motivations given above the same technological areas were assigned: B27, C02, and C09.

[12] A compound is a substance (molecule) which contain different elements bonded. Mercury compounds can be organic or inorganic substances which contain mercury in its structure.

[13] `http://www.epa.gov/epaoswer/hazwaste/mercury/con-prod.htm`, visited in 13 November 2007.

1998 Mercury: *Member States shall prohibit, as from 1 January 2000 at the latest, the marketing of batteries and accumulators, containing more than 0,0005% of mercury by weight, including in those cases where these batteries and accumulators are incorporated into appliances. Button cells and batteries composed of button cells with a mercury content of no more than 2% by weight shall be exempted from this prohibition.*

Technological areas assigned In 1998 the regulation focused other than chemical processes or products, causing no impact on the chemical industry. Given this, there were no technological areas assigned.

Monomethyl-dibromo-diphenyl methane (DBBT)

No information could be obtained from the databases quoted previously, perhaps because the substance was banned from the European market in 1991.

A data-sheet from BASF clarifies the industrial applications of this substance as an organic reagent used in the synthesis of boron enolates, an intermediate in organic chemistry used to produce building blocks for basic commodities and drugs[14].

1991 DBBT: *The marketing and use of this substance and of preparations and products containing it shall be prohibited.*

Technological areas assigned The technological area `C07` related to organic chemistry was assigned as impacted by the regulation.

Benzene

This substance is an important input for the organic industry chain, employed in several organic processes. The ESIS database brings summarized information on the industries which use benzene as input. The EPA provides more detailed information on industrial applications of benzene and its role in pollution[15].

Benzene is an important organic solvent for the extraction of oils and fats from seeds and nuts, and is also used in the production of waxes, resins, inks, paints, plastics and rubber. It is an intermediate for basic industry in the manufacture of paints, lacquers, varnishes, aniline, dyestuffs, adhesives, and coatings. Benzene is also used for artistic printing and preparation of lithographic inks in the graphic arts industries, and as a thinner for paints. It is present in significant measure in fossil fuels, lubricants, and additives. Combustion of coal and oil derivatives results the majority of emissions released into the environment.

It is used in dry cleaning and in the production of detergents (alkylbenzenes) as a degreasing agent. It is a raw material in the synthesis of several polymers such as styrene (polystyrene plastics and synthetic rubbers), phenol (phenolic resins), cyclohexane (nylon), and maleic anhydride (polyester resins). It is also an intermediate in

[14] `http://www.basf.com/inorganics/pdfs/tech_datasheet/DBBT.pdf` and `http://www.basf.com/inorganics/products/developmental/dbbt_toluene.html`, visited in 16 December 2007.

[15] `http://www.epa.gov/ttn/uatw/hlthef/benzene.html`, visited on 20 December 2007.

the production of drugs, biocides, and explosives, besides being used as a laboratory chemical.

Benzene was regulated in three different years, and in 1997 it was included in the Appendix I of the Directive, labelled as a carcinogenic substance Category 1.

1982 *Not permitted in toys or parts of toys as placed on the market where the concentration of benzene in the free state is in excess of 5 mg/kg of the weight of the toy or part of toy.*

Technological areas assigned This restriction was linked to the IPC areas C08 and C09. The former refers to macromolecules such as polymers, and the latter to the production of dyes and paints, among others. These are used in the production of toys, and may contain residues of benzene if the processes are not well controlled.

1989 *May not be used in concentrations equal to, or greater than, 0,1% by mass in substances or preparations placed on the market.*

However, this provision shall not apply to: (a) motor fuels which are covered by Directive 85/210/EEC; (b) substances and preparations for use in industrial processes not allowing for the emission of benzene in quantities in excess of those laid down in existing legislation; (c) waste covered by Directives 75/442/EEC (4) and 78/319/ EEC (5).

Technological areas assigned This regulation amplified the scope of the previous restriction to substances and preparations placed on the market with a number of exemptions. More technological areas were assigned besides the previous ones, C08 and C09, which now the restriction impacts on polymers and paints for all other applications of benzene. A01, A61, C05, and C11 were included as technological areas impacted. They are related to agrochemicals, medical preparations, medical and cosmetics preparations, mixtures (additions of additives) for fertilizers, and the extraction of oils and productions of detergents, respectively.

1997 *Without prejudice to the other points of Annex I to Directive 76/769/EEC: May not be used in substances and preparations placed on the market for sale to the general public in individual concentration equal to or greater than: either the concentration specified in Annex I to Council Directive 67/548/EEC, or the concentration specified in point 6, Table VI, of Annex I to Council Directive 88/379/EEC, where no concentration limit appears in Annex I to Directive 67/ 548/EEC.*

Without prejudice to the implementation of other Community provisions relating to the classification, packaging and labeling of dangerous substances and preparations, the packaging of such substances and preparations must be marked legibly and indelibly as follows: 'Restricted to professional users.'

By way of derogation, this provision shall not apply to: (a) medicinal or veterinary products as defined by Council Directive 65/65/EEC; (b) cosmetic products as defined by Council Directive 76/768/EEC; (c) motor fuels which are covered by Council Directive 85/210/EEC, mineral oil products intended for use as fuel in mobile or fixed combustion plants, fuels sold in closed systems (e.g. liquid gas bottles); (d) artists' paints covered by Council Directive 88/379/EEC.

Technological areas assigned This regulation again expanded the previous restrictions, including exemptions for medical and veterinary use, artist paints, and cosmetics, which have specific regulations. The IPC areas assigned were as before, A01, C05, C06, C08, C09, and C11, excluding this time IPC-A61 related to drugs and cosmetic formulas, exempted by the regulation.

Even though benzene is heavily employed in basic organic processes, in neither year it was linked to IPC C07 (organic chemistry). This is because regulated substances were not related to all technological areas in which they are used, but just to those which might have been impacted by the restriction. The Directive mainly focuses on the diminution or removal of a substance from the final product, with the aim of minimizing or eliminating residues. Rarely impacts industrial consumers of intermediate chemicals.

Carbon tetrachloride

Data on industrial uses of carbon tetrachloride was found on the ESIS database and more detailed information was extracted from the EPA website.[16]

Carbon tetrachloride can act as a solvent, degreasing agent, chemical intermediate, and catalyst. By the end of the 1980s, in the US, most production of carbon tetrachloride was related to the synthesis of fluorocarbons. These have a number of applications such as propellants, solvents, lubrificants, and pharmaceutical products. It works as a solvent for oils, fats, lacquers, varnishes, rubber waxes, and resins. In relation to macromolecular technology it acts also as an intermediate product and catalyst in diverse synthesis, among them, organic chlorination processes. Carbon tetrachloride is also employed in dry cleaning agents, fire extinguishers, soaps, insecticides, fungicides, and drugs. It is also a fuel additive, a laboratory chemical, and has diverse applications in the electronic industry.

Carbon tetrachloride was restricted on a single occasion, as follows:

1996 *May not be used in concentrations equal to or greater than 0,1% by weight in substances and preparations placed on the market for sale to the general public and/or in diffusive applications such as in surface cleaning and cleaning of fabrics.*

Without prejudice to the application of other Community provisions on the classification, packaging and labeling of dangerous substances and preparations, the packaging of such substances and preparations containing them in concentrations equal to or greater than 0,1% shall be legible and indelibly marked as follows: 'For use in industrial installations only.'

By way of derogation this provision shall not apply to: (a) medicinal or veterinary products as defined by Directive 65/65/EEC, as last amended by Directive 93/39/EEC; (b) cosmetic products as defined by Directive 76/768/EEC, as last amended by Directive 93/35/EEC.

Technological areas assigned This restriction imposed limitations on the concentration of carbon tetrachloride in products placed on the market. Drugs and cosmetics are exempt. Technological areas assigned were C07, C08, C09, and C11, related to organic chemistry; macromolecular technology; lacquers and varnishes; and oils, fats, soaps, and waxes, respectively.

[16] `http://www.epa.gov/safewater/dwh/t-voc/carbonte.html` and `http://www.epa.gov/ttn/atw/hlthef/carbonte.html`, visited in 20 December 2007.

Differently from benzene, carbon tetrachloride is a chemical intermediate in organic synthesis which acts in the middle of the organic chemical industry chain. Residues in the final products are more likely to arise if there are problems in the control of the chemical process. For this motive, the organic chemistry technological area – C07 – was assigned.

1-Methyl-3-nitro-1-nitrosoguanidine

The safety data sheet provided by the American National Institutes of Health and the article by Kilgore and Greenberg (1961) describes the use of 1-methyl-3-nitro-1-nitrosoguanidine in experimental research in drugs[17]. In 1997 it was regulated and classified by the Directive as carcinogenic Category 2, and the following restriction was imposed:

1997 *Without prejudice to the other points of Annex I to Directive 76/769/EEC: May not be used in substances and preparations placed on the market for sale to the general public in individual concentration equal to or greater than: either the concentration specified in Annex I to Council Directive 67/548/EEC, or the concentration specified in point 6, Table VI, of Annex I to Council Directive 88/379/EEC, where no concentration limit appears in Annex I to Directive 67/ 548/EEC.*

Without prejudice to the implementation of other Community provisions relating to the classification, packaging and labeling of dangerous substances and preparations, the packaging of such substances and preparations must be marked legibly and indelibly as follows: 'Restricted to professional users.'

By way of derogation, this provision shall not apply to: (a) medicinal or veterinary products as defined by Council Directive 65/65/EEC; (b) cosmetic products as defined by Council Directive 76/768/EEC; (c) motor fuels which are covered by Council Directive 85/210/EEC, mineral oil products intended for use as fuel in mobile or fixed combustion plants, fuels sold in closed systems (e.g. liquid gas bottles); (d) artists' paints covered by Council Directive 88/379/EEC.

Technological areas assigned Given that the substance was found to have no industrial scale application, it was judged that the regulation had no impact on any industrial process or product. Thus, no technological areas were assigned.

Benzidine, its salts and derivatives

Benzidine is an aromatic amine compound which has been regulated five times, alone or in conjunction with its salts and derivatives. The substance profile provided by American National Toxicology Program specifies the use of the benzidine as an important intermediate in the production of dyeing compounds such as azo dyes, sulfur dyes, fast color salts, and has also other laboratory applications. Past uses quoted by the document are in plastics, rubber, and laboratory tests[18].

[17] `http://dohs.ors.od.nih.gov/pdf/1-methyl-3-nitro-1-nitrosoguanidine%20REVISED.pdf`, visited on 20 December 2007.

[18] `http://ntp.niehs.nih.gov/ntp/roc/eleventh/profiles/s020benz.pdf`, visited in 15 January 2008.

Other documents were also used as sources of information. Articles on the journal *Dyes and Pigments*, such as Liua, Yulana, and Qian (2004), also quote benzidine as an intermediate for the production of dyes. The main advantage noted in the specialized literature on benzidine-derived dyes is its characteristics of fixing in cotton. Its derivatives are employed in the synthesis of dyes, pigments, paints, rubber compounding agents, and a wide range of other organic chemicals. It has also an application as a laboratory chemical mainly in research and development purposes.

In 1997, benzidine, 4,4'-diaminobiphenyl, biphenyl-4,4'-ylenediamine, and also salts of benzidine were classified as carcinogenic Category 1. In 1999, benzidine-based azo dyes and 4,4'-diarylazobiphenyl dyes were classified as carcinogenic Category 2. Finally, in 2003, benzidine was included in the list of Azocolourants in the Appendix of the Directive. The following restrictions were imposed on chemicals from 1983 to 2003:

1983 Benzidine and its derivatives *may not be used in jokes and hoaxes or in objects intended to be used as such, for instance as a constituent of sneezing powder and stink bombs. However, Member States may tolerate on their territory stink bombs containing not more than 1,5 ml.*

Technological areas assigned The technological area C09, which also refers to pigments, was assigned given that the chemical may be present in sneezing powder and stink bombs.

1989 Benzidine and its salts *may not be used in concentrations equal to or greater than 0,1% by weight in substances and preparations placed on the market. However, this provision shall not apply to waste containing one or more of these substances and covered by Directives 75/442/EEC and 78/319/EEC.*

Technological areas assigned This new rule restricted the concentration of benzidine and its salts to all substances and preparations placed on the market. The technological areas assigned were C08 and C09, the former because of the impact on the processes of production of plastics and rubbers, and the latter because of the generalized impact on the production of dyes, paints, and pigments in general. The limitations imposed do not prohibit the use of benzidine and its salts as an industrial intermediate, but do impose a greater control on the industrial process to avoid residues in the final product.

1997 Benzidine; 4,4'-diaminobiphenyl; biphenyl-4,4'-ylenediamine, and salts of benzidine: *Without prejudice to the other points of Annex I to Directive 76/769/EEC: May not be used in substances and preparations placed on the market for sale to the general public in individual concentration equal to or greater than: either the concentration specified in Annex I to Council Directive 67/548/EEC, or the concentration specified in point 6, Table VI, of Annex I to Council Directive 88/379/EEC, where no concentration limit appears in Annex I to Directive 67/ 548/EEC.*

Without prejudice to the implementation of other Community provisions relating to the classification, packaging and labeling of dangerous substances and preparations, the packaging of such substances and preparations must be marked legibly and indelibly as follows: 'Restricted to professional users.' By way of derogation, this provision shall not apply to: (a) medicinal or veterinary products as defined by Council Directive 65/65/EEC; (b) cosmetic products *as defined by Council Directive 76/768/EEC; (c) motor fuels which are covered by Council Directive 85/210/EEC, mineral oil products intended for use as fuel in mobile or fixed combustion plants, fuels sold in closed systems (e.g. liquid gas bottles); (d) artists' paints covered by Council Directive 88/379/EEC.*

Technological areas assigned The assigned technological areas were the same as in 1989: C08 and C09. This rule was a generalization of the previous regulation which already affected benzidine and its salts, however including exceptions.

1999 Benzidine-based azo dyes, 4,4'-diarylazobiphenyl dyes, with the exception of those specified elsewhere in Annex I to Directive 67/548/EEC: *Without prejudice to the other points of Annex I to Directive 76/769/EEC: May not be used in substances and preparations placed on the market for sale to the general public in individual concentration equal to or greater than: either the concentration specified in Annex I to Council Directive 67/548/EEC, or the concentration specified in point 6, Table VI, of Annex I to Council Directive 88/379/EEC, where no concentration limit appears in Annex I to Directive 67/ 548/EEC. Without prejudice to the implementation of other Community provisions relating to the classification, packaging and labeling of dangerous substances and preparations, the packaging of such substances and preparations must be marked legibly and indelibly as follows: 'Restricted to professional users.'*

By way of derogation, this provision shall not apply to: (a) medicinal or veterinary products as defined by Council Directive 65/65/EEC; (b) cosmetic products as defined by Council Directive 76/768/EEC; (c) motor fuels which are covered by Council Directive 85/210/EEC, mineral oil products intended for use as fuel in mobile or fixed combustion plants, fuels sold in closed systems (e.g. liquid gas bottles); (d) artists' paints covered by Council Directive 88/379/EEC.

Technological areas assigned Restrictions were not applied to benzidine itself, but azodyes derived from benzidine. Again, technological areas affected were C08 and C09.

2003 Benzidine: *Azodyes which, by reductive cleavage of one or more azo groups, may release one or more of the aromatic amines listed in the Appendix, in detectable concentrations, i.e. above 30 ppm in the finished articles or in the dyed parts there of, according to the testing methods listed in that Appendix, may not be used in textile and leather articles which may come into direct and prolonged contact with the human skin or oral cavity, such as: clothing, bedding, towels, hairpieces, wigs, hats, nap and other sanitary items, sleeping bags, footwear, gloves, wristwatch straps, handbags, purses/wallets, briefcases, chair covers, purses worn round the neck, textile or leather toys and toys which include textile or leather garments, yarn and fabrics intended for use by the final consumer. fibers 2. Furthermore, the textile and leather Articles referred to in point 1 above may not be placed on the market unless they conform to the requirements set out in that point. By way of derogation, until 1 January 2005, this provision shall not apply to textile articles made of recycled fibers if the amines are released by residues deriving from previous dyeing of the same fibers and if the listed amines are released in concentrations below 70 ppm. 3. Azodyes, which are contained in the List of azodyes that is here by added to the Appendix, may not be placed on the market or used for coloring textile and leather articles as a substance or constituent of preparations in concentrations higher than 0,1% by mass. 4. Not later than 11 September 2005, the Commission shall, in the light of new scientific knowledge, review the provisions on azocolourants.*

Technological areas assigned In 2003 a general rule for azodyes was implemented, limiting residues of azocolourants listed in the Annex I of the Directive, specifying applications which have direct contact with the final consumer, such as textiles, leather, and toys. The technological area assigned was C09 given that more specific restrictions were applied on the use of benzidine in the production of azodyes. The technological area C14, which refers to leather chemical treatment and tanning, was not included given that benzidine azodyes are not commonly use in the tanning of leather products.

Benzo[a]pyrene; benzo[d,e,f]chrysene

BaP, as it is commonly known, is a polycyclic aromatic hydrocarbon which is not manufactured and has no commercial uses registered. As quoted by the US EPA Toxicity and Exposure Assessment for ChildrenÕs Health – TEACH Chemical Summary – among other sources of information (e.g. Risk Assessment Information System – US RAIS), BaP is not produced commercially but derives from incomplete combustion of organic materials such as wood, oil, coal, cigarettes, motor vehicle exhaust, and smoked, grilled, or charcoal-broiled foods. It also occurs as a consequence of the industrial processes in asphalt, siderurgy, and metallurgy (emissions from coke ovens). High incidence of skin cancer among workers in these sectors during last two centuries has been attributed to the emissions of BaP[19].

BaP was classified in 1997 as toxic for reproduction, carcinogen and mutagen Category 2. Although it appears three times in the Directive, the restrictions imposed is the same for all three categories.

1997 *Without prejudice to the other points of Annex I to Directive 76/769/EEC: May not be used in substances and preparations placed on the market for sale to the general public in individual concentration equal to or greater than: either the concentration specified in Annex I to Council Directive 67/548/EEC, or the concentration specified in point 6, Table VI, of Annex I to Council Directive 88/379/EEC, where no concentration limit appears in Annex I to Directive 67/ 548/EEC. Without prejudice to the implementation of other Community provisions relating to the classification, packaging and labeling of dangerous substances and preparations, the packaging of such substances and preparations must be marked legibly and indelibly as follows: 'Restricted to professional users.' By way of derogation, this provision shall not apply to: (a) medicinal or veterinary products as defined by Council Directive 65/65/EEC; (b) cosmetic products as defined by Council Directive 76/768/EEC; (c) motor fuels which are covered by Council Directive 85/210/EEC, mineral oil products intended for use as fuel in mobile or fixed combustion plants, fuels sold in closed systems (e.g. liquid gas bottles); (d) artists' paints covered by Council Directive 88/379/EEC.*

Technological areas assigned The regulation refers to substances and preparations placed on the market and excludes fuels, which could be a source of BaP residual emissions. Substances which were regulated by the Directive but are not manufactured or commercialized by the industry had no technological areas assigned as impacted.

[19]US EPA TEACH Chemical Summary at `http://www.epa.gov/teach/chem_summ/BaP_summary.pdf`; and RAIS Toxicity Profile at `http://rais.ornl.gov/tox/profiles/bap_c.shtml`.

2-Bromopropane

The American National Toxicological Program and the US EPA cite the use of 2-bromopropane as a laboratory reagent, and a solvent on aerosol, inks, and adhesives. It is also a contaminant in the production process of 1-bromopropane[20].

2- Bromopropane was classified in 2003 by the Directive as toxic for reproduction Category 1.

2003 *Without prejudice to the other points of Annex I to Directive 76/769/EEC May not be used in substances and preparations placed on the market for sale to the general public in individual concentration equal to or greater than: either the concentration specified in Annex I to Directive 67/548/EEC, or the concentration specified in point 6, Table VI, of Annex I to Directive 88/379/EEC where no concentration limit appears in Annex I to Directive 67/548/EEC.*

Without prejudice to the implementation of other Community provisions relating to the classification, packaging and labeling of dangerous substances and preparations, the packaging of such substances and preparations must be marked legibly and indelibly as follows: 'Restricted to professional users.'

By way of derogation, this provision shall not apply to: (a) medicinal or veterinary products as defined by Directive 65/65/EEC; (b) cosmetic products as defined by Directive 76/768/EEC; (c) motor fuels which are covered by Council Directive 85/210/EEC, mineral oil products intended for use as fuel in mobile or fixed combustion plants, fuels sold in closed systems (e.g. liquid gas bottles); (d) artists' paints covered by Directive 88/379/EEC.

Technological areas assigned 2-bromopropane is a contaminant present during the synthesis of 1-bromopropane. Given this, the restriction impose greater controls on the industrial process of production and use of 1-bromopropane. The technological areas assigned were `C07` and `C09`, which refer respectively to organic chemistry; and inks and adhesives technologies.

4.1.3 Restrictions not associated with any technological area

In the previous section several examples on how restrictions were linked to technological areas were described. Nevertheless, some restrictions were not linked to any technological area for different motivations. From the total of 986 restrictions, 705 (or 71.5%) were considered to have no impact over technological areas of the chemical industry.

First, there were restrictions imposed on chemicals judged to impact technological areas not related to the chemical industry. As an example the case of mercury when regulated in 1998. Second, there were restrictions imposed on substances with no industrial application previously registered. For example, 1-methyl-3-nitro-1-nitrosoguanidine, regulated in 1997, is only used in R&D. Third, there were restrictions imposed on substances not produced commercially, but involuntary byproducts of industrial processes, for example, Benzo[a]pyrene (BaP).

[20]USEPA at `http://www.epa.gov/Ozone/fedregstr/64fr8043.pdf`; and the US NTP at `http://ntp.niehs.nih.gov/?objectid=BD3C3B10-123F-7908-7B87D2DD5D55E4F4`, visited in 18 January 2008.

The fourth case, responsible for omitting the majority of the restrictions, were restrictions imposed on petroleum derivatives which were considered to be ineffective. The regulation imposed quantitative limits of the presence of substances used in the beginning of the basic organic industry chain on products to final consumers. The regulation was considered to be incompatible to its regulated substances. When restrictions seemed to have no impact, or even indirect effects on the chemical industry, no technological areas were assigned.

In 1997 a range of petroleum extracts, derivatives from the distillation process were regulated. From the lighter extracts, temperatures which vary from $-40°C$ to $390°C$, it is produced fuel gas and naphtha. The naphtha is the basis for the production of petrochemicals, and also from where it is derived gasoline, diesel, and other fuels. Extracts derived from higher temperatures, in the range from $370°C$ to $> 540°C$, are the source of lubricants, heavy fuels, and asphalt.

From the naphtha, the basic organic industry produces ethane, propane and butane, substances from which the primary petrochemicals (olefins, aromatics and methanol) are derived. Petrochemical intermediates are then produced from the conversion of these products into more complex molecules through other intermediates, polymerization processes and other chemical reactions.

All these petroleum extracts were classified as carcinogens Category 2 and received the following restriction:

1997 *Without prejudice to the other points of Annex I to Directive 76/769/EEC: May not be used in substances and preparations placed on the market for sale to the general public in individual concentration equal to or greater than: either the concentration specified in Annex I to Council Directive 67/548/EEC, or the concentration specified in point 6, Table VI, of Annex I to Council Directive 88/379/EEC, where no concentration limit appears in Annex I to Directive 67/ 548/EEC.*

Without prejudice to the implementation of other Community provisions relating to the classification, packaging and labeling of dangerous substances and preparations, the packaging of such substances and preparations must be marked legibly and indelibly as follows: 'Restricted to professional users.' By way of derogation, this provision shall not apply to: (a) medicinal or veterinary products as defined by Council Directive 65/65/EEC; (b) cosmetic products as defined by Council Directive 76/768/EEC; (c) motor fuels which are covered by Council Directive 85/210/EEC, mineral oil products intended for use as fuel in mobile or fixed combustion plants, fuels sold in closed systems (e.g. liquid gas bottles); (d) artists' paints covered by Council Directive 88/379/EEC.

The restriction imposes quantitative limits of the presence of extracts of petroleum distillation, used in the beginning of the basic organic industry chain, on products to final consumers. Professional use is permitted, and cosmetics, pharmaceuticals, and fuels are excluded from this regulation. There is a remote possibility of these substances finish as a residue in the final product, given the very large number of processes and transformations in which they are involved. The restriction was considered to be incompatible to the regulated substances. It was then decided to not assign any technological areas as impacted by this regulation.

4.2 Findings

In this section I report descriptive statistics on the evolution of the restrictions imposed on the different technological areas. Overall, 281 restrictions were linked to seventeen technological areas. The majority, 145 (51.6%), were linked each to more than one technological area. Table 4.5 shows the distribution of restrictions per technological area, and Table 4.6 shows the relative growth of restrictions on each technological area, from 1976 to 2003.[21]

Covering the entire Directive three technological areas account for more than 70% of the total impact. They are: C09, A01, and C08, which received respectively 33.3%, 18.9%, and 19.0% of the total impact mapped. Among the other technological areas under investigation, none accounted for more than 6.0% of restrictions.

Analyzing the relative stringency growth, three technological areas show increasing relative stringency: A01, C11, and C14. Other four show decreasing relative stringency: A61, B05, B27, and C02. This can be partially explained by the change on the organization of the regulation starting from 1997. A common restriction was established to all substances classified as Carcinogen, Mutagen, and Toxic for Reproduction, which were almost all chemicals regulated afterward. In these three classes the restrictions excluded medicinal products, cosmetics, and fuels which may impact technological areas A61, B05, and C10. Another feature of this common restriction is that it imposes limits on substances on final products, thus it diminished the restrictions on technological areas mostly related to intermediate products sold to other firms, or industrial processes which occur to treat other than the core product of the firm (e.g. may impact technological area C02 which refers also to the treatment of industrial waste water).

Figure 4.1 shows the evolution of the three most restricted technological areas for the whole period. Two "jumps" in the number of restrictions of all three most impacted technological areas stand out. These occurred in 1997 and 2003 when amendments added to the regulation inserted the majority of the restricted substances.

The restrictions over the technological areas A01, C08, and C09, were expanded to its sub-technological areas in order to facilitate the analysis. Next, these IPC groups are described in more details.

[21] The complete table with all data is available at the link https://docs.google.com/fileview?id=0BwlprME39J-LNWE5NWI5NGQtZWY2MC00MDhkLWEwNzQtYzg2ZTNkNDBjZTg4&hl=en_GB or http://tiny.cc/p7faa.

Table 4.5: Measure of regulatory stringency

Year	A23	A01	A61	B05	B27	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C14	
1976			1	1	1		1							1				5
1979														1				1
1982													1	1				2
1983	1												5	5				11
1985		1							1				2	2	2			8
1989		4	3				1		1	1			6	11	2	1		30
1991												1	2	2	2			7
1994																		
1996												7	4	7	1	3	1	23
1997	6	**56**					3	5	8	5	5	2	**51**	**77**		11	6	**235**
1998																		
1999	1	8							1				6	16			4	36
2001		2			9			1						1				13
2002		1												1	1		1	4
2003	4	**32**	1			2	2		3	3	3	23	**28**	**59**	4	9	5	**178**
Total	12	**104**	5	1	10	2	7	6	14	9	8	33	**105**	**184**	12	24	17	553

Table 4.6: Relative measure of regulatory stringency

Year	A23	A01	A61	B05	B27	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C14
1976			20.0%	20.0%	20.0%		20.0%							20.0%			
1979			16.7%	16.7%	16.7%		16.7%							33.3%			
1982			12.5%	12.5%	12.5%		12.5%						12.5%	37.5%			
1983	5.3%		5.3%	5.3%	5.3%		5.3%						31.6%	42.1%			
1985	3.7%	3.7%	3.7%	3.7%	3.7%		3.7%		3.7%				29.6%	37.0%	7.4%		
1989	1.8%	8.8%	7.0%	1.8%	1.8%		3.5%		3.5%	1.8%			24.6%	36.8%	7.0%	1.8%	
1991	1.6%	7.8%	6.3%	1.6%	1.6%		3.1%		3.1%	1.6%		1.6%	25.0%	35.9%	9.4%	1.6%	
1994	1.6%	7.8%	6.3%	1.6%	1.6%		3.1%		3.1%	1.6%		1.6%	25.0%	35.9%	9.4%	1.6%	
1996	1.1%	5.7%	4.6%	1.1%	1.1%		2.3%		2.3%	1.1%		9.2%	23.0%	34.5%	8.0%	4.6%	1.1%
1997	2.2%	18.9%	1.2%	0.3%	0.3%		1.6%	1.6%	3.1%	1.9%	1.6%	3.1%	22.0%	33.2%	2.2%	4.7%	2.2%
1998	2.2%	18.9%	1.2%	0.3%	0.3%		1.6%	1.6%	3.1%	1.9%	1.6%	3.1%	22.0%	33.2%	2.2%	4.7%	2.2%
1999	2.2%	19.3%	1.1%	0.3%	0.3%		1.4%	1.4%	3.1%	1.7%	1.4%	2.8%	21.5%	34.4%	2.0%	4.2%	3.1%
2001	2.2%	19.1%	1.1%	0.3%	2.7%		1.3%	1.6%	3.0%	1.6%	1.3%	2.7%	20.8%	33.4%	1.9%	4.0%	3.0%
2002	2.1%	19.2%	1.1%	0.3%	2.7%		1.3%	1.6%	2.9%	1.6%	1.3%	2.7%	20.5%	33.3%	2.1%	4.0%	3.2%
2003	2.2%	18.8%	0.9%	0.2%	1.8%	0.4%	1.3%	1.1%	2.5%	1.6%	1.4%	6.0%	19.0%	33.3%	2.2%	4.3%	3.1%

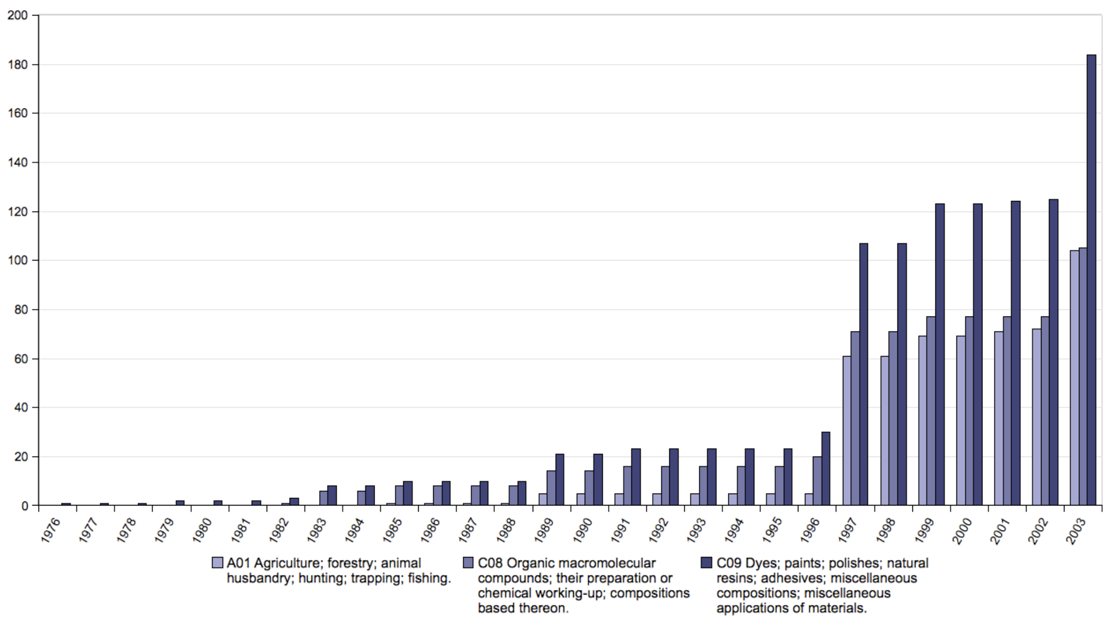

Figure 4.1: The evolution of the number of restrictions imposed on the three most regulated technological areas from 1976 to 2003.

4.2.1 IPC-A01

Agriculture; forestry; animal husbandry; hunting; trapping; and fishing.

The technological area A01 focus on agriculture, forestry, animal husbandry, hunting, trapping, and fishing. All restrictions classified in this technological area were related to the subarea A01N, which refers to the *preservation of bodies of humans or animals or plants or parts thereof*, including biocides (pesticides and herbicides).

The subarea A01N is directly related to the agrochemicals industry. Part of life-science, this industry uses as input basic and speciality chemicals, producing formulations directed to other firms or individual consumers.

This finding corroborates with previous studies which cite the agrochemicals industry as being highly regulated. For example, the regulatory costs of the agrochemical industry has already been the focus of the study by Ollinger and Fernandez-Cornejo (1998) in the US for the period from 1972 to 1989. Over the investigated period, the authors found out that the health and environment testing increased from 17% to 47% of total research costs, which negatively affected the number of firms in the industry, impacting more smaller than larger firms.

4.2.2 IPC-C08

Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon.

Technological area C08 refers to products and processes related to organic macromolecular substances – commonly known as polymers (e.g. rubbers and plastics) – and their compositions. The measure of regulatory stringency was then expanded to the sub technological areas, detailed in Table 4.7. The subareas C08K, C08J, and C08F, with 39.5%, 25.5%, and 14.0% of the total restrictions imposed, exhibited most of the impact. Table 4.8 shows the measure of regulatory stringency inside the IPC-C08, and Figure 4.2 the evolution of the most impacted subareas.

Table 4.7: IPC-C08

C08B	Polysaccharides; derivatives thereof.
C08C	Treatment or chemical modification of rubbers.
C08F	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds.
C08G	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds.
C08H	Derivatives of natural macromolecular compounds.
C08J	Working-up; general processes of compounding; after-treatment not covered by subclasses C08B, C08C, C08F, C08G.
C08K	Use of inorganic or non-macromolecular organic substances as compounding ingredients.
C08L	Compositions of macromolecular compounds.

Table 4.8: Measure of regulatory stringency for the IPC-C08

Year	C08C	C08F	C08G	C08J	C08K	C08L
1982		1				
1983		1	2		2	1
1985		1	2		2	3
1989	3	2	2		3	4
1991	3	2	2		5	4
1996	5	2	4	4	7	4
1997	14	16	11	30	37	4
1999	14	17	11	31	43	4
2003	18	22	11	40	62	4

The subarea C08K refers to the use of inorganic or non-macromolecular organic substances as compounding ingredients for macromolecular products. Different chemicals are added to the a macromolecular substance with the aim of giving certain characteristics and physicochemical properties to the final product, such as malleability, resistance, color, and others. In the case of the subarea C08K, the compounding ingredients can be, for example, fibers (e.g. asbestos), biocides, paints, inks, lubrificants, and detergents.

The subarea C08J refers to processes of treating or compounding macromolecular substances. These include the process of making solutions, powdering, or plasticizing; the manufacture of shaped articles containing macromolecular substances; chem-

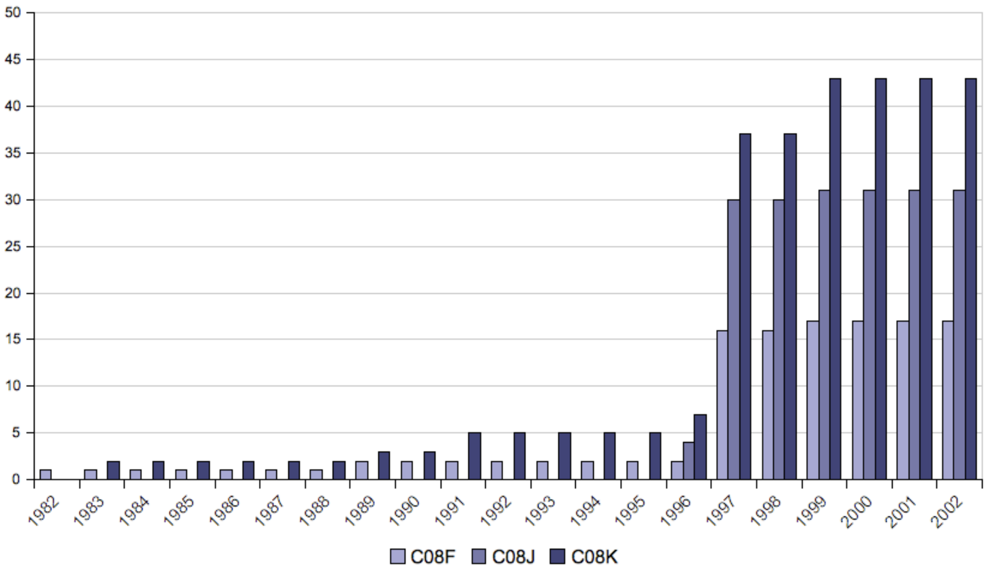

Figure 4.2: Cumulative number of restrictions imposed on subareas C08F, C08J, and C08K.

ical modification or coating of shaped articles made of macromolecular substances; working-up of macromolecular substances to porous or cellular articles or materials; processes of recovery or working-up of waste materials such as solvents, additives, unreacted monomers and polymers.

Finally, C08F is specific to processes and catalysts used in the development of macromolecular substances obtained by reactions only involving carbon-to-carbon unsaturated bonds, which are reactions which occur bonding one carbon atom to another[22].

The development of the link between restricted substances to the subarea C08 was more difficult to map given the complexity of the technology. The development and use of polymers are present in all manufacturing industries, as hence this is a technological area which impacts different industrial sectors. Given these characteristics, it is not possible to make a direct relation between this technological area to an specific industrial sector.

Macromolecular technology is used in the automobiles, toys, textiles, furniture, and in the production of many other products. For example, the automobiles industry has research on more resistant and non flammable polymers for the production of cars. Shoes and textiles are other two examples of sectors which also do research macromolecular technology.

However, there are sectors focused on macromolecular technology, the plastic and rubber producers. The former is characterized by SMEs which produce a large variety

[22] Another technological sub-area, C08G, refers to macromolecular substances obtained by otherwise than above.

of plastic products, buying resins and different speciality chemicals and developing formulations. The latter is characterized by a small number of large companies producing tires, which account for half of the production value of rubber (Commission, 2004).

Among the restrictions imposed on the majority of substances linked to the C08 technological area the prohibition of several substances on macromolecular products used on toys and textiles can be highlighted. A more detailed study of the effects of the stringency of the regulation in this technological area would be necessary to see which industrial sectors have been most impacted.

4.2.3 IPC-C09

Dyes; paints; polishes; natural resins; adhesives; miscellaneous compositions; miscellaneous applications of materials.

Technological area C09 related to a wide branch of products and processes related to coats, dyes, paints, natural resins, adhesives, and related compositions described in Table 4.9. After detailed study of the subareas, shown in Table 4.10, it was observed that four were the most heavily impacted. The main two are C09D and C09B, with respectively 37% and 32% of all restrictions. The former covers technologies on paints, inks, related products and processes. The latter mainly covers organic dyes, its products and processes. The evolution of these two subgroups is described in Figure 4.3.

Table 4.9: IPC-C09

C09B	Organic dyes or closely-related compounds for producing dyes; mordants; lakes.
C09C	Treatment of inorganic materials, other than fibrous fillers, to enhance their pigmenting or filling properties; preparation of carbon black.
C09D	Coating compositions; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes or solids or solids for coloring or printing; use of materials therefor.
C09F	Natural resins; french polish; drying-oils; driers (siccatives); turpentine.
C09G	Polishing compositions other than french polish; ski waxes.
C09H	Preparation of glue or gelatin.
C09J	Adhesives; adhesive processes in general (non-mechanical part); adhesive processes not provided for elsewhere; use of materials as adhesives.
C09K	Materials for applications not otherwise provided for; applications of materials not otherwise provided for.

The other two detached subareas are C09J and C09C, with respectively 14% and 13% of the all restrictions. These two subareas related to adhesives, their products and processes; and physical and chemical treatment of inorganic materials to improve their pigmenting and filling properties.

The IPC C09 related directly to the paints and dyes industrial sectors, which has been also noted in the previous literature as being highly regulated. Porter (1990)

Table 4.10: Measure of regulatory stringency for the IPC-C09

Year	C09B	C09C	C09D	C09J
1976				
1979	1			
1982	1		1	
1983	3		4	
1985	3	1	6	2
1989	7	6	11	3
1991	7	7	13	4
1994	7	7	13	4
1996	7	7	20	6
1997	43	21	65	27
1998	43	21	65	27
1999	48	27	74	29
2001	49	27	75	29
2002	49	27	76	29
2003	87	35	102	38

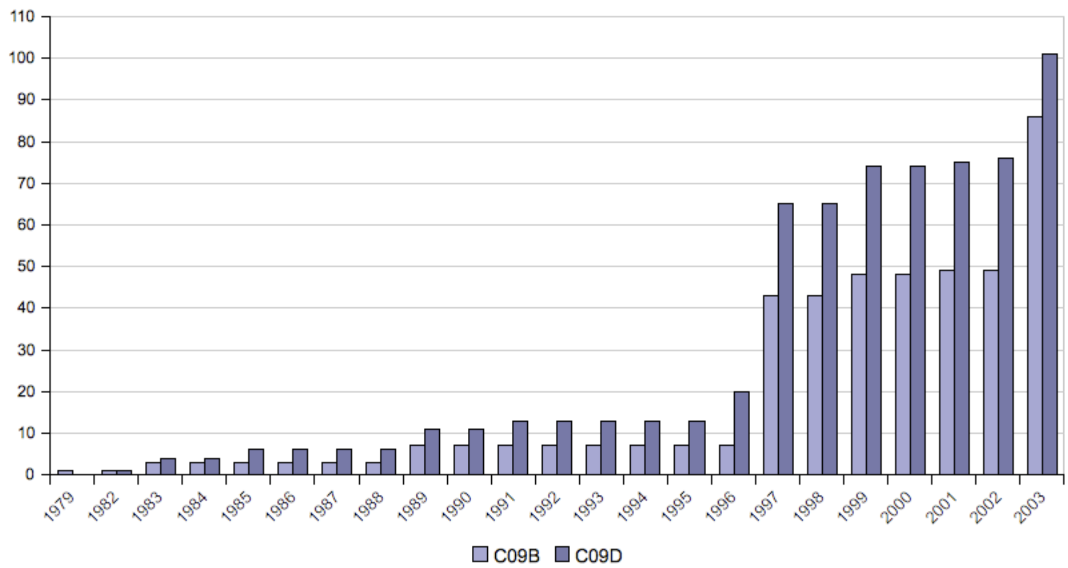

Figure 4.3: Cumulative number of restrictions imposed on only sub-areas C09B and C09D

cited the paints industry as one of the most regulated manufacturing industries in the US[23]. In a more recent study, Brusoni (2004) also focused on the European paints industry, studying the impact of regulation on the reduction of VOC emissions and the innovative behavior of European firms.

[23]In his book, he shows that this sector gained competitiveness over the years, and justifies it given the regulatory constraints it had faced and its innovative capability.

4.3 Conclusion

One of the main difficulties identified in the economic literature when studying the impact of environment, health, and safety regulation on firms is finding an appropriate measure of regulatory stringency. Various proxies have been previously used; however, finding a quantitative measure, directly related to the industry under study, remains difficult.

The main purpose of this study has been to develop a quantitative measure of regulatory stringency in order to examine the relationship between environment, health, and safety regulation and innovation in the chemical industry. This measure was created linking regulated substances to the technological areas of the IPC-7, given the importance of chemicals regulation for the chemical industry.

This chapter has described the methodology used to quantify Council Directive 76/769/EEC from 1976 to 2003, that impacted firms that produced or commercialized regulated chemical substances in the European market. The measure proposed illustrates the evolution of regulatory stringency over technological areas related to the chemical industry for almost thirty years.

The results show that the most regulated technological areas are A01N, C08, and C09, related respectively to agrochemicals, macromolecules, and paints and dyes. These findings are consistent with previous literature, supporting the methodology used in this study. Related industrial sectors, agrochemicals, coating, inks and adhesives, are also classified as part of the formulated chemicals sector which is characterized by a high R&D intensity (Commission, 2004).

Even though not all aspects of environmental, health, and safety regulations are covered, the Council Directive 76/769/EEC concerns large part of impacts caused by regulations on all industry chain. This measure is directly related to the chemical industry and opens room for different routes of research on the relationship between stringent regulation and innovation.

Initially, as a first attempt to correlate the stringency of regulation with innovative activity, it is necessary to compare the evolution of regulatory stringency and patenting in Europe for the most regulated technological areas. Case studies can help clarify some aspects of this issue, such as whether the regulated substances in a specific technological area are crucial for the development of the sector, since they are key substances in the chemical process. Alternatively, regulated substances are not relevant in the overall innovation of the technological area, probably by being easily substituted.

The fact that the measure of regulatory stringency is based on technological areas causes some common problems for the development of empirical studies. Frequently, the number of patents is used as a proxy for innovative activity in an industrial sector. It is frequently noted in the economic literature is that there is no direct relationship between technological areas and industrial sectors, even though some relational tables try to establish a convergence among both classification systems. When studying manufacturing industry as a whole, the resulting errors are likely to be small, but when studying a particular industry, or even sectors within an industry, classification errors may be problematic for interpretation of empirical results.

Given this problem, there are two different routes for applying this measure in an empirical study. One route would be to conduct a more extended study across technological areas. There would be three possible ways of obtaining a list of firms to have their innovative behavior examined.

The first is to extract a list of firms from the patent documents on the regulated technological areas. A selected sample of the most representative firms would have their innovative behavior mapped over time. A second alternative approach would be to use the list of firms that have notified the regulator the use or commercialization of new substances in the EU, maintained by the CPS&Q. The third approach would be to use list of producers and importers of each regulated chemical substance (unfortunately there are missing data on some substances' profiles), found at the ISIC database.

Studying the patenting behavior of these firms along with the evolution of regulatory stringency could be analyzed if the regulation induced a change in the innovative path or if a technological area was substituted by others. If the research were to focus just on the regulated technological areas, it would not be able to highlight these changes.

For instance, the stringent regulatory framework imposed over time on the agrochemicals industry may have induced more investment in R&D related to genetically modified organisms (GMOs). Instead of using chemicals to avoid certain diseases, a new strain of plant resistant to the disease might be designed. A more extended study on the innovative behavior of firms which were patenting on the technological areas which have suffered from regulatory stringency would be necessary if we are to analyze whether a technological area was substituted by another. GMOs may be a substitute for agrochemicals, but their development is part of another field: biotechnology. This means that a fall in innovative activity in a technological area which had a growth in its regulatory stringency does not mean necessarily that firms innovated less. In other words, heavy regulation on a technological area can incentivize investments on other technological areas, or even the development of new fields of technology. These three approaches correlated to other firm level data opens new possibilities of more detailed empirical studies.

The second route would be to use the measure of regulatory stringency developed in this research as a proxy for econometric studies on the previous cited industrial sectors, particularly associated with the most regulated technological areas. Even though there are several problems when transferring technological area data to industrial sectors, the quantitative measure on A01N, C09B, and C09D are found to be a consistent proxy of regulatory stringency on, respectively, agrochemicals, organic dyes, and coating, paints and inks industrial sectors. This would open the possibility of replicating previous empirical studies on a specific sector with firm level data.

The main advantage of the methodology developed in this research is that it creates new approaches for studying the relationship between stringent regulation and innovation.

Chapter 5

Innovation in Regulated Technological Areas

The study on the EU Council Directive 76/769/EEC in Chapter 4 analyzed the evolution of the restrictions imposed on the use of and market for chemical substances from 1976 to 2003. Each substance and its restriction was associated with the different technological fields linked to the chemical industry. This chapter investigates the evolution of patenting activity in these highly regulated technological areas from 1990 to 2006, from 1990 to 2006, a period during which two big jumps in the level of regulatory stringency occurred.

The starting point of the analysis is the measure of regulatory stringency developed in the previous chapter. This measure shows that within the most heavily regulated technological fields – A01, C08, and C09 – the most impacted areas are A01N associated with agrochemicals; C08F, J, and K associated with organic macromolecular compounds; and C09B and D associated with dyes, paints, resins among other compositions.

In order to overcome the restrictions imposed on the use of certain substances, firms might pursue different strategies. For instance, firms might substitute the regulated substance, change the process route, or acquire end-of-pipe equipment, new control systems (for its processes), or more precise tools to measure residues in the final product. Differently from previous studies which use firm-level data and employ indirect proxies of regulatory stringency, I look at the overall patenting activity in the most heavily regulated areas.

This chapter is organized as follows. Section 5.1 describes the data used. Section 5.2 discusses four research questions suggested by the economic literature regarding the relationship between regulation and innovation, and also details the methodology employed for the investigation. Section 5.3 reports the analyses developed for each technological area. Section 5.4 concludes this chapter.

5.1 Data

The measure of regulatory stringency is the starting point and motivation of this chapter. Table 5.1 summarizes the evolution of this measure for those technological fields that were most heavily impacted by the EU chemicals regulation: A01, C08, and C09. As observed in the previous chapter there were two jumps in stringency, in 1997 and 2003, and the areas mostly regulated in the impacted fields are A01N; C08F, J, and K; and C09B and D.

Table 5.1: Measure of regulatory stringency for the most regulated technological areas

Year	A01N	C08C	C08F	C08G	C08J	C08K	C08L	C09B	C09C	C09D	C09J
1976											
1979								1			
1982			1					1		1	
1983			1	2		2	1	3		4	
1984			1	2		2	1	3		4	
1985	1		1	2		2	3	3	1	6	2
1986	1		1	2		2	3	3	1	6	2
1987	1		1	2		2	3	3	1	6	2
1988	1		1	2		2	3	3	1	6	2
1989	5	3	2	2		3	4	7	6	11	3
1990	5	3	2	2		3	4	7	6	11	3
1991	5	3	2	2		5	4	7	7	13	4
1992	5	3	2	2		5	4	7	7	13	4
1993	5	3	2	2		5	4	7	7	13	4
1994	5	3	2	2		5	4	7	7	13	4
1995	5	3	2	2		5	4	7	7	13	4
1996	5	5	2	4	4	7	4	7	7	20	6
1997	61	14	16	11	30	37	4	43	21	65	27
1998	61	14	16	11	30	37	4	43	21	65	27
1999	69	14	17	11	31	43	4	48	27	74	29
2000	69	14	17	11	31	43	4	48	27	74	29
2001	71	14	17	11	31	43	4	49	27	75	29
2002	72	14	17	11	31	43	4	49	27	76	29
2003	104	18	22	11	40	62	4	86	35	101	38
%	100%	12%	14%	7%	26%	40%	3%	33%	14%	39%	15%
	100%						100%				100%

As observed, all the 104 restrictions imposed on the technological field A01 were associated with area A01N. In field C08, areas C08F, J, and K received 22, 40, and 62 restrictions respectively, corresponding to 80% of the overall number of restrictions imposed on this field. Finally, C09 received 260 restrictions, and the most impacted areas were C09B, and D, with 86 and 101 restrictions respectively, equivalent to 72% of the total restrictions over the field.

Some aspects associated with these technological areas and their importance to the chemical industry must also be pointed out. Several reports relate technological fields to industrial sectors. The work by Schmoch, Laville, Patel, and Frietsch (2003) developed a concordance table between technological areas and industrial sectors studying patenting applications on US, Japan, Germany, France, and UK, from 1997 to 1999.[1]

Each industrial sector was associated with one or more technological areas. Specif-

[1] They considered all applicants with at least five patent applications over this period.

ically, pesticides and agrochemical products (NACE code 24.2) is linked just to one technological area, A01N. Thus, the evolution of area A01N can be a good proxy to evaluate the evolution of the innovation on pesticides and agrochemical products.

Conversely, given the complexity and variety of products and processes, the basic chemicals sector (NACE code 24.1) is associated with forty one areas, including C08F, C08J, C08K, C09B, and C09D. Thus, one cannot associate the evolution of the other five technological areas here analyzed to this industrial sector.

In the analysis that follows I use patent applications as a proxy for innovative activity. It is well known that chemical firms have a high propensity to patent their inventions. This fact is highlighted in the OECD Patent Manual (OECD, 1994, pg. 41):

> Some fields of technology lend themselves better to patenting than others. In electronics, for example, the patenting process may not keep up with fast-moving technological advance, so a firm may prefer to keep its inventions secret rather than seek patent protection. [...] In other fields (chemicals and engineering, to cite just two leading areas), filing for a patent is the usual way for a firm to protect itself in the market.

Therefore, patents represent a good proxy that reflects innovative activity of the chemical industry and consequently chemicals technology. In addition, using patent applications a direct relationship can be established between innovation and the measure of regulatory stringency given that both use the IPC classification.

Given that the regulation I am considering affects the production and market of products in the EU, it is reasonable to study the impact of this regulation over innovative activity in the EU. After highlighting the most regulated technological fields, the data on patent applications was extracted from the ESPACE Bulletin database maintained by the European Patent Office (EPO).

The ESPACE database was chosen given the easy access to bibliographic data of all patents applied, published, and granted in Europe since the EPO was founded. There are more than seventy search fields, such: applicant's country, date of filing, applicant(s), designated contracting states, proprietor's country, proprietor(s), classifications advanced level, all classification, inventor's country, inventor(s), English title, among others. The entire document can be extracted, as well as a database format file with all information regarding patents resulted from the search.

The number of patent applications received by each EU country from 1990 to 2005 for technological fields A01, C08, and C09, are shown in Table 5.2.[2] It is interesting to observe that for most countries there are two peaks in the level of patenting activity, the first around 1990 and the second around 2000. The table also shows that three countries received the largest number of applications: Germany (DE),

[2]In this Table it was considered the first fifteen countries to join the European Community: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and Great Britain.

Great Britain (GB), and France (FR). These three countries represent the largest chemical producers and the leading economies in the EU. Germany represents 26% of the share of chemicals sales, around 296 billion of euros; France represents 13%; and the UK, 12% (Hadhri and Weigel, 2006).

Table 5.2: Total number of patent applications per country of filling from 1990 to 2005

							A01								
Year	AT	BE	DK	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	SE	GB
1990	1,113	1,369	1,175		1,763	1,802	671		1,573	813	1,519		1,276	1,074	1,711
1991	974	1,123	1,009		1,516	1,516	815		1,337	743	1,281		1,157	924	1,449
1992	953	1,101	985		1,549	1,561	739	255	1,346	639	1,262	452	1,129	899	1,454
1993	872	996	913		1,423	1,454	686	688	1,194	613	1,195	716	1,051	893	1,375
1994	949	1,104	958		1,536	1,550	777	775	1,302	645	1,251	806	1,129	936	1,469
1995	926	1,115	967		1,636	1,650	775	782	1,394	625	1,323	804	1,163	973	1,586
1996	1,069	1,228	1,092	697	1,735	1,758	874	889	1,483	717	1,379	921	1,320	1,073	1,641
1997	1,199	1,351	1,276	948	1,960	1,961	1,016	1,040	1,724	832	1,560	1,064	1,471	1,180	1,874
1998	1,393	1,539	1,464	1,140	2,177	2,189	1,144	1,217	1,904	994	1,683	1,200	1,638	1,316	2,071
1999	1,790	1,835	1,800	1,638	2,340	2,353	1,637	1,657	2,134	1,558	1,990	1,659	1,945	1,735	2,266
2000	2,170	2,189	2,187	2,133	2,534	2,545	2,136	2,134	2,389	2,121	2,251	2,126	2,255	2,132	2,453
2001	2,075	2,091	2,071	2,041	2,321	2,332	2,042	2,037	2,207	2,038	2,124	2,044	2,118	2,061	2,268
2002	2,013	2,041	2,053	1,992	2,303	2,306	2,000	1,993	2,150	1,989	2,097	2,000	2,087	2,023	2,236
2003	1,950	1,986	1,986	1,952	2,206	2,203	1,952	1,948	2,072	1,945	2,028	1,951	2,006	1,967	2,146
2004	1,852	1,886	1,864	1,855	2,044	2,055	1,853	1,850	1,968	1,847	1,902	1,852	1,899	1,867	1,992
2005	1,967	1,990	1,969	1,960	2,107	2,118	1,961	1,963	2,050	1,959	1,985	1,961	2,004	1,974	2,087
							C08								
Year	AT	BE	DK	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	SE	GB
1990	2,098	3,193	1,685		4,736	4,887	1,142		3,991	1,395	3,629		2,836	2,514	4,829
1991	1,683	2,564	1,454		4,121	4,245	1,159		3,420	1,167	2,992		2,390	2,009	4,194
1992	1,628	2,510	1,428		4,095	4,225	1,032	367	3,386	1,024	2,948	684	2,370	1,994	4,154
1993	1,584	2,463	1,248		4,035	4,142	934	935	3,325	915	2,838	1,070	2,396	1,882	4,066
1994	1,521	2,303	1,181		3,879	4,035	814	869	3,245	772	2,811	959	2,309	1,730	3,934
1995	1,525	2,259	1,149		3,813	3,991	811	842	3,192	729	2,686	956	2,243	1,682	3,843
1996	1,575	2,342	1,242	926	4,047	4,218	887	976	3,382	809	2,821	1,036	2,423	1,787	4,081
1997	1,703	2,507	1,287	1,289	4,281	4,456	974	1,051	3,601	917	2,963	1,149	2,638	1,908	4,284
1998	1,772	2,621	1,500	1,478	4,328	4,479	1,173	1,247	3,671	1,133	3,000	1,326	2,783	2,028	4,298
1999	2,236	2,812	2,114	2,116	4,517	4,701	1,940	1,996	3,802	1,890	3,211	2,021	2,999	2,396	4,483
2000	2,987	3,195	2,902	2,917	4,506	4,662	2,878	2,897	3,867	2,887	3,363	2,882	3,276	2,932	4,476
2001	3,036	3,234	2,926	2,929	4,412	4,595	2,901	2,924	3,837	2,949	3,378	2,900	3,270	2,960	4,398
2002	3,052	3,214	3,016	3,017	4,142	4,274	3,005	3,011	3,603	3,017	3,275	3,010	3,225	3,064	4,126
2003	3,093	3,242	3,092	3,105	4,184	4,340	3,082	3,099	3,670	3,095	3,363	3,088	3,316	3,136	4,202
2004	3,133	3,258	3,122	3,136	4,078	4,181	3,122	3,134	3,574	3,132	3,323	3,129	3,262	3,143	4,045
2005	3,262	3,382	3,249	3,269	4,130	4,252	3,249	3,267	3,677	3,260	3,433	3,250	3,400	3,268	4,082
							C09								
Year	AT	BE	DK	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	SE	GB
1990	917	1,308	793		2,156	2,294	487		1,692	594	1,442		1,219	1,112	2,265
1991	786	1,121	723		1,940	2,085	542		1,569	533	1,289		1,106	977	2,042
1992	765	1,117	704		2,066	2,176	472	183	1,640	458	1,333	358	1,126	978	2,138
1993	797	1,120	669		2,064	2,151	478	457	1,610	419	1,297	551	1,157	928	2,110
1994	806	1,130	670		2,122	2,208	464	491	1,691	411	1,357	538	1,200	945	2,158
1995	771	1,069	651		2,123	2,259	425	441	1,706	366	1,321	490	1,141	931	2,204
1996	805	1,092	685	490	2,169	2,289	442	518	1,693	425	1,314	551	1,204	962	2,242
1997	882	1,175	755	680	2,342	2,476	525	616	1,810	481	1,472	624	1,309	1,040	2,419
1998	818	1,085	724	661	2,254	2,363	525	601	1,751	500	1,349	636	1,269	946	2,294
1999	1,111	1,301	1,076	1,063	2,363	2,493	964	1,026	1,880	930	1,516	1,013	1,469	1,196	2,405
2000	1,515	1,558	1,451	1,459	2,371	2,451	1,437	1,452	1,941	1,441	1,668	1,430	1,680	1,464	2,374
2001	1,662	1,702	1,582	1,583	2,448	2,524	1,558	1,572	2,021	1,565	1,791	1,561	1,767	1,606	2,464
2002	1,718	1,756	1,687	1,688	2,417	2,483	1,673	1,679	2,001	1,676	1,863	1,675	1,820	1,701	2,425
2003	1,777	1,808	1,765	1,768	2,454	2,531	1,754	1,754	2,077	1,751	1,948	1,753	1,909	1,777	2,469
2004	1,692	1,745	1,695	1,699	2,260	2,347	1,682	1,686	1,915	1,684	1,826	1,684	1,771	1,709	2,270
2005	1,836	1,882	1,842	1,846	2,385	2,485	1,827	1,835	2,064	1,828	1,988	1,828	1,911	1,840	2,404

Since a firm needs to patent its invention in each country where it seeks to be guaranteed protection, then the number of inventions in the EU per year is smaller than the sum of patent applications in these countries for that specific year. In other words, in Table 5.2 the same innovation appears several times, once for each country where the patent was applied.

In order to avoid double counting the patents in my analysis, instead of considering each EU country I will focus on Germany as a representative of the total applications in the EU. Through out the period investigated, Germany has been the country where the largest number of patents were sought. Therefore, it is reasonable to believe that the vast majority of innovations applied in the EU were also applied in Germany.

5.2 Research questions

In this chapter I will concentrate on the relationship between regulatory stringency and innovative activity, to check whether and how tighter restrictions affect innovative behavior of economic agents. However, given that innovative activity of firms depends on a number of different issues, the findings that I am going to highlight must be interpreted as initial evidence. It is useful to start with a summary of the main issues raised by the economic literature and reviewed in Chapter 3.

Since 1990, the Porter Hypothesis has been at the center of this debate. Contradicting the orthodox view according to which a stricter regulation harms firms, Porter asserts that stricter environmental regulation induces firms to innovate, leading to a competitive advantage. As illustrated in Chapter 3, Jaffe and Palmer (1997, pg. 610) identified three possible interpretations of the Porter Hypothesis:

1. Some kinds of environmental regulation – specifically the ones that focus in outcomes rather than processes – provide incentives for innovation.
2. Environmental regulation stimulates some types of innovations, since it constrains a firm's profits and, as a result, the firm will rearrange their investments focusing in certain kinds of R&D.
3. A new regulation induces firms to look for new products and processes that will obey the regulation and also be more profitable.

This Chapter investigates these interpretations for each regulated technological field.

As detailed in Chapter 3 and measured in Chapter 4, chemicals regulation focuses on outcomes rather than processes. Consequently, according to the first interpretation, the increase of regulatory stringency will incentivize innovation.

The second and third interpretations are both associated with the change in the direction of innovative activity. They state that regulatory stringency will influence the kind of innovation that will be pursued by the firm. The motivation for this change in innovative activity is what distinguishes them. According to the second interpretation, firms change the direction of their research because they have their profits constrained, while according to the third, firms change the focus of their research to comply with the regulation. This chapter investigates four research questions.

Did regulation spur patenting activity?

The first question addressed analyzes whether an increase in the stringency of regulation incentivizes firms to innovate more. In the light of the first interpretation of the Porter hypothesis, an increase in the regulatory stringency encourages innovative activity. To answer this question firstly, two different aggregate levels of panel data with fixed-effect are estimated.

$$npat_{it} = \alpha + \beta restrict_{it} + u_{it} \tag{5.1}$$

- $npat_{it}$: number of patents *per* IPC class *per* year
- $restrict_{it}$: number of restrictions imposed *per* IPC class *per* year
- t: year, from 1990 to 2006
- i: IPC classes

The first panel considers patent applications from the twenty seven IPC classes belonging to the three most regulated groups: A01, C08, and C09. Among these classes, eleven are restricted and sixteen unrestricted by this regulation. The second panel considers just the eleven restricted classes.

Secondly, I examine the evolution of the number of patent applications in the most heavily regulated technological areas. As explained above, the orthodox and Porterian views about the effect of regulation on innovation are divergent. In particular, and given the characteristics of regulation under analysis (product regulation), in the light of the first interpretation of the Porter hypothesis an increase in the stringency of regulation incentivizes firms to innovate more.

In order to verify if the most heavily regulated technological areas followed the average of their respective field, the evolution in the number of applications in a given technological area and the share with respect to the patents applied in the technological field are examined. Therefore, the question addressed is whether a technological area (e.g. A01N) increased more or less in comparison to its field (e.g. A01).

In addition, to evaluate whether the two jumps in regulatory stringency (in 1997 and 2003) had an effect on patenting two regressions were computed. Dummy variables were used to identify the two regulatory jumps. In these regressions I analyzed whether regulation caused an effect in the number or in the rate of growth of patent applications.

The first regression proposed investigates whether regulation did not affect the number of patent applications (H_0) against the alternative hypothesis that regulation caused a fall or an increase in the number of patent applications (H_1). The regression and hypotheses are the following:

$$n_t = \alpha + \beta t + \gamma_1 d_{1t} + \gamma_2 d_{2t} + u_t \tag{5.2}$$

- $H_0 : \gamma_1 = 0$ against $H_1 : \gamma_1 \neq 0$
- $H_0^{'} : \gamma_2 = 0$ against $H_1^{'} : \gamma_2 \neq 0$
- $H_0^{''} : \gamma_1 = \gamma_2 = 0$ against $H_1^{''} : \neg(\gamma_1 = \gamma_2 = 0)$

The second regression proposed is a spline. The aim is to verify if there was a change in the rate of growth of patent applications after the regulatory jumps ($t_1 = 1997$ and $t_2 = 2003$). The spline enables to compare the rate of growth of a certain period with the previous one. Thus, if regulation did not affect the rate of growth of patent applications (H_0) against the alternative hypothesis that regulation caused a fall or an increase in the rate of growth of patent applications (H_1). The regression and hypotheses are the following:

$$n_t = (\alpha + \beta t) + \beta^{'}(t - t_1)d_{1t} + \beta^{''}(t - t_2)d_{2t} + u_t \tag{5.3}$$

- $H_0 : \beta^{'} = 0$ against $H_1 : \beta^{'} \neq 0$
- $H_0^{'} : \beta^{''} = 0$ against $H_1^{'} : \beta^{''} \neq 0$
- $H_0^{''} : \beta^{'} = \beta^{''} = 0$ against $H_1^{''} : \neg(\beta^{'} = \beta^{''} = 0)$

Taking into account that there might have been a time-lag between the year when regulation becomes stricter and the year when this has an effect on patenting, I performed two sets of regressions. First, with no lag effect so that the 1997 jump in regulatory stringency has an effect up to 2002, while the 2003 jump will have any effects from 2003 to 2006. Second, with one year time-lag so that the jumps in regulatory stringency have an effect from 1998 to 2003 and from 2004 to 2006.

- n_t: number of patents in a technological area per year
- t: year, from 1990 to 2006
  - $d_1 = 1 \; \forall \; t \in [1997, 2002]$, zero otherwise
  - $d_2 = 1 \; \forall \; t \in [2003, 2006]$, zero otherwise
- or
  - $d_1 = 1 \; \forall \; t \in [1998, 2003]$, zero otherwise
  - $d_2 = 1 \; \forall \; t \in [2004, 2006]$, zero otherwise

These regressions have drawbacks due to the short period of investigation. The hypothesis tests will be valid to check for possible influences in the number or rate of growth of patenting in regulated technological areas, although perhaps not powerful given the small sample size. The regressions results are discussed in the following sections and the complete tables with all parameters are provided in the Appendix C.

Has there been a change in the country of origin of patents?

As emphasized in Chapter 3, a central concern about regulation is that it might cause the delocalization of production towards the so-called "pollution havens." This argument, which is strongly advocated by the orthodox view, states that restrictive regulation increases production costs, justifying the belief that the impact of environmental regulation causes loss of competitiveness and can induce firms to move to countries where the marginal social cost of production would be lower, as people in less regulated countries would have a lower marginal valuation on the environment.

Even though I do not investigate the location of chemical plants, I acknowledge that regulation might have impact over location of R&D activities. Chemical plants, mainly basic and intermediate chemicals, are not easily relocated. Still, regulation may divert resources from firms located in the EU that would otherwise be employed in R&D.

In order to study this issue I examine whether a change in the origin of innovative activity occurred over the period of increasing regulatory stringency in the European Union. I focus on the share of patents originating from EU and non-EU countries to check whether there has been a significant change over the period under investigation.[3]

Two sets of regressions are computed using as dependent variable the difference between non-EU and EU patent applications. The aim is to observe whether the two jumps in regulatory stringency (in 1997 and 2003) caused an impact in the absolute number or in the trend of the difference between non-EU and EU patent applications. The regressions are similar to Equations 5.2 and 5.3, with dummy variables being used to identify the two regulatory jumps.

The first regression verifies if regulation did not affect the the difference between non-EU and EU patent applications (H_0) against the alternative hypothesis that regulation caused a an increase or decrease of this difference (H_1). If this difference increases it is because increased the number of patents applied in Germany originated from non-EU countries. The regression and hypotheses are the following:

$$dpatent_t = \alpha + \beta t + \gamma_1 d_{1t} + \gamma_2 d_{2t} + u_t \tag{5.4}$$

- $H_0 : \gamma_1 = 0$ against $H_1 : \gamma_1 \neq 0$
- $H_0^{'} : \gamma_2 = 0$ against $H_1^{'} : \gamma_2 \neq 0$
- $H_0^{''} : \gamma_1 = \gamma_2 = 0$ against $H_1^{''} : \neg(\gamma_1 = \gamma_2 = 0)$

[3]From 1990 to 1994 there were twelve countries (EU12): Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, Portugal, Spain, The Netherlands, and United Kingdom. From 1995 to 2003 there were fifteen EU countries (EU15): (adding) Austria, Sweden, and Finland. From 2004 to 2006 it was considered the twenty five EU countries (EU25): (adding) Czech Republic, Cyprus, Estonia, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia, and Slovakia.

The second regression is the spline to check whether there was a change in the trend of this difference (between non-EU and EU applications in Germany) after the regulatory jumps ($t_1 = 1997$ and $t_2 = 2003$) in comparison to the previous period. Hence, if regulation did not affect this trend (H_0) against the alternative hypothesis that regulation caused a fall or an increase in this trend. The regression and hypotheses are the following:

$$dpatent_t = (\alpha + \beta t) + \beta^{'}(t - t_1)d_{1t} + \beta^{''}(t - t_2)d_{2t} + u_t \tag{5.5}$$

- $H_0 : \beta^{'} = 0$ against $H_1 : \beta^{'} \neq 0$
- $H_0^{'} : \beta^{''} = 0$ against $H_1^{'} : \beta^{''} \neq 0$
- $H_0^{''} : \beta^{'} = \beta^{''} = 0$ against $H_1^{''} : \neg(\beta^{'} = \beta^{''} = 0)$

To better investigate a possible effect on the origin of the innovative activity a one-year lag effect was also considered.

- $dpatent_t =$ (non-EU patents $-$ EU patents), for a given technological area per year
- t: year, from 1990 to 2006
  - $d_1 = 1 \ \forall \ t \in [1997, 2002]$, zero otherwise
  - $d_2 = 1 \ \forall \ t \in [2003, 2006]$, zero otherwise
- or
  - $d_1 = 1 \ \forall \ t \in [1998, 2003]$, zero otherwise
  - $d_2 = 1 \ \forall \ t \in [2004, 2006]$, zero otherwise

The results are discussed in the following sections and the complete tables containing all parameters are provided in the Appendix C.

Has there been any increase in patenting concentration?

Mahdi, Nightingale, and Berkhout (2002) state that even though regulatory stringency might induce market concentration, bigger firms can take advantage of their scale of production and spread the cost of compliance with the regulation over a larger amount of production. Thus, one large firm might innovate more than several small firms. Therefore, I decided to analyze whether a stricter regulation has induced a concentration in the patenting activity.

The procedure developed for this analysis was the following. I downloaded from the ESPACE Bulletin database information on all patents classified in the technological areas under concern for the years 1990 and 2006. This data includes the name and the country of the applicant among other information.

Next, I identified two groups of applicants: "top ten applicants" (first ten entities in terms of the number of applications in a given technological area, in a given year), and "small players" (those entities which applied for a single patent in the specified area in a given year). Subsequently, I compared the share of patent applications by these two groups in the years 1990 and 2006, to investigate if stricter regulation might have caused a concentration of innovative activity.

The ideal would be to have a proper measure of concentration or even better to data on the distribution of the number of applications per firm, per year. Given this impossibility, looking at these two samples – number of applications by the top ten applicants and the "small players" – can suggest possible changes in these distributions and give hints to help future research.[4]

Has there been a change in the direction of patenting?

As previously discussed, Eads (1980) states that regulation might also impact the direction of innovative activity. Even though several authors have stressed the importance of this issue, there is a lack of empirical analysis to demonstrate whether or not it occurs.

The Oslo Manual (OECD, 1997a, pg. 12) describes the information which can be obtained from the analysis of patent statistics:

> Patent statistics are increasingly used in various ways by technology students as indicators of the output of invention activities. The [...] examination of the technologies patented can give some hints on the directions of technological change.

Patent information is then used to verify if there was a change in the direction of innovative activity from 1990 to 2006. In fact, the Patent Manual states (OECD, 1994, pg. 58):

> The fields in which a firm takes out patents indicate its technology profile. This can be expressed numerically, as a percentage of the firm's patent filings by technology sector.
>
> [...] the firm's specialization profile [...] will partly reflect the firm's innovation policy decisions or marketing and competition strategies.

In addition (OECD, 1994, pg. 59):

> Patents can be particularly helpful in identifying the direction taken by the R&D and innovation effort of a firm [...] The patent portfolios of large firms can be investigated in order to study a company's innovation strategy, its technological diversification and how different fields of knowledge are combined in the firm's activity.

In order to verify whether there was a change in the direction of innovation, I study the evolution of IPC codes linked to the highly regulated technological areas. The

[4] The main pitfall of the data used in this examination was the fact the applicant name is often written with variations in each document. Extra spaces, commas, periods, or even the applicant name written in extent or in shorter forms made this analysis lengthly for a more accurate result. This made difficult to identify the distributions of patent applications by firms for each technological area and their standard deviations.

study of the relationship of these different IPC codes can illustrate the technological trends in a given period of time.

Patent applications are classified under one or as many IPC codes needed to describe the innovation, its different characteristics, functionalities, and usages. As more complex or multidisciplinary the innovation, the patent application will be associated with more IPC codes. For example, the US E.I. Du Pont de Nemours and Company applied the patent "Novel heterocyclic amidines and guanidines as plant fungicides" in 1990. In order to describe this innovation, the selected codes were C07D, indicating that it is an *acyclic or carbocyclic compound*, and A01N indicating that it is used as a *biocide*.

Another example is the following. The firm Arkema France and the Centre National de la Recherche Scientifique (FR) applied in 2006 the patent named "Polymer materials containing dispersed carbon nanotubes." The patent was classified under these six different technological areas, all defined in Table 5.3.

Table 5.3: IPC Classification of the patent application "Polymer materials containing dispersed carbon nanotubes"

IPC code	Definition
C01B	Non-metallic elements; Compounds thereof
C08K	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C08L	Compositions of macromolecular compounds
C09D	Coating compositions, e.g. paints, varnishes, lacquers; Filling pastes; Chemical paint or ink removers; Inks; Correcting fluids; Wood stains; Pastes or solids for coloring or printing; Use of materials therefor
F16L	Pipes; Joints or fittings for pipes; Supports for pipes, cables or protective tubing; Means for thermal insulation in general
H01B	Cables; Conductors; Insulators; Selection of materials for their conductive, insulating, or dielectric properties

Starting from the classification codes the researcher can "read" the innovation and comprehend it better, even without reading all patent document. For example, this innovation is an *electrically-conducting paint* (C09D), given that it contains a *conductive material dispersed in non-conductive organic material* (H01B). Accordingly, it is a coating composition made of a *mixture of different polymers* (C08L), *containing a nonmetallic element* – carbon – (C01B), and a *non-macromolecular organic substance as compounding ingredient on a macromolecular compound* (C08K), which was *engineered in the format of flexible pipes*, nanotubes (F16L).

In order to study the technologies associated with area, for example C09D, in 1990 or 2006, the following procedure was adopted. First, all patents applied under the classification code C09D were downloaded for the year under investigation. The set of other codes linked to the area under consideration was recorded, the code for the area itself being excluded.

Second, in the analysis each patent received equal weight. To obtain the patent application profile in a given year, relative value of the classification codes per patent was calculated. If the patent was classified under two codes, each code received weighting of "0.50", if it was classified under four codes, each received weighting of "0.25" and so forth. The sum of these weights reflects the most important codes, portraying the innovative profile at a given time. The larger the total score of a code, the more closely linked to the investigated area it is.

An example is provided in Table 5.4, with ten patent applications involving technological area C09B. As a result, the "patent profile" has as most important technological areas associated with code C09B, codes C07D and G03G with 17.5% each.

Table 5.4: Example to calculate the "patent profile" in technological area C09B

Patent	C09B	A61K	A61P	A61Q	C07C	C07D	C07K	C08B	D06P	G01N	G02F	G03G	G11B	H04N	∑
# 1: C07D C07K C08B C09B	x					1	1	1							3
# 2: C07D C09B G01N	x					1				1					2
# 3: C07D C09B G01N G11B	x					1				1			1		3
# 4: A61K A61Q C07C C09B D06P	x	1		1	1				1						4
# 5: A61K A61Q C07D C09B	x	1		1		1									3
# 6: C07D C09B G02F G03G G11B	x					1					1	1	1		4
# 7: A61K A61P C07C C09B	x	1	1		1										3
# 8: C09B G03G	x											1			1
# 9: C09B G03G H04N	x											1		1	2
# 10: C09B D06P	x								1						1
# 1: C07D C07K C08B C09B	x					0.33	0.33	0.33							1.00
# 2: C07D C09B G01N	x					0.50				0.50					1.00
# 3: C07D C09B G01N G11B	x					0.33				0.33			0.33		1.00
# 4: A61K A61Q C07C C09B D06P	x	0.25		0.25	0.25				0.25						1.00
# 5: A61K A61Q C07D C09B	x	0.33		0.33		0.33									1.00
# 6: C07D C09B G02F G03G G11B	x					0.25					0.25	0.25	0.25		1.00
# 7: A61K A61P C07C C09B	x	0.33	0.33		0.33										1.00
# 8: C09B G03G	x											1.00			1.00
# 9: C09B G03G H04N	x											0.50		0.50	1.00
# 10: C09B D06P	x								1.00						1.00
"patent profile"		9.1%	3.3%	5.8%	5.8%	17.5%	3.3%	3.3%	12.5%	8.3%	2.5%	17.5%	5.8%	5.0%	100.0%

If the same analysis is undertaken after a period of time it may be observed whether or not a change in the direction of innovative activity occurred. Thus, this last research question analyzes whether the commonly associated technological areas gained or lost importance after the increase in regulatory stringency. This relationship characterizes the direction of the technological development and a change in the most associated technological areas may infer a change in the pattern of investments in R&D by the majority of the applicants. This new path can also provide indications of whether there were changes in the direction and if they were caused by the regulation imposed between 1990 and 2006. The Pearson χ^2 test is calculated and the complete table with all results are provided in the Appendix D.

In addition, I will further ask whether the "patent profile" represents a process or product innovation. In the case of new products, I will ask whether the patent relates to new formulation of existing substances (meaning incremental development) or if it relates instead to new substances (true novel developments). The following analyses will help clarify how this can be observed.

5.3 Empirical analysis

5.3.1 Aggregate level: The Porter hypothesis

This analysis verifies if regulatory restrictiveness impacted positively or negatively innovation. Two groups of IPC classes were proposed to build the panels. Table 5.5 shows the results for these panels with no lag (*restrict*), one-year ($L1$), and two-year ($L2$) lag variation.

Table 5.5: Aggregate: 1990 – 2006

Sample	Coefficient	t-value	P > |t|	
A01, C08, C09				
restrict	3.168	6.14	0.000	F(1,431) = 37.67 (0.000)
L1	3.411	6.63	0.000	F(1,404) = 44.02 (0.000)
L2	3.405	6.06	0.000	F(1,377) = 36.74 (0.000)
11 restricted classes				
restrict	3.168	4.47	0.000	F(1,175) = 19.98 (0.000)
L1	3.411	4.94	0.000	F(1,164) = 24.43 (0.000)
L2	3.405	4.49	0.000	F(1,153) = 20.16 (0.000)

Both panels show that regulatory stringency has impacted positively patenting activity, supporting the Porter hypothesis. The best results are observed with one year lag-effect.

5.3.2 IPC-A01

Agriculture; forestry; animal husbandry; hunting; trapping; and fishing.

Evolution of patenting activity

Table 5.6 illustrates the evolution of the number of patent applications in the field A01, its area A01N, and the share (A01N/A01). The technological field A01 experienced an increase of 26% in the number of applications from 1990 to 2006. However, starting from 2000 the number of applications have been declining.

Table 5.6: Patent applications in Germany: Evolution of patenting in IPC-A01 and A01N

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
A01	**1802**	1516	1561	1454	1550	1650	1758	**1961**	2189	2353	2545	2332	2306	**2203**	2055	2118	**2267**
A01N	**940**	768	791	724	746	756	850	**897**	901	913	929	801	946	**870**	778	918	**1023**
A01N/A01	**0.52**	0.51	0.51	0.50	0.48	0.46	0.48	**0.46**	0.41	0.39	0.37	0.34	0.41	**0.39**	0.38	0.43	**0.45**

The regulated area A01N increased less than its field, by 9% from 1990 to 2000. Thus, the share of A01N has decreased over time, from 52% in 1990 to 45% in 2006. Given that the area A01N does not show the same decreasing trend over the 2000s as its field, since 1998 the share has remained somehow stable, with a noticeable increase in the last two years.

I also computed two regressions in order to verify if regulation caused a fall in the number of patent applications or in the rate of growth. Summarized results are illustrated in Table 5.7.[5]

Table 5.7: A01N: Modeling patents by OLS

	Sample:	**1990 - 2006**		**Sample:**	**1991 - 2006**	**(1 year lag)**
	Coefficient	t-value	P > |t|	Coefficient	t-value	P > |t|
Equation 5.2						
d_1	108.999	1.320	0.211	8.627	0.115	0.911
d_2	114.257	0.851	0.410	-43.742	-0.366	0.721
	F(3,13) =	2.352 (0.120)		F(3,12) =	3.931 (0.036)	
Equation 5.3						
d_1 t	27.246	1.780	0.098	11.816	0.760	0.462
d_2 t	56.328	1.660	0.120	36.954	0.851	0.411
	F(3,13) =	2.911 (0.075)		F(3,12) =	3.85 (0.038)	

Starting with the non-lag regressions (left column) non of the null hypotheses are rejected. Turning to the lagged regressions (right column) I fail to reject H_0 and $H_0^{'}$ but marginally rejects $H_0^{''}$. These offers at most weak evidence for regulatory effect.

In summary, technological area A01N increased although not as much as its field. Additionally, the regressions showed no clear impact of regulation on patent applications in this technological area.

Geographic origin of patent applications

The country of origin of innovations for which application was made in Germany for the area A01N experienced major changes over this period. Table 5.8 which looks at the picture of the evolution in the EU and non-EU patenting in Germany, shows an increase in the number of patent applications and the share of non-EU countries.

Table 5.8: Patent applications in Germany: EU vs non-EU patent applications in A01N

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
EU	**461**	324	362	316	348	364	388	**378**	362	327	369	312	325	**301**	332	350	**411**
	0.49	0.42	0.46	0.44	0.47	0.48	0.46	**0.42**	0.40	0.36	0.40	0.39	0.34	**0.35**	0.43	0.38	**0.40**
non-EU	**479**	444	429	408	398	392	462	**519**	539	586	560	489	621	**569**	446	568	**612**
	0.51	0.58	0.54	0.56	0.53	0.52	0.54	**0.58**	0.60	0.64	0.60	0.61	0.66	**0.65**	0.57	0.62	**0.60**

From 1990 to 2006 there was an increase by 28% in the number of patents originating from non-EU countries. Conversely, applications originating from EU countries diminished by 11%. This fact is reflected in the proportion between EU and non-EU applications, where EU innovations have decreased from 49% to 40% in the total patenting classified under area A01N, in Germany.

Table 5.9 shows the most important countries which have been patenting in Germany from 1990 to 2006, their respective share, and the total quota that these coun-

[5]The complete results are shown in Tables C.1 and C.2.

tries represent over all patent applications.

Table 5.9: Patent applications in Germany: Main countries in A01N

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
DE	294	186	203	193	192	221	248	250	229	227	225	191	198	192	221	218	272
	0.31							0.28						0.22			0.27
US	249	256	255	218	226	247	307	367	364	399	377	298	420	420	321	393	421
	0.27							0.41						0.48			0.41
JP	140	111	107	119	102	91	99	103	105	94	85	98	89	54	50	64	61
	0.15							0.11						0.06			0.06
GB	76	47	57	54	70	57	54	56	53	31	53	35	30	37	38	47	45
	0.08							0.06						0.04			0.04
CH	67	65	52	49	43	49	34	38	34	62	52	42	57	61	32	55	60
	0.07							0.04						0.07			0.06
FR	49	51	66	37	34	37	51	42	34	36	34	43	48	33	35	39	40
	0.05							0.05						0.04			0.04
Total share	0.93	0.93	0.94	0.93	0.89	0.93	0.93	0.95	0.91	0.93	0.89	0.88	0.89	0.92	0.90	0.89	0.88

The increase in the share of non-EU countries was mainly due to US inventors whose share increased from 27% to 41%. Conversely, over the same period there was a decline in patents applied by Japanese inventors, dropping from 15% down to 6% its share. The main EU contributors, Germany, France, and Great Britain, all have decreased in number and share of patent applications.

As anticipated in Section 5.2, I also computed two regressions in order to check whether the change in patenting activity originating from EU and non-EU countries was impacted with the increase of regulatory stringency. The outcomes from Equations 5.4 and 5.5 showed high F-statistics significant at $p < 0.01$ both with and without lag effect, although models with one year lag exhibit higher F-statistics. Summarized results are illustrated in Table 5.10.[6]

Table 5.10: A01N: Modeling patents by OLS

	Sample:	**1990 - 2006**		**Sample:**	**1991 - 2006**	**(1 year lag)**
	Coefficient	t-value	P > |t|	Coefficient	t-value	P > |t|
Equation 5.4						
d_1	107.681	1.920	0.077	94.833	1.850	0.089
d_2	74.167	0.817	0.429	8.879	0.109	0.915
	F(3,13) =	10.04 (0.001)		F(3,12) =	11.29 (0.001)	
Equation 5.5						
d_1 t	14.721	1.340	0.203	27.824	2.550	0.026
d_2 t	-6.593	-0.272	0.790	23.762	0.780	0.451
	F(3,13) =	9.516 (0.001)		F(3,12) =	10.220 (0.001)	

Starting with the non-lag regressions (left column), Eq. 5.4 marginally fails to reject H_0 and fails to reject H_0'. Furthermore Eq. 5.5 fails to reject H_0 and H_0'. Turning to the lagged regressions (right column), Eq. 5.4 marginally fails to reject H_0 and fails to reject H_0', while Eq. 5.5 rejects H_0 and fails to reject H_0'. These

[6]The complete results are illustrated in Tables C.13 and C.14.

offers a weak evidence for regulatory effect of an increase of patents originated from non-EU countries after the first regulatory knot.

In summary, from 1990 to 2006 there was an increase in the share of non-EU applications from 51% to 60% in technological area A01N. The empirical models with one-year lag impact fitted better the data and suggested a positive impact of the first knot of regulatory stringency in number and rate of growth of the difference between non-EU and EU patent applications. This indicates that EU regulation has favored the increase of patenting from non-EU applicants in Germany.

Top applicants and the concentration of innovative activity

One of the issues under investigation concerns the effect of a stricter regulation on the concentration of innovative activity. As set out in Section 5.2, in order to study this issue I looked at the patenting behavior of the "top ten applicants" and of the "small players" in 1990 and 2006. Table 5.11 shows the behavior of these two different groups for technological area A01N.

Table 5.11: Patent applications in Germany: Top applicants and small players on technological area A01N

	1990	2006
# Applications by the top ten applicants	393	355
Share of the top ten applicants	42%	35%
# Small players	257	458
# Applications by small players	225	400
Share of the small players	24%	39%

From 1990 to 2006, the top ten applicants saw a 10% decrease in their total number of patent applications with their share of total patenting activity declining from 42% to 35%.[7] Conversely, applications by small players increased by 78% over the same period, and this reflected also in their contribution to the total applications, from 24% up to 39%. These numbers suggest a decrease in the concentration of innovative activity over the period under study.

It is important to stress that small players are not necessarily small firms. Table 5.12 illustrates other characteristics of the patent applications in these two years that help clarify the previous findings. Considering all applicants, firms diminished their total share in the patenting activity, while universities, research centers, and individual inventors have increased their contribution, from 6% to 18%. This is also associated with the increase in patents with more than one applicant, from 5% to 9% of the total.

[7] In the Appendix B, Table B.1 illustrates the top ten applicants, their country of origin, and number of applications.

Table 5.12: Patent applications in Germany: Profile of applications in technological area A01N

	1990	2006
Type of applicants:		
Firms	94%	82%
Universities or research centers	4%	11%
Individual inventors	2%	7%
# Applications with shared ownership	47	89
Percentage of shared ownership	5%	9%

As seen in Table 5.11 the number of small players is larger than the number of patents applied by them. This happens because individual inventors, as well as research centers and universities, have a more pronounced tendency to develop technology in partnership while firms rarely do this.

However, the increased role of institutions other than firms as applicants does not by itself explain the increase by 78% on the number of patent applications by small players. These has been an increase in the number of firms responsible for a smaller number of patent applications in 2006 relative to 1990.

In summary, the role of small players was enhanced, and the share of the top ten applicants decreased. Thus, innovative activity became less concentrated for technological area A01N, from 1990 to 2006. Nevertheless, it was not possible to correlate the regulatory stringency with patent activity.

The evolution of the relationship among technological areas

Finally, I investigated whether there was a change in the pattern of the innovation in area A01N from 1990 to 2006. As explained in Section 5.2, the patent application profile for both years was computed. Table 5.13 shows all those technological areas which had a relative score greater than 1%, for at least one of the years analyzed.

There was a drastic change in the patent application profile in 1990 in comparison with 2006. In 1990, patents in area A01N were highly concentrated in areas belonging to field C, which has seen a reduction in relative score in 2006 from 75.4% to 46.7%. Meanwhile, technological areas belonging to field A grew in importance, from 18.2% to 45.8%. A Pearson χ^2 test gives a value of 94.8, significant at $p < 0.001$ (4 df) confirming the visual impression of a substantial difference.[8]

Next, Table 5.14 illustrates the areas most closely related to A01N.

In 1990, patent applications in area A01N were mainly associated with new products, new organic substances (codes C07C and C07D). Some examples of patents with these characteristics are illustrated in Table 5.15.

[8]It was calculated based on the number of applications in each field in 1990 and 2006. The complete table is available at Appendix D, Table D.1.

Table 5.13: Patent applications in Germany: Associated technological areas to A01N

		1990	2006
A		**18.2%**	**45.8%**
	A01C	<1%	1.2%
	A23L	1.0%	<1%
	A61K	**6.0%**	**32.9%**
	A61L	2.5%	2.6%
	A61P	2.2%	1.5%
	A61Q	1.0%	1.2%
B		**3.5%**	**4.9%**
	B01J	1.4%	1.3%
	B27K	1.2%	2.0%
C		**75.4%**	**46.7%**
	C02F	1.8%	<1%
	C05G	<1%	1.1%
	C07C	**11.6%**	**4.7%**
	C07D	**42.8%**	**21.8%**
	C07F	**3.7%**	<1%
	C07H	1.0%	1.7%
	C07K	1.6%	1.6%
	C09D	<1%	1.7%
	C12N	2.4%	4.6%
	C12P	1.1%	<1%
	C12Q	<1%	1.0%
	C12R	1.0%	<1%
D		**1.0%**	**<1%**
E		**<1%**	**<1%**
F		**<1%**	**<1%**
G		**<1%**	**1.2%**
H		**<1%**	**<1%**

Table 5.14: A01N: *Preservation of bodies of humans or animals or plants or parts thereof; biocides; pest repellants or attractants; plant growth regulators.*

IPC		1990	2006	Definition
A		18.2%	45.8%	Human necessities
	A61K	6.0%	32.9%	Preparations for medical, dental, or toilet purposes
C		75.4%	46.7%	Chemistry; metallurgy
	C07C	11.6%	4.7%	Acyclic or carbocyclic compounds
	C07D	42.8%	21.8%	Heterocyclic compounds
	C07F	3.7%	< 1%	Acyclic, carbocyclic, or heterocyclic compounds containing elements other than carbon, hydrogen, halogen, oxygen, nitrogen, sulfur, selenium, or tellurium
	C12N	2.4%	4.6%	Micro-organisms or enzymes; compositions thereof; propagating, preserving, or maintaining micro-organisms; mutation or genetic engineering; culture media
				Pearson χ^2 = 192.0 (p-value = 0.000; df = 4)

Table 5.15: A01N: Example of patent applications in 1990.

Classification	Patent application title	Applicant name
A01N C07C C07D	"1-Phenyl-piperidine-2,4-dione with herbicidal activity"	Ciba-Geigy AG (CH)
A01N C07C C07D	"1-Aza-butadienes and fungicides containing them"	BASF AG (DE)
A01N C07C C07D	"Substituted phenoxybenzonitrile derivatives, processes for their preparation and their use as herbicides and plant growth regulators"	Bayer AG (DE)
A01N C07C C07D	"Crotonic acid amide derivatives and insecticides containing the same"	SDS Biotech K.K. (JP)
A01N C07C C07D	"Substituted bicycloheptandione derivatives"	Nippon Soda Co. Ltd. (JP)
A01N C07C C07D	"Biocidal azoxime compounds"	Shell Internationale B.V. (NL)

In 2006 this pattern has changed. Field A grew over this period given the enhanced importance of area A61K latter associated with medical or dental products. Conversely, field C lost importance mainly due to the decrease of areas C07C and C07D, both associated with new organic synthetic compounds. Some examples of patents including area A61K are illustrated in Table 5.16.

Table 5.16: A01N: Example of patent applications in 2006.

Classification	Patent application title	Applicant name
A01N A61K	"Phosphoinositide modulation for the treatment of Alzheimer's disease"	The Trustees of Columbia University in the City of New York (US)
A01N A61K	"Facially amphiphilic polymers and oligomers, compositions thereof, and use thereof in methods of treating cancer"	The Trustees of the University of Pennsylvania (US) and University of Massachusetts (US)
A01N A61K	"Prevention of neurodegeneration by macrolide antibiotics"	The UAB Research Foundation (US)
A01N A61K C12N	"Isolated myeloid-like bone marrow cell populations and methods of treatment therewith"	The Scripps Research Institute (US)
A01N A61K A61P C12N	"Method for isolating stem cells from cryopreserved dental tissue"	Stiftung Caesar (DE)

In 2006 there also occurred a small increase in the relative share of area C12N associated with recent technological fields on micro-organisms and genetic engineering (biotechnology). This growth reflects the growth of patent applications on preservation of bodies, biocides, and plant growth regulators associated with enzymes and micro-organisms, and not to new synthetic organic compounds. Some examples are shown in Table 5.17.

Table 5.17: A01N: Example of patent applications in 2006.

Classification	Patent application title	Applicant name
A01N C12N	"Cancer-targeted viral vectors"	The Trustees of Columbia University in the City of New York (US)
A01N C12N	"Transgenic ungulates expressing CTLA4-IG and uses thereof"	Revivicor, Inc. (US)
A01N C12N	"Recovery of tissue function following administration of B cells to injured tissue"	ACTX, Inc. (US)
A01N C07K C12N	"Insect-specific protease recognition sequences"	Pioneer-Hi-Bred International, Inc. (US) and E.I. Du Pont de Nemours and Co. (US)
A01H A01N C07K C12N	"Improvement of disease resistance of plant by introducing transcription factor gene"	National Institute of Agrobiological Sciences (JP)

Clearly, there was a change in the direction of innovative activity associated with code A01N. The patent application profile in 1990 is undoubtedly different than the patent application profile in 2006.

As seen in Chapter 4, in 1997 the majority of restrictions imposed were not applied on:

> *(a) medicinal or veterinary products; (b) cosmetic products; (c) motor fuels, mineral oil products intended for use as fuel in mobile or fixed combustion plants, fuels sold in closed systems; (d) artists' paints.*

Therefore, the change in the direction of the innovation coincides with the regulation imposed on technological area A01N in 1997. There was an increase in importance of code A61K, the uses of which remained unrestricted by regulation.

5.3.3 IPC-C08

Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon.

Evolution of patenting activity

From 1990 to 2006, the number of patent applications in field C08 decreased by 9%, with a short period of growth between 1995 and 1999. Table 5.18 illustrates the evolution in the number of patent applications in technological field C08 and its most regulated areas.

Table 5.18: Evolution of patent applications in Germany: IPC-C08, F, J and K.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
C08	**4887**	4245	4225	4142	4035	3991	4218	**4456**	4479	4701	4662	4595	4274	**4340**	4181	4252	**4447**
C08F	**1346**	1207	1100	1189	1182	1140	1252	**1325**	1315	1492	1433	1410	1169	**1188**	1090	1115	**1069**
C08F/C08	**0.28**	0.28	0.26	0.29	0.29	0.29	0.30	**0.30**	0.29	0.32	0.31	0.31	0.27	**0.27**	0.26	0.26	**0.24**
C08J	**1022**	942	945	910	943	906	899	**1016**	959	1053	1049	1018	889	**876**	864	910	**930**
C08J/C08	**0.21**	0.22	0.22	0.22	0.23	0.23	0.21	**0.23**	0.21	0.22	0.23	0.22	0.21	**0.20**	0.21	0.21	**0.21**
C08K	**1143**	1047	963	936	931	897	986	**1011**	1047	1053	1089	1033	955	**974**	998	1021	**1062**
C08K/C08	**0.23**	0.25	0.23	0.23	0.23	0.22	0.23	**0.23**	0.23	0.22	0.23	0.22	0.22	**0.22**	0.24	0.24	**0.24**

The most regulated areas followed the same pattern of field C08. Areas C08F, J, and K had small variations through the years, decreasing after 2000. Overall, these areas dropped their number of applications by 21%, 9%, and 7%, respectively.

As explained in Section 5.2 and already demonstrated for technological area A01N, two regressions were computed for each regulated area. Summarized results are shown in Table 5.19.[9]

Starting with the unlagged regressions (left column), for area C08F H_0 is marginally rejected, $H_0^{'}$ fail to be rejected, and $H_0^{''}$ is rejected. Looking at the lagged regressions, H_0 and $H_0^{'}$ fail to be rejected, while $H_0^{''}$ is marginally rejected.

For area C08J, unlagged regressions marginally rejected H_0 and $H_0^{''}$, while fails to reject $H_0^{'}$. Turning to the lagged regressions non of the null hypotheses are rejected.

Lastly, for area C08K unlagged regressions marginally rejected H_0 and $H_0^{'}$, while fails to reject $H_0^{''}$. Turning to the lagged regressions H_0 is marginally rejected, while $H_0^{'}$ and $H_0^{''}$ fails to be rejected.

In summary there was a decrease in patenting for these three regulated areas. From 1990 to 2006 technological area C08F showed a decrease higher than its field, while areas C08J and K followed more closely the average behavior of their field (C08). Regarding the proposed regressions, overall unlagged models showed more

[9] The complete results are illustrated in the Appendix C.

Table 5.19: C08F, J and K: Modeling patents by OLS

	Sample: 1990 - 2006 Coefficient	t-value	P > |t|	Sample: 1991 - 2006 (1 year lag) Coefficient	t-value	P > |t|
C08F						
Equation 5.2						
d_1	255.058	2.730	0.017	166.072	1.510	0.158
d_2	90.155	0.595	0.562	-55.731	-0.318	0.756
	F(3,13) =	7.270 (0.004)		F(3,12) =	4.296 (0.028)	
Equation 5.3						
d_1 t	24.447	1.120	0.282	-9.319	-0.355	0.729
d_2 t	-48.592	-1.010	0.332	-133.175	-1.820	0.094
	F(3,13) =	3.567 (0.044)		F(3,12) =	2.191 (0.142)	
C08J						
Equation 5.2						
d_1	132.557	2.740	0.017	74.620	1.170	0.266
d_2	86.659	1.100	0.289	28.195	0.277	0.786
	F(3,13) =	5.374 (0.013)		F(3,12) =	1.247 (0.336)	
Equation 5.3						
d_1 t	22.098	1.930	0.075	-1.644	-0.113	0.912
d_2 t	18.399	0.728	0.480	-22.305	-0.547	0.594
	F(3,13) =	2.097 (0.150)		F(3,12) =	0.259 (0.853)	
C08K						
Equation 5.2						
d_1	148.483	2.380	0.033	111.865	2.130	0.055
d_2	210.355	2.080	0.058	151.072	1.810	0.095
	F(3,13) =	1.916 (0.177)		F(3,12) =	2.426 (0.116)	
Equation 5.3						
d_1 t	22.723	1.790	0.097	0.888	0.070	0.945
d_2 t	50.521	1.800	0.096	9.055	0.257	0.801
	F(3,13) =	1.229 (0.339)		F(3,12) =	0.707 (0.566)	

significant results than the one-year lag ones. For areas C08F and C08J it is observed a positive effect of the first regulatory knot (significant at $p < 0.05$) in the number of applications. While for area C08K both regulatory knots are found to have a positive effect over the number of patent applications, however the jointed effect is found not significant. Hence, little evidence is found of a regulatory impact on both number and trend of applications in these three regulated areas.

Geographic origin of patent applications

There was little variation in the share of EU innovations applied in Germany from 1990 to 2006. For areas C08F and J, there was a small increase in patenting from EU countries, while for area C08K EU patents remained stable. However, over 60% of the innovations are originated from non-EU countries. Table 5.20 shows the evolution of patent applications in Germany from EU and non-EU countries.

Table 5.21 illustrates the patenting activity per country for these three technological areas. Three countries contribute with similar shares in these areas: US, Germany, and Japan. For C08F and C08K the leading origin of the applications is the US, followed by Japan and Germany for the whole period. In the case of C08J, in 1990 the most of the patents were originated from US, followed by Japan and Germany, while in 2006 Japan has taken the leadership over the US.

Table 5.20: EU vs non-EU patent applications in Germany: C08F, C08J, and C08K

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C08F									
EU	**482**	418	370	459	438	459	477	**535**	499	577	515	558	460	**476**	434	442	**411**
	0.36	0.35	0.34	0.39	0.37	0.40	0.38	**0.40**	0.38	0.39	0.36	0.40	0.39	**0.40**	0.40	0.40	**0.38**
non-EU	**864**	789	730	730	744	681	775	**790**	816	915	918	852	709	**712**	656	673	**658**
	0.64	0.65	0.66	0.61	0.63	0.60	0.62	**0.60**	0.62	0.61	0.64	0.60	0.61	**0.60**	0.60	0.60	**0.62**
								C08J									
EU	**350**	312	325	297	354	368	349	**371**	332	375	369	370	252	**315**	307	329	**354**
	0.34	0.33	0.34	0.33	0.38	0.41	0.39	**0.37**	0.35	0.36	0.35	0.36	0.28	**0.36**	0.36	0.36	**0.38**
non-EU	**672**	630	620	613	589	538	550	**645**	627	678	680	648	637	**561**	557	581	**576**
	0.66	0.67	0.66	0.67	0.62	0.59	0.61	**0.63**	0.65	0.64	0.65	0.64	0.72	**0.64**	0.64	0.64	**0.62**
								C08K									
EU	**385**	351	315	268	312	348	352	**326**	335	354	357	375	342	**349**	354	324	**365**
	0.34	0.34	0.33	0.29	0.34	0.39	0.36	**0.32**	0.32	0.34	0.33	0.36	0.36	**0.36**	0.35	0.32	**0.34**
non-EU	**758**	696	648	668	619	549	634	**685**	712	699	732	658	613	**625**	644	697	**697**
	0.66	0.66	0.67	0.71	0.66	0.61	0.64	**0.68**	0.68	0.66	0.67	0.64	0.64	**0.64**	0.65	0.68	**0.66**

The main EU contributor is Germany which has in all three regulated areas decreased in number of applications, however there was little variation in the correspondent share from 1990 to 2006. Other representative EU countries, France and Great Britain, also experienced little variation in their respective share over the same period.

The most important non-EU countries, US and JP, also saw their shares of total patenting in all three areas diminish. The US contribution to the total number of patent application in Germany in area C08K experienced the largest fall from its 1998 peak. Japan saw small variations in the share over of the total applications for the areas F and K, with an increase since 1995 for area J.

In addition, from 1990 to 2006 the total share of the main EU and non-EU contributors decreased for all three regulated areas from field C08. In 1990, C08F the top five contributors summed 87% of the total applications, while in 2006 this sum decreased to 80%. Similar numbers are observed for the other two areas. Hence, given that occurred a decrease in the sum of the two main non-EU countries (US and JP), other non-EU countries must have been patenting patenting more.

The following Table, 5.22, illustrates a summary of the regression results regarding Equations 5.4 and 5.5. These were computed to check whether the patenting activity from EU or non-EU countries were impacted by the increase of regulatory stringency in the EU.

Starting with area C08F, unlagged regressions (left column) fails to reject H_0 and $H_0^{'}$ while rejects $H_0^{''}$. Lagged regression fails to reject H_0 and $H_0^{'}$ while for Equation 5.4 rejects $H_0^{''}$ and Equation 5.5 fails to reject $H_0^{''}$.

Unlagged regressions for area C08J rejects H_0, fails to reject $H_0^{'}$, and marginally rejects $H_0^{''}$. Lagged regressions marginally rejects H_0 and fails to reject $H_0^{'}$ and $H_0^{''}$.

For area C08K, unlagged Equation 5.4 fails to reject H_0 and $H_0^{'}$, but rejects $H_0^{''}$.

Table 5.21: Origin of patent applications in Germany: C08F, C08J, and C08K

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C08F									
DE	248	216	219	266	262	251	262	279	254	300	274	259	211	244	203	195	199
	0.18					0.22		0.21						0.21			0.19
US	465	437	406	421	464	425	456	467	490	517	535	432	339	360	321	326	323
	0.35				0.39			0.35						0.30			0.30
JP	327	287	260	256	217	231	263	262	279	303	303	328	271	266	264	266	251
	0.24				0.18			0.20						0.22			0.24
FR	58	62	25	54	26	51	69	82	76	61	72	84	63	58	50	45	49
	0.04							0.06						0.05			0.05
GB	73	53	44	35	39	37	29	46	46	68	39	47	32	31	21	25	30
	0.05							0.03						0.03			0.03
Total share	0.87	0.87	0.87	0.87	0.85	0.87	0.86	0.86	0.87	0.84	0.85	0.82	0.78	0.81	0.79	0.77	0.80
								C08J									
DE	186	171	189	197	224	238	221	229	203	214	216	222	144	167	150	183	179
	0.18					0.26		0.23						0.19			0.19
US	370	369	373	360	352	332	330	386	356	377	346	303	270	263	255	226	248
	0.36			0.40				0.38						0.30			0.27
JP	241	215	189	197	170	161	188	209	219	262	286	300	298	241	238	268	261
	0.24					0.18		0.21					0.34	0.28			0.28
FR	58	50	49	24	40	25	40	49	32	31	38	48	32	40	32	38	39
	0.06							0.05						0.05			0.04
GB	51	34	40	29	27	25	22	27	21	35	21	20	15	25	17	19	15
	0.05							0.03						0.03			0.02
Total share	0.89	0.89	0.89	0.89	0.86	0.86	0.89	0.89	0.87	0.87	0.86	0.88	0.85	0.84	0.80	0.81	0.80
								C08K									
DE	214	187	170	170	204	219	213	208	191	213	213	212	211	190	173	176	191
	0.19					0.24		0.21						0.20			0.18
US	377	352	329	342	324	285	321	332	386	383	336	289	289	282	268	289	321
	0.33							0.33	0.37					0.29			0.30
JP	297	271	245	234	214	192	252	282	241	243	313	302	242	242	266	297	277
	0.26							0.28						0.25			0.26
FR	59	43	32	27	36	39	52	46	67	34	60	59	42	49	53	48	47
	0.05							0.05						0.05			0.04
GB	40	39	39	22	21	32	21	22	15	33	9	14	15	20	12	15	17
	0.03							0.02						0.02			0.02
Total share	0.86	0.85	0.85	0.85	0.86	0.86	0.87	0.88	0.86	0.85	0.85	0.85	0.84	0.80	0.77	0.81	0.80

For unlagged Equation 5.5 none of the null hypotheses are rejected. Regarding the lagged regressions, none of the null hypotheses are rejected.

In summary, in all three regulated areas, when comparing the evolution of EU and non-EU patent applications there was little variation through these years. Adding to it, for area C08F regressions infer no regulatory impact of regulatory stringency in the geographical origin of patent applications. For area C08J regressions infer an effect of the first regulatory knot favoring non-EU applicants in Germany. Lastly, for area C08K there is little evidence of regulatory impact on the origin of patent applications.

Table 5.22: C08F, J and K: Modeling patents by OLS

	Sample: Coefficient	1990 - 2006 t-value	P > |t|	Sample: Coefficient	1991 - 2006 t-value	(1 year lag) P > |t|
C08F						
Equation 5.4						
*d*_1	70.847	1.370	0.194	94.833	1.850	0.089
*d*_2	54.919	0.656	0.523	8.879	0.109	0.915
	F(3,13) =	3.755 (0.038)		F(3,12) =	11.29 (0.001)	
Equation 5.5						
*d*_1 t	19.329	2.030	0.064	9.850	0.826	0.425
*d*_2 t	24.547	1.170	0.265	12.675	0.381	0.710
	F(3,13) =	4.462 (0.023)		F(3,12) =	1.743 (0.211)	
C08J						
Equation 5.4						
*d*_1	106.480	2.170	0.050	114.361	2.250	0.044
*d*_2	90.620	1.140	0.276	101.010	1.250	0.235
	F(3,13) =	2.559 (0.100)		F(3,12) =	2.369 (0.122)	
Equation 5.5						
*d*_1 t	26.419	3.170	0.007	15.427	1.330	0.208
*d*_2 t	25.708	1.400	0.186	8.485	0.262	0.798
	F(3,13) =	4.545 (0.022)		F(3,12) =	1.188 (0.356)	
C08K						
Equation 5.4						
*d*_1	118.793	2.330	0.037	88.755	1.560	0.144
*d*_2	181.493	2.200	0.047	158.608	1.760	0.104
	F(3,13) =	2.042 (0.158)		F(3,12) =	1.073 (0.397)	
Equation 5.5						
*d*_1 t	11.302	1.040	0.318	-2.798	-0.222	0.828
*d*_2 t	34.331	1.430	0.177	14.457	0.412	0.688
	F(3,13) =	0.841 (0.495)		F(3,12) =	0.359 (0.784)	

Top applicants and the concentration of innovative activity

The following issue under investigation is the effect of a stricter regulation on the concentration of innovative activity. Table 5.23 illustrates the number of applications and the shares of the "top ten applicants" and "small players" in 1990 and 2006. The three areas here analyzed evolved similarly, even though in different scales.

Table 5.23: Patent applications in Germany: Top applicants and small players in technological areas C08F, J, and K

	C08F 1990	C08F 2006	C08J 1990	C08J 2006	C08K 1990	C08K 2006
# Applications by the top ten applicants	319	309	197	210	259	238
Share of the top ten applicants	24%	29%	19%	23%	23%	22%
# Small players	184	225	236	347	248	289
# Applications by small players	176	214	222	308	233	265
Share of the small players	13%	20%	22%	33%	20%	25%

From 1990 to 2006 the top ten applicants in areas C08F and J increased their share, while for area C08K fell by 1%.[10] For all three technological areas there was

[10] In the appendix B, Tables B.2, B.3, and B.4 list the top applicants for the technological areas C08F, J, and K.

an increase in number and share of total applications by small players.

Table 5.24 illustrates other characteristics of the patent applications in these two years that help clarify the previous findings. As already observed in technological area A01N, in all three areas the kind of applicants also changed from 1990 to 2006. The share of universities, research centers, and individual inventors increased their importance. Again, it can be observed that this is associated with the increase on the applications with shared ownership, and in the number of small players.

Table 5.24: Patent applications in Germany: Profile of technological areas C08F, J, and K

	C08F		C08J		C08K	
	1990	2006	1990	2006	1990	2006
Type of applicant:						
Firms	98%	92%	98%	91%	98%	94%
Universities or research centers	1%	7%	1%	6%	1%	4%
Individual inventors	1%	1%	1%	3%	1%	2%
# Applications with shared ownership	49	70	35	74	51	64
Percentage of shared ownership	4%	7%	3%	8%	4%	6%

Summarizing, there was no increase in patenting concentration. For areas C08F and J the share of applications by small players have increased to a larger extent than the share by the top ten players. For area C08K there was an increase in the share of small players and a small decrease in the share of top ten players. In all cases, this indicates a decrease in the concentration of innovative activity for all three areas, from 1990 to 2006.[11] Nevertheless, it was not possible to correlate the regulatory stringency with the concentration of the patenting activity.

The evolution of the relationship among technological areas

In order to draw a clearer picture of how these three regulated areas have evolved, I investigated whether there was a change in the patent application profile of areas C08F, J, and K from 1990 to 2006. Table 5.25 shows this evolution for both years in all three regulated areas (technological areas which scored less than 1% in both years were not included).

Differently from patent applications in area A01N, there were no major changes in the pattern from 1990 to 2006. Results from the Pearson χ^2 test calculated comparing the number of applications in each field in 1990 and 2006 are significant at $p < 0.001$ and much lower than for area A01N, valuing 15.6, 24.4, and 26.5 respectively for regulated areas C08F, J, and K.[12]

There is a broader variety of related technological areas from all fields, which can

[11] Results regarding the increase in the share of small players seems robust. Even when defining "small players" as entities that applied three or less patents in a given year, obtained similar results.

[12] The complete tables are available at Appendix D, Tables D.3, D.5, and D.7.

Table 5.25: C08F, J, and K: Related technological areas

C08F		1990	2006	C08J		1990	2006	C08K		1990	2006
A		**6.0%**	**8.0%**	A		**3.3%**	**6.4%**	A		**3.4%**	**3.2%**
	A61K	2.4%	3.7%		A61K	<1%	1.2%		A61K	1.2%	<1%
	A61L	1.2%	2.6%		A61L	**1.1%**	**2.5%**				
B		**9.3%**	**12.2%**	B		**28.0%**	**24.8%**	B		**6.9%**	**12.5%**
	B01D	<1%	1.0%		B01D	3.0%	1.2%		B29C	1.5%	1.7%
	B01F	1.0%	<1%		B01J	1.5%	1.4%		B32B	**<1%**	**3.0%**
	B01J	**3.7%**	**6.1%**		B05D	1.1%	1.5%		B60C	**<1%**	**3.9%**
	B32B	<1%	1.4%		B29B	1.8%	2.0%				
					B29C	**7.3%**	**5.2%**				
					B29K	**2.9%**	**<1%**				
					B29L	1.2%	<1%				
					B32B	**5.3%**	**7.1%**				
					B65D	<1%	1.1%				
C		**69.8%**	**67.4%**	C		**57.5%**	**57.5%**	C		**79.4%**	**74.6%**
	C04B	<1%	1.7%		C03C	<1%	1.0%		C01B	<1%	1.5%
	C07C	4.9%	3.9%		C08F	**6.0%**	**7.0%**		C04B	1.0%	<1%
	C07D	1.6%	<1%		C08G	**12.8%**	**6.1%**		C07C	1.6%	1.4%
	C07F	4.3%	3.8%		C08K	**8.0%**	**10.1%**		C07D	**3.0%**	**1.1%**
	C08C	2.3%	2.4%		C08L	**18.1%**	**21.4%**		C07F	1.6%	1.1%
	C08G	**9.5%**	**6.0%**		C09D	3.3%	4.6%		C08F	**3.2%**	**3.1%**
	C08J	**5.2%**	**7.5%**		C09J	1.6%	<1%		C08G	**6.4%**	**4.5%**
	C08K	3.2%	4.0%		C09K	2.0%	1.4%		C08J	**6.9%**	**10.4%**
	C08L	**13.9%**	**16.4%**						C08L	**41.2%**	**36.6%**
	C09D	**9.2%**	**8.6%**						C09C	1.4%	2.2%
	C09J	3.7%	3.8%						C09D	**4.3%**	**5.1%**
	C09K	1.7%	1.8%						C09J	1.5%	2.0%
	C10L	1.1%	<1%						C09K	**3.4%**	**1.7%**
	C10M	2.0%	2.1%								
	C11D	1.3%	<1%								
D		**2.8%**	**2.7%**	D		**3.9%**	**2.8%**	D		**1.8%**	**1.8%**
									D01F	<1%	1.0%
	D21H	1.1%	<1%		D01F	1.4%	<1%				
					D06M	<1%	1.0%				
E		**0.2%**	–	E		**0.3%**	**0.1%**	E		**0.3%**	**0.1%**
F		**0.5%**	**0.8%**	F		**1.2%**	**0.5%**	F		**0.8%**	**0.9%**
G		**9.4%**	**6.5%**	G		**2.9%**	**2.3%**	G		**2.6%**	**2.5%**
	G01N	<1%	1.4%								
	G02B	2.6%	1.9%								
	G03F	3.5%	1.4%								
H		**2.1%**	**2.4%**	H		**2.9%**	**5.6%**	H		**4.9%**	**4.3%**
					H01B	1.0%	1.2%		H01B	2.3%	1.8%
					H01M	<1%	2.6%				

be explained by the horizontal scope of applicability of macromolecular compounds. Polymers are present in all kinds of products, for different industries and direct consumer use. However, in all three cases and for both years, most related areas came from field C. Next, I discuss separately the three technological areas.

C08F Starting with C08F, Table 5.26 defines its most closely related technological areas. Through these years there was no perceptive change in the trend of the technological development or in the direction of the innovation. In addition, field C kept the largest share of related areas, from 69.8% in 1990 to 67.4% in 2006.

The four areas highlighted in field C are associated with different compositions within macromolecular or non-macromolecular substances (C08G), new products (C08L and C09D), and better processes (C08J).

Table 5.26: C08F: *Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds*

IPC		1990	2006	Definition
A		**6.0%**	**8.0%**	**Human necessities**
	A61K	2.4%	3.7%	Preparations for medical, dental, or toilet purposes
B		**9.3%**	**12.2%**	**Performing operations; transporting**
	B01J	3.7%	6.1%	Chemical or physical processes (e.g. catalysis, colloid chemistry; their relevant apparatus)
C		**69.8%**	**67.4%**	**Chemistry; metallurgy**
	C08G	9.5%	6.0%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
	C08J	5.2%	7.5%	Working-up; general processes of compounding; after-treatment not covered by subclasses
	C08L	13.9%	16.4%	Compositions of macromolecular compounds
	C09D	9.2%	8.6%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes pr solids for coloring or printing; use of materials therefor)
G		**9.4%**	**6.5%**	**Physics**
	G02B	2.6%	1.9%	Optical elements, systems, or apparatus
	G03F	3.5%	1.4%	Photomechanical production of textured or patterned surfaces (e.g. for printing, for processing of semiconductor devices; materials therefor; originals therefor; apparatus specially adapted therefor)
				Pearson χ^2 = 24.2 (p-value = 0.001; df = 7)

The presence of area B01J is associated with improvements in the chemical process such the use of catalysts, a key issue that affects the production process of polymers in efficiency and costs. Areas A61K, G02B, and G03F are associated with the application of organic macromolecular compounds in medical or dental care (e.g. dentures and other prosthesis), optical apparatus, and photosensitive materials (e.g. screens). Some examples of these patents area illustrated in Table 5.27.

Table 5.27: C08F: Examples of patent applications.

Year	Classification	Patent application title	Applicant name
1990	C08F C08G C08L G02B	"Interpenetrating network of a polyol (allyl carbonate) and epoxy resin, and a process for the preparation thereof"	Akzo Nobel N.V. (NL)
1990	C08F C09D	"Radiation-curable blend of a cellulose ester and a multifunctional (meth)acrylate"	Aqualon Co. (US)
1990	B01J C08F C08G	"Recovery of double metal cyanide complex catalyst from a polymer"	Arco Chemical Technology L.P. (US)
1990	C07C C07F C08F G03F	"Cationic photo-initiated polymerization process and the preparation of relief motifs or photo-images using sulfonium salts"	BASF AG (DE)
1990	C08F G02B	"Graft copolymer, solution containing the graft copolymer, and method of treating contact lens with the solution"	Tomei Sangyo Kabushiki Kaisha (JP)
2006	B01J C08F C08L	"Recovery of fluorinated surfactants from a basic anion exchange resin having quaternary ammonium groups"	3M Innovative Properties Co. (US)
2006	B01J C01G C08F	"Improved polymer halogenation process with catalyst recovery"	Albemarle Corp. (US)
2006	A61K C08F	"Contact drug delivery system"	Auburn University (US)
2006	A61K A61Q C08F	"Use of a water-in-water emulsion polymers in the form of a thickener for cosmetic preparations"	BASF SE (DE)
2006	C08C C08F C08J C08L	"Method for inhibiting agglomeration of block copolymers"	Firestone Polymers LLC (US)

The areas which grew in relative importance over the period 1990 to 2006 were B01J and C08J both associated with process developments, C08L, associated with the development of new products from existing substances, and A61K, associated with medical or dental products.

C08J Table 5.28 shows the definitions of the most relevant areas regarding C08J. In both years, these areas belong to fields B and C.

Table 5.28: C08J: *Working-up; general processes of compounding; after-treatment not covered by subclasses C08B, C08C, C08F, C08G*

IPC		1990	2006	Definition
B		28.0%	24.8%	Performing operations; transporting
	B29C	7.3%	5.2%	Shaping or joining plastics; shaping of substances in a plastic state, in general; after-treatment of the shaped products (e.g. repairing)
	B32B	5.3%	7.1%	Layered products, i.e. products built-up of strata of flat (e.g. cellular or honeycomb, form)
C		57.5%	57.5%	Chemistry; metallurgy
	C08F	6.0%	7.0%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
	C08G	12.8%	6.1%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
	C08K	8.0%	10.1%	Use of inorganic or non-macromolecular organic substances as compounding ingredients
	C08L	18.1%	21.4%	Compositions of macromolecular compounds
				Pearson χ^2 = 38.0 (p-value = 0.000; df = 5)

In field B, highlighted areas (B29C and B32) are associated with the production process of articles made of polymers (e.g. joining or layering plastics). In field C, the stressed areas are associated with macromolecular developments and compositions (of organic or inorganic substances). Examples are shown in Table 5.29.

Table 5.29: C08J: Examples of patent applications.

Year	Classification	Patent application title	Applicant name
1990	B29C B32B C08J	"Method for manufacturing an element with a synthetic foam layer and element obtained by that method"	Astechnologies Inc. (US)
1990	C08G C08J	"Process for the preparation of elastic compact or cellular moulded articles on the basis of elastomers containing N-benzylurea groups, such elastomers and N-benzyl-polyoxyalkylene-polyamines suitable therefor"	BASF AG (DE)
1990	B29C C08J C08K C08L	"Resin composition for film and process for producing film using the same"	Mitsui Petrochemical Ind. Ltd. (JP)
1990	B29C C08F C08G C08J C08K C08L	"Process for the production of molded article of fiber-reinforced thermosetting resin, and materials therefor"	Toyota Jidosha Kabushiki Kaisha (JP) and A. G. International Chemical Co. Inc. (JP)
2006	B32B C08J C23C	"Microporous article having metallic nano-particle coating"	3M Innovative Properties Co. (US)
2006	C08F C08J	"Aqueous dispersion of hybrid particles consisting of organic or inorganic pigment particles and organic nano-particles and process for preparing the same"	Topchim N.V. (BE)
2006	B60C C08J C08K C08L	"Rubber composition for coating textile cord and tire using the same"	Sumitomo Rubber Ind. Ltd. (JP)
2006	B32B C08J C08L	"Methods of making water-soluble film with resistance to solubility prior to being immersed in water"	The Procter and Gamble Co. (US)

From 1990 to 2006 the areas which showed a relative increase (even though small) were B32B associated with new processes, C08F regarding new macromolecular substances, and C08K and C08L regarding new products.

C08K In both years, the two main fields associated with area C08K are B and C, as described in Table 5.30.

Field B was responsible for 6.9% in 1990 and 12.5% in 2006 of relative importance. The most relevant areas within this field are B32B and B60C, the former already de-

Table 5.30: C08K: *Use of inorganic or non-macromolecular organic substances as compounding ingredients*

IPC		1990	2006	Definition
B		6.9%	12.5%	Performing operations; transporting
	B32B	<1%	3.0%	Layered products, i.e. products built-up of strata of flat (e.g. cellular or honeycomb, form)
	B60C	<1%	3.9%	Vehicle tires; tyre inflation; tyre changing; connecting valves to inflatable elastic bodies in general; devices or arrangements related to tires
C		79.4%	74.6%	Chemistry; metallurgy
	C07D	3.0%	1.1%	Heterocyclic compounds
	C08G	6.4%	4.5%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
	C08J	6.9%	10.4%	Working-up; general processes of compounding; after-treatment not covered by subclasses
	C08L	41.2%	36.6%	Compositions of macromolecular compounds
	C09D	4.3%	5.1%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes or solids for coloring or printing; use of materials therefor)
	C09K	3.4%	1.7%	Materials for miscellaneous applications, not provided for elsewhere
				Pearson χ^2 = 107.0 (p-value = 0.000; df = 7)

scribed and the latter associated with developments of macromolecular compositions (product innovation) to be applied in tires, elastic bodies, and related devices.

Field C represents the majority of the related technological areas, responsible for 79.4% in 1990 and 74.6% in 2006. Six technological areas were stressed. Related to new substances there are C07D (cyclic organic substance containing other than carbon atoms in the ring), and C08G (macromolecular compounds). Related to product innovation based on new formulations there are C08L (compositions of macromolecular compounds) and C09D (formulations of non-macromolecular substances). The last two areas are C08J associated with new processes and C09K associated with new applications of substances (e.g. heat-transfer, drilling, luminescent materials, among others). Examples are described in Table 5.31.

Table 5.31: C08K: Examples of patent applications.

Year	Classification	Patent application title	Applicant name
1990	C07C C07D C07H C08K C08L C09K	"Organic sulfide antioxidants"	Atochem North America Inc. (US)
1990	C07F C08G C08K C08L C09K	"Reaction products of 2-(aminoethyl) aminopropyl alkoxysilanes with chlorosilanes"	Bayer AG (DE)
1990	A01N C07D C08K	"Composition and method for inhibiting the growth of micro-organisms"	Zeneca Ltd. (GB)
1990	C07D C08K C08L C09D D01F	"Brightening and light-stabilizing salts"	Sandoz-Patent-Gmbh (DE) and Sandoz Ltd. (CH)
1990	C03C C08G C08K C08L C09D D21H G03F H05K	"UV curable compositions for use, in particular, in the field of antiadherent-paper and optical fibers"	Rhone-Poulenc Chimie (FR)
2006	B32B C08K	"White light diffusing thermoplastic composition"	Arkema France (FR)
2006	B32B C08K	"UV-Stabilized molded polycarbonate products"	Bayer MaterialScience AG (DE)
2006	B60C C08C C08G C08K C08L	"Functionalized polymers and improved tires therefrom"	Bridgestone Corp. (JP)
2006	C08J C08K C09D	"Method and device for producing nano-composites"	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. (DE) and Ruhr-Universität Bochum (DE)
2006	C08J C08K C08L C09K	"Reactive flame retardant and flame retardant resin processed article"	Fuji Electric Holdings Co. Ltd. (JP) and National University Corp. Tokyo University of Agriculture and Technology (JP)

The Pearson χ^2 value for areas highlighted in regulated area C08K is higher than for C08F and J. Even though it is not possible to perceive any drastic change in the pattern of patenting from 1990 to 2006, there were some minor changes which are interesting to remark.

First, area C08L is the one with the biggest presence on the patent applications for both years, even though there was a decrease in its relative share (from 41.2% to 36.6%). This area represents the compositions of macromolecular compounds, in other words new products made of formulations just of macromolecular compounds, and this might suggest that new formulations have been developed with non-macromolecular substances which are associated with area C09D, that has in fact increased its relative share over the same period (from 4.3% to 5.1%).

Second, the drop in the relative importance of area C07D might be associated with the nature of the substances it represents. This area represents heterocyclic organic substances, and a large number of such class of substances were regulated as carcinogenic category 1 or 2. As previously explained in Section 4.1.1, given the molecular structure regulators preventively restricted a number of substances assuming that there is risk even if it was not scientifically confirmed, but just because there are substances with similar structure which were found to be carcinogenic. This might have influenced this drop in the relative importance of area C07D.

Third, there was an increase in the relative share of field B, from 6.9% to 12.5%. Two areas were the main responsible for this increase: B60C and B32B. A speculation one might do is that with a decrease of the relative importance of areas associated with new substances and use of certain kinds of substances in formulations, areas associated with processes for new uses (B32B) and applicability with guaranteed demand (B60C) gained relative importance.

Hence, no consistent change can be perceived in the direction of innovation in the three regulated areas which I have investigated – C08F, C08J, and C08K. Nevertheless, a number of changes can be noticed in the pattern of innovation in specific sectors. One possible explanation is that from field C08 this area was the one which received the largest number of restrictions (62, against 40 for area C08J, and 22 for area C08F). Overall an increase in technological areas associated with processes can be noticed matched by a decrease in areas associated with new substances.

5.3.4 IPC-C09

Dyes; paints; polishes; natural resins; adhesives; miscellaneous compositions; miscellaneous applications of materials.

Evolution of patenting activity

The last two technological areas analyzed in this Chapter are C09B and C09D. Their field – C09 – experienced a peak in the patenting activity in 2001. Hence, from 1990 to 2006 there was little variation in the total number of patent applications. In spite of that, areas C09B and D behaved in dissimilar ways as illustrated in Table 5.32.

Table 5.32: Evolution of patent applications in Germany: IPC-C09, B, and D.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
C09	2294	2085	2176	2151	2208	2259	2289	2476	2363	2493	2451	2524	2483	2531	2347	2485	2274
C09B	**302**	313	323	348	292	312	271	**304**	258	259	270	263	272	**254**	240	249	**228**
C09B/C09	**13%**	15%	15%	16%	13%	14%	12%	**12%**	11%	10%	11%	10%	11%	**10%**	10%	10%	**10%**
C09D	**871**	818	888	911	963	1005	1040	**1097**	1106	1095	1108	1169	1112	**1132**	1052	1105	**1155**
C09D/C09	**38%**	39%	41%	42%	44%	44%	45%	**44%**	47%	44%	45%	46%	45%	**45%**	45%	44%	**51%**

Area C09B has been decreasing over the years both in absolute numbers and as percentage of the total patents from the field C09. Conversely, C09D increased in absolute numbers as well as in terms of its share over its field, C09. Hence, the most highly regulated areas in field C09 have developed in opposite directions.

Area C09B is characterized by a small number of patent applications per year and has decreased by 25%, from 1990 to 2006. In contrast, technological area C09D increased by 33% in the total number of applications over the same period. Next, Table 5.33 illustrates the summarized results of the computed regressions.

Table 5.33: C09B and D: Modeling patents by OLS

	Sample:	**1990 - 2006**		**Sample:**	**1991 - 2006**	**(1 year lag)**
	Coefficient	t-value	P > |t|	Coefficient	t-value	P > |t|
C09B						
Equation 5.2						
d_1	-8.432	-0.430	0.674	-22.660	-1.240	0.239
d_2	-14.157	-0.446	0.663	-29.937	-1.030	0.323
	F(3,13) =	12.760 (0.000)		F(3,12) =	15.940 (0.000)	
Equation 5.3						
d_1 t	-0.170	-0.045	0.965	2.417	0.615	0.550
d_2 t	-1.472	-0.176	0.863	5.860	0.534	0.603
	F(3,13) =	12.560 (0.000)		F(3,12) =	14.240 (0.000)	
C09D						
Equation 5.2						
d_1	37.772	0.896	0.387	-39.605	-0.909	0.381
d_2	-80.134	-1.170	0.262	-194.159	-2.800	0.016
	F(3,13) =	36.000 (0.000)		F(3,12) =	29.340 (0.000)	
Equation 5.3						
d_1 t	-0.053	-0.006	0.996	-4.754	-0.408	0.691
d_2 t	-41.417	-2.040	0.062	-54.883	-1.690	0.118
	F(3,13) =	27.240 (0.000)		F(3,12) =	15.670 (0.000)	

Starting with area C09B only H_0'' was rejected for both lagged and unlagged regressions. These results infer no impact of regulation in the number or trend of patenting in Germany.

Regarding area C09D for unlagged regressions, H_0 failed to be rejected, $H_0^{'}$ was marginally rejected, and $H_0^{''}$ was rejected. Turning to lagged regressions, H_0 failed to be rejected while $H_0^{''}$ was rejected. $H_0^{'}$ was rejected for Equation 5.2 and failed to be rejected for Equation 5.3. Lagged Equation 5.2 infer a negative impact of the second regulatory knot in the number of applications (significant at $p < 0.05$), while unlagged Equation 5.3 infer a negative impact of the second regulatory knot in the trend of growth (significant at $p < 0.1$).

In short, technological area C09B decreased while area C09D increased. Computed regressions for area C09B did not indicate any regulatory impact, while for area C09D there is little evidence of a possible negative impact of the second regulatory knot over the number and growth of patent applications.

Even though these results are shown to be initially contradictory it must be reminded first the limitations of the regressions, second the different number of restrictions which these areas received (101 for area C09D and 86 for area C09B), and third the nature of the technologies associated with these areas. This last issue will be better understood when analyzing the different patterns of patents applied in 1990 and 2006.

Geographic origin of patent applications

Table 5.34 shows the evolution of patent applications in the EU and non-EU countries for technological areas C09B and D. Areas C09B and C09D showed contrasting behaviors, from 1990 to 2006.

Table 5.34: EU vs non-EU patent applications in Germany: C09B and C09D

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C09B									
EU	**143**	127	132	185	142	149	121	**114**	90	106	86	92	105	**87**	85	91	**94**
	0.47	0.41	0.41	0.53	0.49	0.48	0.45	**0.38**	0.35	0.41	0.32	0.35	0.39	**0.34**	0.35	0.37	**0.41**
non-EU	**159**	186	191	163	150	163	150	**190**	168	153	184	171	167	**167**	155	158	**134**
	0.53	0.59	0.59	0.47	0.51	0.52	0.55	**0.63**	0.65	0.59	0.68	0.65	0.61	**0.66**	0.65	0.63	**0.59**
								C09D									
EU	**313**	307	326	372	378	420	390	**450**	394	399	416	419	402	**389**	389	398	**423**
	0.36	0.38	0.37	0.41	0.39	0.42	0.38	**0.41**	0.36	0.36	0.38	0.36	0.36	**0.34**	0.37	0.36	**0.37**
non-EU	**558**	511	562	539	585	585	650	**647**	712	696	692	750	710	**743**	663	707	**732**
	0.64	0.62	0.63	0.59	0.61	0.58	0.63	**0.59**	0.64	0.64	0.62	0.64	0.64	**0.66**	0.63	0.64	**0.63**

In area C09B, the absolute number of patent applications originating from EU and non-EU countries have decreased. From 1990 to 2006, the share of innovations originating from EU countries have decreased from 47% down to 41%. This drop occurred mainly after 1997.

The number of applications originating both from EU and non-EU countries increased for technological area C09D. When analyzing the share of EU patent applications, they have increased until 1997 and dropped afterward. Comparing the years

1990 and 2006 there was little variation in the share of EU and non-EU countries.

The following Table 5.35 disaggregates the data and shows the main countries responsible for the innovations applied in Germany. Differently from the other areas, C09B has four countries contributing with the majority of these applications. Besides Germany, US, and Japan, also Switzerland (CH) has an important role.

Table 5.35: Origin of patent applications in Germany: C09B and C09D

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C09B									
DE	**117**	91	103	132	108	125	87	**86**	62	87	64	75	69	**57**	62	55	**56**
	0.39					0.40		**0.28**						**0.22**			**0.25**
US	**47**	65	93	54	45	61	57	**80**	59	70	77	68	47	**49**	45	34	**35**
	0.16					0.20		**0.26**			0.29			**0.19**			**0.15**
JP	**58**	67	68	65	53	47	38	**51**	29	35	52	53	44	**57**	60	72	**50**
	0.19							**0.17**	0.11					**0.22**			**0.22**
CH	**51**	53	33	42	43	53	49	**47**	62	31	44	26	49	**47**	33	35	**41**
	0.17							**0.16**	0.24					**0.19**			**0.18**
Total share	0.90	0.88	0.92	0.84	0.85	0.92	0.85	0.87	0.82	0.86	0.88	0.84	0.77	0.83	0.83	0.79	0.80
								C09D									
DE	**192**	183	198	264	265	272	254	**283**	245	238	255	241	238	**222**	214	226	**226**
	0.22			0.29				**0.26**						**0.20**			**0.20**
US	**294**	291	323	328	303	327	404	**358**	426	427	406	386	354	**381**	346	360	**341**
	0.34						0.39	**0.33**		0.39				**0.34**			**0.30**
JP	**204**	178	183	177	228	227	221	**234**	222	229	231	315	286	**293**	264	297	**296**
	0.23							**0.21**	0.20			0.27		**0.26**			**0.26**
CH	**36**	23	32	22	25	32	28	**45**	53	31	33	32	37	**41**	28	34	**47**
	0.04							**0.04**						**0.04**			**0.04**
GB	**45**	43	53	34	37	31	44	**45**	39	49	39	29	28	**31**	41	32	**36**
	0.05							**0.04**						**0.03**			**0.03**
FR	**30**	35	32	29	24	56	46	**57**	40	34	35	43	37	**36**	34	33	**40**
	0.03							**0.05**						**0.03**			**0.03**
Total share	0.92	0.92	0.92	0.94	0.92	0.94	0.96	0.93	0.93	0.92	0.90	0.89	0.88	0.89	0.88	0.89	0.85

Considering the main non-EU countries in area C09B, innovations originated from the US increased in number and share over the 1990s, decreasing subsequently. Comparing 1990 with 2006 the US maintained its share (16% against 15%). Innovations originating in Japan and Switzerland showed only minor share variations over the period, with a small increase from 19% to 22% and 17% to 18%, respectively.

Conversely, the main EU contributor of area C09B – Germany – has decreased in number and share, from 39% in 1990 to 25% in 2006. Thus, this reflected the ratio of EU and non-EU applicants.

Patents applied in Germany in technological area C09D originated in the majority from the US. They increased in numbers until 1999, with a subsequent decrease. The total share also followed this pattern, but overall there was a decrease from 34% in 1990 down to 30% in 2006. The other major non-EU contributor was Japan which saw an increase both in the number and share of patent applications, from 23% in

1990 to 26% in 2006.

The main EU contributor for area C09D was also Germany. Innovations originating from this country increased its share over the 1990s, however lost importance over the 2000s, varying from 22% to 20% in the whole period.

Moreover, the main countries responsible for the origin of the innovations applied in Germany have decreased their importance for the two areas. In C09B they summed 90% in 1990 and dropped to 80% in 2006. Also in area C09D, the main countries summed 92% in 1990, falling down to 85% in 2006. Next, results from the two regressions computed – Equations 5.4 and 5.5 – are illustrated in Table 5.36.

Table 5.36: C09B and D: Modeling patents by OLS

	Sample:	**1990 - 2006**		**Sample:**	**1991 - 2006**	**(1 year lag)**
	Coefficient	t-value	P > |t|	Coefficient	t-value	P > |t|
C09B						
Equation 5.4						
d_1	72.122	2.950	0.011	40.090	1.320	0.213
d_2	80.019	2.020	0.065	23.669	0.489	0.633
	F(3,13) =	6.156 (0.008)		F(3,12) =	2.536 (0.106)	
Equation 5.5						
d_1 t	1.767	0.310	0.761	0.866	0.134	0.895
d_2 t	-9.811	-0.779	0.450	-15.588	-0.867	0.403
	F(3,13) =	2.831 (0.080)		F(3,12) =	2.174 (0.144)	
C09D						
Equation 5.4						
d_1	53.373	1.200	0.253	82.310	2.510	0.028
d_2	59.762	0.826	0.423	47.264	0.906	0.383
	F(3,13) =	6.126 (0.008)		F(3,12) =	16.070 (0.000)	
Equation 5.5						
d_1 t	6.723	0.784	0.447	13.815	1.750	0.105
d_2 t	-0.667	-0.035	0.972	7.305	0.332	0.746
	F(3,13) =	6.140 (0.008)		F(3,12) =	10.710 (0.001)	

Starting with area C09B, unlagged Equation 5.4 rejected H_0 and $H_0^{''}$, and marginally rejected $H_0^{'}$. For unlagged Equation 5.5 and for both lagged regressions none of the null hypothesis are rejected. Hence, these results infer a positive impact of the first regulatory knot on the difference between non-EU and EU patent applications, suggesting that an increase of applications originated from non-EU countries.

For area C09D unlagged regressions failed to reject H_0 and $H_0^{'}$ while $H_0^{''}$ was rejected. Lagged regressions marginally rejected H_0, failed to reject $H_0^{'}$, and rejected $H_0^{''}$. These results suggests an increase of applications originated from non-EU countries.

Summarizing, for technological area C09B EU innovations decreased from 47% down to 41%, while for area C09D EU innovations showed similar shares (36% and 37%). Furthermore, the computed regressions suggested that the first regulatory knot may have favored an increase of non-EU patent applications in Germany, for both regulated areas.

Top applicants and the concentration of innovative activity

The two areas under study behaved differently also with respect to the concentration of innovative activity. This is highlighted in Table 5.37.

Table 5.37: Patent applications in Germany: Top applicants and small players in technological areas C09B and D

	C09B 1990	C09B 2006	C09D 1990	C09D 2006
# Applications by the top ten applicants	177	116	218	327
Share of the top ten applicants	59%	51%	25%	28%
# Small players	53	59	204	252
# Applications by small players	48	54	195	222
Share of the small players	16%	24%	22%	19%

From 1990 to 2006, the number of small players in area C09B increased by 11%, and their share in the total applications was enhanced from 16% up to 24%.[13] Conversely, the share of the top ten applicants dropped, from 59% down to 51%.

In the Appendix B, Table B.5 shows that there was a decrease in the difference between the number of applications by the leading firm and the tenth applicant. The top applicant in 1990 had forty-five applications against twenty-three in 2006, and in both years the tenth firm had just five patent applications. These facts indicate a decrease in the standard deviation of the distribution of number of applications per firms, and that innovative activity became less concentrated with time.

The number of small players also increased in area C09D, by 24%. However, their share dropped from 1990 to 2006 from 22% down to 19%.[14] On the contrary, the share of the top ten applicants increased from 25% to 28%. Thus, innovative activity became more concentrated over this period.

Table 5.38 illustrates the variation in the kind of applicants and patents with shared ownership, in 1990 and 2006. For both technological areas there was little variation.

Differently from other technological areas analyzed in this chapter, the contribution of firms in C09B and C09D showed a small decrease, 2% and 3%, respectively.

This fact has reflected also in the number of applications with shared ownership, given that universities, research centers, and individual inventors are the ones which usually applied technologies developed in partnership. Hence, patent applications involving more than two applicants increased from 2% to 4% in area C09B, and from

[13]The same analysis was done defining small players as entities that applied three or less patents. Similarly, the share of small players increased from 27% to 45%.

[14]The same analysis was done defining small players as entities that applied three or less patents. Considering this definition the number of small players also increased by 31%, and the share of small players also decreased from 37% to 36%.

Table 5.38: Patent applications in Germany: Profile of technological areas C09B and D

	C09B 1990	C09B 2006	C09D 1990	C09D 2006
# Applications with shared ownership	6	10	40	67
Percentage of shared ownership	2%	4%	5%	6%
Type of applicant				
Firms	99%	97%	98%	95%
Universities or research centers	<1%	3%	1%	3%
Individual inventors	<1%	<1%	2%	2%

5% to 6% in area C09D.

In summary, for technological area C09B there was a decline in the concentration of innovative activity, while for area C09D it became more concentrated. Nevertheless, it was not possible to relate these changes in concentration to change in regulatory stringency.

The evolution of the relationship among technological areas

Finally, I investigated if there was a change in the direction of the patent applications in areas C09B and D, from 1990 to 2006. The patent application profiles for both years and technological areas are shown in Table 5.39.

Following the definitions of the IPC, area C09B is to a large extent associated with new substances (organic dyes), and area C09D is related to new formulations, compositions of different (and not necessarily new) substances (organic or inorganic) for diverse applications.

C09B Result from the Pearson χ^2 test comparing the patents applied in the different fields in 1990 and 2006 is 59.9, significant at $p < 0.001$.[15] Next, Table 5.40 illustrates the definitions of the most important areas and the ones that experienced substantial changes from 1990 to 2006. In this comparison can be observed a clear change in the pattern of innovative activity.

In 1990, patent applications in area C09B were largely associated with fields C, D, and G. Field C was mostly represented by areas C07C, C07D, and C09D, which regard the preparation (new process) of new organic substances with specific characteristics (acyclic, carbocyclic, and heterocyclic compounds – new substances), and new compositions for paints, inks among others. In summary, these three areas represent mainly new substances and formulations.

In field D the most important area is D06P associated with the processes of dyeing of furs, leather, and textiles. Field G showed two highly pertinent areas, G03C and G03G, associated with photographic processes for coloring and apparatus for

[15]The complete table is available in the Appendix D.

Table 5.39: C09B and D: Related technological areas

C09B		1990	2006	C09D		1990	2006
A		**4.2%**	**11.7%**	A		**3.3%**	**3.6%**
	A61K	**2.1%**	**6.2%**		A01N	<1%	1.0%
	A61Q	1.5%	3.6%		A61L	<1%	1.1%
B		**9.2%**	**8.1%**	B		**15.1%**	**20.3%**
	B01F	<1%	1.0%		B05D	**5.6%**	**4.5%**
	B22F	–	1.0%		B32B	2.1%	2.4%
	B41C	–	1.4%		B41C	–	1.0%
	B41M	**7.6%**	**2.7%**		B41J	**1.4%**	**3.5%**
					B41M	**2.5%**	**4.2%**
C		**37.9%**	**52.0%**	C		**67.7%**	**65.9%**
	C07C	**6.0%**	**1.8%**		C03C	<1%	1.0%
	C07D	**9.3%**	**7.1%**		C04B	1.6%	1.1%
	C08F	1.2%	<1%		C07C	1.0%	<1%
	C08G	1.8%	<1%		C07D	1.2%	1.4%
	C08J	1.6%	<1%		C08F	**11.8%**	**7.3%**
	C08K	2.0%	4.1%		C08G	**14.6%**	**17.2%**
	C08L	<1%	1.2%		C08J	3.7%	4.1%
	C09C	1.9%	3.6%		C08K	**5.7%**	**5.6%**
	C09D	**6.8%**	**27.9%**		C08L	**11.7%**	**7.8%**
	C09K	1.3%	1.8%		C09B	**2.4%**	**6.1%**
	C11D	1.7%	<1%		C09C	2.2%	3.0%
					C09J	3.0%	2.7%
					C09K	1.7%	1.5%
					C23C	<1%	1.7%
					C25D	1.1%	<1%
D		**31.7%**	**4.9%**	D		**2.2%**	**1.8%**
	D06P	**29.3%**	**2.9%**		D21H	1.0%	<1%
	D21H	1.6%	1.9%				
G		**16.2%**	**21.8%**	G		**5.7%**	**4.5%**
	G01N	**1.6%**	**4.3%**		G02B	<1%	1.5%
	G02B	**1.0%**	**6.9%**		G03F	1.0%	<1%
	G02F	1.0%	1.3%		G11B	2.1%	<1%
	G03C	**4.2%**	–				
	G03F	1.0%	1.8%				
	G03G	**5.5%**	**1.9%**				
	G11B	**1.6%**	**4.6%**				
H		**0.7%**	**1.5%**	H		**4.7%**	**2.7%**
					H01B	1.4%	<1%
					H01L	<1%	1.2%
					H05K	1.1%	<1%

producing multicolored copies, among others. Some examples of these patents area illustrated in Table 5.41.

In 2006 this picture has changed. The most important fields became C (increased its relative weight from 37.9% to 52.0%), G (increased from 16.2% to 21.8%), and A (increased from 4.2% to 11.7%).

In field C areas associated with organic chemistry (C07) decreased, and there was an increase in the relative score of area C09D (from 6.8% to 27.9%). These facts indicate a drop in the development of new organic substances and an increase in formulations of existing substances.

Field G increased its relative weight and changed its most related areas. Areas G03C and G03G diminished, and areas G01N, G02B, and G11B increased. These last three represent the application of organic dyes (area C09B) in methods for analysis of physical or chemical properties of materials, in optical elements, systems or apparatus, and in the process of manufacturing parts and accessories of apparatus for storage of

Table 5.40: C09B: *Organic dyes or closely-related compounds for producing dyes; mordants; lakes*

IPC		1990	2006	Definition
A		4.2%	11.7%	Human necessities
	A61K	2.1%	6.2%	Preparations for medical, dental, or toilet purposes
B		9.2%	8.1%	Performing operations; transporting
	B41M	7.6%	2.7%	Printing, duplicating, marking, or copying processes; color printing
C		37.9%	52.0%	Chemistry; metallurgy
	C07C	6.0%	1.8%	Acyclic or carbocyclic compounds
	C07D	9.3%	7.1%	Heterocyclic compounds
	C09D	6.8%	27.9%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes or solids for coloring or printing; use of materials therefor)
D		31.7%	4.9%	Textiles; paper
	D06P	29.3%	2.9%	Dyeing or printing textiles; dyeing leather, furs, or solid macromolecular substances in any form
G		16.2%	21.8%	Physics
	G01N	1.6%	4.3%	Investigating or analyzing materials by determining their chemical or physical properties
	G02B	1.0%	6.9%	Optical elements, systems, or apparatus
	G03C	4.2%	–	Photosensitive materials for photographic purposes; photographic processes (e.g. cine, x-ray, color, stereo-photographic processes; auxiliary processes in photography)
	G03G	5.5%	1.9%	Electrography; electrophotography; magnetography
	G11B	1.6%	4.6%	Information storage based on relative movement between record carrier and transducer
				Pearson $\chi^2 = 130.0$ (p-value = 0.000; df = 8)

Table 5.41: C09B: Examples of patent applications in 1990.

Classification	Patent application title	Applicant name
C09B G03G	"Electrophotographic recording material"	Agfa-Gevaert NV (BE)
B41M C07D C09B D06P	"Thiazole dyes of the merocyanine type and a thermal transfer process using these dyes"	BASF AG (DE)
C07C C09B G03C	"Improved method of synthesizing phenolic cyan-dye-forming photographic couplers"	Eastman Kodak Co. (US)
C07D C08K C09B	"High stability pigments belonging to the 1,4-diketone pyrrole-3,4-C-pyrroles and new pyrrole-3,4-C-pyrroles series, suitable for the purpose"	Enichem Synthesis S.p.A. (IT)
A23L A61K B01F C07C C09B	"Process for the production of carotinoid preparations"	F. Hoffmann-La Roche AG (CH)
C09B C09C	"Production process of purified pigments, and purified pigments"	Fine Clay Co. Ltd. (JP) and Kimoto & Co. Ltd. (JP)
C07D C07F C09B G02F	"Triophene compounds having a non-linear optical activity, materials and devices containing them"	Flamel Technologies (FR)
C09B G03C G03F	"Light-sensitive composition"	Fuji Photo Film Co. Ltd. (JP)
C07C C07D C09B D06P	"Azo compounds and their use as dyes, 1-sulpho-6-carboxyl-amino naphthaline, its use as a diazo component and process for the production of these compounds"	Hoechst AG (DE)
C07D C09B	"Method of producing 3-dibutylamino-6-methyl-7-anilinofluoran"	Yamamoto Chemicals Inc. (JP)

information (tapes, cards, or discs).

Finally, field A increased its relative share given the increase of the use of organic dyes on medical, dental, and cosmetic products (e.g. preparations for dyeing the hair) represented by area A61K. Some examples are shown in Table 5.42.

There are two possible regulatory causes which might explain the some of these changes. First, as detailed in Chapter 4 and also explained for regulated area A01N, in 1997 almost all restrictions imposed on substances were not applied to:

> *(a) medicinal or veterinary products; (b) cosmetic products.*[16]

[16]See Table 4.3 in Chapter 4.

Table 5.42: C09B: Examples of patent applications in 2006.

Classification	Patent application title	Applicant name
C09B C09D	"Water-based inks for ink-jet printing"	Kao Corporation (JP)
C09B C09D	"Non-aqueous pigment dispersions using dispersion synergists"	Agfa Graphics NV (BE)
C09B C09J C09K G02B	"Pressure-sensitive adhesive containing near infrared absorbing coloring matter"	API Corporation (JP)
C09B G02B	"Green pigment preparations based on C.I. Pigment Green 36"	BASF SE (DE)
C09B G11B	"Nitro schiff base metal complex dyes and their use in optical layers for optical data recording"	Clariant International Ltd. (CH)
C09B G02B G02F	"Pigment preparation based on an azo pigment"	Clariant Produkte GmbH (DE)
C09B C09D	"Process for preparation of a novel pigmented composition for use in offset inks"	Ciba Holding Inc. (CH)
C09B G01N	"Near infrared fluorophore for the selective labeling of membranes in cells"	Universität Heidelberg (DE)
A61K C07D C09B G01N	"Biocompatible fluorescent imaging agents"	Visen Medical Inc. (US)
A61K A61Q C09B	"Use of cationic azacyanine dyes for coloring keratin fibers"	Wella AG (DE)

Therefore, this might explain the growth in the relative importance of technological area A61K (which had its uses not restricted by regulation).

Second, in 2003 several organic substances used in dyes (azocolourants) were restricted for several applications, including:

> *may not be used in textile and leather articles which may come into direct and prolonged contact with the human skin or oral cavity intended for use by the final consumer.*[17]

All these regulated substances (azocolourants) were converted into restrictions in technological areas C09B. Hence, this might explain drop in the relative importance of area D06P, from 29.3% to 2.9%, given the prohibition of the use of organic dyes (azocolourants represented by area C09B) for dyeing textiles, leather, and furs.

C09D Differently from C09B, technological area C09D experienced minor changes over the same period. Result from the Pearson χ^2 test comparing the patents applied in the different fields in 1990 and 2006 is 39.0, significant at $p < 0.001$.[18] The most important fields for both years were B and C, and their main areas are defined in Table 5.43.

In 1990, field B had as most important area B05D, associated with the after-treatment of applied coatings[19] (process innovation). Field C, responsible for the vast majority of technological areas associated (67.7%), had three areas highly relevant – C08F, G, and L – associated with the development of new macromolecules (new substances), and compositions containing macromolecules (new formulations of existing substances). Some examples are shown in Table 5.44.

In 2006 there were minor changes. The relative importance of field B increased (from 15.1% to 20.3%), and its three most important areas were B05D, B41J, and B41M. The first is associated with new processes of applying fluids to surfaces, and

[17] See Table 4.3 in Chapter 4.

[18] The complete table is available in the Appendix D.

[19] Intermediate treating of an applied coating preparatory to subsequent applications of liquids or other fluent materials.

Table 5.43: C09D: *Coating compositions; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes or solids or solids for coloring or printing; use of materials therefor*

IPC		1990	2006	Definition
B		15.1%	20.3%	Performing operations; transporting
	B05D	5.6%	4.5%	Processes for applying liquids or other fluent materials to surfaces, in general
	B41J	1.4%	3.5%	Typewriters; selective printing mechanisms, i.e. mechanisms printing otherwise than from a forme; correction of typographical errors
	B41M	2.5%	4.2%	Printing, duplicating, marking, or copying processes; color printing
C		67.7%	65.9%	Chemistry; metallurgy
	C08F	11.8%	7.3%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
	C08G	14.6%	17.2%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
	C08L	11.7%	7.8%	Compositions of macromolecular compounds
	C09B	2.4%	6.1%	Organic dyes or closely-related compounds for producing dyes; mordants; lakes
				Pearson χ^2 = 73.0 (p-value = 0.000; df = 6)

Table 5.44: C09D: Examples of patent applications in 1990.

Classification	Patent application title	Applicant name
B05D C08F C09D	"Use of a process for producing a multi-layered coating"	BASF Coatings AG (DE)
C08F C08G C08K C08L C09D C09J	"Reaction products as adhesion additives for UV curable compositions and compositions containing same"	Dow Corning Corp. (US)
B05D C09D	"Supercritical fluids as diluents in liquid spray applications of adhesives"	Union Carbide Chemicals & Plastics Co. Inc. (US)
C08B C08L C09D	"Polysaccharides with alkaryl or aralkyl hydrophobes and latex compositions containing same"	Union Carbide Chemicals & Plastics Co. Inc. (US)
C08F C09D	"Water-based autoxidisable coating composition"	Imperial Chemical Ind. Plc. (GB)

the other two represent the use associated with printers, disposition of the dyes and accessories (e.g. ink ribbon cartridges), inking, printing processes, and after-treatment of printed works. The relative rise of these two areas might be explained by the increase in the development of copiers and printers from the 1990s to the 2000s.

Field C kept in 2006 the main influence on patent applications associated with the regulated area C09D, varying from 67.7% to 65.9%. Regarding its most important areas, increased the relative shares of areas C08G associated with processes to obtain new macromolecular substances and C09B associated with the increasing use of organic dyes in new formulations. Conversely, decreased the relative shares of areas C08F associated with the development of new substances and C08L associated with new formulations of only macromolecular compounds. Examples are illustrated in Table 5.45.

In short, for technological area C09B there was clearly a change in the direction of innovative activity. The patent application profile applied in 1990 was found to be different than in 2006. In summary, there was a clear change in the direction of the innovation for technological area C09B which correspond to regulations imposed over this period, suggesting a regulatory cause in this change of path. Conversely,

Table 5.45: C09D: Examples of patent applications in 2006.

Classification	Patent application title	Applicant name
C09B C09C C09D	"Modified colorants and inkjet ink compositions comprising modified colorants"	Cabot Corp. (US)
C08F C08G C09D	"Ultraviolet-curable resin composition, ultraviolet-curable coating material, and coated article"	DIC Corp. (JP)
B41J B41M C08F C09D H05K	"Curable resin composition for ink-jet printing, cured object obtained therefrom, and printed wiring board obtained with the same"	Taiyo Ink Mfg. Co. Ltd. (JP)
C08J C08L C09D	"Multilayer silk protein films"	Technische Universität München (DE)
B05D B29C B41M C09D	"Process for producing ink and relevant to the process, ink, printed matter and molding"	Teikoku Printing Inks Mfg. Co. Ltd. (JP)

for area C09D, even though there were some changes of relative importance for some technological areas, cannot be detached a change in the direction of the innovation, in the pattern of patents applied in 2006 differently from 1990.

5.4 Findings

The aim of this chapter has been to investigate the relationship between regulatory stringency and innovation in the chemical industry from 1990 to 2006. Other determinants of innovation have not been considered and thus these findings must be interpreted as initial and perhaps partial evidence of this relationship.

Chapter 4 identified the three most regulated technological fields by the EU chemicals regulation and their most restricted areas. To measure innovation, I examined patent applications in Germany. Based on the issues raised by the economic literature, four questions were addressed by this chapter and Table 5.46 summarizes the findings.

Table 5.46: Summarized results

	Panel 1			Panel 2		
1. Did regulation spur patenting activity?	yes			yes		
	A01N	C08F	C08J	C08K	C09B	C09D
1. Has an increase or decrease in patenting occurred?	increased	decreased	decreased	decreased	decreased	increased
Has the share of its technological field increased or decreased?	decreased	decreased	stable	increased	decreased	increased
2. Has there been a change in the country of origin of patents? The share of EU patent applications has ...	decreased	increased	increased	stable	decreased	increased
3. Has there been any increase in patenting concentration?	decreased	decreased	decreased	decreased	decreased	increased
4. Has there been a change in the direction of patenting?	yes	no	no	no	yes	no

First, the aggregate panel showed a positive relationship between regulatory stringency and innovative activity. Specifically, only two areas – A01N and C09D – have seen an increase in patent applications with C09D having increased at a faster rate than its field. The remaining areas have seen a decreased number of applications over the period analyzed – those in C08J moving in line with the field, C08K increasing at a faster rate, and C08F and C09B losing importance in their respective fields. Regressions results suggested a positive impact in applications from areas C08F, J, and K, and a negative impact in area C09D.

Second, only two areas – A01N and C09B – have seen a decreased share of patent applications originating from EU countries. At the same time, the major EU contributors have accounted for a decreased share of total applications across all sectors analyzed. Overall, the total share of the leading countries diminished from five to eleven percent. This indicates a decentralization of the innovation in the world. Firms from a broader number of countries have been patenting more. Regression results inferred that regulatory stringency has favored non-EU applicants in areas A01N, C08J, C09B, and C09D. Nevertheless, this effect might be due to the increasing patenting activity from emerging economies over the 1990s.

For instance, previous to the TRIPS[20] agreement, most emerging economies and among other industrialized countries did not have an intellectual property rights regulation, or the existing regulation did not comprise patents for chemicals, foodstuffs, and pharmaceuticals. This effect might have been favored an overall increase of patenting from firms in non-EU countries.

Third, innovative activity became less concentrated in five regulated areas. There was an overall increase in patents applied by "small players." The only exception was area C09D, which showed a concentration of innovative activity in the same period.

Lastly, technological areas A01N and C09B showed a clear change in the direction of innovative activity. Both show the highest values of the Pearson χ^2 test among the investigated regulated areas. In addition, the change in the direction of the innovation coincides with the restrictions imposed by the EU chemicals regulation. This finding supports the view that regulation alters the direction of the innovative efforts of economic agents.

These findings illustrate the heterogeneous behavior of innovative activity over periods of increasing regulatory stringency in 1997 and 2003. If environment, health, and safety regulations impact technological areas differently, this would be a reason why previous studies have highlighted that these regulations impact industrial sectors differently. Some specific observations should be highlighted.

Certainly, other non-regulatory factors may play a role in the development of these technological areas. However, the impact of the chemicals regulation on innovative activity is also heterogeneous. Restriction in the uses of the substances can have a

[20]TRIPS: Trade-related aspects of intellectual property rights agreement imposed on all countries which are part of World Trade Organization – 1994.

different impact on the various areas.

Overall, there was an increase in innovations associated with new process and formulations – meaning more incremental innovation – and a decrease in new substances. The applicability of new patents also changed to non-regulated uses and new technologies (e.g. biotechnology).

Areas which showed major changes over this period were also those that bore the largest number of restrictions: A01N with 104, C09B with 86, and C09D with 101 restrictions. Conversely, areas which were more stable were also those that received less restrictions: C08F with 22, C08J with 40, and C08K with 62 restrictions.

Despite the fact that area A01N was the most restricted, new developments and new applications permitted it to maintain innovation, as evidenced in new patent applications. In this case, there was an increase in patenting associated with non-regulated usages, while patents associated with new organic substances – highly evident in 1990 – lost importance. Also, applications associated with biotechnology grew, illustrating the possibilities opened by this technological field.

In the case of area C09D, the fact that it represents new formulations or applications of new and existing substances might have facilitated the increasing trend in patenting. Conversely, the development of new substances is what characterizes area C09B, which might have been a reason for the decreasing trend in the number of innovations.

The research questions analyzed in this chapter have been inspired by Porter's argument that regulatory stringency positively impacts innovation and consequently competitiveness. My results in relation to the impact of chemicals regulation on technology are mixed. My findings suggest that the impact will depend on the technological point at the time the regulation is imposed. In other words, "new" technologies appear to be favored by regulatory stringency while "old" technologies appear to be disadvantaged.

The technological areas I have analyzed find themselves at different stages of the innovation cycle. The most heavily regulated sectors in the EU are A01N (agrochemicals), C09B (organic dyes) and C09D (new compositions of existing substances). Areas A01N and C09B are associated with technologies which originated in the nineteenth century. The early growth in the A01N sector was based around the nineteenth century organic chemicals technology, but, over the most recent two decades that technology has been largely substituted by biotechnology. I find that this area has benefited from regulation in line with the Porter hypothesis. By contrast, sector C09B where the technology remains largely based on nineteenth science and which was subjected to specific EC regulations in 2003, has seen reduced levels of innovation contrary to the Porter predictions. The regulatory impact on sector C09D, where there is no clear link to a technological cycle, appears to have been minimal.

This evidence comes from a particular industry in a specific jurisdiction. It is nevertheless an industry in which regulation has been both important and controversial. They have implications for chemicals regulation worldwide. If supported by studies in other industries, they will imply that there are no simple answers to regulatory issues. It is nevertheless encouraging that the Porter hypothesis does appear to be supported in relation to new technologies where innovation presumably has the greatest potential returns.

Chapter 6

The Innovative Behavior of Firms

In Chapter 5 I analyzed the evolution of patent applications from 1990 to 2006 in Germany for the technological areas belonging to the most regulated fields: A01, C08, and C09. The research questions raised by the literature were investigated in a global perspective the direct relationship between regulated chemicals and chemicals technology. The development of these heavily regulated technological areas was described.

The aim of this Chapter is to provide a different perspective of the evolution of regulated chemical industry over this period. In order to bring this distinct point of view, I turn to investigate the behavior of big players in these technological areas over the period of increasing regulatory stringency in the EU. The same analysis developed in the previous chapter will be replicated at the firm level. Not only to exemplify and complement the analysis of the previous findings, but also to investigate initial evidence that the top applicants lost space to "small players" in the innovative field. This fact goes against the conventional wisdom that says that more regulation leads to higher concentration of the innovative activity and that bigger firms would innovate more than several small firms. Thus, looking more closely to the firm level is important.

From the top innovative firms seen in the previous section, two European and two non-European were chosen, in an attempt to understand different strategies designed by these firms through time. The OECD Patent Manual explains (OECD, 1994, pg.59):

> The patent portfolios of large firms can be investigated in order to study a company's innovation strategy, its technological diversification and how different fields of knowledge are combined in the firm's activity.

and adds:

> In fact, most large firms carry out technological activities in a range of fields broader than their production activities in order to explore potential future areas of activity.

As previously, innovation trends and actual technological choices may be observed through the study of the evolution of patent portfolios.

6.1 Data and methodology

The previous chapter showed that top applicants appear to have decreased in importance on highly regulated technological areas from 1990 to 2006. Taking this into account, three parameters were used in order to select four firms. First, they were leaders in patent applications in the most regulated technological areas. Second they are main responsible for the development the technological development of these technological areas since the nineteenth century. Third, preference was also given to two firms originally from the EU and two non-EU firms. This enables to draw a parallel analysis of the previous chapter in a firm level looking at the impact of a regulation which applies within the European market in EU and non-EU firms.

The four selected firms are shown in Table 6.1, also their positions when they figure among the top ten applicants in Germany (in 1990 and 2006) in the regulated technological areas.

Table 6.1: Position of the investigated firms among the top ten applicants

	Bayer		**BASF**		**3M**		**DuPont**	
	1990	2006	1990	2006	1990	2006	1990	2006
A01N	1	2	2	1	-	-	8	8
C08F	2	-	1	1	7	8	8	4
C08J	3	-	1	1	4	3	2	2
C08K	1	-	4	4	-	8	10	1
C09B	3	-	2	3	10	-	-	-
C09D	1	6	5	1	7	-	-	2

Throughout their existence these firms exited or entered in different business sectors. From 1990 to 2006 this fact can be observed given their different positions in the previous table. Their R&D choices are what characterizes the technology in use today, therefore their history is mixed with the history of the chemical industry. A brief history of these firms is provided for the reasons stated above.

Bayer (DE), BASF (DE), DuPont (US), were responsible for the evolution of the three big technological cycles which marked the chemical industry, the eras of synthetic dyes, agrochemicals, and polymers. The technological development that enabled these expansions were done inside their laboratories.

3M (US), the fourth firm here analyzed, has a different approach towards chemical technology. Since the twentieth century their business focus on a large branch of different use products which have largely in common material-science. From magnetic films, dental prosthesis, adhesives, and abrasives are some of the many products which are applications of polymeric science. This becomes clear when I study the technological areas which are the most important in its patent portfolio. Even acting in many other areas (such pharmaceuticals), this characteristics is what made 3M also a leader on several technological areas related to chemicals.

These case studies focus on two research questions which were previously discussed in Chapter 5, Section 5.2. First, *Did regulation spur patenting activity?* Following the Porter hypothesis, I consider whether an increase in the stringency of regulation incentivizes firms to innovate.

Second, *has there been a change in the direction of patenting?* Eads (1980) states that regulation might also impact the direction of innovative activity. In Chapter 5 I looked at the overall patenting activity in regulated technological areas, in this chapter I seek to verify if these firms have changed their patenting profile according to more demanding regulation. The Patent Manual by OECD (1994, pg. 59) helps clarify this issue:

> Patents can be particularly helpful in identifying the direction taken by the R&D and innovation effort of a firm [. . .] The patent portfolios of large firms can be investigated in order to study a company's innovation strategy, its technological diversification and how different fields of knowledge are combined in the firm's activity.

Patent applications in Germany, from 1991 to 2006, were examined in all technological areas and respective fields. The methodology employed was a keyword search in the ESPACE Bulletin Database. Over the 1990s and the 2000s the chemical industry went through several corporative changes, mergers, and acquisitions. Furthermore, firms designed different strategies regarding location of production plants and research centers. Thus, I will analyze these multinationals in a global extent.[1]

The analysis of these firms required three steps. First, I entered the name of the company – or parts of – and downloaded all patent applications made by each firm in Germany, over the period 1991 to 2006. This made it possible to depict the evolution of innovation and its origin through time.

Second, for the two years 1991 and 2006, I highlighted the complete set of technological areas to which these the patent applications related in order to observe the technological areas in which these firms innovated. Definitions of the fields associated with the technological areas are provided in the Appendix A and a summary is provided in Table 6.2.

Finally, I analyzed the evolution of patent applications in the most regulated technological areas. (It was not possible to undertake this analysis for either 3M in relation to area A01N or for DuPont in relation to area C09B, since they do not figure

[1]This methodology also has its shortcomings. If a firm belongs to a holding, but its name does not contain the keywords used (related to the name of the holding) it will not be counted. Conversely, if a firm contain the keyword used but does not belong to the major group it will not be discarded. In order to overcome these problems I developed a brief study of the corporative structure of each firm over this period.

Table 6.2: International Patent Classification: IPC-7

Code	Definition
A	Human necessities
B	Performing operations and transporting
C	Chemistry and metallurgy
D	Textiles and paper
E	Fixed constructions
F	Mechanical engineering; lighting; heating; weapons; and blasting
G	Physics
H	Electricity

among the top ten applicants in these areas in either year or given, and 3M in relation to area C09B because of the small number of applications.) This methodology will become clearer after I present the first case.

In order to better organize these case studies, the complete tables illustrating the country of origin of patent applications in regulated areas are available in the Appendix E and their complete patent profiles (for 1991 and 2006) are available in the Appendix F. The Pearson χ^2 test is calculated and the complete tables, containing all the results, are in the Appendix G.

6.2 Case studies

6.2.1 Bayer Group

Founded in 1863 by Friedrich Bayer and Johann Friedrich Weskott as "Friedr. Bayer et comp.," the company had as expertise the manufacture of synthetic dyestuffs. In the nineteenth century, the production of synthetic dyes – derived from coal-tar – substituted natural dyes in the market of the textile industry.

By the beginning of the twentieth century, over 80% of Bayer sales came from exports and the company was already established in the US and Europe.[2] In that period, dyes continued as the core business of Bayer but the company had already started its business on pharmaceuticals, basic chemicals and intermediates, rubber synthesis, and modern polymer chemistry (with the development in the 1930s of polyurethanes).

Crop protection research grew from an expansion of the pharmaceutical business of Bayer by the 1970s. Over this decade, Bayer launched important anti-fungal crop protection products. By the 1980s, Bayer had business on pharmaceuticals, crop protection, plastics and coating raw materials, specialty metals, and high-performance ceramics.

[2]Russia, France, Belgium, the United Kingdom.

Over the 1990s Bayer passed through structural transformations. In 1994 the company regained the right to use its brand in the US and acquired an US self-medication business that was renamed as Bayer Corporation in 1995. Still in 1994, Bayer established a third research center on pharmaceuticals in Japan, summing up to the ones in Europe and US. The study over its innovative activity reflects these changes, altering the origin and the technological areas of the patents applied.

Over the 2000s there were other important acquisitions. In 2001 Bayer acquired Lyondell Chemical Company, a US producer of raw materials for polyurethanes (polymers – polyols business). Still in 2001 the company acquired the Aventis CropScience, which became in 2002 the Bayer CropScience AG. Moreover, in 2005 Bayer acquired the Roche consumer health business, expanding its pharmaceutical business.

The restructuring also involved the creation of other independent entities in 2003, Bayer Chemicals AG and Bayer HealthCare AG. In 2005, Lanxess AG was created, a spin off from Bayer Group on the businesses of chemicals and polymers.[3]

In order to obtain all patents applied by Bayer Group in Germany, I entered with the keyword "bayer" in ESPACE Bulletin database, and all patent applications by any firm or individual inventor containing "bayer" were downloaded. Subsequently, firms or individuals not related to the Bayer Group were discarded.

Evolution of patenting activity

First I illustrate the evolution of overall patenting activity of Bayer Group. Table 6.3 shows all patents applied in Germany, irrespectively of the technological field, classified by country of origin. The last two rows show the share of patents originating from Germany and the US, the two most important countries in terms of number of applications.

Table 6.3: Patent applications in Germany by Bayer Group classified per country of origin

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
DE	**367**	460	432	380	505	444	**481**	390	478	475	512	443	**419**	391	417	**365**
US	**34**	70		66	74	89	**82**	103	100	56	52	61	**78**	104	98	**106**
FR		5	2	1	3	10	**8**	25	13	19	23	27	**14**	19	20	**22**
BE	**6**	4	8	8	6	20	**8**	6	19	13	5	7	**8**	6	2	**7**
JP	**3**	10	12	11	15	12	**6**	7	8	6	7	4				**1**
CA	**2**	4	8	6	3	2	**1**	3	9	4	4	2	**3**		1	
GB			2	3	2			3	1	2						
IT		2	1		1	1								1		
ES						1						1				
Total	**412**	555	495	475	609	579	**586**	537	625	574	603	543	**522**	521	538	**501**
% DE	**0.89**	0.83	0.87	0.80	0.83	0.77	**0.82**	0.73	0.76	0.83	0.85	0.81	**0.80**	0.75	0.78	**0.73**
% US	**0.08**	0.13	0.06	0.14	0.12	0.15	**0.14**	0.19	0.16	0.10	0.09	0.11	**0.15**	0.20	0.18	**0.21**

There was an increase of twenty two percent in the total number of patent applications with a peak in 1999. Taken together, Germany and the US are responsible

[3]Information on the Bayer company was extracted from BayerGroup (2009).

for more than ninety percent of the applications. Patent applications originated in the US more than tripled both in absolute numbers as well as in the share of the total, while applications originated in Germany kept stable, from 1991 to 2006.

A fixed effect panel data was estimated to better understand if regulatory stringency has affected Bayer's patent profile positively or negatively. The panel includes all patents applied by Bayer in all technological areas from 1991 to 2006. Table 6.4 shows these results.

Table 6.4: Bayer and the Porter hypothesis: 1991 – 2006

Patent profile	Coefficient	t-value	P > |t|	
restrict	-0.141	-3.86	0.000	F(1,1739) = 14.88 (0.000)
L1	-0.219	-5.89	0.000	F(1,1623) = 34.70 (0.000)
L2	-0.203	-4.97	0.000	F(1,1507) = 24.68 (0.000)

The results from the proposed panel show a significant negative impact of regulatory stringency on Bayer's patenting activity. The most significant result is seen for one-year lag effect.

The evolution of the relationship among technological areas

The second step in the analysis was to calculate the patenting profile in 1991 and 2006, to observe the share of the different technological field in these two years.[4] The results are shown in Table 6.5.

Table 6.5: Bayer Group: Patenting profile in 1991 and 2006

	A	B	C	D	E	F	G	H	Total
1991	**16.0%**	9.4%	**65.5%**	2.9%	0.0%	0.4%	3.8%	2.0%	100.0%
2006	**45.2%**	4.3%	**40.7%**	0.1%	0.3%	0.7%	8.3%	0.4%	100.0%
Pearson χ^2 = 265.0 (p-value = 0.000; df = 7)									

The two most relevant fields are A (human necessities) and C (chemistry and metallurgy), representing more than eighty percent for both years. Even so, there was a change of pattern over this period. The share of field A increased from 16.0% to 45.2%, while the share of field C decreased from 65.5% to 40.7%.

Analyzing the Bayer's patent profile subdivided by the different technological areas, the sum of the relative share of the regulated areas kept stable around twenty two percent from 1991 to 2006. Table 6.6 shows the percentage of the regulated technological areas in the patent profile.

[4]The methodology employed is described in Section 5.2 of Chapter 5.

Table 6.6: Share of regulated technological areas in Bayer's patent profile

	A01N	C08F	C08J	C08K	C09B	C09D	Total share
1991	7.1%	3.9%	3.1%	3.7%	2.5%	2.4%	22.6%
2006	17.3%	0.2%	0.7%	1.1%	–	3.0%	22.3%

As shown in this table, there was an increase in the share of patent applications in areas A01N and C09D, while the other four areas decreased. Next, I analyze the patenting behavior of Bayer Group in these areas.

A01N Patent applications in area A01N increased over the years. Table 6.7 illustrates this evolution. In addition it shows the share of applications in field A and with respect to all patent applications by Bayer Group.[5]

Table 6.7: A01N: Evolution of patenting in Germany by Bayer Group

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Total	**49**	84	95	87	114	109	**116**	85	110	109	103	111	**87**	109	119	**118**
A01N/ A	**0.52**	0.56	0.63	0.54	0.60	0.60	**0.59**	0.49	0.60	0.53	0.39	0.43	**0.32**	0.45	0.42	**0.39**
A01N/ total pat.	**0.12**	0.15	0.19	0.18	0.19	0.19	**0.20**	0.16	0.18	0.19	0.17	0.20	**0.17**	0.21	0.22	**0.24**

Applications classified in area A01N more than doubled from 1991 to 2006. However, in 1991 fifty two percent of all patents in field A were classified in area A01N while in 2006 just thirty nine percent. This suggests that the firm has been patenting in a wider branch of areas from field A. Considering all patents applied by Bayer, in 1991 twelve percent were classified in area A01N and in 2006 this share increased to twenty four percent.

The next step is to analyze the direction of the innovative activity. The same procedure employed in Chapter 5 is used, analyzing all technological areas linked to patent applications in regulated area A01N. Table 6.8 shows the patent application profile of area A01N in 1991 and 2006.[6]

From 1991 to 2006 there were few changes in the patent profile associated with area A01N comparing to the ones found in the previous chapter. In 1991 applications were characterized by new organic substances (C07C and C07D). In 2006 the association with these areas decreased while areas A61K, A61P, C05G, and C12N, increased.

As observed in Chapter 5 (Section 5.3), technologies associated with areas A61K and A61P were not regulated. Also, it was observed the increasing trend of new products based on new formulations (instead of new substances), and new technologies. This fact can be observed in Bayer's patent profile, given the increasing importance

[5] Number of patent applications in area A01N divided by the number of patent applications in field field A and number of patent applications in area A01N divided by the all patent applications by Bayer Group.

[6] Only areas with more than one percent of relative weight are shown.

Table 6.8: A01N: Summarized patent application profile and definitions – Bayer Group

IPC	1991	2006	Definition
A61K	3.4%	4.5%	Preparations for medical, dental, or toilet purposes
A61P	1.2%	3.6%	Therapeutic activity of chemical compounds or medicinal preparations
C05G	–	2.4%	Mixtures of fertilizer covered individually by different subclasses of class C05; mixtures of one or more fertilizers with materials not having a specific fertilizing activity (e.g. pesticides, soil-conditioners, wetting agents); fertilizers characterized by their form
C07C	13.0%	11.8%	Acyclic or carbocyclic compounds
C07D	71.3%	69.1%	Heterocyclic compounds
C07F	5.6%	–	Acyclic, carbocyclic, or heterocyclic compounds containing elements other than carbon, hydrogen, halogen, oxygen, nitrogen, sulfur, selenium, or tellurium
C12N	–	1.8%	Micro-organisms or enzymes; compositions thereof; propagating, preserving, or maintaining micro-organisms; mutation or genetic engineering; culture media
			Pearson χ^2 = 8.43 (p-value = 0.208; df = 6)

of areas C05G, associated with new substances and mixtures of fertilizers, and C12N, associated with biotechnology.

The acquisition in 2001 of the Aventis CropScience reflected the interest of Bayer Group in investing in technologies associated with crop growth (A01N). Table 6.9 shows some examples of patent applications by Bayer Group in 2006.

Table 6.9: A01N: Examples of patent applications in 2006.

Classification	Patent application title	Applicant name
A01N C12N	"Methods for increasing the resistance of plants to hypoxic conditions"	Bayer BioScience NV (BE)
A01N C07D	"New heterocyclylethylbenzamide derivatives"	Bayer CropScience SA (FR)
A01N C07C C07D	"Pesticide benzyloxy- and phenetyl- substituted phenyl-amidine derivatives"	Bayer CropScience AG (DE)
A01N C07C C07D	"Pesticide phenyloxy substituted phenylamidine derivatives"	Bayer CropScience AG (DE)
A01N C07C C07D	"Dioxazine- and oxadiazine- substituted arylamides"	Bayer CropScience AG (DE)
A01N A01P A61K A61P	"Endoparasiticide"	Bayer Animal Health GmbH (DE)
A01N A01P C05G	"Use of tetramic acid derivatives with fertilizers"	Bayer CropScience AG (DE)

When looking at Chapter 5, it was observed that area A01N increased in number of applications and changed in direction. This can also be observed in this case study. Also, in the previous chapter there was a decrease in the association with areas C07C and C07D.

C08F, C08J, and C08K The number of patent applications in highly regulated areas from macromolecular technology (C08) was stable over the 1990s and afterward decreased. Table 6.10 illustrates this evolution showing the number of patent applications in these areas per year, the percentage of applications in each of these areas with respect to their field C and with respect to the total number of patents applied by Bayer Group.

Overall, area C08F decreased almost one hundred percent, C08J by sixty six percent, and C08K by fifty eight percent.

The analysis of the patent profiles in these areas has pitfalls given the small number of applications in 2006. Nevertheless, Table 6.11 shows the summarized

Table 6.10: C08F, C08J, and C08K: Evolution of patenting in Germany by Bayer Group

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C08F								
Total	**30**	28	33	19	31	31	**34**	33	56	40	25	19	**9**	7	9	**1**
C08F/ C	**0.10**	0.06	0.08	0.05	0.06	0.07	**0.07**	0.08	0.13	0.09	0.06	0.05	**0.02**	0.02	0.03	**0.00**
C08F/ total pat.	**0.07**	0.05	0.07	0.04	0.05	0.05	**0.06**	0.06	0.09	0.07	0.04	0.03	**0.02**	0.01	0.02	**0.00**
								C08J								
Total	**29**	32	35	33	43	21	**34**	28	29	46	19	7	**13**	11	15	**10**
C08J/ C	**0.10**	0.07	0.09	0.09	0.09	0.05	**0.07**	0.06	0.07	0.10	0.04	0.02	**0.03**	0.03	0.04	**0.03**
C08J/ total pat.	**0.07**	0.06	0.07	0.07	0.07	0.04	**0.06**	0.05	0.05	0.08	0.03	0.01	**0.02**	0.02	0.03	**0.02**
								C08K								
Total	**33**	43	40	29	46	30	**33**	45	48	46	35	21	**18**	9	13	**14**
C08K/ C	**0.11**	0.10	0.10	0.08	0.09	0.07	**0.07**	0.10	0.11	0.10	0.08	0.05	**0.05**	0.03	0.04	**0.05**
C08K/ total pat.	**0.08**	0.08	0.08	0.06	0.08	0.05	**0.06**	0.08	0.08	0.08	0.06	0.04	**0.03**	0.02	0.02	**0.03**

patent application profile of areas C08F, J, and K, in 1991 and 2006.

Table 6.11: C08F, C08J, and C08K: Summarized patent application profile and definitions – Bayer Group

IPC	1991	2006	Definition
			C08F
B01J	10.0%	–	Chemical or physical processes (e.g. catalysis, colloid chemistry; their relevant apparatus)
C08C	12.3%	–	Treatment or chemical modification of rubbers
C08L	12.8%	–	Compositions of macromolecular compounds
			C08J
B29C	3.0%	10.0%	Shaping or joining of plastics; shaping of substances in a plastic state, in general; after-treatment of the shaped products, e.g. repairing
C08G	25.5%	33.7%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08K	11.9%	13.7%	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C08L	26.9%	19.7%	Compositions of macromolecular compounds
			Pearson χ^2 = 0.67 (p-value = 0.880; df = 3)
			C08K
A61L	–	14.3%	Methods or apparatus for sterilizing materials or objects in general; disinfection, sterilization, or deodorization of air; chemical aspects of bandages, dressings, absorbent pads, or surgical articles; materials for bandages, dressings, absorbent pads, or surgical articles
B32B	–	16.7%	Layered products, i.e. products built-up of strata of flat (e.g. cellular or honeycomb, form)
C08J	10.1%	9.8%	Working-up; general processes of compounding; after-treatment not covered by subclasses
C08L	57.7%	31.0%	Compositions of macromolecular compounds
			Pearson χ^2 = 16.20 (p-value = 0.001; df = 3)

In 1991 patents in area C08F were highly associated with compositions of new or existing macromolecular substances (C08L) and new processes (C08C and B01J). In area C08J patents were highly associated with composition of new or existing substances (C08L and C08K), and development of new macromolecular substances (C08G). In area C08K, patents were highly associated with composition of new or existing macromolecular substances (C08L) and new processes (C08J).

In 2006 increased the association of area C08J with mechanical processes over plastics on their final state (work over final product, B29C). The previous cited areas in 1991 kept their importance. In area C08K the association with mechanical processes over plastic on their final state (B32B) and with objects for medical, veterinary, or hygienization uses (A61L) increased. Overall, for both areas increased patent applications associated with mechanical processes to manipulate the plastic object (macromolecular compounds in their final state) and with new uses.

When comparing these findings with results obtained in Chapter 5 (Section 5.3), there is coincidence in some technological areas. There occurred an overall increase in technological areas associated with processes and a decrease in areas associated with new substances. However, considering patents applied in area C08J the association with areas C08G and C08K related to the development of new substances increased. Nevertheless, Bayer made few 2006 patent applications in these areas.

As described in the brief history of Bayer Group, even though in 2001 there was an acquisition of a producer of raw material for polyurethanes, associated with classification C08G, in 2005 a spin off in the polymers business – associated with areas C08F, J, and K – was created. This is consistent with the view that the firm wishes to exit this market and was therefore no longer prepared to invest or innovate in these technological areas as illustrated in Table 6.10.

C09B and D For the last two areas analyzed the overall contribution of patent applications was small. However, these areas show different behaviors, as illustrated in Table 6.12.[7]

Table 6.12: C09B and C09D: Evolution of patenting in Germany by Bayer Group

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C09B								
Total	**18**	40	29	25	27	17	**22**	11	11	9	1	2	**2**			
C09B/ C	**0.06**	0.09	0.07	0.07	0.05	0.04	**0.05**	0.03	0.03	0.02	0.00	0.01	**0.01**			
C09B/ total pat.	**0.04**	0.07	0.06	0.05	0.04	0.03	**0.04**	0.02	0.02	0.02						
								C09D								
Total	**25**	45	50	38	60	36	**50**	43	57	34	30	30	**32**	38	41	**33**
C09D/ C	**0.09**	0.10	0.12	0.10	0.12	0.08	**0.11**	0.10	0.13	0.08	0.07	0.08	**0.08**	0.11	0.12	**0.11**
C09D/ total pat.	**0.06**	0.08	0.10	0.08	**0.10**	0.06	**0.09**	0.08	0.09	0.06	0.05	0.06	**0.06**	0.07	0.08	**0.07**

Area C09B showed a stable pattern until 1997 and thereafter decreased until 2003, when Bayer applied the last patents. Area C09D achieved a higher number of applications over the 1990s comparing to the 2000s, however the share kept stable, both when looking at all patent applications in field C and at the all applications by Bayer.

[7]In both technological areas Germany is the origin of the vast majority of the patent applications as observed in the Appendix E, Table E.3

Next, Table 6.13 illustrates the summarized patent profile and definitions of the most important areas in 1991 for both areas, and in 2006 for area C09D.

Table 6.13: C09B and C09D: Summarized patent application profile and definitions – Bayer Group

IPC	1991	2006	Definition
			C09B
C07D	13.9%	–	Heterocyclic compounds
D06P	48.2%	–	Dyeing or printing textiles; dyeing leather, furs, or solid macromolecular substances in any form
			C09D
C08G	33.6%	85.5%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08L	13.1%	4.2%	Compositions of macromolecular compounds
			Pearson χ^2 = 5.97 (p-value = 0.015; df = 1)

In 1991 regulated area C09B was mostly associated with codes C07D and D06P. In 2006 Bayer had left new developments associated with this technology.

In 1991 regulated area C09D was mostly associated with codes C08G and C08L. In 2006 increase the association with area C08G and decrease the association with area C08L. In addition, a decrease in the range of areas associated with applications in 1991 to 2006, from nineteen to six areas with more than one percent in the total patent profile is noticed (Table F.3). This indicates a more focused research on innovations in area C09D.

When comparing this behavior with results obtained in Chapter 5, the most relevant areas in 1991 coincide for both regulated areas. For area C09B, Bayer's patenting behavior followed the same decreasing trend observed when looking at the overall behavior of this regulated area. Chapter 5 showed how area C09B was highly regulated in uses associated with code D06P. Thus, the most relevant associated area in Bayer's in 1991 patent applications was also the one with the highest fall when looking at the overall patenting, coinciding with regulation imposed over the years.

For area C09D Bayer's patenting behavior kept a stable pattern while the overall patenting in this regulated area has increased. The most important areas – C08G and C08L – were also previously highlighted as important in the overall patenting in both years. However, in the case of Bayer's applications in area C09D, area C08G increased its importance from 33.6% to 85.5%, while when looking at overall patents there was a smaller increase, from 14.6% to 17.2%.

As described in the brief history of the Bayer Group, in 2001 they acquired Lyondell Chemical Company a US producer of raw materials for polyurethanes directly associated with code C08G. This fact might explain the increasing relationship between areas C09D and C08G.

Remarks

The panel data showed that regulatory stringency has impacted negatively Bayer's patent profile. For this firm the Porter hypothesis is not supported.

Patent applications in area A01N more than doubled in the period under investigation. In 1991 area A01N was present in twelve percent of all Bayer's applications and in 2006 increased to twenty four percent. Applications in areas C08F, J, and K diminished over the period under investigation. This was reflected in the rank of the top ten applicants in these areas, disappearing from this rank in 2006. Bayer stopped applying patents in area C09B in 2003 and in area C09D there was an increase from 1991 to 2006, however reached higher number of applications by the end of the 1990s diminishing afterward.

Investigating the direction of patenting the Pearson χ^2 was shown to be not significant in areas A01N and C08J, while significant in areas C08K and C09D.

In summary, from 1990 to 2006 Bayer Group kept between the top ten applicants in areas A01N and C09D, left the market in areas C08F and C09B, and kept a decreasing trend in areas C08J and C08K.

This overall view corroborates with the results obtained in Chapter 5. It is noticed an increasing trend towards process innovation and away from product innovation. Also, new products are characterized by new formulations and new technologies.

In addition, from the analysis of the patenting profile in 1991 and 2006 it may be observed that the technological path designed by the firm which matches with the description of acquisitions and spin-offs detailed in the summary of the firm's history. This corroborates the interpretation and methodology employed because my analysis from the patent profile reflects the history of the firm in the last decades.

6.2.2 BASF

Similarly to Bayer, Badische Anilin & Soda Fabrik (BASF) was founded in 1865 in order to supply with synthetic dyes the growing textile industry. In 1913 BASF expanded its business to agricultural products manufacturing mineral fertilizers, given the increasing demand for food production in Europe.

The company developed the "Haber-Bosch process" enabling the fixation of atmospheric nitrogen to produce synthetic ammonia, a solution for the demand of nitrogen sources. This breakthrough process innovation was possible given the developments on catalysis technology and equipments that allowed chemical reactions under high-pressures (gas machines and compressors). In addition, in the first half of the twentieth century the company developed new processes for the synthesis of methanol (another raw material which was previously dependent on wood alcohol), urea (from ammonia and carbon dioxide), and sulfuric acid.

The 1950s marked the entrance of BASF in macromolecular technology. The acetylene chemistry supported the development of plastics and other raw materials for the production of coatings.

In the 1960s BASF expanded its production plants in industrialized countries. This expansion secured the company's raw materials base given the importance of basic and intermediate chemicals to the company's business. In the 1990s BASF expanded its investments in large scale chemical plants in Asia to provide petrochemicals, basic and intermediate chemicals, important raw materials for the production of different polymers, elastomers, and fibers which are used in different industries from electronics to textile.

Over the 1990s and 2000s there were further expansions and acquisitions on several sectors of the industry. Starting with polymers, there were investments on production plants in the US and Europe. Polyurethane basic materials and specialties in Germany (1990), petrochemical feedstocks in Belgium (1994), naphtha steam cracker to produce propylene and ethylene and other feedstocks in the US (2001), polymer dispersions for coating binders for the paper industry in Finland (2002). Furthermore, BASF acquired Honeywell's engineering plastics business in 2003 and Johnson Polymer resins portfolio in 2006, increasing its presence in the US market.

There were also investments in the food and agrochemicals sector. In 1999 the company created BASF Plant Science in partnership with the Swedish seed manufacturer Svalof Weibull.[8] In 2000 BASF acquired the crop protection business of American Home Products Corporation (AHP), in 2001 the vitamins business of Takeda Chemical Industries, and in 2003 the insecticide fipronil and other selected seed treatment fungicides from Bayer CropScience, increasing its portfolio and global sales of the agricultural products division.

Other acquisitions were Merck KgaA (DE, 2005), Engelhard Corporation (US, 2006), and Degussa AG (DE, 2006), accounting for electronic chemicals, catalysts for special pigments, and construction chemicals. In summary, over these sixteen years the company has expanded its chemical plants in petrochemicals and intermediates for the manufacture of polymers such plastics, elastomers to the industries from electronic to textile.

BASF also left some businesses. In 2000 BASF created together with Bayer and Hoechst a joint-venture on dyes to increase in competitiveness, the Dystar Textilfarben GmbH & Co. Deutschland KG. BASF's part of the largest supplier of textile dyes (associated with technological areas C09B and C09D) was sold in 2004 to the US private equity group Platinum Equity. In addition, in 2001 BASF sold its pharmaceutical business to Abbott Laboratories Inc..[9]

The company's name was the keyword used to obtain the patent applications in

[8]In 1999 BASF owned 85% of the biotechnology research company on the fields of agriculture and nutrition, both associated with technological area A01N.

[9]Information on the BASF company was extracted from BASF (2008).

Germany. All patents applied by any firm or individual inventor containing “basf” in its name or part of were downloaded from the ESPACE Bulletin database. Subsequently, firms or individuals not related were selected and discarded.

Evolution of patenting activity

Overall, BASF’s patenting activity increased from 1990 to 2006. Table 6.14 shows the number of patents applied per country of origin and the share of applications originating from Germany and the US.

Table 6.14: Patent applications in Germany by BASF classified per country of origin

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
DE	**501**	502	539	448	581	622	**696**	600	661	652	648	598	**619**	621	653	**800**
US	**39**	26	54	50	37	38	**29**	45	45	40	42	56	**30**	17	24	**45**
JP			3	3	3	4	**1**		2		1	1	**1**		3	**8**
CH						3		2	3	3	1	1	**2**			
FR	**1**															**2**
NL															2	**1**
IT			1		1											
BR		1														
DK									1							
ES								1								
Total	**541**	529	597	501	622	667	**726**	648	712	695	692	656	**652**	638	682	**856**
% DE	**0.93**	0.95	0.90	0.89	0.93	0.93	**0.96**	0.93	0.93	0.94	0.94	0.91	**0.95**	0.97	0.96	**0.93**
% US	**0.07**	0.05	0.09	0.10	0.06	0.06	**0.04**	0.07	0.06	0.06	0.06	0.09	**0.05**	0.03	0.04	**0.05**

There was an increase of fifty eight percent in the total number of patents applied from 1991 to 2006. More than ninety percent of these applications applied by BASF have originated from research centers located in Germany.

A fixed effect panel data was estimated to better understand if regulatory stringency has affected BASF’s patent profile positively or negatively. The panel includes all patents applied by BASF in all technological areas from 1991 to 2006. Table 6.15 shows these results.

Table 6.15: BASF and the Porter hypothesis: 1991 – 2006

Patent profile	Coefficient	t-value	P > |t|	
restrict	-0.002	-0.07	0.945	F(1,1829) = 0.00 (0.945)
L1	-0.048	-1.66	0.097	F(1,1707) = 2.76 (0.097)
L2	-0.071	-2.35	0.019	F(1,1585) = 5.50 (0.019)

Similarly to Bayer, when analyzing BASF’s patent profile there is a small but significant negative impact of regulatory stringency on patenting activity. Nevertheless, this effect can be observed just with a two-year lag panel.

The evolution of the relationship among technological areas

The following step in the analysis was to calculate BASF's patenting profile for the years of 1991 and 2006. Table 6.16 shows this profile in the different technological fields, for both years.

Table 6.16: BASF: Patenting profile in 1991 and 2006

	A	B	C	D	E	F	G	H	Total
1991	**9.9%**	11.1%	**66.8%**	4.8%	0.1%	1.2%	5.3%	0.8%	100.0%
2006	**17.5%**	12.7%	**62.1%**	1.9%	0.4%	1.4%	1.3%	2.6%	100.0%
Pearson $\chi^2 = 71.00$ (p-value = 0.000; df = 7)									

BASF's patenting activity is shown to be highly concentrated in field C, for both years. The most relevant areas in this field are associated with the development of new organic substances and their respective processes (C07C and C07D), the development of macromolecular substances and compositions (C08F, C08L, and C08G), and coating compositions, inks, paints (C09D). In 2006 the presence of area C08L decreased, while C08J increased, meaning a decrease in macromolecules formulations and an increase in after-treatment and working-up processes related to the final product (polymer).

Field A almost doubled from 1991 to 2006, being area A01N associated with biocides the most relevant in the profile for both years. Field B, associated with performing operations, saw a small increase in the same period. Specifically, the most important areas in this field were associated with equipment and apparatus applied in the chemical industry, for the separation of solids, chemical or physical processes, catalysis, colloid chemistry, shaping or joining plastics, printing, color printing and copying processes.[10]

Observing the regulated areas under investigation, Table 6.17 shows the relative share of these six technological areas in BASF's patent profile. The sum of these shares saw a small increase in this period, from 27.5% to 29.3%, as observed in Table 6.17.

Table 6.17: Share of regulated technological areas in BASF's patent profile

	A01N	C08F	C08J	C08K	C09B	C09D	Total share
1991	6.5%	8.4%	2.0%	2.5%	3.7%	4.4%	27.5%
2006	9.9%	6.3%	4.8%	1.8%	1.0%	5.5%	29.3%

Overall, the shares of areas A01N, C08J, and C09D increased, while the shares of areas C08F, C08K, and C09B decreased. Next, I analyze the behavior of each of these technological areas separately.

[10] In 1991: B01D, B01J, and B29C. In 2006: B01D, B01J, and B41M.

A01N Patent applications in area A01N increased by eighty four percent from 1991 to 2006. Table 6.18 illustrates the evolution of the number of patent application in this area, the share of A01N applications in field A, and the share of A01N in all BASF's patent applications.

Table 6.18: A01N: Evolution of patenting in Germany by BASF

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Total	**61**	44	42	51	61	91	**84**	103	76	64	50	52	**63**	80	86	**112**
A01N/ A	**0.70**	0.59	0.59	0.67	0.61	0.61	**0.54**	0.66	0.52	0.48	0.40	0.52	**0.50**	0.68	0.60	**0.53**
A01N/ total pat.	**0.11**	0.08	0.07	0.10	0.10	0.14	**0.12**	0.16	0.11	0.09	0.07	0.08	**0.10**	0.13	0.13	**0.13**

Considering all patents applied by BASF, the share of patents in area A01N saw a small increase (from 11% to 13%). In contrast, considering all patents applied by BASF in field A, the share of patents in area A01N decreased (from 70% to 53%). Summarizing, even though there was a growth in the number of applications in this area there was a decrease in the importance of it in its field (A). In addition, as observed in Chapter 5, applications in this area continued growing, but not as much as the total applications in field A01.

The next step is to analyze the direction of the innovative activity of patent applications in area A01N. Table 6.19 shows a summarized patent profile in 1991 and 2006, for applications in area A01N by BASF.[11]

Table 6.19: A01N: Summarized patent application profile and definitions – BASF

IPC	1991	2006	Definition
A	2.9%	14.5%	**Human necessities**
A01C		8.2%	Planting; sowing; fertilizing
C	95.4%	81.6%	**Chemistry; metallurgy**
C07C	21.6%	10.0%	Acyclic or carbocyclic compounds
C07D	70.4%	58.5%	Heterocyclic compounds
C07F	<1.0%	2.4%	Acyclic, carbocyclic, or heterocyclic compounds containing elements other than carbon, hydrogen, halogen, oxygen, nitrogen, sulfur, selenium, or tellurium
C12N		1.8%	Micro-organisms or enzymes; compositions thereof; propagating, preserving, or maintaining micro-organisms; mutation or genetic engineering; culture media
C23C		3.9%	Coating metallic material; coating material with metallic material; surface treatment of metallic material by diffusion into the surface, by chemical conversion or substitution; coating by vacuum evaporation, by sputtering, by ion implantation or by chemical vapor deposition, in general
			Pearson χ^2 = 18.30 (p-value = 0.003; df = 5)

From 1991 to 2006 changes can be perceived in the patent profile associated with area A01N. For instance, in 1991 applications were mainly associated with areas in field C and characterized by new organic substances (C07C and C07D).

In 2006 the association with areas C07C and C07D decreased even though they continued to be the most important. Many other areas arose with smaller shares. Applications were characterized by new products such new organic substances (C07F),

[11] The complete patent profile is available in the Appendix F, Table F.4.

new formulations with macromolecular compounds (C08L), new micro-organisms, enzymes and compositions thereof (C12N). New processes were characterized by the use of genetic engineering (C12N) and development of catalysts (C23C). In addition, development of new methods or apparatus for fertilizing and planting (A01C). Table 6.20 provides some examples to illustrate patent applications in 2006.

Table 6.20: A01N: Examples of patent applications in 2006.

Classification	Patent application title	Applicant name
A01N C23C	"Film forming spreading agents"	BASF Catalysts LLC (US) and The USA Secretary of Agriculture (US)
A01N C23C	"Volumizing agents"	BASF Catalysts LLC (US) and The USA Secretary of Agriculture (US)
A01H A01N C07K C12N	"Yield increase in plants over expressing the HSRP genes"	BASF Plant Science GmbH (DE)
A01C A01N C08L	"Seed dressing formulation comprising a biodegradable partially aromatic polyester"	BASF SE (DE)
A01C A01N A01P	"Triazole-based fungicidal mixtures"	BASF SE (DE)

The arise of new technologies associated with regulated area A01N, such C12N on biotechnology has been already observed in Chapter 5. Also, the increasing trend of new processes (C23C) and new products based on new formulations instead of new substances.

C08F, J, and K Regulated areas from macromolecular technology increased in number by 35%, 174%, and 3% respectively, from 1990 to 2006. Nevertheless, there was a peak in 1997 and a subsequent decrease, recovering in the last years as shown in Table 6.21.

Table 6.21: C08F, C08J, and C08K: Evolution of patenting in Germany by BASF

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C08F								
Total	**74**	87	105	88	91	96	**135**	74	105	89	91	68	**67**	75	61	**100**
C08F/ C	**0.18**	0.21	0.20	0.22	0.18	0.18	**0.24**	0.15	0.18	0.15	0.16	0.13	**0.13**	0.15	0.12	**0.15**
C08F/ total pat.	**0.14**	0.16	0.18	0.18	0.15	0.14	**0.19**	0.11	0.15	0.13	0.13	0.10	**0.10**	0.12	0.09	**0.12**
								C08J								
Total	**27**	39	38	27	53	54	**67**	40	53	31	38	27	**28**	39	48	**74**
C08J/ C	**0.07**	0.09	0.07	0.07	0.10	0.10	**0.12**	0.08	0.09	0.05	0.07	0.05	**0.05**	0.08	0.09	**0.11**
C08J/ total pat.	**0.05**	0.07	0.06	0.05	0.09	0.08	**0.09**	0.06	0.07	0.04	0.05	0.04	**0.04**	0.06	0.07	**0.09**
								C08K								
Total	**35**	41	37	39	39	32	**46**	23	35	37	26	34	**22**	17	29	**36**
C08K/ C	**0.09**	0.10	0.07	0.10	0.08	0.06	**0.08**	0.05	0.06	0.06	0.05	0.06	**0.04**	0.03	0.06	**0.06**
C08K/ total pat.	**0.06**	0.08	0.06	0.08	0.06	0.05	**0.06**	0.04	0.05	0.05	0.04	0.05	**0.03**	0.03	0.04	**0.04**

Among these three, area C08F has the highest number of applications and by consequence the highest share of patents in field C and all patents by BASF. Nevertheless, regulated areas C08F and C08K lost importance over the years while C08J gained.

Next I turn to observe if there was a change in the direction of the patenting activity in these regulated areas. Table 6.22 shows their respective summarized patent profiles and definitions of the most important technological areas associated with them, in 1991 and 2006. For all three regulated areas field C showed the highest shares in both years and field A emerged in 2006.[12]

Table 6.22: C08F, C08J, and C08K: Summarized patent application profile and definitions – BASF

IPC	1991	2006	Definition
		C08F	
A	4.8%	22.0%	Human necessities
A61K	3.3%	12.0%	Preparations for medical, dental, or toilet purposes
A61L		7.3%	Methods or apparatus for sterilizing materials or objects in general; disinfection, sterilization, or deodorization of air; chemical aspects of bandages, dressings, absorbent pads, or surgical articles; materials for bandages, dressings, absorbent pads, or surgical articles
B	12.5%	12.6%	Performing operations; transporting
B01J	5.7%	5.4%	Chemical or physical processes, e.g. catalysis, colloid chemistry; their relevant apparatus
C	77.2%	60.3%	Chemistry; metallurgy
C08G	7.5%	4.8%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08K	10.3%	4.6%	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C08L	21.9%	9.4%	Compositions of macromolecular compounds
C09D	8.9%	16.6%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes pr solids for coloring or printing; use of materials therefor)
			Pearson χ^2 = 17.90 (p-value = 0.006; df = 6)
		C08J	
A		11.6%	Human necessities
A61L		7.9%	Methods or apparatus for sterilizing materials or objects in general; disinfection, sterilization, or deodorization of air; chemical aspects of bandages, dressings, absorbent pads, or surgical articles; materials for bandages, dressings, absorbent pads, or surgical articles
B	22.3%	18.2%	Performing operations; transporting
B29C	6.3%	2.5%	Shaping or joining plastics; shaping of substances in a plastic state, in general; after-treatment of the shaped products (e.g. repairing)
B29K	6.3%		Indexing scheme associated with subclasses B29B, B29C or B29D, relating to moulding materials or to materials for reinforcements, fillers or preformed parts, e.g. inserts
C	67.9%	55.8%	Chemistry; metallurgy
C08F	8.1%	5.4%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
C08G	16.9%	7.5%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08K	14.1%	10.0%	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C08L	14.9%	12.5%	Compositions of macromolecular compounds
C09D	5.8%	12.5%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes pr solids for coloring or printing; use of materials therefor)
			Pearson χ^2 = 22.20 (p-value = 0.002; df = 7)
		C08K	
A		7.6%	Human necessities
A61L		5.6%	Methods or apparatus for sterilizing materials or objects in general; disinfection, sterilization, or deodorization of air; chemical aspects of bandages, dressings, absorbent pads, or surgical articles; materials for bandages, dressings, absorbent pads, or surgical articles
C	94.1%	87.4%	Chemistry; metallurgy
C08F	16.4%	10.5%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
C08G	12.9%	3.0%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08J	10.1%	16.0%	Working-up; general processes of compounding; after-treatment not covered by subclasses
C08L	39.9%	33.2%	Compositions of macromolecular compounds
C09D	3.9%	14.5%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes pr solids for coloring or printing; use of materials therefor)
			Pearson χ^2 = 12.20 (p-value = 0.032; df = 5)

Concerning regulated area C08F, in 1991 the most important areas were associ-

[12]The complete patent profile is available in the Appendix F, Table F.5.

ated with new processes and new products, substances and formulations related to areas C08G, C08K, C08L, and C09D. In 2006 areas C08G, C08K, and C08L decreased its importance while in field C increased the development of formulations of finished products (C09D) and in field A increased the shares of areas associated with preparations and products for medical, dental, and toilet purposes (A61K and A61L).

The pattern observed in the patent profile of area C08F can also be observed in the patent profiles of regulated areas C08J and C08K. When looking at findings highlighted in Chapter 5, technologies associated with areas A61K and A61L were not regulated. Comparing 1991 to 2006 can be observed the trend towards the development of new products based on new formulations (instead of new substances) and working-up of finished products represented by, for instance, areas C09D and C08J.

C09B and D The last two areas analyzed show different patterns as illustrated in Table 6.23. Regulated area C09B decreased by sixty five percent from 1991 to 2006. The share of patents applied by BASF under C09B regarding all BASF's applications and all applications under field C has also diminished over this period, not reaching more than ten percent.

Table 6.23: C09B and C09D: Evolution of patenting in Germany by BASF

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C09B								
Total	**37**	32	52	36	36	22	**27**	17	15	9	16	14	**16**	11	15	**13**
C09B/ C	**0.09**	0.08	0.10	0.09	0.07	0.04	**0.05**	0.03	0.02	0.02	0.03	0.03	**0.03**	0.02	0.03	0.02
C09B/ total pat.	**0.07**	0.06	0.09	0.07	0.06	0.03	**0.04**	0.03	0.02	0.01	0.02	0.02	**0.02**	0.02	0.02	**0.02**
								C09D								
Total	**49**	52	72	82	72	80	**74**	67	89	99	93	93	**64**	47	53	**89**
C09D/ C	**0.12**	0.13	0.14	0.20	0.14	0.15	**0.13**	0.14	0.15	0.17	0.17	0.18	**0.12**	0.09	0.10	**0.14**
C09D/ total pat.	**0.09**	0.10	0.12	0.16	0.12	0.12	**0.10**	0.10	0.13	0.14	0.13	0.14	**0.10**	0.07	0.08	**0.10**

The evolution of the number of patents applied in regulated area C09D by BASF illustrate a different pattern. There was overall increase of eighty two percent in the number of applications, however this growth was discontinued in the beginning of the 2000s recovering after 2005. The shares regarding the total applications and regarding field C had little variation. In 2006 ten percent of the total applications and fourteen percent of all applications in field C were classified under area C09D.

Next, in order to observe if occurred a change in the direction of patenting from 1991 to 2006, the patent profile of these regulated areas were calculated. Table 6.24 shows the summarized patent profile and definitions of the most important areas associated with regulated areas C09B and C09D, for both years.

Concerning the profile of area C09B, in 1991 the most important areas were associated with the use of dyes on printing and copying processes (B41M), dyeing textiles,

Table 6.24: C09B and C09D: Summarized patent application profile and definitions – BASF

IPC	1991	2006	Definition
		C09B	
A		**8.3%**	**Human necessities**
A23L		4.2%	Foods, foodstuffs, or non-alcoholic beverages, not covered by subclasses A23B to A23J; their preparation or treatment, e.g. cooking, modification of nutritive qualities, physical treatment; preservation of foods or foodstuffs, in general
A61K		4.2%	Preparations for medical, dental, or toilet purposes
B	**26.5%**		**Performing operations; transporting**
B41M	25%		Printing, duplicating, marking, or copying processes; color printing
C	**29.2%**	**66.7%**	**Chemistry; metallurgy**
C07C	8.1%	8.3%	Acyclic or carbocyclic compounds
C07D	10.2%	29.2%	Heterocyclic compounds
C08K		18.8%	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C08L	<1%	6.3%	Compositions of macromolecular compounds
C09D	4.7%		Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes pr solids for coloring or printing; use of materials therefor)
D	**37.8%**	**12.5%**	**Textiles and paper**
D06P	34.5%	12.5%	Dyeing or printing textiles; dyeing leather, furs, or solid macromolecular substances in any form
G	**5.6%**	**12.5%**	**Physics**
			Pearson χ^2 = 28.60 (p-value = 0.000; df = 8)
		C09D	
B	**20.6%**	**10.5%**	**Performing operations; transporting**
B05D	15.2%	3.3%	Processes for applying liquids or other fluent materials to surfaces, in general
C	**67.0%**	**85.2%**	**Chemistry; metallurgy**
C04B	5.0%	1.2%	Lime; magnesia; slag; cements; compositions thereof, e.g. mortars, concrete or like building materials; artificial stone; ceramics; refractories; treatment of natural stone
C08F	11.1%	18.1%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
C08G	21.1%	28.6%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08J	3.2%	9.6%	Working-up; general processes of compounding; after-treatment not covered by subclasses
C08L	10.8%	6.3%	Compositions of macromolecular compounds
			Pearson χ^2 = 10.30 (p-value = 0.067; df = 5)

leather, furs (D06P), and the development of new organic substances (C07C and C07D). In 2006 increased the share of areas associated with the development of new substances (C07C, C07D, C07F, and C08K), and new compositions of new or existing substances (C08L). Decreased the previous applications and emerged the uses for medical or dental preparations (A61K) and food additives (A23L).

Regarding the patent profile of area C09D, in 1991 the most important areas were associated with new products based on macromolecular compositions (C08F, C08G, and C08L) and new processes to apply dyes, paints, lacquers, and coatings (B05D). In 2006 there were no big changes, however increased the share of areas from field C (from 67.0% to 85.2%). New patent applications were more concentrated on macromolecular technology (C08F, C08G, and C08J). Some examples of both regulated areas are illustrated in Table 6.25.

When comparing BASF's patenting behavior with results obtained in Chapter 5, in regulated area C09B BASF's applications followed the same decreasing trend observed when looking at the overall behavior of this area. The behavior of the highly associated areas was also similar. There were less patents applied in 2006 and they were concentrated in field C, decreasing previous uses and emerging others.

Table 6.25: C09B and C09D: Examples of patent applications in 1991 and 2006.

Classification	Patent application title	Applicant name
	1991	
B41M C09B D06P	"Use of azo-dyes for thermal transfer printing"	BASF AG (DE)
C07D C09B D06P D21H	"Biscationic azo dyes and their intermediates"	BASF AG (DE)
C04B C09D	"Polymer-coated concrete"	BASF AG (DE)
C08G C08L C09D	"Mineral oil solutions of urethane resins curable by oxydation"	BASF Coatings AG (DE)
B05D C08F C08G C09D	"Process for producing a multi-layer paint coating and aqueous paint"	BASF Lacke + Farben AG (DE)
	2006	
C09B G02B	"Green pigment preparations based on C.I. pigment green 36"	BASF SE (DE)
A23L A61K C07C C09B	"Method for producing an aqueous suspension and a powdered preparation of one or more carotinoids"	BASF SE (DE)
C07C C08F C08J C08K C08L C09D	"Coating material, method for the production and use thereof, for producing adhesive, corrosion-inhibiting coatings"	BASF Coatings AG (DE)
C08K C08L C09D	"Mixture containing a solvent, which can be cured with UV-A radiation, method for its production and use thereof"	BASF Coatings AG (DE)

For instance, the development of dyes associated with code D06P was highly regulated (as seen in Chapter 5) and the overall patenting with this characteristics has decreased. This behavior is also observed in BASF's C09B patent profile, corroborating with a possible regulatory cause as reported in the previous chapter.

The brief history of BASF exposes that a joint-venture on textile dyes was created in 2000 (C09B associated with D06P) and afterward sold, in 2004. The fact that azocolorants (C09B) were highly regulated in 2003 might have influenced BASF to exit the market of textile dyes.[13]

In the case of regulated area C09D, BASF's patenting behavior followed the same increasing trend observed when looking the overall behavior of this area (describe in Chapter 5). The areas with highest shares illustrated in BASF's C09D patent profile – C08F, C08G, and C08L – were also previously seen in the previous chapter, for both years. However, in the case of BASF's applications there was a higher concentration of developments in field C (macromolecular technology).

This emphasis on macromolecular technology is observed when looking at the recent history of BASF. The expansion of production plants on basic and intermediate chemicals for the production of polymers occurred in 1994, 2001, and 2002. In addition, there were acquisitions of engineering plastics and resins business in 2003 and 2004 (associated with codes C08 and C09D). Accordingly, in 1990 BASF was the fifth in number of patent applications in regulated area C09D jumping to the first place in 2006.

Remarks

The panel data showed that regulatory stringency has impacted negatively BASF's patent profile. For this firm the Porter hypothesis is not supported.

[13]See Table 4.3.

Concerning the first research question, if occurred an increase or decrease in patenting, BASF's patent applications in areas A01N, C08F, C08J, and C09D increased from 1991 to 2006. While for area C08K kept stable and for C09B decreased. Differently from Bayer, BASF kept among the top ten applicants in the six investigated areas.

When investigating the direction of patenting, the Pearson χ^2 was shown to be significant for areas A01N, C08F, C08J, C08K, and C09B, while not significant in area C09D.

From 1991 to 2006 BASF kept among the top ten applicants in all regulated areas. In 2006 it was the leader in the number of patent applications in four of the six regulated areas here investigated: A01N, C08F, C08J, and C09D. As already stated when analyzing the pattern of patenting profiles in these areas, BASF kept innovating developing more processes, and products associated with new formulations and working up of finished plastics.

There was an increasing trend of the association of patents on regulated areas with areas from group "A61" where its uses, in most cases, were not restricted by this regulation. Also, the association of technological area associated with he development of paints and dyes for textiles, fur, and leather decreased, as previously seen in Chapter 5, restricted in 2003.

6.2.3 DuPont

Founded in 1802 with French capital by Eleuthère Irénée du Pont, E. I. du Pont de Nemours and Company brought to US the latest technology on powder-making, Alfred Nobel's invention of dynamite and smokeless powder. In spite of the developments over the nineteenth century on powder-making, DuPont is known in the chemical engineering field by its long history in the development of macromolecular technology.

Since the beginning of the twentieth century DuPont has invested on materials science. The company developed the polymerization process through condensation producing fibers, films, and plastic resins. From the forty major commercially produced polymers in the twentieth century, almost three fourths were developed by DuPont. The new processes developed by them redesigned the polymers technology, previously based in cellulose chemistry, enabling the development of diverse synthetic new substances.

For instance, in the 1930s DuPont developed the synthetic rubber that substituted the natural rubber given its resistance to water, oils, heat, and solvents. With further developments, synthetic rubber started to be applied not only in industrial equipments and automobiles, but became popular in diverse consumer goods using the derived materials in accessories and shoes. Since the 1950s synthetic rubbers (neoprene) started to be essential for the production of adhesives, sealants, power transmission belts, hoses and tubes.[14]

Such experience and knowledge of synthetic fibers enabled DuPont to grow and develop its textile and fabric division. In 1981 DuPont acquired Conoco Incorporation – a petroleum manufacturer – securing the supply of raw material for the production of synthetic fibers and plastics. After 1996 this line of products became a responsibility of the DuPont Dow Elastomers, a joint venture made with The Dow Chemical Company (US). Headquartered in the US, it is responsible for the production of a variety of products from more general rubber (commodities) to high performance fluoro-elastomers, employed on general rubber firms, chemical processing, and automotive industries. After the 1990s, process innovations enabled further technological developments, and combinations of known monomers and additives created new families of polymers for end-use markets.

With the development of biotechnology in the 1980s, the company initiated R&D on synthetic polymers based on biological raw materials through fermentation processes. The bio-polymers created a new branch of products with different applications and characteristics, such biodegradability. In 1999 DuPont sold its Conoco shares in order to obtain capital for investments in other fields, marking a change of focus of the corporation from petroleum-based synthetic polymers to the development of chemicals from different plants.

The developments of products such resins, coatings, and lacquers grew simultaneously to macromolecular technology. Since the 1930s, along with other chemical companies,[15] DuPont developed acrylic fibers (based on methyl methacrylate) and improved processes for its production. In the 1950s the company started its business of acrylic resin coatings, acrylic automobile finish lacquers, acrylic paints, and enamels. However, in 1983 DuPont sold its paints division and in 1993 its acrylic resins division, keeping just the production of acrylic automotive lacquers. By the end of the 1990s DuPont acquired the coatings subsidiary of Hoechst AG (Herberts GmbH), this amplified the production of automotive coatings.[16]

The company initiated its agriculture and nutrition business in the beginning of the twentieth century. By the 1920s it started producing seed disinfectants and acquired other chemical companies[17] in order to expand its business to inorganic

[14]In order to keep its name associated with the vanguardism in science-based materials, DuPont chose to protect the commercial name of each new product through trademark. In this way, even though the patent protection expires after fifteen to twenty-five years (depending on the country), the trademark protection can be renewed continuously keeping the consumer link to the product, even without the monopoly over the innovation. Some of the most well known polymeric fibers in the world were invented by DuPont: nylon (1930s), acrylic (1940s), polyester (1950s), *Lycra*®, *Teflon*® (1960s), *Supplex*® (1980s), and *Tactel*® (1990s), among others.

[15]Rohm & Haas and Imperial Chemical Industries (ICI).

[16]In 2000 DuPont became the major supplier of automotive coatings, and third largest coatings producer in the world.

[17]Grasselli and Roessler & Hasslacher Chemical Company (R&H).

insecticides and fungicides. Over the 1940s and 1950s technological developments in crop and insect research lead to new synthetic organic herbicides. Finally, in the 1970s were introduced a new line of herbicides designed for large scale food crops.

The development of biotechnology in the 1980s allowed the expansion of research on seeds, foods, and natural fibers. DuPont also invested in this field of research and in 1997 created the joint venture Optimum Quality Grains and in 1999 acquired Pioneer to develop R&D on superior seed hybrids. In the 2000s DuPont drove its agricultural division to the production of herbicide-resistant soybeans, higher-yielding, healthier oilseeds for consumers, and crops that reduce the amount of nitrogen and phosphorous in livestock waste. As a consequence its food division also grew focusing on soy protein food and beverage.

The macromolecular developments was also the start-up of DuPont's biomedical products such x-ray films in the 1930s. It expanded the industry segment in the 1970s with diagnostic instruments and afterward technology on pathogen screening, DNA-based identification, and new materials for diapers. On pharmaceuticals DuPont marketed its first drug in 1966 on flu prevention. In 1969 acquired Endo Pharmaceuticals and in the 1980s New England Nuclear Corporation and American Critical Care to expand its medicinal area on drugs, radiopharmaceutical tracers, and hospital care products.[18] In 1991 the company formed a joint venture with Merck Pharmaceutical for drug development and in 1998 DuPont bought Merck's part.[19] In 1996 DuPont sold its diagnostic and medical instrument business and five years later sold its pharmaceutical division.

Over the 2000s DuPont focused on five business segments: electronic and communication technologies, performance materials, coatings and color technologies, safety and protection, and agricultural and nutrition.

In order to extract data from the ESPACE Bulletin database were applied the keywords "nemours," "du pont," and "dupont" in order to minimize the risk of miscounting patents owned by DuPont, its divisions and joint ventures.

Evolution of patenting activity

From 1991 to 2006 occurred a six percent increase in DuPont's patenting activity in Germany. Table 6.26 shows the number of patents applied per country of origin and the share of applications originated from DuPont divisions in the US. Although patent applications have originated from fourteen different countries, more than ninety percent of these came from DuPont's divisions in the US.

The fixed effect panel data estimated for DuPont's patent profile is shown next in Table 6.27. Differently from Bayer and BASF, the panel estimated for DuPont

[18]Developments included the first transgenic mice for research and organ preservation solutions to use on transplant procedures.

[19]This joint venture developed drugs such anti-hypertensives, anti-coagulants, and for HIV treatment.

Table 6.26: Patent applications in Germany by DuPont classified per country of origin

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
US	**450**	343	302	290	279	305	**354**	351	365	333	290	307	**383**	375	465	**492**
JP	**4**	2		3	7	3	**5**	10	10	15	14	12	**14**	14	20	**14**
DE	**9**	7	3	7	3	3	**6**	2	4	3						
CA	**7**	5	4	6	1	2	**7**	3	4	1		1	**1**	1	2	
NL	**9**								1							
CH	**1**	3		1	1					1	1					**1**
GB	**2**	3	3													
FR			2		1		**1**				2					**2**
SE						2										
ES										2						
AU					1											
AT							**1**									
CN																**1**
BR																**1**
Total	**482**	363	314	307	293	315	**374**	366	384	355	307	320	**398**	390	487	**511**
%US	**0.93**	0.94	0.96	0.94	0.95	0.97	**0.95**	0.96	0.95	0.94	0.94	0.96	**0.96**	0.96	0.95	**0.96**

showed no significant relationship between regulatory stringency and the patenting activity of the firm. Thus, regulation caused no effect on DuPont's patent profile.

Table 6.27: DuPont and the Porter hypothesis: 1991 – 2006

Patent profile	Coefficient	t-value	P > |t|	
restrict	0.025	1.35	0.179	F(1,1874) = 1.81 (0.179)
L1	0.023	1.22	0.223	F(1,1749) = 1.49 (0.223)
L2	0.023	1.11	0.265	F(1,1624) = 1.24 (0.265)

The evolution of the relationship among technological areas

Following the analysis of DuPont's patenting activity, its profile was calculated for the years of 1991 and 2006. Table 6.28 shows this profile, with the share of the different technological fields.

Table 6.28: DuPont: Patent profile in 1991 and 2006

	A	B	C	D	E	F	G	H	Total
1991	**5.4%**	13.7%	**44.1%**	12.7%	0.4%	0.8%	15.1%	7.8%	100.0%
2006	**8.1%**	12.7%	**51.0%**	8.0%	0.6%	2.4%	4.8%	12.4%	100.0%
Pearson χ^2 = 67.10 (p-value = 0.000; df = 7)									

Over the years there were significant changes in this patenting profile. In 1991 the most important fields were C, G, and B. In 2006 field G – on physics – decreased and the share of field H – on technologies associated with electricity – increased.

Field C had the highest shares in both years, increasing from 44.1% to 51.0%. Technological areas associated with organic macromolecular technology (C08) and polishes, adhesives, miscellaneous compositions and applications of materials (C09), were responsible for this increase. Field A in 2006 increased its share given areas associated with human necessities such preparations for medical, dental purposes, and selection of special materials for outerwear, details of garments, and accessories (A41D and A61K). Field H in 2006 arose given the increasing application of organic materials in electric devices and integrated circuits (H01L).

From 1991 to 2006 decreased the shares of mechanical methods or apparatus in the manufacture of artificial filaments, fibers, and chemical features in the manufacture of artificial filaments. Predominantly, these technological areas are associated with processes and mechanical apparatus for the production of polymeric fibers (D01). Also decreased patent applications associated with the treatment of yarns, fabrics, feathers, or fibrous goods made from such materials (D06).

Looking at the regulated technological areas under investigation, Table 6.29 shows the share of these six areas in DuPont's patent profile. The sum of these shares increased from fourteen percent in 1991 to twenty percent in 2006, illustrating an increase of relative importance of these areas in DuPont's patenting activity.

Table 6.29: Share of regulated technological areas in Du Pont's patent profile

	A01N	C08F	C08J	C08K	C09B	C09D	Total share
1991	2.5%	2.8%	3.7%	1.9%	0.4%	2.7%	14.0%
2006	2.1%	3.9%	3.3%	3.1%	0.1%	7.5%	20.0%

From 1991 to 2006 The shares of areas C08F, C08K, and mainly C09D increased, while the other three regulated areas decreased. Next I analyze the behavior of regulated areas with exception to area C09B, given that DuPont does not figure among the top ten players in either years.

A01N The number of patent applications in area A01N is shown in Table 6.30, together with the share of applications in area A01N with respect to field A and the share with respect to all applications by DuPont in Germany. All these patents have originated from DuPont's divisions in the US.

Table 6.30: A01N: Evolution of patenting in Germany by DuPont

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Total	**18**	14	23	12	6	16	**12**	10	2		7	16	**15**	9	17	**16**
A01N/ A	**0.44**	0.35	0.52	0.32	0.24	0.50	**0.27**	0.23	0.05		0.27	0.47	**0.33**	0.29	0.37	**0.27**
A01N/ total pat.	**0.04**	0.04	0.07	0.04	0.02	0.05	**0.03**	0.03	0.01		0.02	0.05	**0.04**	0.02	0.03	**0.03**

From 1991 to 2006 the total number of applications varied without a specific pattern. The share of patents in area A01N in field A reached fifty percent in 1996, however in 2006 summed twenty seven percent. The share of patents in area A01N with respect to all patents applied by DuPont kept in most of this period under five percent.

In order to analyze the direction of the innovative activity in this area, the DuPont's A01N patent profile in 1991 and 2006 was calculated. Table 6.31 shows the summarized profile and definitions of the most relevant areas associated with patents in area A01N applied by DuPont in these years.

Table 6.31: A01N: Summarized patent application profile and definitions – DuPont

IPC	1991	2006	Definition
A	–	**8.3%**	**Human necessities**
A61K	–	5.0%	Preparations for medical, dental, or toilet purposes
A61Q	–	3.3%	Use of cosmetics or similar toilet preparations (IPC)
B	–	**30.0%**	**Performing operations; transporting**
B27K	–	30.0%	Processes, apparatus or selection of substances for impregnating, staining, dyeing, bleaching of wood or similar materials, or treating of of wood or similar materials with permeant liquids, not otherwise provided for; chemical or physical treatment of cork, cane, reed, straw or similar materials
C	**100.0%**	**61.7%**	**Chemistry; metallurgy**
C07C	15.5%	3.3%	Acyclic or carbocyclic compounds
C07D	69.0%	48.3%	Heterocyclic compounds
C07F	8.3%	–	Acyclic, carbocyclic, or heterocyclic compounds containing elements other than carbon, hydrogen, halogen, oxygen, nitrogen, sulfur, selenium, or tellurium
C07K		5.0%	Peptides
C12N	–	5.0%	Micro-organisms or enzymes; compositions thereof; propagating, preserving, or maintaining micro-organisms; mutation or genetic engineering; culture media
C12Q	7.1%		Measuring or testing processes involving enzymes or micro-organisms (immunoassay G01N 33/53); compositions or test papers therefor; processes of preparing such compositions; condition-response control in microbiological or enzymological processes
			Pearson χ^2 = 15.20 (p-value = 0.055; df = 8)

From 1991 to 2006 the patent profile associated with area A01N saw major changes. In 1991 applications were associated only with field C. Patents were characterized by new substances (C07C and C07F), new formulations of new or existing substances (C07D), and microbiological or enzymological processes (C12Q) .

In 2006 the association with areas C07C and C07D decreased even though they continued to be important areas. New products emerged associated with preparations for medical, dental, and cosmetic uses (A61Q and A61K), preparations for wood preservation (B27K), and genetic engineering (C12N). Some examples are shown in Table 6.32.

In 1997, with the creation of the joint venture Optimum Quality Grains, there was an increase in the developments of hybrid seeds not necessarily associated with biocides (A01N). After 2000 the company initiated the development of herbicides-resistant seeds – all innovations associated with code A01N. These two events might have favored the re-emergence of applications in this regulated area in the beginning of the 2000s.

In addition, as observed in Chapter 5 (Section 5.3), technologies associated with areas A61K and A61Q were not regulated. This might have favored the application of biocides in non-regulated uses.

Table 6.32: A01N: Examples of patent applications in 1991 and 2006.

Classification	Patent application title	Applicant name
	1991	
A01N C12Q	"Anthraquinones as inhibitors of sulfide production from sulfate-reducing bacteria"	E. I. du Pont de Nemours and Co. (US)
A01N C07C C07D C07F	"Crop-selective herbicidal sulfonamides"	E. I. du Pont de Nemours and Co. (US)
A01N C07C C07D C07F	"Arthropodicidal pyrazolines, pyrazolidines and hydrazines"	E. I. du Pont de Nemours and Co. (US)
	2006	
A01N A61Q C07C C07D	"Puleganic amides as insect repellants"	E. I. du Pont de Nemours and Co. (US)
A01N C07K C12N	"Insect-specific protease recognition sequences"	E. I. du Pont de Nemours and Co. (US) and Pioneer-Hi-Bred International Inc. (US)
A01N B27K	"Tropolone complexes as wood preservatives"	E. I. du Pont de Nemours and Co. (US)
A01N A61K C07D	"5-aryl isoxazolines for controlling invertebrate pests"	E. I. du Pont de Nemours and Co. (US)

C08F, J, and K The number of patent applications in macromolecular technology is shown in Table 6.33, from 1991 to 2006. In addition, it is shown the share of each of these regulated areas with respect to field C and with respect to all patents applied by DuPont.

Table 6.33: C08F, C08J, and C08K: Evolution of patenting in Germany by DuPont

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C08F								
Total	**22**	16	29	20	25	49	**41**	43	56	49	38	30	**27**	15	25	**36**
C08F/ C	**0.09**	0.07	0.15	0.10	0.12	0.21	**0.16**	0.17	0.20	0.21	0.19	0.16	**0.11**	0.06	0.08	**0.12**
C08F/ total pat.	**0.05**	0.04	0.09	0.07	0.09	0.16	**0.11**	0.12	0.15	0.14	0.12	0.09	**0.07**	0.04	0.05	**0.07**
								C08J								
Total	**50**	45	31	42	28	28	**46**	22	26	25	20	26	**25**	25	42	**41**
C08J/ C	**0.20**	0.20	0.16	0.21	0.14	0.12	**0.18**	0.08	0.09	0.11	0.10	0.13	**0.11**	0.10	0.13	**0.13**
C08J/ total pat.	**0.10**	0.12	0.10	0.14	0.10	0.09	**0.12**	0.06	0.07	0.07	0.07	0.08	**0.06**	0.06	0.09	**0.08**
								C08K								
Total	**26**	30	20	24	25	31	**27**	29	28	24	21	16	**38**	33	41	**39**
C08K/ C	**0.11**	0.14	0.10	0.12	0.12	0.13	**0.10**	0.11	0.10	0.10	0.11	0.08	**0.16**	0.14	0.13	**0.13**
C08K/ total pat.	**0.05**	0.08	0.06	0.08	0.09	0.10	**0.07**	0.08	0.07	0.07	0.07	0.05	**0.10**	0.08	0.08	**0.08**

From 1991 to 2006, areas C08F and C08K increased sixty four and fifty percent, respectively. Their respective shares in field C and in all patents by DuPont also increased.

Conversely, area C08J decreased over the 1990s, recovering after 2001. However, from 1991 to 2006 decreased eighteen percent. Yet, area C08J is responsible for the largest number of applications per year among the three regulated areas from macromolecular technology. In 1991 twenty percent of patents applied by DuPont in field C were associated with area C08J, while in 2006 this share decreased down to thirteen percent.

Nevertheless, these three regulated areas are associated with the core business of the company: material science. Next, the patent application profiles are analyzed to observe if there is a change in the direction of the patenting activity. Table 6.34 shows the summarized profile and definitions of the most important areas associated with these three regulated areas, in 1991 and 2006.

Table 6.34: C08F, C08J, and C08K: Summarized patent application profile and definitions – DuPont

IPC	1991	2006	Definition
		C08F	
C	68.5%	76.0%	Chemistry; metallurgy
C07C	13.6%	3.8%	Acyclic or carbocyclic compounds
C08G	6.9%	6.7%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08J	4.7%	10.9%	Working-up; general processes of compounding; after-treatment not covered by subclasses
C08K	10.6%	3.2%	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C08L	17.1%	26.6%	Compositions of macromolecular compounds
C09D	5.6%	19.9%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes or solids for coloring or printing; use of materials therefor)
			Pearson χ^2 = 7.72 (p-value = 0.172; df = 5)
		C08J	
B	21.4%	14.5%	Performing operations; transporting
B32B	4.9%	11.1%	Layered products, i.e. products built-up of strata of flat (e.g. cellular or honeycomb, form)
C	57.3%	66.1%	Chemistry; metallurgy
C07C	5.3%		Acyclic or carbocyclic compounds
C08F	1.5%	7.7%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
C08G	11.1%	4.3%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08K	5.6%	9.3%	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C08L	11.8%	25.2%	Compositions of macromolecular compounds
C09D	1.5%	7.7%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes pr solids for coloring or printing; use of materials therefor)
C09K	8.0%	9.5%	Materials for miscellaneous applications, not provided elsewhere
D	10.5%	3.2%	Textiles and paper
			Pearson χ^2 = 21.50 (p-value = 0.003; df = 7)
		C08K	
B	5.8%	15.7%	Performing operations; transporting
B32B		10.8%	Layered products, i.e. products built-up of strata of flat (e.g. cellular or honeycomb, form)
C	76.2%	58.3%	Chemistry; metallurgy
C08F	6.1%	2.4%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
C08G	11.0%	<1%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08J	10.4%	9.9%	Working-up; general processes of compounding; after-treatment not covered by subclasses
C08L	36.0%	28.9%	Compositions of macromolecular compounds
C09D	3.2%	6.0%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes pr solids for coloring or printing; use of materials therefor)
D	9.6%	4.1%	Textiles and paper
D01F	9.6%	2.9%	Chemical features in the manufacture of artificial filaments, threads, fibers, bristles, or ribbons; apparatus specially adapted for the manufacture of carbon filaments
H	6.5%	16.0%	Electricity
			Pearson χ^2 = 22.10 (p-value = 0.001; df = 6)

Concerning area C08F, from 1991 to 2006 decreased the association with the development of new organic substances (C07C) and the use of non-macromolecular substances as ingredient for new formulations (C08K). Conversely, increased the association with processes (C08J), compositions of macromolecular compounds and of finished products (C08L and C09D).

Concerning area C08J, from 1991 to 2006 decreased the association with processes for the development of new organic substances and new polymers (C07C and C08G).

Conversely, increased the association with new processes for new formulations, compositions of macromolecular or not substances, and compositions of final products (C08F, C08K, C09D, and B32B).

Concerning area C08K, decreased the association with new substances (polymers – C08F and C08G). Conversely, increased the association with development of mechanical processes (B32B).

C09D The evolution of DuPont's patenting activity in area C09D is illustrated by Table 6.35. From 1991 to 2006 the number of patent applications more than tripled from 1991 to 2006. The share of C09D applications with respect to field C and with respect to the total number of applications increased. In 1991 nine percent of all patents applied in field C belonged to area C09D, in 2006 this share reached against twenty one percent.

Table 6.35: C09D: Evolution of patenting in Germany by DuPont

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Total	**21**	21	27	23	34	45	**49**	56	46	43	33	29	**42**	67	69	**66**
C09D/ C	**0.09**	0.10	0.14	0.11	0.17	0.19	**0.19**	0.22	0.16	0.18	0.17	0.15	**0.18**	0.28	0.22	**0.21**
C09D/ total pat.	**0.04**	0.06	0.09	0.07	0.12	0.14	**0.13**	0.15	0.12	0.12	0.11	0.09	**0.11**	0.17	0.14	**0.13**

In order to observe if occurred a change in the direction of patenting from 1991 to 2006, the DuPont's C09D patent profile was calculated. Table 6.36 shows the summarized proÞle and definitions of the most important areas associated with C09D, in 1991 and 2006.

Table 6.36: C09D: Summarized patent application profile and definitions – DuPont

IPC	1991	2006	Definition
B	**17.7%**	**17.7%**	**Performing operations; transporting**
B05D	8.5%	11.0%	Processes for applying liquids or other fluent materials to surfaces, in general
B32B	6.7%	2.4%	Layered products, i.e. products built-up of strata of flat (e.g. cellular or honeycomb, form)
C	**67.7%**	**75.2%**	**Chemistry; metallurgy**
C08F	5.2%	11.0%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
C08G	24.4%	32.3%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08J	4.6%	6.0%	Working-up; general processes of compounding; after-treatment not covered by subclasses
C08K	5.2%	4.5%	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C08L	27.1%	9.9%	Compositions of macromolecular compounds
H	**12.5%**		**Electricity**
H01B	12.5%		Cables; conductors; insulators; selection of materials for their conductive, insulating, or dielectric properties
			Pearson χ^2 = 8.06 (p-value = 0.328; df = 7)

In 1991 the most important areas were related to area C09D were new products (substances and formulations of new or existing substances) and processes on macromolecular technology (C08). Also, the development of processes for applying dyes, paints, lacquers, and coatings (B05D and B32B), and development of new materials special insulating or dielectric properties (H01B).

In 2006 there was an increase of areas related to macromolecular technology (C08), new substances and their respective processes (C08F and C08G). Some examples are illustrated in Table 6.37.

Table 6.37: C09D: Examples of patent applications in 1991 and 2006.

Year	Classification	Patent application title	Applicant name
1991	C09D H01B	"Non-carbon black containing conductive coating composition"	E. I. du Pont de Nemours and Co. (US)
1991	B05D B32B C08L C09D	"Non-stick coating system with PTFE and PFA or FEP for concentration gradient"	E. I. du Pont de Nemours and Co. (US)
2006	C08G C09D	"Durable coating compositions containing aspartic amine compounds with improved potlife"	E. I. du Pont de Nemours and Co. (US)
2006	C08F C08L C09D	"Rapid drying lacquers containing triblock copolymer"	E. I. du Pont de Nemours and Co. (US)

In Chapter 5 regulated area C09D also showed an increasing trend. The most important areas in chemicals technology (field C) associated with C09D for DuPont – C08G and C08L – were also highlighted as important in the overall patenting for both years. As observed in BASF's case, in 2006 DuPont also concentrated developments in macromolecular technology (C08).

When looking at the company's recent history, even though DuPont sold its acrylic resins division in 1993 (C09D), by the end of the 1990s the company acquired Herberts GmbH, the coatings division of Hoechst AG focusing on commercial acrylic (C08) and automotive lacquers (C09D). Accordingly, in 1990 DuPont did not figure among the top ten applicants in this regulated area, while in 2006 the company reached the second place.

Remarks

The panel data showed neither positive nor negative regulatory impact on this firm's overall patent profile. From 1991 to 2006 DuPont's patent applications increased in areas C08F, C08K, and C09D, decreased in area C08J, and decreased over the 1990s and increased over the 2000s in area A01N.

When investigating the direction of patenting, the Pearson χ^2 was shown to be significant for areas A01N, C08J, and C08K.

6.2.4 3M

Founded in 1902 under the name "Minnesota Mining and Manufacturing Company," it first started as a mining company and fast moved to the production of abrasives and sandpaper. During the twentieth century 3M developed a vast branch of different goods, from pressure-sensitive tapes to defense materials. After the 1970s 3M expanded its business to radiology, energy control, and health care (medical and dental care and pharmaceuticals).

In the 1980s there was an expansion in production plants, establishing wholly owned companies in the United Arab Emirates, China, India, and Turkey. The expansion was also marked by the acquisition of Unitek Corporation, a supplier of orthodontic products, and the creation of a joint venture with Harris Corporation, on copiers and facsimile machines. 3M also established another research center in the US (Texas) and six in Europe.

3M has been over the years focusing on customer requirements over a wide range of technological areas. The company introduced the *Post-it Notes*, improved technologies related to magnetic films, and started commercializing the pharmaceutical *Tambocor*.[20]

In the beginning of the 1990s most of 3M sales came from outside the US and one third of sales derived from recently introduced products (less than five years). By the end of the decade the company expanded its operations in Europe, Asia, Middle East, and Africa.[21]

Products continued to be developed in diverse areas and by the end of the decade the company was reorganized by the company into six major fields: industrial; transportation, graphics and safety; health care; consumer and office; electro and communications; and specialty material.[22]

In all these business fields the company has diverse products associated with the chemicals technology. These innovations are present in polymers, films, adhesives, dyes, surface materials, abrasives, constituents of computer screens, flexible electronic circuits, HFEs (hydrofluoroethers), chlorofluorocarbon substitutes (free of ozone depleting chlorofluorocarbons), and pharmaceuticals. In 1999, Dyneon LLC became a subsidiary of 3M, leader on fluoropolymers products and processes.

In the 2000s more than one third of total sales came from new products (introduced in four years or less). On chemicals there was an increase in R&D, new pharmaceuticals (immune response modifiers) and cleaning products were marketed. In addition, optical films, abrasives, adhesives, and other products which have chemical components.[23]

In order to extract data from the ESPACE Bulletin database, keywords used were "minnesota," "3M," "dyneon," and "unitek". The last two referred to the Business unit Dyneon LLC and 3M Unitek Corporation, however patents from all business units of 3M were found to be applied with the names "Minnesota Mining and Company" or "3M Innovative Properties Company." This data is described in the following sections.

[20] Drug approved by the US FDA in 1985 for heart diseases.

[21] Czech Republic, Hungary, Poland, Russia, Pakistan, Egypt, Sri Lanka, Vietnam, Israel, Morocco, and Romania.

[22] Products included *Including immune response modifier pharmaceuticals; brightness enhancement films for electronic displays; and flexible circuits used in inkjet printers, cell phones and other electronic devices.*

[23] Information on the 3M company were extracted from the website `http://solutions.3m.com/wps/portal/3M/en_US/about-3M/information/more-info/history/` (visited between 26 May and 15 July 2009) and the book "A century of innovation: The 3M story," 2002.

Evolution of patenting activity

From 1991 to 2006 the number of patent applications by 3M in Germany almost doubled. Table 6.38 illustrates this increasing trend where the vast majority of patent applications have originated from 3M research centers in the US (over 94%).

Table 6.38: Patent applications in Germany by 3M classified per country of origin

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
US	**277**	396	401	490	453	579	**390**	393	485	425	420	561	**504**	586	510	**534**
DE					1		**3**	18	9	26	27	13	**18**	22	16	**3**
KN												1				
AU						2										
IT			1						1							
Total	**277**	396	402	490	454	581	**393**	411	495	451	447	575	**522**	608	526	**537**
% US	**1.00**	1.00	0.99	1.00	0.99	0.99	**0.99**	0.96	0.98	0.94	0.94	0.98	**0.97**	0.96	0.97	**0.99**

Similarly to the other firms, a fixed effect panel data was estimated with 3M's patent profile. Table 6.39 shows these results.

Table 6.39: 3M and the Porter hypothesis: 1991 – 2006

Patent profile	Coefficient	t-value	P > |t|	
restrict	-0.039	-2.13	0.033	F(1,1844) = 4.55 (0.033)
*L*1	-0.057	-2.98	0.003	F(1,1721) = 8.90 (0.003)
*L*2	-0.056	-2.72	0.007	F(1,1598) = 7.41 (0.007)

Results indicate a small but significant negative impact of regulatory stringency on 3M's patent profile.

The evolution of the relationship among technological areas

Differently from the other three firms studied in this chapter, 3M has patent applications distributed among the different technological fields. 3M's patent profile is shown in Table 6.40.

Table 6.40: 3M: Patent profile in 1991 and 2006

	A	B	C	D	E	F	G	H	Total
1991	16.8%	24.3%	25.7%	1.2%	1.4%	1.3%	23.0%	6.3%	100.0%
2006	16.8%	23.7%	21.4%	1.0%	1.0%	1.8%	19.3%	15.0%	100.0%
Pearson χ^2 = 21.90 (p-value = 0.003; df = 7)									

In 1991 patent applications were associated mostly with fields A, B, C, and G. In 2006 also field H appeared as highly relevant.

In field A, for both years, the most important areas were associated with hygiene, medical and veterinary science. These reflect innovation on pharmaceuticals and odontology business. In field C, for both years, the most important technological areas belonged to organic macromolecular technology (preparations and compositions) and adhesives (processes, compositions, and applications).

In 1991, most important areas from field B were associated with layered products, packaging elements, printing, or copying processes. In 2006 arose technological areas associated with shaping or joining plastics, shaping of substances in a plastic state, after-treatment methods and separation processes (by wet, magnetic, or electrostatic methods).

In 1991, most important technological areas from field G – on physics – were associated with photosensitive materials for photographic purposes, photomechanical production of textured or patterned surfaces (for printing, processing of semiconductor devices, and materials therefor), electrography, electrophotography, and magnetography. In 2006, most important areas were associated with the application of this science to optical elements, systems, or apparatus; and electric digital data processing (related to computers) associated with the investigation or analysis of materials by determining their chemical or physical properties.

From 1991 to 2006 the share of field H more than doubled. In 1991 the importance of this field was associated with semiconductor devices, electrically-conductive connections, structural associations of mutually-insulated electrical connecting elements. In 2006 these technological areas increased their importance and, in addition, increased the share of technological areas associated with batteries (conversion of chemical into electrical energy).

Observing the behavior of the concerning regulated technological areas, Table 6.41 shows that they represent a small share in 3M patent profile. Overall the sum of these shares is small, with little variation from 1991 to 2006.

Table 6.41: Share of regulated technological areas in 3M's patent profile

	A01N	C08F	C08J	C08K	C09B	C09D	Total share
1991	–	2.8%	0.6%	1.0%	0.5%	1.7%	6.6%
2006	0.5%	2.1%	1.6%	1.6%	–	1.3%	7.1%

This data corroborates with the strategy and focus of the company described above. For 3M, chemicals technology is a tool for the development of new products associated with all kinds of consumer goods.

The behavior of the patenting activity in these areas by 3M is detailed next. However, area A01N will not be investigated given that the company does not figure among the top ten in either years. Thus, it is not an important field for the firm's technological development.

C08F, J, and K Table 6.42 shows the number of patent applications per country of origin from 1991 to 2006, in the areas C08F, C08J, and C08K. With few exceptions, nearly all applications are originated in the US. In addition, it is shown the share of each of these regulated areas with respect to Þeld C and with respect to all patents applied by 3M.

Table 6.42: C08F, C08J, and C08K: Evolution of patenting in Germany by 3M

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C08F								
Total	**24**	37	26	41	30	35	**31**	22	30	33	34	30	**40**	29	23	**17**
C08F/ C	**0.25**	0.24	0.06	0.19	0.18	0.17	**0.23**	0.16	0.16	0.19	0.19	0.14	**0.24**	0.14	0.16	**0.12**
C08F/ total pat.	**0.09**	0.09	0.06	0.08	0.07	0.06	**0.08**	0.05	0.06	0.07	0.08	0.05	**0.08**	0.05	0.04	**0.03**
								C08J								
Total	**8**	25	22	31	19	16	**27**	20	28	23	19	25	**13**	30	22	**17**
C08J/ C	**0.08**	0.16	0.05	0.14	0.12	0.08	**0.20**	0.14	0.16	0.14	0.11	0.12	**0.08**	0.15	0.16	**0.12**
C08J/ total pat.	**0.03**	0.06	0.05	0.06	0.04	0.03	**0.07**	0.05	0.06	0.05	0.04	0.04	**0.02**	0.05	0.04	**0.03**
								C08K								
Total	**9**	17	16	14	12	20	**12**	13	16	13	9	26	**17**	12	28	**20**
C08K/ C	**0.09**	0.11	0.04	0.07	0.07	0.10	**0.09**	0.09	0.09	0.08	0.05	0.13	**0.10**	0.06	0.19	**0.14**
C08K/ total pat.	**0.03**	0.04	0.04	0.03	0.03	0.03	**0.03**	0.03	0.03	0.03	0.02	0.05	**0.03**	0.02	0.05	**0.04**

In 1991, 9% of the total patent applications by 3M were also classified under the technological area C08F (new macromolecular substances). Over the 2000s there was a decrease in the share of applications containing this classification code, down to 3% in 2006, although with a small decrease in the absolute numbers.

From 1991 to 2006 there was an increase in the absolute numbers of patent applications by 3M classified under technological areas C08J and C08K. Differently from C08F, these last two technological areas are associated with compounding of polymers with non-macromolecular or inorganic ingredients, new processes of compounding and after-treatments. This may indicate that 3M has developed more innovations in processing and new combinations of existing macromolecular substances with other substances, and decreased the number of innovations in the development of new macromolecules.

Next, Table 6.43 shows the summarized patent application profiles of these three regulated areas. Investigating whether there was a change in the direction of patenting, the Pearson χ^2 tests indicate no significant results for C08F and C08J.

Table 6.43: C08F, C08J, and C08K: Summarized patent application profile and definitions – 3M

IPC	1991	2006	Definition
		C08F	
A	2.0%	5.6%	Human necessities
A61K	<1%	5.6%	Preparations for medical, dental, or toilet purposes
B	13.8%	5.6%	Performing operations; transporting

IPC	1991	2006	Definition
C	69.1%	77.8%	Chemistry; metallurgy
C08G	13.8%	18.9%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08J	1.0%	22.2%	Working-up; general processes of compounding; after-treatment not covered by subclasses
C08L	6.8%	16.7%	Compositions of macromolecular compounds
C09D	8.6%	7.8%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes pr solids for coloring or printing; use of materials therefor)
C09J	14.1%	5.6%	Adhesives; adhesive processes in general (non-mechanical part); adhesive processes not provided for elsewhere; use of materials as adhesives
G	10.8%	11.1%	Physics
G01N	2.8%	11.1%	Investigating or analyzing materials by determining their chemical or physical properties
			Pearson χ^2 = 3.73 (p-value = 0.713; df = 6)
		C08J	
B	35.0%	29.5%	Performing operations; transporting
B01D	5.1%	7.7%	Separation
B29C		6.4%	Shaping or joining plastics; shaping of substances in a plastic state, in general; after-treatment of the shaped products (e.g. repairing)
B32B	13.5%	10.3%	Layered products, i.e. products built-up of strata of flat (e.g. cellular or honeycomb, form)
B41M	7.2%		Printing, duplicating, marking, or copying processes; color printing
C	41.3%	50.0%	Chemistry; metallurgy
C08F	3.1%	15.4%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
C08K	6.3%	18.6%	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C08L	12.5%	6.4%	Compositions of macromolecular compounds
C09D	7.2%		Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes pr solids for coloring or printing; use of materials therefor)
C09K	6.3%		Materials for miscellaneous applications, not provided elsewhere
G	10.4%	6.4%	Physics
H	10.3%	14.1%	Electricity
			Pearson χ^2 = 12.20 (p-value = 0.141; df = 8)
		C08K	
A	3.4%	5.6%	Human necessities
A61K	3.4%	5.6%	Preparations for medical, dental, or toilet purposes
C	88.2%	81.9%	Chemistry; metallurgy
C01G		8.3%	Compounds containing metals not covered by subclasses C01D or C01F
C07F	6.2%		Acyclic, carbocyclic, or heterocyclic compounds containing elements other than carbon, hydrogen, halogen, oxygen, nitrogen, sulfur, selenium, or tellurium
C08F	9.9%	1.1%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
C08G	9.0%	5.3%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08J	5.6%	13.4%	Working-up; general processes of compounding; after-treatment not covered by subclasses C08B, C, F, and G
C08L	20.1%	33.8%	Compositions of macromolecular compounds
C09C		8.3%	Treatment of inorganic materials, other than fibrous fillers, to enhance their pigmenting or filling properties; preparation of carbon black
C09D	9.0%	6.7%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes pr solids for coloring or printing; use of materials therefor)
C09J	22.9%		Adhesives; adhesive processes in general (non-mechanical part); adhesive processes not provided for elsewhere; use of materials as adhesives
			Pearson χ^2 = 17.70 (p-value = 0.024; df = 8)

Regarding area C08K, from 1991 to 2006 increased the association with the application on medical, dental, or toilet products, new inorganic compounds and formulations of existing macromolecular compounds (C01G and C08L), and after treatment processes to mold the final products (C08J and C09C). Conversely, decreased the association with new substances (C07F, C08F, and C08G) and the application on adhesives and their processes (C09J).

C09B and D The evolution of the last two technological areas analyzed is shown in Table 6.44. There was small number of applications in area C09B, reaching at most eight patents during the 1990s, and disappearing over the 2000s.

Table 6.44: C09B and C09D: Evolution of patenting in Germany by 3M

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C09B								
Total	**3**	6	6	6	8	7		3		1	2	2	**1**			
C09B/ C	**0.03**	0.04	0.01	0.03	0.05	0.03		0.02		0.01	0.01	0.01	**0.01**			
C09B/ total pat.	**0.01**	0.02	0.01	0.01	0.02	0.01		0.01		<0.01	<0.01	<0.01	**<0.01**			
								C09D								
Total	**17**	18	26	28	28	38	**29**	21	31	18	17	24	**21**	19	23	**14**
C09D/ C	**0.18**	0.12	0.06	0.14	0.17	0.18	**0.22**	0.15	0.18	0.11	0.10	0.12	**0.13**	0.09	0.16	**0.10**
C09D/ total pat.	**0.06**	0.05	0.06	0.06	0.06	0.07	**0.07**	0.05	0.06	0.04	0.04	0.04	**0.04**	0.03	0.04	**0.03**

The evolution of 3M's patenting activity in area C09D was different, but without a specific trent. Concerning the share in field C, in 1991 was eighteen percent, increasing to twenty two in 1997, and decreasing to ten percent in 2006. Concerning the share in all applications by 3M, it decreased from six to three percent over this period.

Next, Table 6.45 shows the summarized patent profile of applications in 1991 and 2006 for technological area C09D. This analysis was not developed for C09B given that 3M stopped innovating in this area.

Table 6.45: C09D: Summarized patent application profile and definitions – 3M

IPC	1991	2006	Definition
B	**12.6%**	**9.1%**	**Performing operations; transporting**
B32B	5.4%	9.1%	Layered products, i.e. products built-up of strata of flat (e.g. cellular or honeycomb, form)
C	**75.0%**	**87.9%**	**Chemistry; metallurgy**
C08F	12.1%	6.4%	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
C08G	14.1%	35.2%	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds
C08K	4.8%	10.9%	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C08L	9.2%	16.7%	Compositions of macromolecular compounds
C09J	18.5%	12.1%	Adhesives; adhesive processes in general (non-mechanical part); adhesive processes not provided for elsewhere; use of materials as adhesives
			Pearson χ^2 = 2.94 (p-value = 0.710; df = 5)

In 1991 the most important areas associated with area C09D were related to new macromolecular compounds and their respective processes (C08F, C08G, and C08L) and adhesives (C09J). In 2006 there was an increase of the development of new macromolecular substances, the use of inorganic substances in these compositions, and respective processes (C08G, C08K, and C08L). The Pearson χ^2 test shows no significant change. Some examples are illustrated in Table 6.46.

Remarks

The panel data for 3M showed that regulatory stringency has impacted negatively the firm's patent profile. Also in this case the Porter hypothesis is not supported.

3M is a particular case among the selected group of firms because the company

Table 6.46: C09D: Examples of patent applications in 1991 and 2006.

Year	Classification	Patent application title	Applicant name
1991	B41M C08J C08K C08L C09D	"Transparent liquid absorbent materials for use as ink-receptive layers"	Minnesota Mining and Co. (US)
1991	C07D C08G C09D C09J	"Process for the preparation of azlactone-functional Michael adducts"	Minnesota Mining and Co. (US)
2006	C08G C08L C09D C09J	"Adhesive composition and articles made therefrom"	3M Innovative Properties Co. (US)
2006	C08K C08L C09D	"Damage-resistant epoxy compound"	3M Innovative Properties Co. (US)

uses the chemicals technology as a way to obtain its products, but the chemicals *per se* are not the firm's final output. Their final products are not chemical products, but consumer products which contain chemicals. However, it figures among the top applicants in five of the six investigated regulated areas. Nevertheless, although the chemicals field has shared importance with several other fields as seen in its patent profile (Table 6.40).

Concerning the first research question, if occurred an increase or decrease in patenting from 1991 to 2006, 3M's patent applications increased in areas C08J and C08K, decreased in areas C08F and C09D, and exited the market in area C09B.

When investigating the direction of patenting, the Pearson χ^2 was shown to be significant for area C08K, and not significant for areas C08F, C08J, and C09D.

6.3 Findings

The aim of this chapter has been to investigate the innovative behavior of firms impacted by the EU chemicals regulation from 1991 to 2006. Four firms, from among the top ten patent applicants in 1990 in the most regulated technological areas, were chosen to illustrate findings discussed previously in Chapter 5.

This chapter has focused on two of the research questions introduced in Chapter 5. First, *did regulation spur patenting activity?* Second, *has there been a change in the direction of patenting?* In order to simplify the analysis and enable comparison with the findings obtained in the previous chapter, Tables 6.47 and 6.48 list the results relative to each research question for each firm and in addition show the overall findings obtained in Chapter 5.

A first interesting result can be observed when comparing the panels estimated for each firm and the aggregate level estimated in Chapter 5. In the aggregate level there is an overall positive significant impact of regulatory stringency on patenting activity, while for three of the four investigated top players this effect was negative. This suggests that regulation might impact in dissimilar ways different-size players; or it might alter the market by stimulating new entrants in the market for innovation. Next, I discuss separately the most impacted technological areas.

In Section 5.4, which summarized the results in Chapter 5, I argued that those

Table 6.47: Summarized results.

	Did regulation spur patenting activity?	Has an increase or decrease in patenting occurred?					
	Panel	A01N	C08F	C08J	C08K	C09B	C09D
Aggregate	positive effect	increased	decreased	decreased	decreased	decreased	increased
Bayer	negative effect	increased	decreased	decreased	decreased	exited	increased
BASF	negative effect	increased	increased	increased	stable	decreased	increased
DuPont	no significant effect	stable	increased	decreased	increased	–	increased
3M	negative effect	–	decreased	increased	increased	exited	decreased

Table 6.48: Summarized results: Has there been a change in the direction of patenting?

	A01N	C08F	C08J	C08K	C09B	C09D
Aggregate level	yes	no	no	no	yes	no
Bayer Group	no	yes	no	yes	–	yes
BASF	yes	yes	yes	yes	yes	no
DuPont	yes	no	yes	yes	–	no
3M	–	no	no	yes	–	no

areas which showed the greatest changes in patent activity over this period were also those mostly restricted: A01N with 104, C09B with 86, and C09D with 101 restrictions. However, the changes in patenting activity in these highly regulated areas were not consistently positive or negative. Regulated areas A01N and C09D have seen an increase in the number of patent applications over this period despite being highly regulated, while area C09B, which is also highly regulated, has seen a decrease.

I first discuss area A01N where there was an increase in patent applications. This area witnessed a number of new developments and new applications which permitted firms to maintain innovative activity resulting in patents associated with non-regulated usages. Applications associated with biotechnology also grew. At the same time, there was less innovative activity relating to new organic substances which bore the brunt of the increased regulation. Thus, in order to keep innovating in this area firms needed to change the direction of technological innovation. This behavior can be seen in BASF's and DuPont's A01N applications. By contrast, Bayer increased its patenting in this area without changing substantially the pattern of its patent profile over the period 1991 to 2006. Consistently with this lack of change is direction, Bayer increased patent applications in this are proportionately less than BASF and DuPont. (3M does not participate in A01N.)

Area C09D also saw an increase in patent applications despite being highly regulated. Much of the innovation in this area involves new formulations or applications of new and existing substances. Innovative activity depends little on new science and existing knowledge imparts inertia to the innovative process which is therefore less sensitive to regulatory impact. Bayer's, BASF's, and DuPont's C09D patent applications all increased from 1991 to 2006, although 3M decreased patent applications. BASF, DuPont and 3M maintained the same general research direction in this area whereas Bayer, whose patenting activity in this area was stable over the 2000s, changed its innovative path from 1991 to 2006.

Area C09B, which is also highly regulated, saw a decrease in patenting activity. It is characterized by the development of new substances. I argued in Chapter 5 that this may explain the decreasing trend in the number of innovations. In the last years Bayer and 3M have not applied any patents in this area, effectively exiting the market. BASF has decreased the number of patents and it left the market for textile dyes, the use of which was restricted by the regulations introduced in 2003. Regulation has effectively eliminated this product range with replacements falling in other technological areas.

Detailed observation of firms' managerial choices in conjunction with their patent profiles has enabled a more precise characterization of the evolution of these technological areas over the most recent decades, during which most of the regulatory restrictions have been imposed. These case studies have emphasized the claim made in the previous chapter that, in order to continue innovating in areas intrinsically associated with regulated families of substances, firms need to develop new technological directions. The choice is between doing this or exiting the area. The balance of advantage differs across technological areas some of which therefore show increases in patent activity while others show declines. To a lesser extent, firms choose different strategies with some increasing patenting in the regulated area while others decrease activity or even exit. This is consistent with a link between regulation and innovative push but the chemicals experience shows that this link is not universal even within relatively narrowly defined areas.

Chapter 7

Conclusion

Economic problems and difficulties faced by researchers

The aim of this thesis has been to investigate and contribute to the study of the relationship between innovation and regulatory stringency in the chemical industry. Chapter 3 discusses the economic empirical literature on the possible impacts of the regulatory stringency on firms. There are two different positions supported by researchers on the relationship between innovation and regulation. From the orthodox perspective, many economists claim that regulation implies extra costs for firms and this may reduce funds available for R&D in order to comply with these extra costs thereby reducing competitiveness in relation to less regulated firms.

Other researchers believe that regulation favors innovation because it signals new opportunities. These may either be investment opportunities which were available prior to regulation but were ignored by firms, or they may be opportunities created by the need to comply with the regulations. This is not necessarily inconsistent with the orthodox view that regulation increases costs since the need to circumvent these cost may be a spur to innovation. Furthermore, the imposition of costs on one technology can make other technologies economically viable. Regulation might also reduce uncertainty about future returns on investments in more environmental friendly products and processes thus spurring innovation and hence competitiveness.

The literature discussed in Chapter 3 and my subsequent analysis looked at different kinds of regulation – impacting products or processes – and different regulatory instruments – command and control or market-based. For Popp, Newell, and Jaffe (2009), these different kinds of regulation are able to induce or oblige firms to undertake technological changes of a desired type. Their contention is that regulation will require firms to act in a manner differently from their previous practice.

It is difficult to estimate the extent of technological improvement toward higher efficiency and greener products and this may vary across technological areas. As Jaffe and Palmer (1997, pg.618) state, the impact of environmental regulation on innovation is likely to differ for different manufacturing industries.

> These studies could focus on firms in heavily regulated industries (such as petroleum refining, chemicals, metal products, and paper) and could include a more detailed analysis of the impacts of particular classes of regulation, say, by media, on innovative effort. Ideally an in-depth study of one or two companies in a particular industry, such as chemicals, could be used to develop an understanding about how regulated firms respond to new regulations and some related hypotheses which could then be tested using data from other firms in the industry.

My analysis in Chapter 3 supported this conclusion.

A new approach toward the economic problem

In order to develop this thesis I have adopted a new approach, not previously applied in the economic literature, to investigate the relationship between environment, health, and safety regulation and innovation. First, I selected a specific industrial sector, the chemical industry, because product and process innovation is a key issue for this science-based industry which uses its own resources to support R&D projects. This industrial sector that emerged in the nineteenth century is responsible for providing inputs into all other industrial sectors and was a significant contributor factor in the worldwide increase in wealth over the twentieth century.

At the same time, the chemical industry has seen major environmental accidents. For this reason, starting in the second half of the twentieth century, the chemical industry has been the focus of regulation in the most industrialized countries, which were the first to face hazardous impacts of chemicals on human health and the environment. A proper understanding of the relationship of this regulatory framework on the innovative activity of this industry is fundamental for the strategic development of the industry.

Second, a key problem faced by economists when studying regulation is how to develop a reliable quantitative measure which can form the basis for empirical analysis. My contribution in this thesis has been to derive a direct quantitative measure of regulatory impact which I am able to relate to innovative activity. By doing this, I have transformed the economic measurement problem into a technological classification issue.

Following on from the analysis of the regulatory framework developed in Section 3.4, I argued that the chemicals regulation has had a greater impact of the chemical industry than have other environmental, health and safety regulations. This claim is supported by the detail of the chemicals regulation embodied in REACH and implemented by the EU in 2007 – see Section 3.3.1. Over the period 2001 to 2007 governments, firms, and NGOs debated the importance of easy access to information on possible hazardous impacts of chemicals: firms defended their rights to industrial secrecy while non-EU governments, in particular that of the United States, were concerned about the possible negative impact on the exports of their chemical industries to EU countries.

Based on the finding that chemicals regulation resulted in the highest impact, both direct and indirect, on the industry throughout the production chain, I chose to research EU chemicals regulation from 1976 to 2003. Over this period, in excess of nine hundred substances were restricted or prohibited for use and commercialization.

The measure of regulatory stringency

Chapter 4 was devoted to the implementation of the methodology developed to measure the evolution of regulatory stringency over chemical substances in the EU (EU Council Directive 76/769/EEC). The quantitative measure which I developed, was the outcome of the impact imposed by each restriction on different chemicals on technological areas associated with the products and processes of the chemical industry (IPC-7). It was thereby possible to develop a quantitative measure, year by year, of the stringency of regulation in the different technological areas.

Accordingly, six technological areas were selected given that they cover the most impacted areas in their respective groups. In group A01 all restrictions implied by the regulations were imposed over area A01N. In group C08, seventy nine percent of the restrictions were imposed upon areas C08F, C08J, and C08K. In group C09, sixty nine percent of the restrictions were imposed upon areas C09B and C09D. These technological areas are directly associated to the sectors of agrochemicals and basic chemicals. Table 7.1 illustrates the total number of restrictions over substances in fields A and C, their groups A01, C08, and C09, and their most highly restricted technological areas.

Table 7.1: Most regulated technological areas

A	C				
114	238				
A01	C08			C09	
104	105			184	
A01N	C08F	C08J	C08K	C09B	C09D
104	22	40	62	86	101

After the development of the measure of regulatory stringency over technological areas I observed that most of the restrictions were imposed in two years: 1997 and 2003. The following step in my research was to investigate the patenting activity in these restricted technological areas from 1990 to 2006.

Main findings and the economic hypotheses

Chapter 5 focused on four research questions derived from issues raised by the economic literature to guide my empirical analysis.

1. *Did regulation spur patenting activity?*

2. *Has there been a change in the country of origin of patents?*
3. *Has there been any increase in patenting concentration?*
4. *Has there been a change in the direction of patenting?*

As shown in Section 5.1, from 1990 to 2006, within the EU, Germany received the highest number of patent applications in these technological groups. Since firms need to patent their inventions in each country where they seek protection it is reasonable to believe that the vast majority of innovations for which application was made in the EU also resulted in applications in Germany. Therefore, I decided to focus only on patent applications in Germany as representative of total EU patent applications.

My results shows heterogeneous behavior of innovative activity during the periods of increasing regulatory stringency (1997 and 2003). A number of authors have suggested that environmental, health, and safety regulations have different impacts across industrial sectors. I find the same conclusion applies in relation to the impact of regulation across different technological areas.

My main findings show an overall increase in innovations associated with new processes and formulations. This results from increased incremental innovation and fewer novel substances. There was also a shift from patenting in regulated to non-regulated uses and in new technologies (e.g. biotechnology).

Areas which showed major changes over this period were also those that bore the largest number of restrictions: A01N, C09B, and C09D. Conversely, among those areas which I investigated those which had a stable patenting behavior were also those which were less restricted.

Accordingly, technological areas which did not depend on novel substances (C09D), or which had space to innovate in non-regulated uses (A01N), found space to continue expanding patenting activity. By contrast, the number of applications in areas in which these conditions did not apply saw a drastic fall (C09B).

An interesting issue which emerged from this research is the reduction in the concentration of the innovative activity in five of the six regulated areas. In these five areas there was an overall increase in patents applied by “small players,” meaning a larger number of applicants with a smaller number of patents.

In Chapter 6 four case studies were developed to corroborate the aggregate results obtained previously at firm level. A brief history of managerial decision-making regarding investments, mergers, and acquisitions complemented the foregoing study of the patenting activity of these companies.

The research questions were inspired by the Porter’s Hypothesis which says that regulatory stringency positively impacts innovation and, by consequence, competitiveness. This thesis shows that the Porter hypothesis is supported for the chemical industry. Yet, this occurs not because Þrms innovate under more stringent regulation, but because it stimulates new entrants in the market of innovation.

Moreover, my results suggest that "new" technologies appear to be benefited by regulatory stringency while "old" technologies appear to be discouraged. Or, it can be that regulation is imposed when there is enough knowledge about a specific technology and while restricting it regulation might spur the development of substitutes better adapted to the regulatory framework.

General observations

The most highly regulated areas concern technologies developed prior to the 1950s. It took decades for governments to realize the dangers presented by these technologies and to decide to regulate them. Similarly, we must expect that it may take a number of decades to accumulate the evidence and experience which will enable us to evaluate the risks imposed by today's new technologies and to reach an informed judgment on whether and how they should be regulated.

Innovation is a crucial factor in economic development but it can also be responsible for environmental pollution and health hazards. Society, through the agency of government, must regulate in order to choose the best trade off between development and possible hazards that might emerge as a cost for society and the environment.

The concentration of power in large groups may be a matter for concern. Nevertheless, larger firms are more easily able to cope with the risks of the technological development and the costs of regulations. With new regulatory frameworks such as REACH, the public authorities recognize that it is firms that are most capable of accessing the risks of its products and processes. Given the increasing level of technological specialization and emerging technologies (such as biotechnology and nanotechnology) with new uses emerging every day, it is firms that must manage the risk and assist the development of impact studies in parallel.

The reality of the twenty first century brings new problems. In a number of manufacturing industries such as, textiles and clothing, ceramics, toys, the third industrial revolution with instant communication and market globalization has resulted in disconnection of production from the ownership of intellectual property. Developing economies have benefited from the relocation of large production facilities and outsourcing by multinational companies. Usually, these products are produced using relatively poorly qualified labor. The intellectual property capital continues to reside in the developed economies. Multinational firms own trademarks and patents, focusing their strength on R&D for new products and developing new market strategies. Concerns about production processes, and labor health and safety, have been largely transferred to producing firms, many of which are located in the developing economies.

The chemical industry does not conform to this paradigm. As seen in Chapter 6, the three chemical firms analyzed – Bayer, BASF, and DuPont – did not experience this kind of behavior. The last decades saw both expansion of their plants in Europe and North America and development of new plants in emerging markets. Outsourcing has not been a feature of chemicals production. Differently from many of these industries, the chemicals industry is characterized by a low share of labor in total costs, reliance on skilled and specifically trained personnel, and a dominant importance of product quality. Furthermore, because it is more difficult to protect intellectual property in many emerging markets, firms in the chemical industry are also very wary of transferring processes which may allow developing countries competitors to benefit from their experience.

The process of innovation is also different in the chemicals industry. Basic chemicals have been known since the beginning of the twentieth century. In this sector, innovation entirely takes the form of process innovation. Processes can be patented but patents on the basic chemicals have now expired. The consequence is that firms have differing production costs for the same basic chemicals, depending on the success with which they have innovated. Oligopolistic competition will result in the price being set in relation to the production costs of the marginal producer. Firms compete through process innovation which allows them to reduce production costs and obtain competitive advantage gaining an implied rent relative to the costs of the marginal (non innovating) producers.

Future research: directions and open questions

Two issues are crucial in order to better understand the relationship between regulation and innovation in the chemical industry, and as a consequence, help develop better regulation. The first issue concerns the impact of regulation on the innovative activity on different size firms. The second relates to regulation under uncertainty.

I have argued that large corporations can cope with regulation more easily than smaller firms. Given the increasingly complexity of the dossiers requested by regulators, a multidisciplinary group of experts (biologists, toxicologists, chemists, lawyers, among others) is needed in order to complete all studies to assure safety of the new product.

However, even though regulation may favor larger firms, I observed that this has not translated into increased concentration in innovative activity. Two reasons may be advanced to explain this phenomena. First, because compliance is costly, large companies might have diverted resources from R&D to be able to comply with regulation when marketing a new product. Secondly, and in specific relationship to specialty chemicals, large firms might be too cumbersome (given their complex corporative structure) to move away from well established technological paths to new ones. Smaller and more nimble players would be "lighter" enabling faster movement into emerging technologies. A possible consequence is that large corporations would become specialized in logistics, know-how about chemical processes, and regulatory issues in marketing new chemicals, while small players would concentrate their efforts on developing new products.

The second issue which I have highlighted as important is the effects of uncertainty in relation to new substances. A group of methodologies is available to investigate the possible hazards and negative impacts on the environment and human health in dealing with such new chemicals. These methodologies have been developed and improved throughout the decades. Nevertheless, it can happen that a chemical can generate an unexpected impact not anticipated by existing methodologies. Alternatively, it may be that there were no methodologies to test for this impact. The impact will only become apparent subsequently, perhaps after an extended period of time. For example, a food additive can be discovered to cause anxiety after decades in the market. As this kind of impact on health was not anticipated, no tests were undertaken which might have suggested this impact.

Novel technologies have the disadvantage of a lack of empirical tests to acquire information on possible future impacts. The initial focus is on possible market applications of the new substance. Subsequently, researchers explore possible impacts of the substance on the environment and human health. Two current examples that have stimulated debate since the 1980s were developments derived from biotechnology (GMOs) and nanotechnology (nano materials). Recently, in launching a report on the environmental impact of nanotechnology (RCEP, 2008), the UK Royal Commission on Environmental Pollution (RCEP) has highlighted the lack of scientific evidence in favor or against the partial or total restriction of new nano-substances.

Regulatory suggestions

The complexity of the chemical industry and its allied technologies poses a challenge for regulators, who are required to reduce the knowledge asymmetry between producers and consumers and to devise timely regulation. In Chapter 3 a summary of the chemicals for the European Union (past and actual), the US, and Japan was provided. This overview illustrated three different regulatory regimes to control production, commercialization, and uses of chemicals.

Given the increasingly level of technological specialization and with new technologies and new uses of old technologies emerging continuously, firms must simultaneously manage risks and undertake impact studies. My findings showed that, in the three major technological cycles of the chemical industry, regulation arrived decades after the substances were first marketed. In the same spirit, the RCEP (2008) highlighted the time gap between the emergence of new nano-substances and the generation of environmental, health, and safety data.

Another study developed by the UK RCEP (RCEP, 2003) focused on chemicals regulation. They recommended the formation of a new body, as part of the environmental agency, specifically to assess and manage chemical risks, and monitor and enforce restrictions on the use of chemicals. This body would also be *responsible for* *sponsoring the research that we see as necessary to take forward longer-term improvements in our understanding of the fate and effects of chemicals and new techniques for assessing chemicals* (RCEP, 2003, pg.168).

The proposal to create a new and independent body is a useful response to the continuous development and commercialization of new products. Prohibition of the commercialization of new products deriving from new technological paths would harm not only innovation but also prevent society from benefiting from these new developments. However, as already stated, it is the innovating company which is the most able to undertake research on possible hazards coming from innovation. Innovating firms are better able than regulators to evaluate the costs and benefits derived from a new technology. At the same time, they will be less interested in diminishing knowledge asymmetry between producers and consumers. An independent body, formed not only by the regulator (government represented by all involved agencies), but also by representative industry associations, research centers and universities, would be well placed to monitor technological developments and arrive at an informed judgement on issues regarding possible positive and negative impacts. Ideally, this body should be a pan-European level.

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Appendix A

International Patent Classification (IPC)

Table A.1: International Patent Classification: IPC-7

Code	Definition
A	Human necessities
B	Performing operations and transporting
C	Chemistry and metallurgy
D	Textiles and paper
E	Fixed constructions
F	Mechanical engineering; lighting; heating; weapons; and blasting
G	Physics
H	Electricity

Table A.2: SECTION A — HUMAN NECESSITIES CONTENTS OF SECTION

	Subsection: AGRICULTURE A 01 AGRICULTURE; FORESTRY; ANIMAL HUSBANDRY; HUNTING; TRAPPING; FISHING
A 01 B	Soil working in agriculture or forestry; Parts, details, or accessories of agricultural machines or implements, in general
A 01 C	Planting; Sowing; Fertilising
A 01 D	Harvesting; Mowing
A 01 F	Processing of harvested produce; Hay or straw presses; Devices for storing agricultural or horticultural produce
A 01 G	Horticulture; Cultivation of vegetables, flowers, rice, fruit, vines, hops, or seaweed; Forestry; Watering
A 01 H	New plants or processes for obtaining them; Plant reproduction by tissue culture techniques
A 01 J	Manufacture of dairy products
A 01 K	Animal husbandry; Care of birds, fishes, insects; Fishing; Rearing or breeding animals, not otherwise provided for; New breeds of animals
A 01 L	Shoeing of animals
A 01 M	Catching, trapping or scaring of animals; Apparatus for the destruction of noxious animals or noxious plants

A. INTERNATIONAL PATENT CLASSIFICATION (IPC)

	Subsection: AGRICULTURE A 01 AGRICULTURE; FORESTRY; ANIMAL HUSBANDRY; HUNTING; TRAPPING; FISHING
A 01 N	Preservation of bodies of humans or animals or plants or parts thereof; Biocides, e.g. as disinfectants, as pesticides, as herbicides; Pest repellants or attractants; Plant growth regulators
	Subsection: FOODSTUFFS; TOBACCO
A 21	BAKING; EDIBLE DOUGHS
A 21 B	Bakers' ovens; Machines or equipment for baking
A 21 C	Machines or equipment for making or processing doughs; Handling baked articles made from dough
A 21 D	Treatment, e.g. preservation, of flour or dough, e.g. by addition of materials; Baking; Bakery products; Preservation thereof
A 22	BUTCHERING; MEAT TREATMENT; PROCESSING POULTRY OR FISH
A 22 B	Slaughtering
A 22 C	Processing meat, poultry, or fish
A 23	FOODS OR FOODSTUFFS; THEIR TREATMENT, NOT COVERED BY OTHER CLASSES
A 23 B	Preserving, e.g. by canning, meat, fish, eggs, fruit, vegetables, edible seeds; Chemical ripening of fruit or vegetables; The preserved, ripened, or canned products
A 23 C	Dairy products, e.g. milk, butter, cheese; Milk or cheese substitutes; Making thereof
A 23 D	Edible oils or fats, e.g. margarines, shortenings, cooking oils
A 23 F	Coffee; Tea; Their substitutes; Manufacture, preparation, or infusion thereof
A 23 G	Cocoa; Chocolate; Confectionery; Ice-cream
A 23 J	Protein compositions for foodstuffs; Working-up proteins for foodstuffs; Phosphatide compositions for foodstuffs
A 23 K	Fodder
A 23 L	Foods, foodstuffs, or non-alcoholic beverages, not covered by subclasses A 23 B to J; Their preparation or treatment, e.g. cooking, modification of nutritive qualities, physical treatment; Preservation of foods or foodstuffs, in general
A 23 N	Machines or apparatus for treating harvested fruit, vegetables, or flower bulbs in bulk, not otherwise provided for; Peeling vegetables or fruit in bulk; Apparatus for preparing animal feeding-stuffs
A 23 P	Shaping or working of foodstuffs, not fully covered by a single other subclass
A 24	TOBACCO; CIGARS; CIGARETTES; SMOKERSÕ REQUISITES
A 24 B	Manufacture or preparation of tobacco for smoking or chewing; Tobacco; Snuff
A 24 C	Machines for making cigars or cigarettes
A 24 D	Cigars; Cigarettes; Tobacco smoke filters; Mouthpieces for cigars or cigarettes; Manufacture of tobacco smoke filters or mouthpieces
A 24 F	Smokers' requisites; Match boxes
	Subsection: PERSONAL OR DOMESTIC ARTICLES
A 41	WEARING APPAREL
A 41 B	Shirts; Underwear; Baby linen; Handkerchiefs
A 41 C	Corsets; Brassières
A 41 D	Outerwear; Protective garments; Accessories
A 41 F	Garment fastenings; Suspenders
A 41 G	Artificial flowers; Wigs; Masks; Feathers
A 41 H	Appliances or methods for making clothes, e.g. for dress-making, for tailoring, not otherwise provided for
A 42	HEADWEAR
A 42 B	Hats; Head coverings
A 42 C	Manufacturing or trimming hats or other head coverings
A 43	FOOTWEAR
A 43 B	Characteristic features of footwear; Parts of footwear
A 43 C	Fastenings or attachments for footwear; Laces in general
A 43 D	Machines, tools, equipment or methods for manufacturing or repairing footwear
A 44	HABERDASHERY; JEWELLERY
A 44 B	Buttons, pins, buckles, slide fasteners, or the like
A 44 C	Jewellery; Bracelets; Other personal adornments; Coins
A 45	HAND OR TRAVELLING ARTICLES
A 45 B	Walking sticks; Umbrellas; Ladies' or like fans
A 45 C	Purses; Travelling bags or baskets; Suitcases

	Subsection: AGRICULTURE A 01 AGRICULTURE; FORESTRY; ANIMAL HUSBANDRY; HUNTING; TRAPPING; FISHING
A 45 D	Hairdressing or shaving equipment; Manicuring or other cosmetic treatment
A 45 F	Travelling or camp equipment
A 46	BRUSHWARE
A 46 B	Brushes
A 46 D	Manufacture of brushes
A 47	FURNITURE; DOMESTIC ARTICLES OR APPLIANCES; COFFEE MILLS; SPICE MILLS; SUCTION CLEANERS IN GENERAL
A 47 B	Tables; Desks; Office furniture; Cabinets; Drawers; General details of furniture
A 47 C	Chairs; Sofas; Beds
A 47 D	Furniture specially adapted for children
A 47 F	Special furniture, fittings, or accessories for shops, storehouses, bars, restaurants, or the like; Paying counters
A 47 G	Household or table equipment
A 47 H	Furnishings for windows or doors
A 47 J	Kitchen equipment; Coffee mills; Spice mills; Apparatus for making beverages
A 47 K	Sanitary equipment not otherwise provided for; Toilet accessories
A 47 L	Domestic washing or cleaning; Suction cleaners in general
	Subsection: HEALTH; AMUSEMENT
A 61	MEDICAL OR VETERINARY SCIENCE; HYGIENE
A 61 B	Diagnosis; Surgery; Identification
A 61 C	Dentistry; Oral or dental hygiene
A 61 D	Veterinary instruments, implements, tools, or methods
A 61 F	Filters implantable into blood vessels; Prostheses; Orthopaedic, nursing or contraceptive devices; Fomentation; Treatment or protection of eyes or ears; Bandages, dressings or absorbent pads; First-aid kits
A 61 G	Transport or accommodation for patients; Operating tables or chairs; Chairs for dentistry; Funereal devices
A 61 H	Physical therapy apparatus, e.g. devices for locating or stimulating reflex points in the body; Artificial respiration; Massage; Bathing devices for special therapeutic or hygienic purposes or specific parts of the body
A 61 J	Containers specially adapted for medical or pharmaceutical purposes; Devices or methods specially adapted for bringing pharmaceutical products into particular physical or administering forms; Devices for administering food or medicines orally; Baby comforters; Devices for receiving spittle
A 61 K	Preparations for medical, dental, or toilet purposes
	Subsection: HEALTH; AMUSEMENT
A 61 L	Methods or apparatus for sterilising materials or objects in general; Disinfection, sterilisation, or deodorisation of air; Chemical aspects of bandages, dressings, absorbent pads, or surgical articles; Materials for bandages, dressings, absorbent pads, or surgical articles
A 61 M	Devices for introducing media into, or onto, the body; Devices for transducing body media or for taking media from the body; Devices for producing or ending sleep or stupor
A 61 N	Electrotherapy; Magnetotherapy; Radiation therapy; Ultrasound therapy
A 61 P	Therapeutic activity of chemical compounds or medicinal preparations
A 62	LIFE-SAVING; FIRE-FIGHTING
A 62 B	Devices, apparatus, or methods for life-saving
A 62 C	Fire-fighting
A 62 D	Chemical means for extinguishing fires or for combating or protecting against harmful chemical agents; Chemical materials for use in breathing apparatus
A 63	SPORTS; GAMES; AMUSEMENTS
A 63 B	Apparatus for physical training, gymnastics, swimming, climbing, or fencing; Ball games; Training equipment
A 63 C	Skates; Skis; Roller skates; Design or layout of courts, rinks or the like
A 63 D	Bowling-alleys; Bowling games; Boccia; Bowls; Bagatelle; Billiards
A 63 F	Card, board, or roulette games; Indoor games using small moving playing bodies; Miscellaneous games
A 63 G	Merry-go-rounds; Swings; Rocking-horses; Chutes; Switchbacks; Similar devices for public amusement
A 63 H	Toys, e.g. tops, dolls, hoops, building blocks
A 63 J	Devices for theatres, circuses, or the like; Conjuring appliances or the like
A 63 K	Racing; Riding sports; Equipment or accessories therefor

	Subsection: AGRICULTURE A 01 AGRICULTURE; FORESTRY; ANIMAL HUSBANDRY; HUNTING; TRAPPING; FISHING

Table A.3: SECTION C — CHEMISTRY; METALLURGY

	Subsection: CHEMISTRY
C 01	INORGANIC CHEMISTRY
C 01 B	Non-metallic elements; Compounds thereof
C 01 C	Ammonia; Cyanogen; Compounds thereof
C 01 D	Compounds of alkali metals, i.e. lithium, sodium, potassium, rubidium, caesium, or francium
C 01 F	Compounds of the metals beryllium, magnesium, aluminium, calcium, strontium, barium, radium, thorium, or of the rare-earth metals
C 01 G	Compounds containing metals not covered by subclasses C 01 D or F
C 02	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE
C 02 F	Treatment of water, waste water, sewage, or sludge
C 03	GLASS; MINERAL OR SLAG WOOL
C 03 B	Manufacture, shaping, or supplementary processes
C 03 C	Chemical composition of glasses, glazes, or vitreous enamels; Surface treatment of glass; Surface treatment of fibres or filaments from glass, minerals or slags; Joining glass to glass or other materials
C 04	CEMENTS; CONCRETE; ARTIFICIAL STONE; CERAMICS; REFRACTORIES
C 04 B	Lime; Magnesia; Slag; Cements; Compositions thereof, e.g. mortars, concrete or like building materials; Artificial stone; Ceramics; Refractories; Treatment of natural stone
C 05	FERTILISERS; MANUFACTURE THEREOF
C 05 B	Phosphatic fertilisers
C 05 C	Nitrogenous fertilisers
C 05 D	Inorganic fertilisers not covered by subclasses C 05 B, C; Fertilisers producing carbon dioxide
C 05 F	Organic fertilisers not covered by subclasses C 05 B, C, e.g. fertilisers from waste or refuse
C 05 G	Mixtures of fertilisers covered individually by different subclasses of class C 05; Mixtures of one or more fertilisers with materials not having a specific fertilising activity, e.g. pesticides, soil-conditioners, wetting agents; Fertilisers characterised by their form
C 06	EXPLOSIVES; MATCHES
C 06 B	Explosive or thermic compositions; Manufacture thereof; Use of single substances as explosives
C 06 C	Detonating or priming devices; Fuses; Chemical lighters; Pyrophoric compositions
C 06 D	Means for generating smoke or mist; Gas-attack compositions; Generation of gas for blasting or propulsion
C 06 F	Matches; Manufacture of matches
C 07	ORGANIC CHEMISTRY
C 07 B	General methods of organic chemistry; Apparatus therefor
C 07 C	Acyclic or carbocyclic compounds
C 07 D	Heterocyclic compounds
C 07 F	Acyclic, carbocyclic, or heterocyclic compounds containing elements other than carbon, hydrogen, halogen, oxygen, nitrogen, sulfur, selenium, or tellurium
C 07 G	Compounds of unknown constitution
C 07 H	Sugars; Derivatives thereof; Nucleosides; Nucleotides; Nucleic acids
C 07 J	Steroids
C 07 K	Peptides
C 07 M	Indexing scheme associated with subclasses C 07 B to K, relating to specific properties of organic compounds
C 08	ORGANIC MACROMOLECULAR COMPOUNDS; THEIR PREPARATION OR CHEMICAL WORKING-UP; COMPOSITIONS BASED THEREON
C 08 B	Polysaccharides; Derivatives thereof
C 08 C	Treatment or chemical modification of rubbers
C 08 F	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds
C 08 G	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds

	Subsection: CHEMISTRY
C 08 H	Derivatives of natural macromolecular compounds
C 08 J	Working-up; General processes of compounding; After-treatment not covered by subclasses C 08 B, C, F, G
C 08 K	Use of inorganic or non-macromolecular organic substances as compounding ingredients
C 08 L	Compositions of macromolecular compounds
C 09	DYES; PAINTS; POLISHES; NATURAL RESINS; ADHESIVES; MISCELLANEOUS COMPOSITIONS; MISCELLANEOUS APPLICATIONS OF MATERIALS
C 09 B	Organic dyes or closely-related compounds for producing dyes; Mordants; Lakes
C 09 C	Treatment of inorganic materials, other than fibrous fillers, to enhance their pigmenting or filling properties; Preparation of carbon black
C 09 D	Coating compositions, e.g. paints, varnishes, lacquers; Filling pastes; Chemical paint or ink removers; Inks; Correcting fluids; Woodstains; Pastes or solids for colouring or printing; Use of materials therefor
C 09 F	Natural resins; French polish; Drying-oils; Driers; Turpentine
C 09 G	Polishing compositions other than french polish; Ski waxes
C 09 H	Preparation of glue or gelatine
C 09 J	Adhesives; Adhesive processes in general; Adhesive processes not provided for elsewhere; Use of materials as adhesives
C 09 K	Materials for miscellaneous applications, not provided for elsewhere
C 10	PETROLEUM, GAS OR COKE INDUSTRIES; TECHNICAL GASES CONTAINING CARBON MONOXIDE; FUELS; LUBRICANTS; PEAT
C 10 B	Destructive distillation of carbonaceous materials for production of gas, coke, tar, or similar materials
C 10 C	Working-up tar, pitch, asphalt, bitumen; Pyroligneous acid
C 10 F	Drying or working-up of peat
C 10 G	Cracking hydrocarbon oils; Production of liquid hydrocarbon mixtures, e.g. by destructive hydrogenation, oligomerisation, polymerisation; Recovery of hydrocarbon oils from oil-shale, oil-sand, or gases; Refining mixtures mainly consisting of hydrocarbons; Reforming of naphtha; Mineral waxes
C 10 H	Production of acetylene by wet methods
C 10 J	Production of producer gas, water-gas, synthesis gas from solid carbonaceous material, or mixtures containing these gases; Carburetting air or other gases
C 10 K	Purifying or modifying the chemical compositions of combustible gases containing carbon monoxide
C 10 L	Fuels not otherwise provided for; Natural gas; Synthetic natural gas obtained by processes not covered by subclasses C 10 G, K; Liquefied petroleum gas; Adding materials to fuels or fires to reduce smoke or undesirable deposits or to facilitate soot removal; Fire-lighters
C 10 M	Lubricating compositions; Use of chemical substances either alone or as lubricating ingredients in a lubricating composition
C 10 N	Indexing scheme associated with subclass C 10 M
C 11	ANIMAL OR VEGETABLE OILS, FATS, FATTY SUBSTANCES OR WAXES; FATTY ACIDS THEREFROM; DETERGENTS; CANDLES
C 11 B	Producing, refining or preserving fats, fatty substances, fatty oils or waxes, including extraction from waste materials; Essential oils; Perfumes
C 11 C	Fatty acids from fats, oils or waxes; Candles; Fats, oils or fatty acids by chemical modification of fats, oils, or fatty acids obtained therefrom
C 11 D	Detergent compositions; Use of single substances as detergents; Soap or soap-making; Resin soaps; Recovery of glycerol
C 12	BIOCHEMISTRY; BEER; SPIRITS; WINE; VINEGAR; MICROBIOLOGY; ENZYMOLOGY; MUTATION OR GENETIC ENGINEERING
C 12 C	Brewing of beer
C 12 F	Recovery of by-products of fermented solutions; Denaturing of, or denatured, alcohol
C 12 G	Wine; Other alcoholic beverages; Preparation thereof
C 12 H	Pasteurisation, sterilisation, preservation, purification, clarification, ageing of alcoholic beverages or removal of alcohol therefrom
C 12 J	Vinegar; Its preparation
C 12 L	Pitching or depitching machines; Cellar tools
C 12 M	Apparatus for enzymology or microbiology
C 12 N	Micro-organisms or enzymes; Compositions thereof; Propagating, preserving, or maintaining micro-organisms; Mutation or genetic engineering; Culture media

	Subsection: CHEMISTRY
C 12 P	Fermentation or enzyme-using processes to synthesise a desired chemical compound or composition or to separate optical isomers from a racemic mixture
C 12 Q	Measuring or testing processes involving enzymes or micro-organisms; Compositions or test papers therefor; Processes of preparing such compositions; Condition-responsive control in microbiological or enzymological processes
C 12 R	Indexing scheme associated with subclasses C 12 C to Q or S, relating to micro-organisms
C 12 S	Processes using enzymes or micro-organisms to liberate, separate or purify a pre-existing compound or composition; Processes using enzymes or micro-organisms to treat textiles or to clean solid surfaces of materials
C 13	SUGAR INDUSTRY
C 13 C	Cutting mills; Shredding knives; Pulp presses
C 13 D	Production or purification of sugar juices
C 13 F	Preparation or processing of raw sugar, sugar, or syrup
C 13 G	Evaporation apparatus; Boiling pans
C 13 H	Cutting machines for sugar; Combined cutting, sorting and packing machines for sugar
C 13 J	Extraction of sugar from molasses
C 13 K	Glucose; Invert sugar; Lactose; Maltose; Synthesis of sugars by hydrolysis of di- or polysaccharides
C 14	SKINS; HIDES; PELTS; LEATHER
C 14 B	Mechanical treatment or processing of skins, hides, or leather in general; Pelt-shearing machines; Intestine-splitting machines
C 14 C	Chemical treatment of hides, skins or leather, e.g. tanning, impregnating, finishing; Apparatus therefor; Compositions for tanning

Table A.4: SECTION C — CHEMISTRY; METALLURGY

	Subsection: METALLURGY
C 21	METALLURGY OF IRON
C 21 B	Manufacture of iron or steel
C 21 C	Processing of pig-iron, e.g. refining, manufacture of wrought-iron or steel; Treatment in molten state of ferrous alloys
C 21 D	Modifying the physical structure of ferrous metals; General devices for heat treatment of ferrous or non-ferrous metals or alloys; Making metal malleable by decarburisation, tempering, or other treatments
C 22	METALLURGY; FERROUS OR NON-FERROUS ALLOYS; TREATMENT OF ALLOYS OR NON-FERROUS METALS
C 22 B	Production or refining of metals; Pretreatment of raw materials
C 22 C	Alloys
C 22 F	Changing the physical structure of non-ferrous metals or non-ferrous alloys
C 22 K	Indexing scheme associated with subclasses C 21 D, C 22 C or F, relating to changing the physical characteristics of alloys
C 23	COATING METALLIC MATERIAL; COATING MATERIAL WITH METALLIC MATERIAL; CHEMICAL SURFACE TREATMENT; DIFFUSION TREATMENT OF METALLIC MATERIAL; COATING BY VACUUM EVAPORATION, BY SPUTTERING, BY ION IMPLANTATION OR BY CHEMICAL VAPOUR DEPOSITION, IN GENERAL; INHIBITING CORROSION OF METALLIC MATERIAL OR INCRUSTATION IN GENERAL
C 23 C	Coating metallic material; Coating material with metallic material; Surface treatment of metallic material by diffusion into the surface, by chemical conversion or substitution; Coating by vacuum evaporation, by sputtering, by ion implantation or by chemical vapour deposition, in general
C 23 D	Enamelling of, or applying a vitreous layer to, metals
C 23 F	Non-mechanical removal of metallic material from surfaces; Inhibiting corrosion of metallic material; Inhibiting incrustation in general; Multi-step processes for surface treatment of metallic material involving at least one process provided for in class C 23 and at least one process covered by subclass C 21 D or C 22 F or class C 25
C 23 G	Cleaning or de-greasing of metallic material by chemical methods other than electrolysis
C 25	ELECTROLYTIC OR ELECTROPHORETIC PROCESSES; APPARATUS THEREFOR
C 25 B	Electrolytic or electrophoretic processes for the production of compounds or non- metals; Apparatus therefor

	Subsection: METALLURGY
C 25 C	Processes for the electrolytic production, recovery or refining of metals; Apparatus therefor
C 25 D	Processes for the electrolytic or electrophoretic production of coatings; Electroforming; Joining workpieces by electrolysis; Apparatus therefor
C 25 F	Processes for the electrolytic removal of materials from objects; Apparatus therefor
C 30	CRYSTAL GROWTH
C 30 B	Single-crystal growth; Unidirectional solidification of eutectic material or unidirectional demixing of eutectoid material; Refining by zone-melting of material; Production of a homogeneous polycrystalline material with defined structure; Single crystals or homogeneous polycrystalline material with defined structure; After-treatment of single crystals or a homogeneous polycrystalline material with defined structure; Apparatus therefor

Appendix B

Top Applicants

B.1 IPC-A01: Agriculture; forestry; animal husbandry; hunting; trapping; and fishing

- In 1990, four of the top applicants were based in Germany and two in US, while in 2006 two were German and four from US.
- From all, five are present in both years however a deeper analysis considering mergers and acquisitions would clarify the perpetuation of the leadership in a given technological area.

Table B.1: Top applicants on the IPC-A01N in Germany

	1990			2006	
DE	Bayer AG	116	DE	Basf SE	107
DE	Basf AG	89	DE	Bayer CropScience AG	91
CH	Ciba-Geigy AG	53	CH	Syngenta Participations AG	44
GB	Zeneca Ltd	24	US	Merck and Co Inc	22
NL	Shell Internationale Research Maatschappij BV	22	FR	Bayer CropScience SA	17
US	Rohm and Haas Company	22	US	Smithkline Beecham Corporation	16
DE	Hoechst Schering AgrEvo GmbH	22	GB	Syngenta Ltd	16
US	E.I. Du Pont de Nemours and Company	16	US	E.I. Du Pont de Nemours and Company	15
JP	Sumitomo Chemical Company Ltd	15	US	Rohm and Haas Company	14
DE	Schering AG	14	JP	Sumitomo Chemical Company Ltd	13
		393			355

B.2 IPC-C08: Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon

- For both years Basf leads the top applicants on the technological areas C08F and C08J.
- For area C08F:
  - In 1990 there were three German and three US firms in the top, while in 2006 there were two German and five US firms.
  - In 2006 the were four applicants with the same number of applications. The fourth firm with seventeen applications is Basell Poliolefine Italia Srl, from Italy.
- For area C08K:
  - In 2006 the were two applicants with the same number of applications. The second firm with fifteen applications is Sabic Innovative Plastics IP BV, from The Netherlands.

Table B.2: Top applicants on the IPC-C08F in Germany

	1990			2006	
DE	Basf AG	61	DE	Basf SE	90
DE	Bayer AG	44	US	Dow Global Technologies Inc	40
DE	Hoechst AG	33	FI	Borealis Technology Oy	35
US	The Dow Chemical Company	31	US	E.I. Du Pont de Nemours and Company	31
CH	Ciba-Geigy AG	29	DE	Basell Polyolefine GmbH	21
US	Exxon Chemical Patents Inc	27	US	Rohm and Haas Company	21
US	Minnesota Mining and Manufacturing Company (3M)	25	JP	Mitsui Chemicals Inc	20
US	E.I. Du Pont de Nemours and Company	25	US	3M Innovative Properties Company	17
NL	Shell Internationale Research Maatschappij BV	24	US	ExxonMobil Chemical Patents Inc	17
FR	Elf Atochem SA	20	CH	Ciba Holding Inc	17
		319			309

Table B.3: Top applicants on the IPC-C08J in Germany

	1990			2006	
DE	Basf AG	35	DE	Basf SE	62
US	E.I. Du Pont de Nemours and Company	33	US	E.I. Du Pont de Nemours and Company	34
DE	Bayer AG	31	US	3M Innovative Properties Company	17
US	Minnesota Mining and Manufacturing Company (3M)	22	JP	FUJIFILM Corporation	16
JP	Mitsui Toatsu Chemicals Inc.	16	KR	LG Chemical Ltd	15
US	The Dow Chemical Company	13	JP	Toray Industries Inc	15
CH	Ciba-Geigy AG	12	US	Dow Global Technologies Inc	14
GB	Imperial Chemical Industries PLC	12	FI	Borealis Technology Oy	13
DE	Hoechst AG	12	US	Eastman Chemical Company	12
FR	Rhone-Poulenc Chimie	11	JP	Tonen Chemical Corporation	12
		197			210

Table B.4: Top applicants on the IPC-C08K in Germany

	1990			2006	
DE	Bayer AG	44	US	E.I. Du Pont de Nemours and Company	35
CH	Ciba-Geigy AG	40	CH	Ciba Holding Inc	30
US	General Electric Company	30	JP	Sumitomo Rubber Industries Ltd	28
DE	Basf AG	29	DE	Basf SE	26
US	Dow Corning Corporation	26	FI	Borealis Technology Oy	23
JP	Sumitomo Chemical Company Ltd	23	US	General Electric Company	22
US	Eastman Kodak Company	18	US	The Goodyear Tire & Rubber Company	22
DE	Hoechst AG	17	US	3M Innovative Properties Company	20
JP	Polyplastics Co Ltd	16	DE	Wacker Chemie AG	17
US	E.I. Du Pont de Nemours and Company	16	DE	Evonik Degussa GmbH	15
		259			238

B.3 IPC-C09: Dyes; paints; polishes; natural resins; adhesives; miscellaneous compositions; miscellaneous applications of materials

- For area C09D:
  - Table B.6 signals an increase in the standard deviation, showing a considerable increase in the difference between the first and the tenth applicant, from twenty-two applications to thirty-nine.
  - In 2006 the were two applicants with the same number of applications in the tenth place of area C09D. The second firm with five applications is Nippon Kayaku Kabushiki Kaisha, from Japan.

Table B.5: Top applicants on the IPC-C09B in Germany

	1990			2006	
CH	Ciba-Geigy AG	45	CH	Ciba Holding Inc.	23
DE	Basf AG	38	BE	Agfa Graphics NV	16
DE	Bayer AG	30	DE	Basf SE	13
DE	Hoechst AG	26	DE	Clariant Produkte GmbH	13
US	Eastman Kodak Company	10	JP	FUJIFILM Corporation	12
JP	Canon Kabushiki Kaisha	6	DE	DyStar Textilfarben GmbH & Co Deutschland KG	11
JP	Sumitomo Chemical Company Ltd	6	GB	FUJIFILM Imaging Colorants Ltd	10
GB	Zeneca Limited	6	CH	Clariant International Ltd	7
JP	Fuji Photo Film Co Ltd	5	CH	Huntsman Advanced Materials GmbH	6
US	Minnesota Mining and Manufacturing Company (3M)	5	DE	Lanxess Deutschland GmbH	5
		177			116

Table B.6: Top applicants on the IPC-C09D in Germany

	1990			2006	
DE	Bayer AG	38	DE	Basf SE	58
US	Dow Corning Corporation	26	US	E.I. Du Pont de Nemours and Company	57
CH	Ciba-Geigy AG	22	JP	FUJIFILM Corporation	42
JP	Nippon Paint Co Ltd	21	BE	Agfa Graphics NV	32
DE	Basf AG	20	US	PPG Industries Ohio Inc	27
DE	Basf Lacke + Farben AG	20	DE	Bayer MaterialScience AG	25
US	Minnesota Mining and Manfacturing Company (3M)	19	US	Hewlett-Packard Development Company LP	25
DE	Hoechst AG	18	US	Rohm and Haas Company	22
US	Basf Corporation	18	CH	Ciba Holding Inc	20
US	Rohm and Haas Company	16	DE	Basf Coatings AG	19
	Total	218			327

Appendix C

Chapter 5: Regressions Results

C.1 Evolution of patenting activity

Table C.1: IPC-A01N: Modeling patents by OLS

	Sample:	1990 - 2006				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	801.102	52.45	15.3	0.0000	0.9472	F(3,13) = 2.352 (0.120)
Trend	-1.16832	10.89	-0.107	0.9162	0.0009	mean(patents): 855.941
d_1	108.999	82.82	1.32	0.2109	0.1176	var(patents): 7059.23
d_2	114.257	134.2	0.851	0.4101	0.0528	R^2: 0.351784
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 1.0545	(0.3764)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	717.654	56.25	12.8	0.0000	0.9313	F(3,12) = 3.931 (0.036)
Trend	14.5263	9.977	1.46	0.1711	0.1501	mean(patents): 850.688
d_1	8.62657	75.29	0.115	0.9107	0.0011	var(patents): 7031.21
d_2	-43.7419	119.6	-0.366	0.7208	0.0110	R^2: 0.495675
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 0.43780	(0.6554)					

Table C.2: IPC-A01N: Modeling patents by OLS (spline)

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	828.922	48.52	17.1	0.0000	0.9574	F(3,13) = 2.911 (0.075)
Trend (T)	-4.41903	8.194	-0.539	0.5988	0.0219	mean(patents): 855.941
d_1 T	27.2458	15.30	1.78	0.0984	0.1960	var(patents): 7059.23
d_2 T	56.3275	33.83	1.66	0.1198	0.1758	R^2: 0.401809
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 1.6862	(0.2233)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	772.038	47.32	16.3	0.0000	0.9569	F(3,12) = 3.85 (0.038)
T	5.79794	8.453	0.686	0.5058	0.0377	mean(patents): 850.688
d_1 T	11.8164	15.55	0.760	0.4621	0.0459	var(patents): 7031.21
d_2 T	36.9543	43.42	0.851	0.4113	0.0569	R^2: 0.49047
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 0.37204	(0.6970)					

Table C.3: IPC-C08F: Modeling patents by OLS

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	1263.83	59.21	21.3	0.0000	0.9723	F(3,13) = 7.27 (0.004)
Trend	-15.3861	12.29	-1.25	0.233	0.1076	mean(patents): 1236.59
d_1	255.058	93.49	2.73	0.017	0.3641	var(patents): 15614.7
d_2	90.1549	151.5	0.595	0.562	0.0265	R^2: 0.626549
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 10.474	(0.0020)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	1223.02	82.43	14.8	0.0000	0.9483	F(3,12) = 4.296 (0.028)
Trend	-4.74737	14.62	-0.325	0.751	0.0087	mean(patents): 1229.75
d_1	166.072	110.3	1.51	0.158	0.1588	var(patents): 15795.7
d_2	-55.7313	175.2	-0.318	0.756	0.0084	R^2: 0.517863
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 6.3720	(0.0130)					

Table C.4: IPC-C08F: Modeling patents by OLS (spline)

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	1222.50	69.10	17.7	0.0000	0.9601	F(3,13) = 3.567 (0.044)
Trend (T)	1.38619	11.67	0.119	0.907	0.0011	mean(patents): 1236.59
d_1 T	24.4466	21.79	1.12	0.282	0.0882	var(patents): 15614.7
d_2 T	-48.5921	48.18	-1.01	0.332	0.0726	R^2: 0.451502
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 5.0570	(0.0237)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	1159.26	79.87	14.5	0.0000	0.9461	F(3,12) = 2.191 (0.142)
T	15.6077	14.27	1.09	0.295	0.0907	mean(patents): 1229.75
d_1 T	-9.31881	26.25	-0.355	0.729	0.0104	var(patents): 15795.7
d_2 T	-133.175	73.28	-1.82	0.094	0.2158	R^2: 0.353854
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 3.2317	(0.0754)					

Table C.5: IPC-C08J: Modeling patents by OLS

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	983.291	30.65	32.1	0.000	0.9875	F(3,13) = 5.374 (0.013)
Trend	-11.2871	6.361	-1.77	0.099	0.1950	mean(patents): 948.882
d_1	132.557	48.39	2.74	0.017	0.3659	var(patents): 3500.1
d_2	86.6591	78.45	1.10	0.289	0.0858	R^2: 0.553584
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 7.2548	(0.0077)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	966.444	47.83	20.2	0.000	0.9714	F(3,12) = 1.247 (0.336)
Trend	-5.83158	8.484	-0.687	0.505	0.0379	mean(patents): 944.313
d_1	74.6195	64.03	1.17	0.266	0.1017	var(patents): 3363.84
d_2	28.1950	101.7	0.277	0.786	0.0064	R^2: 0.23765
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 1.7461	(0.2160)					

Table C.6: IPC-C08J: Modeling patents by OLS (spline)

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	988.624	36.26	27.3	0.000	0.9828	F(3,13) = 2.097 (0.150)
Trend (T)	-8.65135	6.124	-1.41	0.181	0.1331	mean(patents): 948.882
d_1 T	22.0980	11.44	1.93	0.075	0.2231	var(patents): 3500.1
d_2 T	18.3992	25.28	0.728	0.480	0.0391	R^2: 0.32614
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 2.6122	(0.1113)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	942.964	44.43	21.2	0.000	0.9740	F(3,12) = 0.2592 (0.853)
T	1.39664	7.937	0.176	0.863	0.0026	mean(patents): 944.313
d_1 T	-1.64440	14.61	-0.113	0.912	0.0011	var(patents): 3363.84
d_2 T	-22.3053	40.77	-0.547	0.594	0.0243	R^2: 0.0608526
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 0.28791	(0.7549)					

Table C.7: IPC-C08K: Modeling patents by OLS

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	1049.71	39.48	26.6	0.000	0.9819	F(3,13) = 1.916 (0.177)
Trend	-15.8911	8.195	-1.94	0.074	0.2244	mean(patents): 1008.59
d_1	148.483	62.34	2.38	0.033	0.3038	var(patents): 3739.65
d_2	210.355	101.1	2.08	0.058	0.2500	R^2: 0.306568
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 2.8362	(0.0950)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	1008.81	39.25	25.7	0.000	0.9822	F(3,12) = 2.426 (0.116)
Trend	-8.30526	6.962	-1.19	0.256	0.1060	mean(patents): 1000.19
d_1	111.865	52.54	2.13	0.055	0.2742	var(patents): 2773.65
d_2	151.072	83.43	1.81	0.095	0.2146	R^2: 0.377539
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 2.2690	(0.1459)					

Table C.8: IPC-C08K: Modeling patents by OLS (spline)

	Sample:	1990 - 2006				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	1046.26	40.30	26.0	0.000	0.9811	F(3,13) = 1.229 (0.339)
Trend (T)	-10.6060	6.807	-1.56	0.143	0.1574	mean(patents): 1008.59
d_1 T	22.7227	12.71	1.79	0.097	0.1973	var(patents): 3739.65
d_2 T	50.5121	28.10	1.80	0.096	0.1991	R^2: 0.220919
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 1.8098	(0.2026)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	969.616	38.38	25.3	0.000	0.9815	F(3,12) = 0.707 (0.566)
T	3.06006	6.856	0.446	0.663	0.0163	mean(patents): 1000.19
d_1 T	0.887500	12.62	0.0703	0.945	0.0004	var(patents): 2773.65
d_2 T	9.05546	35.21	0.257	0.801	0.0055	R^2: 0.15021
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 0.056950	(0.9449)					

Table C.9: IPC-C09B: Modeling patents by OLS

	Sample:	1990 - 2006				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	326.734	12.41	26.3	0.000	0.9816	F(3,13) = 12.76 (0.000)
Trend	-4.50495	2.576	-1.75	0.104	0.1904	mean(patents): 279.882
d_1	-8.43211	19.60	-0.430	0.674	0.0140	var(patents): 1011.16
d_2	-14.1574	31.77	-0.446	0.663	0.0150	R^2: 0.746518
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 0.10282	(0.9030)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	327.211	13.65	24.0	0.000	0.9795	F(3,12) = 15.94 (0.000)
Trend	-3.64211	2.422	-1.50	0.158	0.1586	mean(patents): 278.5
d_1	-22.6596	18.28	-1.24	0.239	0.1135	var(patents): 1041.88
d_2	-29.9368	29.02	-1.03	0.323	0.0814	R^2: 0.799445
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 0.77202	(0.4837)					

Table C.10: IPC-C09B: Modeling patents by OLS (spline)

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	328.840	12.02	27.3	0.000	0.9829	F(3,13) = 12.56 (0.000)
Trend (T)	-5.32034	2.031	-2.62	0.021	0.3455	mean(patents): 279.882
d_1 T	-0.169248	3.792	-0.0446	0.965	0.0002	var(patents): 1011.16
d_2 T	-1.47156	8.384	-0.176	0.863	0.0024	R^2: 0.74353
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 0.02591	(0.9745)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	335.082	11.95	28.0	0.000	0.9850	F(3,12) = 14.24 (0.000)
T	-7.28838	2.135	-3.41	0.005	0.4927	mean(patents): 278.5
d_1 T	2.41664	3.928	0.615	0.550	0.0306	var(patents): 1041.88
d_2 T	5.85997	10.96	0.534	0.603	0.0232	R^2: 0.780666
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 0.1922	(0.8276)					

Table C.11: IPC-C09D: Modeling patents by OLS

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	836.475	26.71	31.3	0.000	0.9869	F(3,13) = 36 (0.000)
Trend	22.8812	5.543	4.13	0.001	0.5673	mean(patents): 1036.88
d_1	37.7723	42.17	0.896	0.387	0.0581	var(patents): 11042.1
d_2	-80.1337	68.35	-1.17	0.262	0.0956	R^2: 0.892559
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 8.4687	(0.0044)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	806.707	32.56	24.8	0.000	0.9808	F(3,12) = 29.34 (0.000)
Trend	30.7158	5.776	5.32	0.000	0.7021	mean(patents): 1047.25
d_1	-39.6050	43.59	-0.909	0.381	0.0644	var(patents): 9904.94
d_2	-194.159	69.22	-2.80	0.016	0.3960	R^2: 0.880007
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 8.5377	(0.0049)					

Table C.12: IPC-C09D: Modeling patents by OLS (spline)

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	829.831	29.07	28.5	0.000	0.9843	F(3,13) = 27.24 (0.000)
Trend (T)	25.7199	4.909	5.24	0.000	0.6786	mean(patents): 1036.88
d_1 T	-0.0525848	9.168	-0.00574	0.996	0.0000	var(patents): 11042.1
d_2 T	-41.4165	20.27	-2.04	0.062	0.2431	R^2: 0.862737
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 5.2165	(0.0217)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	856.194	35.48	24.1	0.000	0.9798	F(3,12) = 15.67 (0.000)
T	25.6325	6.338	4.04	0.002	0.5768	mean(patents): 1047.25
d_1 T	-4.75408	11.66	-0.408	0.691	0.0137	var(patents): 9904.94
d_2 T	-54.8827	32.56	-1.69	0.118	0.1915	R^2: 0.796624
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 2.5773	(0.1172)					

C.2 Geographic origin of patent applications

Table C.13: IPC-A01N: Modeling patents by OLS

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	42.5983	35.46	1.20	0.251	0.0999	F(3,13) = 10.04 (0.001)
Trend	5.38614	7.359	0.732	0.477	0.0396	mean(dif): 146.529
d_1	107.681	55.99	1.92	0.077	0.2215	var(dif): 6934.96
d_2	74.1665	90.76	0.817	0.429	0.0489	R^2: 0.69843
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 3.4217	(0.0640)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	42.1353	38.27	1.10	0.292	0.0918	F(3,12) = 11.29 (0.001)
Trend	7.91579	6.787	1.17	0.266	0.1018	mean(patents): 154.563
d_1	94.8331	51.22	1.85	0.089	0.2222	var(patents): 6271.37
d_2	8.87870	81.34	0.109	0.915	0.0010	R^2: 0.738317
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 6.1620	(0.0144)					

Table C.14: IPC-A01N: Modeling patents by OLS (spline)

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	25.5645	34.78	0.735	0.475	0.0399	F(3,13) = 9.516 (0.001)
Trend (T)	11.8509	5.874	2.02	0.065	0.2384	mean(dif): 146.529
d_1 T	14.7212	10.97	1.34	0.203	0.1217	var(dif): 6934.96
d_2 T	-6.59294	24.25	-0.272	0.790	0.0057	R^2: 0.687099
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 1.6862	(0.2233)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	74.8147	33.21	2.25	0.044	0.2972	F(3,12) = 10.22 (0.001)
T	4.03740	5.932	0.681	0.509	0.0372	mean(dif): 154.563
d_1 T	27.8241	10.92	2.55	0.026	0.3513	var(dif): 6271.37
d_2 T	23.7622	30.47	0.780	0.451	0.0482	R^2: 0.718647
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 5.3117	(0.0223)					

Table C.15: IPC-C08F: Modeling patents by OLS

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	363.239	32.72	11.1	0.000	0.9046	F(3,13) = 3.755 (0.038)
Trend	-11.8812	6.791	-1.75	0.104	0.1906	mean(dif): 294.235
d_1	70.8468	51.67	1.37	0.194	0.1264	var(dif): 3324.65
d_2	54.9194	83.75	0.656	0.523	0.0320	R^2: 0.464251
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 1.5605	(0.2469)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	42.1353	38.27	1.10	0.292	0.0918	F(3,12) = 11.29 (0.001)
Trend	7.91579	6.787	1.17	0.266	0.1018	mean(dif): 154.563
d_1	94.8331	51.22	1.85	0.089	0.2222	var(dif): 6271.37
d_2	8.87870	81.34	0.109	0.915	0.0010	R^2: 0.738317
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 6.1620	(0.0144)					

Table C.16: IPC-C08F: Modeling patents by OLS (spline)

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	376.083	30.22	12.4	0.000	0.9226	F(3,13) = 4.462 (0.023)
Trend (T)	-13.3516	5.104	-2.62	0.021	0.3449	mean(dif): 294.235
d_1 T	19.3289	9.531	2.03	0.064	0.2403	var(dif): 3324.65
d_2 T	24.5474	21.07	1.17	0.265	0.0945	R^2: 0.507318
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 2.2651	(0.1432)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	7349.612	36.26	9.64	0.000	0.8857	F(3,12) = 1.743 (0.211)
T	-9.24042	6.478	-1.43	0.179	0.1450	mean(dif): 288.75
d_1 T	9.85014	11.92	0.826	0.425	0.0538	var(dif): 3020.94
d_2 T	12.6747	33.27	0.381	0.710	0.0119	R^2: 0.303553
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 0.44207	(0.6528)					

Table C.17: IPC-C08J: Modeling patents by OLS

	Sample:	1990 - 2006				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	304.731	31.15	9.78	0.000	0.8804	F(3,13) = 2.559 (0.100)
Trend	-9.86139	6.464	-1.53	0.151	0.1518	mean(dif): 274.882
d_1	106.480	49.18	2.17	0.050	0.2650	var(dif): 2566.69
d_2	90.6202	79.72	1.14	0.276	0.0904	R^2: 0.371249
Test for excluding:						
(0) = *d_1*						
(1) = *d_2*						
F(2,13) = 3.5460	(0.0590)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	312.113	38.02	8.21	0.000	0.8488	F(3,12) = 2.369 (0.122)
Trend	-10.7368	6.744	-1.59	0.137	0.1744	mean(dif): 271.938
d_1	114.361	50.89	2.25	0.044	0.2962	var(dif): 2579.68
d_2	101.010	80.82	1.25	0.235	0.1152	R^2: 0.371953
Test for excluding:						
(0) = *d_1*						
(1) = *d_2*						
F(2,12) = 3.4886	(0.0639)					

Table C.18: IPC-C08J: Modeling patents by OLS (spline)

	Sample:	1990 - 2006				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	311.017	26.43	11.8	0.000	0.9142	F(3,13) = 4.545 (0.022)
Trend (T)	-9.32136	4.463	-2.09	0.057	0.2512	mean(dif): 274.882
d_1 T	26.4190	8.335	3.17	0.007	0.4359	var(dif): 2566.69
d_2 T	25.7083	18.43	1.40	0.186	0.1302	R^2: 0.511899
Test for excluding:						
(0) = *d_1* T						
(1) = *d_2* T						
F(2,13) = 6.4409	(0.0114)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	287.865	35.26	8.16	0.000	0.8474	F(3,12) = 1.188 (0.356)
T	-4.63021	6.298	-0.735	0.476	0.0431	mean(dif): 271.938
d_1 T	15.4267	11.59	1.33	0.208	0.1286	var(dif): 2579.68
d_2 T	8.48499	32.35	0.262	0.798	0.0057	R^2: 0.228927
Test for excluding:						
(0) = *d_1* T						
(1) = *d_2* T						
F(2,12) = 1.7286	(0.2189)					

Table C.19: IPC-C08K: Modeling patents by OLS

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	384.103	32.28	11.9	0.000	0.9159	F(3,13) = 2.042 (0.158)
Trend	-15.9901	6.700	-2.39	0.033	0.3046	mean(dif): 324.824
d_1	118.793	50.98	2.33	0.037	0.2947	var(dif): 2550.62
d_2	181.493	82.63	2.20	0.047	0.2707	R^2: 0.320266
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 2.7698	(0.0995)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	384.090	42.40	9.06	0.000	0.8724	F(3,12) = 1.073 (0.397)
Trend	-13.1895	7.521	-1.75	0.105	0.2040	mean(dif): 321.813
d_1	88.7554	56.76	1.56	0.144	0.1693	var(dif): 2555.9
d_2	158.608	90.13	1.76	0.104	0.2051	R^2: 0.211552
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 1.5515	(0.2516)					

Table C.20: IPC-C08K: Modeling patents by OLS (spline)

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	372.130	34.51	10.8	0.000	0.8995	F(3,13) = 0.8409 (0.495)
Trend (T)	-9.05136	5.828	-1.55	0.144	0.1565	mean(dif): 324.824
d_1 T	11.3022	10.88	1.04	0.318	0.0766	var(dif): 2550.62
d_2 T	34.3307	24.06	1.43	0.177	0.1354	R^2: 0.162514
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 1.0237	(0.3865)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	338.882	38.29	8.85	0.000	0.8672	F(3,12) = 0.3591 (0.784)
T	-2.21400	6.839	-0.324	0.752	0.0087	mean(dif): 321.813
d_1 T	-2.79776	12.58	-0.222	0.828	0.0041	var(dif): 2555.9
d_2 T	14.4567	35.13	0.412	0.688	0.0139	R^2: 0.082369
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 0.48844	(0.6253)					

Table C.21: IPC-C09B: Modeling patents by OLS

	Sample:	1990 - 2006				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	36.8699	15.50	2.38	0.033	0.3033	F(3,13) = 6.156 (0.008)
Trend	-3.39604	3.217	-1.06	0.310	0.0790	mean(dif): 50.5882
d_1	72.1219	24.47	2.95	0.011	0.4005	var(dif): 967.301
d_2	80.0187	39.67	2.02	0.065	0.2384	R^2: 0.586898
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 4.9984	(0.0245)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	30.2782	22.76	1.33	0.208	0.1286	F(3,12) = 2.536 (0.106)
Trend	0.315789	4.036	0.0782	0.939	0.0005	mean(dif): 52.75
d_1	40.0902	30.46	1.32	0.213	0.1261	var(dif): 948.313
d_2	23.6692	48.37	0.489	0.633	0.0196	R^2: 0.387984
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 1.7085	(0.2224)					

Table C.22: IPC-C09B: Modeling patents by OLS (spline)

	Sample:	1990 - 2006				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	11.2906	18.06	0.625	0.543	0.0292	F(3,13) = 2.831 (0.080)
Trend (T)	4.76507	3.050	1.56	0.142	0.1581	mean(dif): 50.5882
d_1 T	1.76716	5.696	0.310	0.761	0.0073	var(dif): 967.301
d_2 T	-9.81055	12.59	-0.779	0.450	0.0446	R^2: 0.395111
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 1.3527	(0.2926)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	16.5194	19.60	0.843	0.416	0.0559	F(3,12) = 2.174 (0.144)
T	4.81645	3.500	1.38	0.194	0.1363	mean(dif): 52.75
d_1 T	0.865679	6.441	0.134	0.895	0.0015	var(dif): 948.313
d_2 T	-15.5879	17.98	-0.867	0.403	0.0589	R^2: 0.35209
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 1.2815	(0.3130)					

Table C.23: IPC-C09D: Modeling patents by OLS

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	198.178	28.25	7.02	0.000	0.7910	F(3,13) = 6.126 (0.008)
Trend	3.45545	5.863	0.589	0.566	0.0260	mean(dif): 262.176
d_1	53.3729	44.61	1.20	0.253	0.0992	var(dif): 3204.5
d_2	59.7624	72.31	0.826	0.423	0.0499	R^2: 0.585714
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,13) = 0.81685	(0.4633)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	184.722	24.54	7.53	0.000	0.8253	F(3,12) = 16.07 (0.000)
Trend	4.08421	4.352	0.938	0.367	0.0684	mean(dif): 263.25
d_1	82.3098	32.85	2.51	0.028	0.3435	var(dif): 3385.19
d_2	47.2642	52.16	0.906	0.383	0.0640	R^2: 0.800654
Test for excluding:						
(0) = d_1						
(1) = d_2						
F(2,12) = 6.3212	(0.0133)					

Table C.24: IPC-C09D: Modeling patents by OLS (spline)

	Sample:	**1990 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	184.530	27.19	6.79	0.000	0.7799	F(3,13) = 6.14 (0.008)
Trend (T)	7.74828	4.592	1.69	0.115	0.1797	mean(dif): 262.176
d_1 T	6.72290	8.575	0.784	0.447	0.0451	var(dif): 3204.5
d_2 T	-0.667415	18.96	-0.0352	0.972	0.0001	R^2: 0.586264
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,13) = 0.82659	(0.4593)					
1 year lag	**Sample:**	**1991 - 2006**				
	Coefficient	Std. Error	t-value	P > |t|	Part. R^2	
Constant	187.966	23.98	7.84	0.000	0.8366	F(3,12) = 10.71 (0.001)
T	6.40156	4.284	1.49	0.161	0.1569	mean(dif): 263.25
d_1 T	13.8149	7.884	1.75	0.105	0.2037	var(dif): 3385.19
d_2 T	7.30450	22.01	0.332	0.746	0.0091	R^2: 0.728101
Test for excluding:						
(0) = d_1 T						
(1) = d_2 T						
F(2,12) = 3.0335	(0.0859)					

Appendix D

Results from the Pearson's χ^2 test from Chapter 5

The Pearson's χ^2 test was calculated to help analyze the fourth research question raised in Chapter 5 on the change in the direction of the innovative activity. Considering the years of 1990 and 2006 for each regulated area two tests were calculated. Firstly comparing the number of applications classified under the most expressive IPC fields and secondly comparing the number of applications classified under highlighted technological areas. All tables show the real values, the expected values (in parenthesis), Pearson's χ^2 number, and respective p-value.

D.1 IPC-A01: Agriculture; forestry; animal husbandry; hunting; trapping; and fishing

Table D.1: A01N: Results of chi-square test for the main IPC fields

IPC field	1990	2006
A	346 (448.7)	425 (322.3)
B	55 (57.6)	44 (41.4)
C	885 (778.6)	453 (559.4)
D	20 (16.9)	9 (12.1)
G	15 (19.2)	18 (13.8)
	df =	4
	Pearson χ^2 =	94.8
	p-value =	0.000

Table D.2: A01N: Results of chi-square test for Table 5.14

IPC	1990	2006
A61K	120 (222.0)	263 (161.0)
C07C	131 (99.6)	41 (72.4)
C07D	358 (298.0)	156 (216.0)
C07F	54 (34.8)	6 (25.2)
C12N	50 (59.1)	52 (42.9)
	df =	4
	Pearson χ^2 =	192.0
	p-value =	0.000

D.2 IPC-C08: Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon

Table D.3: C08F: Results of chi-square test for the main IPC fields

IPC field	1990	2006
A	153 (156.0)	105 (102.0)
B	215 (233.0)	171 (153.0)
C	1321 (1319.0)	867 (869.0)
D	65 (55.5)	27 (36.5)
G	180 (163.0)	90 (107.0)
H	49 (57.9)	47 (38.1)
	df =	5
	Pearson χ^2 =	15.6
	p-value =	0.008

Table D.4: C08F: Results of chi-square test for Table 5.26

IPC	1990	2006
A61K	57 (57.3)	40 (39.7)
B01J	70 (80.4)	66 (55.6)
C08G	177 (154.0)	83 (106.0)
C08J	106 (119.0)	96 (82.6)
C08L	255 (271.0)	203 (187.0)
C09D	160 (159.0)	109 (110.0)
G02B	48 (42.0)	23 (29.0)
G03F	57 (47.9)	24 (33.1)
	df =	7
	Pearson χ^2 =	24.2
	p-value =	0.001

Table D.5: C08J: Results of chi-square test for the main IPC fields

IPC field	1990	2006
A	90 (110.0)	109 (88.5)
B	615 (588.0)	444 (471.0)
C	1096 (1106.0)	896 (886.0)
D	97 (84.9)	56 (68.1)
F	26 (21.1)	12 (16.9)
G	70 (68.3)	53 (54.7)
H	73 (88.8)	87 (71.2)
	df =	6
	Pearson χ^2 =	24.4
	p-value =	0.000

Table D.6: C08J: Results of chi-square test for Table 5.28

IPC	1990	2006
B29C	153 (133.0)	89 (109.0)
B32B	101 (120.0)	117 (98.3)
C08F	106 (111.0)	96 (91.1)
C08G	193 (156.0)	91 (128.0)
C08K	177 (187.0)	164 (154.0)
C08L	330 (354.0)	314 (290.0)
	df =	5
	Pearson χ^2 =	38.0
	p-value =	0.000

Table D.7: C08K: Results of chi-square test for the main IPC fields

IPC field	1990	2006
A	116 (109.0)	87 (93.9)
B	209 (260.0)	274 (223.0)
C	1612 (1572.0)	1312 (1352.0)
D	56 (55.9)	48 (48.1)
G	65 (69.9)	65 (60.1)
H	132 (124.0)	98 (106.0)
	df =	5
	Pearson χ^2 =	26.5
	p-value =	0.000

Table D.8: C08K: Results of chi-square test for Table 5.30

IPC	1990	2006
B32B	28 (48.9)	64 (43.1)
B60C	16 (43.6)	66 (38.4)
C07D	66 (44.1)	17 (38.9)
C08G	160 (134.0)	92 (118.0)
C08J	177 (202.0)	203 (178.0)
C08L	661 (651.0)	564 (574.0)
C09D	109 (111.0)	100 (97.9)
C09K	86 (68.6)	43 (60.4)
	df =	7
	Pearson χ^2 =	107.0
	p-value =	0.000

D.3 IPC-C09: Dyes; paints; polishes; natural resins; adhesives; miscellaneous compositions; miscellaneous applications of materials

Table D.9: C09B: Results of chi-square test for the main IPC fields

IPC field	1990	2006
A	32 (42.9)	45 (34.1)
B	45 (46.8)	39 (37.2)
C	201 (213.0)	182 (170.0)
D	99 (62.4)	13 (49.6)
G	71 (81.4)	75 (64.6)
H	4 (5.02)	5 (3.98)
	df =	5
	Pearson χ^2 =	59.9
	p-value =	0.000

Table D.10: C09B: Results of chi-square test for Table 5.40

IPC	1990	2006
A61K	16 (22.3)	23 (16.7)
B41M	33 (26.4)	13 (19.6)
C07C	27 (19.5)	7 (14.5)
C07D	49 (44.1)	28 (32.9)
C09D	26 (57.3)	74 (42.7)
D06P	84 (52.7)	8 (39.3)
G01N	8 (12.6)	14 (9.4)
G02B	4 (16.6)	25 (12.4)
G03G	16 (11.5)	4 (8.5)
	df =	8
	Pearson χ^2 =	130.0
	p-value =	0.000

Table D.11: C09D: Results of chi-square test for the main IPC fields

IPC field	1990	2006
A	89 (83.8)	83 (88.2)
B	253 (312.0)	387 (328.0)
C	1111 (1091.0)	1129 (1149.0)
D	48 (43.3)	41 (45.7)
G	98 (93.0)	93 (98.0)
H	97 (73.5)	54 (77.5)
	df =	5
	Pearson χ^2 =	39.0
	p-value =	0.000

Table D.12: C09D: Results of chi-square test for Table 5.43

IPC	1990	2006
B05D	77 (74.4)	83 (85.6)
B41J	16 (35.3)	60 (40.7)
B41M	30 (46.9)	71 (54.1)
C08F	160 (129.0)	118 (149.0)
C08G	195 (202.0)	239 (232.0)
C08L	187 (157.0)	151 (181.0)
C09B	26 (46.5)	74 (53.5)
	df =	6
	Pearson χ^2 =	73.0
	p-value =	0.000

Appendix E

Geographic origin of patents applied by Bayer Group, Basf, 3M, and DuPont

E.1 Bayer Group

Table E.1: A01N: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
DE	**47**	77	82	77	96	92	**104**	71	100	91	80	84	**79**	92	95	**95**
FR		1			1	6	**8**	6		9	14	21	**8**	16	17	**17**
JP	**2**	5	10	6	11	11	**4**	4	8	6	7	4				
US				1	4			3	1	1	1	2		1	6	**5**
GB			2	3	2			1	1	2						
BE		1	1								1					**1**
CA															1	
Total	**49**	84	95	87	114	109	**116**	85	110	109	103	111	**87**	109	119	**118**
% DE	**0.96**	0.92	0.86	0.89	0.84	0.84	**0.90**	0.84	0.91	0.83	0.78	0.76	**0.91**	0.84	0.80	**0.81**

Table E.2: C08F, C08J, and C08K: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
C08F																
DE	**26**	25	24	11	26	30	**32**	29	50	38	21	18	**8**	7	4	
CA	**2**	3	7	5	2	1	**1**		3		3	1	**1**			
US	**1**			3	1			4	3	2	1				5	**1**
BE	**1**		2		2		**1**									
Total	**30**	28	33	19	31	31	**34**	33	56	40	25	19	**9**	7	9	**1**
% DE	**0.87**	0.89	0.73	0.58	0.84	0.97	**0.94**	0.88	0.89	0.95	0.84	0.95	**0.89**	1.00	0.44	
C08J																
DE	**29**	27	34	31	40	15	**30**	20	25	38	18	7	**10**	7	11	**8**
US		3		2		3	**2**	5	2	1	1		**3**	4	4	**2**
BE						3			1	5						
CA		1	1		2			2	1	2						
JP		1			1		**2**	1								
Total	**29**	32	35	33	43	21	**34**	28	29	46	19	**7**	**13**	11	15	**10**
% DE	**1.00**	0.84	0.97	0.94	0.93	0.71	**0.88**	0.71	0.86	0.83	0.95	1.00	**0.77**	0.64	0.73	**0.80**
C08K																
DE	**32**	37	35	25	40	28	**28**	35	40	38	32	21	**17**	8	11	**11**
US		3	2	2	5	2	**4**	8	4	6	2			1	2	**3**
CA		3	1		1			2	4	2	1		**1**			
BE	**1**		1	2												
JP			1				**1**									
Total	**33**	43	40	29	46	30	**33**	45	48	46	35	21	**18**	9	13	**14**
% DE	**0.97**	0.86	0.88	0.86	0.87	0.93	**0.85**	0.78	0.83	0.83	0.91	1.00	**0.94**	0.89	0.85	**0.79**

Table E.3: C09B and C09D: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
C09B																
DE	**18**	32	28	23	22	17	**18**	7	9	8	1	2	**2**			
US		8	1	2	5		**4**	4	2	1						
Total	**18**	40	29	25	27	17	**22**	11	11	9	1	2	**2**			
% DE	**1.00**	0.80	0.97	0.92	0.81	1.00	**0.82**	0.64	0.82	0.89	1.00	1.00	**1.00**			
C09D																
DE	**25**	39	49	34	54	32	**43**	32	46	29	28	30	**29**	26	27	**22**
US		4	1	4	6	4	**7**	10	9	4	2		**3**	12	14	**11**
CA		1						1	2	1						
BE		1														
Total	**25**	45	50	38	60	36	**50**	43	57	34	30	30	**32**	38	41	**33**
% DE	**1.00**	0.87	0.98	0.89	0.90	0.89	**0.86**	0.74	0.81	0.85	0.93	1.00	**0.91**	0.68	0.66	**0.67**

E.2 Basf

Table E.4: A01N: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
DE	59	43	41	49	60	86	83	100	73	59	47	51	61	80	85	110
US	1	1	1	2	1	2	1	2	2	3	2	1	1			2
FR	1															
CH						3		1	1	2	1		1			
NL															1	
Total	61	44	42	51	61	91	84	103	76	64	50	52	63	80	86	112

Table E.5: C08F, C08J, and C08K: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C08F								
DE	74	84	100	86	86	93	135	70	101	83	89	65	62	73	59	96
US		2	4		4	1		4	4	6	2	3	5	2	2	3
BR		1														
JP			1	2	1	2										1
Total	74	87	105	88	91	96	135	74	105	89	91	68	67	75	61	100
% DE	1.00	0.97	0.95	0.98	0.95	0.97	1.00	0.95	0.96	0.93	0.98	0.96	0.93	0.97	0.97	0.96
								C08J								
DE	23	36	35	26	50	50	67	37	52	30	35	25	28	35	45	70
US	3	3	3		1	2		3	1	1	3	2		4	3	2
FR	1															
JP				1	2	2										2
Total	27	39	38	27	53	54	67	40	53	31	38	27	28	39	48	74
% DE	0.85	0.92	0.92	0.96	0.94	0.93	1.00	0.93	0.98	0.97	0.92	0.93	1.00	0.90	0.94	0.95
								C08K								
DE	35	39	29	33	39	31	44	22	34	35	26	31	21	14	28	35
US		2	7	4		1	2	1	1	2		3	1	3	1	1
JP			1	2												
Total	35	41	37	39	39	32	46	23	35	37	26	34	22	17	29	36
% DE	1.00	0.95	0.78	0.85	1.00	0.97	0.96	0.96	0.97	0.95	1.00	0.91	0.95	0.82	0.97	0.97

Table E.6: C09B and C09D: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C09B								
DE	35	32	51	35	36	22	27	17	15	8	14	13	15	11	15	13
US	1			1						1	2	1	1			
FR	1															
JP			1													
Total	37	32	52	36	36	22	27	17	15	9	16	14	16	11	15	13
								C09D								
DE	42	41	51	58	54	64	64	53	63	81	71	65	48	40	42	72
US	7	11	20	22	17	15	9	14	24	18	21	28	16	7	8	9
JP			1	2	1	1	1		2		1				3	8
Total	49	52	72	82	72	80	74	67	89	99	93	93	64	47	53	89
% DE	0.86	0.79	0.71	0.71	0.75	0.80	0.86	0.79	0.71	0.82	0.76	0.70	0.75	0.85	0.79	0.81
% US	0.14	0.21	0.28	0.27	0.24	0.19	0.12	0.21	0.27	0.18	0.23	0.30	0.25	0.15	0.15	0.10

E.3 3M

Table E.7: C08F, C08J, and C08K: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C08F								
US	24	37	26	41	29	35	31	20	30	32	34	30	39	29	23	17
DE					1			2		1			1			
Total	24	37	26	**41**	30	35	31	22	30	33	34	30	40	29	23	**17**
								C08J								
US	**8**	25	22	**31**	19	16	27	20	28	23	19	25	13	30	22	**17**
								C08K								
US	9	17	16	14	12	20	11	13	15	13	9	25	15	12	27	20
DE							1		1			1	2		1	
Total	**9**	17	16	14	12	20	12	13	16	13	9	26	17	12	**28**	20

Table E.8: C09B and C09D: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C09B								
US	3	6	6	6	8	7		3		1	2	2	1			
								C09D								
US	17	18	26	28	28	38	29	20	31	18	17	23	21	19	23	14
DE								1				1				
Total	**17**	18	26	28	28	**38**	29	21	31	18	17	24	21	19	23	**14**

E.4 DuPont

Table E.9: A01N: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
US	18	14	23	12	6	16	12	10	2		7	16	15	9	17	16

Table E.10: C08F, C08J, and C08K: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
								C08F								
US	21	16	29	19	25	47	41	43	56	49	37	30	27	15	25	36
JP						1					1					2
GB	1															
CA				1		1										
DE							2									
Total	22	**16**	29	20	25	49	41	43	**56**	49	38	30	27	**15**	25	**36**
								C08J								
US	49	43	31	40	29	28	46	22	24	22	16	24	21	21	34	37
JP		1								3	4	2	4	4	8	5
CA	1			2					2							
CH		1														
DE					1											
Total	**50**	45	31	42	28	28	46	22	26	25	**20**	26	25	25	**42**	41
								C08K								
US	25	29	20	23	22	31	27	28	28	22	21	14	36	32	40	35
JP				1	2			1		2		2	1	2		4
GB	1															
CA	1	1											1		1	
DE		1			1											
Total	**26**	30	20	24	25	**31**	27	29	28	24	21	**16**	38	33	**41**	39

Table E.11: C09D: Origin of patent applications

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
US	21	20	27	22	32	44	49	54	44	41	33	29	41	65	66	63
JP				1	2			2		2			1	2	2	1
DE							1		2							
CH		1														1
FR																2
CA						1										
SE															1	
ES																1
Total	**21**	21	27	23	34	45	49	**56**	46	43	33	**29**	42	67	69	66

Appendix F

Bayer Group, BASF, DuPont, and 3M: Patent profile of regulated areas

Only technological areas with share summing at least one percent, in 1991 or 2006, are illustrated.

F.1 Bayer Group

Table F.1: A01N: Patent application profile by Bayer Group in Germany

	A01K	A01M	A61K	A61P	B01J	C05G	C07B	C07C	C07D	C07F	C12N
1991	1.1%	1.1%	3.4%	1.2%	1.2%	–	1.2%	**13.0%**	**71.3%**	5.6%	–
2006	–	–	4.5%	3.6%	1.8%	2.4%	–	**11.8%**	**69.1%**	–	1.8%

Table F.2: C08F, C08J, and C08K: Patent application profile by Bayer Group in Germany

	C08F															
	A61K	B01D	B01J	B05D	C07B	C07C	C07D	C07F	C08C	C08G	C08J	C08K	C08L	C09D	C09K	D21H
1991	7.7%	3.3%	**10.0%**	1.4%	3.5%	6.2%	1.4%	4.6%	**12.3%**	8.0%	6.2%	1.7%	**12.8%**	6.4%	1.9%	8.3%
	C08J															
	A47C	B05D	B29C	B29K	B68G	C08F	C08G	C08K	C08L	C09B	C09D	C09K				
1991	1.2%	1.3%	3.0%	3.7%	1.2%	5.7%	**25.5%**	**11.9%**	**26.9%**	1.9%	4.1%	2.2%				
	B29C	B32B	C08G	C08K	C08L	C09D	C14C	D06M	G02B	G02F	G05B					
2006	**10.0%**	3.3%	**33.7%**	**13.7%**	**19.7%**	8.7%	2.0%	2.0%	2.5%	2.5%	2.5%					
	C08K															
	A61K	C01G	C07D	C08F	C08G	C08J	C08L	C09B	C09C	C09D	C09J	C09K	D06P	H05K		
1991	1.5%	1.0%	1.0%	1.4%	6.8%	**10.1%**	**57.7%**	2.6%	1.0%	7.3%	1.0%	1.4%	1.0%	3.0%		
	A01N	A01P	A61L	B32B	C08G	C08J	C08L	C09D	C14C	D06M						
2006	2.4%	2.4%	**14.3%**	**16.7%**	**13.3%**	9.8%	**31.0%**	7.4%	1.4%	1.4%						

Table F.3: C09B and C09D: Patent application profile by Bayer Group in Germany

C09B

	B01F	B01J	C07B	C07C	C07D	C08G	C08J	C08K	C08L	C09D	C09K	C11D	C14C	D06L	D06M	D06P	D21H	G02B	G02F
1991	1.0%	4.4%	1.1%	4.4%	**13.9%**	1.0%	3.6%	5.8%	3.2%	1.7%	2.3%	1.1%	1.0%	1.1%	2.1%	**48.2%**	1.7%	1.3%	1.3%

C09D

	B05D	C01G	C04B	C07D	C08F	C08G	C08J	C08K	C08L	C09B	C09C	C09J	C09K	C23C	D06N	D06P	D21H	G12B	H05K
1991	6.1%	1.3%	1.0%	7.0%	6.6%	**33.6%**	4.6%	9.7%	**13.1%**	1.0%	1.3%	3.3%	2.0%	1.0%	1.3%	1.0%	2.3%	1.0%	1.0%

	C07C	C08G	C08J	C08K	C08L	C09J
2006	1.6%	**85.5%**	2.7%	3.2%	4.2%	1.6%

.

F.2 BASF

Table F.4: A01N: Patent application profile by BASF in Germany

	A01C	A01H	A01K	A23L	A61K	B01J	B27K	B65D	C04B	C07C	C07D	C07F	C07K	C08G	C08L	C12N	C23C
1991			1.7%		<1%			1.7%		**21.6%**	**70.4%**	<1%		2.6%			
2006	**8.2%**	1.5%		1.5%	2.1%	1.8%	1.8%		1.8%	**10.0%**	**58.5%**	2.4%	1.2%		1.5%	1.8%	3.9%

Table F.5: C08F, C08J, and C08K: Patent application profile by BASF in Germany

C08F	1991	2006	C08J	1991	2006	C08K	1991	2006
A	**4.8%**	**22.0%**	A		**11.6%**	A		**7.6%**
A61K	**3.3%**	**12.0%**	A61F		2.5%	A61K		1.0%
A61L		**7.3%**	A61L		**7.9%**	A61L		**5.6%**
A61Q	1.5%	2.7%				A61Q		1.0%
B	**12.5%**	**12.6%**	B	**22.3%**	**18.2%**	B	**1.4%**	**2.5%**
B01D		2.9%	B01D	1.0%	<1%	B01J		2.5%
B01F		2.1%	B01F	1.0%	3.1%	B22F	1.4%	
B01J	5.7%	5.4%	B01J	1.8%	1.1%			
B05D	4.5%		B05D	<1%	3.1%			
B29B		1.4%	B29B	<1%	3.0%			
			B29C	**6.3%**	**2.5%**			
			B29K	**6.3%**				
			B29L	2.6%				
			B32B	1.0%	4.1%			
C	**77.2%**	**60.3%**	C	**67.9%**	**55.8%**	C	**94.1%**	**87.4%**
C04B	1.8%	1.3%	C04B	3.0%		C01B		2.5%
C07C	4.2%	2.5%	C08B		2.8%	C01G	1.4%	
C07F	1.8%	2.0%	C08F	8.1%	5.4%	C04B	2.1%	
C08C	1.8%	1.3%	C08G	16.9%	7.5%	C07F	3.6%	
C08G	7.5%	4.8%	C08K	14.1%	10.0%	C08F	**16.4%**	**10.5%**
C08J	3.6%	3.8%	C08L	14.9%	12.5%	C08G	**12.9%**	**3.0%**
C08K	**10.3%**	**4.6%**	C09B	4.0%		C08J	**10.1%**	**16.0%**
C08L	**21.9%**	**9.4%**	C09D	**5.8%**	**12.5%**	C08L	**39.9%**	**33.2%**
C09D	8.9%	16.6%	C09J	1.0%	<1%	C09B		4.5%
C09J	5.2%	2.6%	C11D		3.8%	C09C	1.4%	2.5%
C09K	1.2%					C09D	3.9%	14.5%
C10L	<1%	2.0%				C09J	1.9%	
C10M	<1%	1.3%						
C11D	5.4%	<1%						
C12N		1.3%						
C14C		1.7%						
C23C		1.3%						
C23F		1.6%						
D	**2.4%**	**4.3%**	D	**3.9%**	**5.7%**	D	**3.0%**	
D06M	1.8%	<1%	D01D	1.0%		D01F	1.0%	
D21H		4.0%	D06M	<1%	2.8%	D06N	1.5%	
			D06N	2.1%	1.9%			
E	**<1%**		E	**2.0%**				
			E04F	2.0%				
F		**<1%**	F	**3.0%**	**2.0%**	F	**1.4%**	
			F16F	2.0%	<1%	F16F	1.4%	
			F16H	1.0%				
			F26B		1.1%			
G	**1.9%**		G		**<1%**			
G03F	1.5%							
H	**<1%**		H	**<1%**	**6.3%**	H		**2.5%**
			H01M		6.3%	H01B		1.5%
						H01M		1.0%

Table F.6: C09B and C09D: Patent application profile by BASF in Germany

C09B

	A23L	A61K	B01F	B41M	C07C	C07D	C07F	C08J	C08K	C08L	C09C	C09D	D06M	D06P	D21H	G01D	G02B	G03F	G11B
1991			1.5%	25.0%	8.1%	10.2%		3.2%		<1%	1.5%	4.7%	<1%	34.5%	2.7%	1.1%		1.1%	3.5%
2006	4.2%	4.2%			8.3%	29.2%	4.2%		18.8%	6.3%				12.5%			12.5%		

C09D

	B05D	B27K	C04B	C08F	C08G	C08J	C08K	C08L	C09B	C09C	C09J	C09K	C25D	D06M	G03F	G11B	H01B	H01F	H05K
1991	15.2%	4.4%	5.0%	11.1%	21.1%	3.2%	3.0%	10.8%	3.2%	4.3%	2.0%	1.5%	1.1%	<1%	1.1%	4.4%	1.1%	2.2%	1.1%

	A61L	B05D	B27K	B27N	B32B	C04B	C08F	C08G	C08J	C08K	C08L	C09C	C09J	C23C	C23F	D06M	H05B
2006	1.2%	3.3%	1.4%	1.4%	2.4%	1.2%	18.1%	28.6%	9.6%	6.9%	6.3%	2.2%	1.6%	3.1%	4.1%	1.8%	<1%

Table F.7: C09B and C09D: Patent application profile by BASF in Germany

C09B

	A	B	C	D	G	H
1991		26.5%	29.2%	37.8%	5.6%	0.8%
2006	8.3%		66.7%	12.5%	12.5%	

C09D

	A	B	C	D	G	H
1991		20.6%	67.0%	1.8%	6.1%	4.4%
2006	1.6%	10.5%	85.2%	1.8%	0.2%	0.7%

.

F.3 DuPont

Table F.8: A01N: Patent application profile – and respective definitions – by DuPont in Germany

IPC	1991	2006	Definition
A	–	**8.3%**	
A61K	–	5.0%	Preparations for medical, dental, or toilet purposes
A61Q	–	3.3%	Use of cosmetics or similar toilet preparations (IPC)
B	–	**30.0%**	
B27K	–	30.0%	Processes, apparatus or selection of substances for impregnating, staining, dyeing, bleaching of wood or similar materials, or treating of of wood or similar materials with permeant liquids, not otherwise provided for (applying liquids or other fluent materials to surfaces in general B05; coating wood or similar material B44D); chemical or physical treatment of cork, cane, reed, straw or similar materials
C	**100.0%**	**61.7%**	
C07C	15.5%	3.3%	Acyclic or carbocyclic compounds
C07D	69.0%	48.3%	Coating compositions (e.g. paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes or solids for coloring or printing; use of materials therefor)
C07F	8.3%	–	Acyclic, carbocyclic, or heterocyclic compounds containing elements other than carbon, hydrogen, halogen, oxygen, nitrogen, sulfur, selenium, or tellurium
C07K		5.0%	Peptides
C12N	–	5.0%	Micro-organisms or enzymes; compositions thereof; propagating, preserving, or maintaining micro-organisms; mutation or genetic engineering; culture media
C12Q	7.1%		Measuring or testing processes involving enzymes or micro-organisms (immunoassay G01N 33/53); compositions or test papers therefor; processes of preparing such compositions; condition-response control in microbiological or enzymological processes

Table F.9: C08F, C08J, and C08K: Patent application profile by DuPont in Germany

C08F	1991	2006	C08J	1991	2006	C08K	1991	2006
A			A	**2.5%**	**4.6%**	A		**1.5%**
			A41D		3.2%	A47J		1.0%
			A62D	<1%	1.4%			
B	**10.8%**	**7.4%**	B	**21.4%**	**14.5%**	B	**5.8%**	**15.7%**
B05D	2.2%	5.1%	B01D	1.0%		B05D		2.5%
B29C	7.6%		B27J	1.0%		B29C	2.9%	
B32B	1.0%	2.2%	B29B	1.0%		B29K	1.9%	
			B29C	6.4%	2.0%	B29L	1.0%	
			B29K	1.9%		B32B		10.8%
			B29L	1.4%				
			B32B	4.9%	11.1%			
			B65D	1.3%	<1%			
C	**68.5%**	**76.0%**	C	**57.3%**	**66.1%**	C	**76.2%**	**58.3%**
C07C	13.6%	3.8%	C03C		1.8%	C03C		3.2%
C07D	3.6%	1.9%	C07C	5.3%		C07D	3.2%	1.0%
C07F	–	1.9%	C07K	1.0%		C08F	6.1%	2.4%
C08C	3.3%	–	C08F	1.5%	7.7%	C08G	11.0%	<1%
C08G	6.9%	6.7%	C08G	11.1%	4.3%	C08J	10.4%	9.9%
C08J	4.7%	10.9%	C08K	5.6%	9.3%	C08L	36.0%	28.9%
C08K	10.6%	3.2%	C08L	11.8%	25.2%	C09B		1.3%
C08L	17.1%	26.6%	C09D	1.5%	7.7%	C09C		4.4%
C09D	5.6%	19.9%	C09K	8.0%	9.5%	C09D	3.2%	6.0%
C09J	3.3%	1.0%	C10G	1.0%		C09J	1.9%	<1%
			C11D	4.4%		C09K	2.7%	
			C12N	1.0%				
			C23G	1.8%				
D	**3.8%**	**7.7%**	D	**10.5%**	**3.2%**	D	**9.6%**	**4.1%**
D01D	1.0%		D01D	1.9%		D01F	9.6%	2.9%
D01F	1.0%		D01F	3.5%	<1%	D06M		1.3%
D04H	1.0%		D04H	4.6%				
D06M		7.7%	D06M	<1%	1.2%			
E			E			E		**1.4%**
						E04C		1.4%

C08F	1991	2006	C08J	1991	2006	C08K	1991	2006
F			F		**1.2%**	F		**1.3%**
			F41H		1.2%	F41H		1.3%
G	**8.6%**	**1.0%**	G	**2.5%**	**2.0%**	G	**1.9%**	**1.7%**
G02F	1.3%		G11B		1.4%	G01N	1.0%	
G03F	7.2%	1.0%				G03F	1.0%	
H	**8.3%**	**8.0%**	H	**5.8%**	**8.3%**	H	**6.5%**	**16.0%**
H01B	2.2%	3.8%	H01B	1.6%	2.7%	H01B	3.2%	
H01L	3.9%		H01L		2.7%	H01G		5.7%
H01M		4.2%	H01M		1.6%	H01L	2.9%	2.9%
H05K	2.2%		H05K	4.2%	1.4%	H01M		1.7%
						H05B		1.4%
						H05K	<1%	4.3%

Table F.10: C09D: Patent application profile by DuPont in Germany

	A	B	C	D	G	H
1991	2.1%	17.7%	67.7%	–	–	12.5%
2006	<1%	17.7%	75.2%	4.3%	2.1%	–

Table F.11: C09D: Patent application profile by DuPont in Germany

	A47J	B01J	B05D	B32B	B65D	C08F	C08G	C08J	C08K	C08L	C23C	H01B						
1991	2.1%	1.3%	8.5%	6.7%	1.3%	5.2%	24.4%	4.6%	5.2%	27.1%	1.3%	12.5%						
	A47J	B01J	B05B	B05D	B32B	C03C	C07D	C07F	C08F	C08G	C08J	C08K	C08L	C09B	C09J	C10M	D06P	G02B
2006	<1%	1.1%	2.1%	11.0%	2.4%	1.7%	1.1%	1.1%	11.0%	32.3%	6.0%	4.5%	9.9%	1.0%	4.3%	1.1%	4.3%	2.1%

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F.4 3M

Table F.12: C08F, C08J, and C08K: Patent application profile by 3M in Germany

C08F	1991	2006	C08J	1991	2006	C08K	1991	2006
A	**2.0%**	**5.6%**	**A**	**2.9%**		**A**	**3.4%**	**5.6%**
A61K	<1%	5.6%	A23L	1.0%		A61K	3.4%	5.6%
			A61K	1.0%				
			A61M	1.0%				
B	**13.8%**	**5.6%**	**B**	**35.0%**	**29.5%**	**B**	**5.6%**	**5.1%**
B01J	1.4%	5.6%	B01D	5.1%	7.7%	B29C		3.2%
B32B	4.9%		B01J	5.1%	3.1%	B32B	2.8%	
B41M	3.8%		B05D		2.6%	B41M	2.8%	
B05D	4.5%		B24D	3.1%		B65D		1.9%
			B29C		6.4%			
			B32B	13.5%	10.3%			
			B41M	7.2%				
			B65D	1.0%	2.6%			
C	**69.1%**	**77.8%**	**C**	**41.3%**	**50.0%**	**C**	**88.2%**	**81.9%**
C07C	4.3%		C04B	1.0%		C01G		8.3%
C07D	4.2%		C08F	3.1%	15.4%	C07C		2.8%
C07F	2.7%		C08G	3.1%	5.8%	C07D	2.8%	
C07K	1.4%		C08K	6.3%	18.6%	C07F	6.2%	
C08C	4.2%		C08L	12.5%	6.4%	C08F	9.9%	1.1%
C08G	13.8%	18.9%	C09D	7.2%		C08G	9.0%	5.3%
C08J	1.0%	22.2%	C09K	6.3%		C08J	5.6%	13.4%
C08K	3.7%	2.2%	C12N	1.0%		C08L	20.1%	33.8%
C08L	6.8%	16.7%	C23C		3.8%	C09C		8.3%
C09D	8.6%	7.8%	C25D	1.0%		C09D	9.0%	6.7%
C09J	14.1%	5.6%				C09J	22.9%	
C09K	2.9%	2.2%				C09K		1.1%
C11D		2.2%				C11D		1.1%
C12N	1.4%					C25B	2.8%	
D	**<1%**		**D**			**D**		
F	**1.4%**		**F**			**F**		
F16F	1.4%							
G	**10.8%**	**11.1%**	**G**	**10.4%**	**6.4%**	**G**	**2.8%**	**6.0%**
G01N	2.8%	11.1%	G01N	4.2%		G02B		3.2%
G03F	2.8%		G02B		4.5%	G02F		2.8%
G11B	4.5%		G02F		1.9%	G11B	2.8%	
			G03C	3.1%				
			G11B	3.1%				
H	**2.1%**		**H**	**10.3%**	**14.1%**	**H**		**1.4%**
H01L	2.1%		H01B	6.3%	3.8%	H01J		1.4%
			H01L		2.6%			
			H01M	1.0%	7.7%			
			H02G	3.1%				

Table F.13: C09D: Patent application profile by 3M in Germany

	A	B	C	G	H
1991	3.2%	12.6%	75.0%	8.8%	<1%
2006		9.1%	87.9%		3.0%

Table F.14: C09D: Patent application profile by 3M in Germany

	A61K	B05D	B32B	B41M	C07D	C07F	C08F	C08G	C08J	C08K	C08L	C09G	C09J	C09K	C11D	G03F	G11B	H05B
1991	2.3%	2.0%	5.4%	3.9%	2.0%	1.8%	12.1%	14.1%	3.4%	4.8%	9.2%	2.9%	18.5%	2.0%	2.9%	3.9%	4.9%	
2006			9.1%				6.4%	35.2%		10.9%	16.7%		12.1%	4.8%	1.8%			3.0%

Appendix G

Results from the Pearson's χ^2 test from Chapter 6

G.1 Bayer Group

Table G.1: Results of chi-square test for the main IPC fields

IPC field	1991	2006
A	132.0 (274.0)	452.0 (310.0)
B	95.0 (60.9)	35.0 (69.1)
C	545.0 (438.0)	390.0 (497.0)
D	28.0 (14.1)	2.0 (15.9)
E	0.0 (1.41)	3.0 (1.59)
F	4.0 (5.62)	8.0 (6.38)
G	30.0 (44.1)	64.0 (49.9)
H	11.0 (7.03)	4.0 (7.97)
	df =	7
	Pearson χ^2 =	265.0
	p-value =	0.000

G.1.1 IPC-A01: Agriculture; forestry; animal husbandry; hunting; trapping; and fishing

Table G.2: A01N: Results of chi-square test for Table 6.8

IPC field	1991	2006
A61K	4.0 (3.53)	3.0 (3.47)
A61P	2.0 (2.52)	3.0 (2.48)
C05G	0.0 (1.01)	2.0 (0.99)
C07C	11.0 (10.6)	10.0 (10.4)
C07D	40.0 (41.3)	42.0 (40.7)
C07F	5.0 (2.52)	0.0 (2.48)
C12N	0.0 (0.504)	1.0 (0.496)
	df =	6
	Pearson χ^2 =	8.43
	p-value =	0.208

G.1.2 IPC-C08: Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon

Table G.3: C08J and C08K: Results of chi-square test for Table 6.11

IPC field	1991	2006
	C08J	
B29C	2.0 (2.17)	1.0 (0.833)
C08G	13.0 (13.7)	6.0 (5.28)
C08K	9.0 (9.39)	4.0 (3.61)
C08L	15.0 (13.7)	4.0 (5.28)
	df =	3
	Pearson χ^2 =	0.669
	p-value =	0.880
	C08K	
A61L	0.0 (1.46)	2.0 (0.538)
B32B	0.0 (2.19)	3.0 (0.808)
C08J	9.0 (9.50)	4.0 (3.50)
C08L	29.0 (24.8)	5.0 (9.15)
	df =	3
	Pearson χ^2 =	16.2
	p-value =	0.001

G.1.3 IPC-C09: Dyes; paints; polishes; natural resins; adhesives; miscellaneous compositions; miscellaneous applications of materials

Table G.4: C09D: Results of chi-square test for Table 6.13

IPC field	1991	2006
C08G	16.0 (19.3)	31.0 (27.7)
C08L	7.0 (3.70)	2.0 (5.30)
	df =	1
	Pearson χ^2 =	5.97
	p-value =	0.015

G.2 BASF

Table G.5: Results of chi-square test for the main IPC fields

IPC field	1991	2006
A	114.0 (161.0)	286.0 (239.0)
B	137.0 (138.0)	206.0 (205.0)
C	667.0 (644.0)	936.0 (959.0)
D	49.0 (32.1)	31.0 (47.9)
E	1.0 (2.81)	6.0 (4.19)
F	11.0 (13.3)	22.0 (19.7)
G	44.0 (24.9)	18.0 (37.1)
H	10.0 (17.3)	33.0 (25.7)
	df =	7
	Pearson χ^2 =	71.0
	p-value =	0.000

G.2.1 IPC-A01: Agriculture; forestry; animal husbandry; hunting; trapping; and fishing

Table G.6: A01N: Results of chi-square test for Table 6.19

IPC field	1991	2006
A01C	0.0 (2.78)	5.0 (2.22)
C07C	20.0 (15.0)	7.0 (12.0)
C07D	48.0 (46.2)	35.0 (36.8)
C07F	1.0 (1.67)	2.0 (1.33)
C12N	0.0 (1.67)	3.0 (1.33)
C23C	0.0 (1.67)	3.0 (1.33)
	df =	5
	Pearson χ^2 =	18.3
	p-value =	0.003

G.2.2 IPC-C08: Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon

Table G.7: C08F, C08J, and C08K: Results of chi-square test for Table 6.22

IPC field	1991	2006
	C08F	
A61K	3.0 (6.20)	11.0 (7.80)
A61L	0.0 (3.99)	9.0 (5.01)
B01J	5.0 (5.31)	7.0 (6.69)
C08G	11.0 (7.53)	6.0 (9.47)
C08K	13.0 (9.74)	9.0 (12.3)
C08L	18.0 (14.2)	14.0 (17.8)
C09D	12.0 (15.1)	22.0 (18.9)
	df =	6
	Pearson χ^2 =	17.9
	p-value =	0.006
	C08J	
A61L	0.0 (3.71)	8.0 (4.29)
B29C	6.0 (3.71)	2.0 (4.29)
B29K	6.0 (2.78)	0.0 (3.22)
C08F	6.0 (6.49)	8.0 (7.51)
C08G	8.0 (6.95)	7.0 (8.05)
C08K	10.0 (8.81)	9.0 (10.2)
C08L	12.0 (11.1)	12.0 (12.9)
C09D	3.0 (7.42)	13.0 (8.58)
	df =	7
	Pearson χ^2 =	22.2
	p-value =	0.002
	C08K	
A61L	0.0 (1.68)	3.0 (1.32)
C08F	13.0 (12.3)	9.0 (9.69)
C08G	12.0 (7.83)	2.0 (6.17)
C08J	10.0 (10.6)	9.0 (8.37)
C08L	26.0 (25.2)	19.0 (19.8)
C09D	5.0 (8.39)	10.0 (6.61)
	df =	5
	Pearson χ^2 =	12.2
	p-value =	0.032

G.2.3 IPC-C09: Dyes; paints; polishes; natural resins; adhesives; miscellaneous compositions; miscellaneous applications of materials

Table G.8: C09B and C09D: Results of chi-square test for Table 6.24

IPC field	1991	2006
	C09B	
A23L	0.0 (0.810)	1.0 (0.190)
A61K	0.0 (0.810)	1.0 (0.190)
B41M	16.0 (13.0)	0.0 (3.03)
C07C	3.0 (4.05)	2.0 (0.948)
C07D	5.0 (6.48)	3.0 (1.52)
C08K	0.0 (1.62)	2.0 (0.379)
C08L	1.0 (1.62)	1.0 (0.379)
C09D	3.0 (2.43)	0.0 (0.569)
D06P	19.0 (16.2)	1.0 (3.79)
	df =	8
	Pearson χ^2 =	28.6
	p-value =	0.000
	C09D	
B05D	11.0 (6.93)	5.0 (9.07)
C04B	3.0 (2.16)	2.0 (2.84)
C08F	12.0 (14.7)	22.0 (19.3)
C08G	18.0 (18.2)	24.0 (23.8)
C08J	3.0 (6.93)	13.0 (9.07)
C08L	11.0 (9.09)	10.0 (11.9)
	df =	5
	Pearson χ^2 =	10.3
	p-value =	0.067

G.3 Du Pont

Table G.9: Results of chi-square test for the main IPC fields

IPC field	1991	2006
A	52.0 (67.3)	76.0 (60.7)
B	160.0 (150.0)	126.0 (136.0)
C	478.0 (502.0)	477.0 (453.0)
D	122.0 (98.8)	66.0 (89.2)
E	5.0 (5.26)	5.0 (4.74)
F	11.0 (17.9)	23.0 (16.1)
G	108.0 (75.2)	35.0 (67.8)
H	72.0 (91.4)	102.0 (82.6)
	df =	7
	Pearson χ^2 =	67.1
	p-value =	0.000

G.3.1 IPC-A01: Agriculture; forestry; animal husbandry; hunting; trapping; and fishing

Table G.10: A01N: Results of chi-square test for Table 6.31

IPC field	1991	2006
A61K	0.0 (0.611)	1.0 (0.389)
A61Q	0.0 (0.611)	1.0 (0.389)
B27K	0.0 (1.83)	3.0 (1.17)
C07C	5.0 (3.67)	1.0 (2.33)
C07D	13.0 (11.6)	6.0 (7.39)
C07F	3.0 (1.83)	0.0 (1.17)
C07K	0.0 (0.611)	1.0 (0.389)
C12N	0.0 (0.611)	1.0 (0.389)
C12Q	1.0 (0.611)	0.0 (0.389)
	df =	8
	Pearson χ^2 =	15.2
	p-value =	0.055

G.3.2 IPC-C08: Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon

Table G.11: C08F, C08J, and C08K: Results of chi-square test for Table 6.34

IPC field	1991	2006
	C08F	
C07C	4.0 (1.90)	1.0 (3.10)
C08G	3.0 (2.28)	3.0 (3.72)
C08J	2.0 (3.41)	7.0 (5.59)
C08K	4.0 (2.66)	3.0 (4.34)
C08L	7.0 (7.97)	14.0 (13.0)
C09D	2.0 (3.79)	8.0 (6.21)
	df =	5
	Pearson χ^2 =	7.72
	p-value =	0.172
	C08J	
B32B	9.0 (11.2)	11.0 (8.77)
C07C	9.0 (5.05)	0.0 (3.95)
C08F	2.0 (5.05)	7.0 (3.95)
C08G	15.0 (10.7)	4.0 (8.33)
C08K	7.0 (8.98)	9.0 (7.02)
C08L	16.0 (18.5)	17.0 (14.5)
C09D	3.0 (4.49)	5.0 (3.51)
C09K	12.0 (8.98)	4.0 (7.02)
	df =	7
	Pearson χ^2 =	21.5
	p-value =	0.003
	C08K	
B32B	0.0 (5.56)	11.0 (5.44)
C08F	4.0 (3.54)	3.0 (3.46)
C08G	8.0 (4.55)	1.0 (4.45)
C08J	7.0 (8.08)	9.0 (7.92)
C08L	21.0 (19.2)	17.0 (18.8)
C09D	2.0 (3.54)	5.0 (3.46)
D01F	6.0 (3.54)	1.0 (3.46)
	df =	6
	Pearson χ^2 =	22.1
	p-value =	0.001

G.3.3 IPC-C09: Dyes; paints; polishes; natural resins; adhesives; miscellaneous compositions; miscellaneous applications of materials

Table G.12: C09D: Results of chi-square test for Table 6.36

IPC field	1991	2006
B05D	4.0 (4.09)	8.0 (7.91)
B32B	4.0 (2.73)	4.0 (5.27)
C08F	2.0 (3.41)	8.0 (6.59)
C08G	6.0 (8.86)	20.0 (17.1)
C08J	3.0 (2.73)	5.0 (5.27)
C08K	2.0 (2.38)	5.0 (4.62)
C08L	8.0 (6.13)	10.0 (11.9)
H01B	2.0 (0.681)	0.0 (1.32)
	df =	7
	Pearson χ^2 =	8.06
	p-value =	0.328

G.4 3M

Table G.13: Results of chi-square test for the main IPC fields

IPC field	1991	2006
A	87.0 (91.0)	126.0 (122.0)
B	146.0 (144.0)	191.0 (193.0)
C	202.0 (176.0)	209.0 (235.0)
D	9.0 (7.26)	8.0 (9.74)
E	5.0 (5.13)	7.0 (6.87)
F	10.0 (11.5)	17.0 (15.5)
G	101.0 (105.0)	144.0 (140.0)
H	36.0 (56.8)	97.0 (76.2)
	df =	7
	Pearson χ^2 =	21.9
	p-value =	0.003

G.4.1 IPC-C08: Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon

Table G.14: C08F, C08J, and C08K: Results of chi-square test for Table 6.43

IPC field	1991	2006
	C08F	
A61K	1.0 (1.42)	1.0 (0.578)
C08G	9.0 (9.24)	4.0 (3.76)
C08J	1.0 (2.13)	2.0 (0.867)
C08L	6.0 (5.69)	2.0 (2.31)
C09D	6.0 (5.69)	2.0 (2.31)
C09J	7.0 (5.69)	1.0 (2.31)
G01N	2.0 (2.13)	1.0 (0.867)
	df =	6
	Pearson χ^2 =	3.73
	p-value =	0.713
	C08J	
B01D	2.0 (1.78)	1.0 (1.22)
C07C	0.0 (1.19)	2.0 (0.811)
C08F	5.0 (4.76)	3.0 (3.24)
C08G	3.0 (1.78)	0.0 (1.22)
C08K	1.0 (1.78)	2.0 (1.22)
C08L	2.0 (4.16)	5.0 (2.84)
C09D	4.0 (3.57)	2.0 (2.43)
C09D	3.0 (1.78)	0.0 (1.22)
C09K	2.0 (1.19)	0.0 (0.811)
	df =	8
	Pearson χ^2 =	12.2
	p-value =	0.141
	C08K	
C01G	0.0 (1.47)	3.0 (1.53)
C07F	3.0 (1.47)	0.0 (1.53)
C08F	3.0 (1.96)	1.0 (2.04)
C08G	4.0 (3.43)	3.0 (3.57)
C08J	2.0 (3.43)	5.0 (3.57)
C08L	5.0 (6.87)	9.0 (7.13)
C09C	0.0 (1.47)	3.0 (1.53)
C09D	4.0 (3.43)	3.0 (3.57)
C09J	5.0 (2.45)	0.0 (2.55)
	df =	8
	Pearson χ^2 =	17.7
	p-value =	0.024

G.4.2 IPC-C09: Dyes; paints; polishes; natural resins; adhesives; miscellaneous compositions; miscellaneous applications of materials

Table G.15: C09D: Results of chi-square test for Table 6.45

IPC field	1991	2006
B32B	4.0 (3.33)	1.0 (1.67)
C08F	6.0 (5.33)	2.0 (2.67)
C08G	8.0 (10.0)	7.0 (5.00)
C08K	4.0 (4.67)	3.0 (2.33)
C08L	6.0 (6.00)	3.0 (3.00)
C09J	8.0 (6.67)	2.0 (3.33)
	df =	5
	Pearson χ^2 =	2.94
	p-value =	0.710