Substitution of hazardous chemicals: A case study in the framework of the project 'Assessing innovation dynamics induced by environment policy'

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Contents

Abstract

This paper addresses the impact of policies that apply the principle of chemicals substitution on innovations in industry. It finds that public policy has become a major driver for innovation in chemicals. Nevertheless, few countries apply a policy of mandatory substitution of hazardous chemicals on environmental grounds. The limited evidence available suggests that such policies do not need to be conflicting with innovativeness in the chemical industry.

Several policy instruments can be applied to achieve substitution. Banning a substance while allowing exemptions (which in any case have to be granted selectively) will often be less cost-effective than a tax. But even direct regulative instruments can be cost-effective, if designed properly (e.g. obligations to meet certain emission or exposure standards or to search for alternatives). In short, the design and implementation are probably at least as important as the choice of instrument type.

Introduction

Reducing the risks that chemical substances may cause for people and the environment can be achieved in various ways. One of them is the substitution of hazardous chemicals by less hazardous alternatives.[1]

In EIM (2006) substitution is defined as "the replacement or reduction of hazardous substances in products and processes by less hazardous or non-hazardous substances, whilst achieving an equivalent functionality via technological or organisational measures." This is almost[2] the same definition as the one used in a study for DG Environment by Ökopol (Lohse *et al.*, 2003).

As this definition already shows, substitution will often involve not just the replacement of one chemical substance by another, less hazardous one, but also other technological and/or organisational changes. Functional equivalence is a key element: if the replacement of the chemical leads to lower product quality or to unsurmountable problems with the process, one cannot speak of a (successful) substitution.

In addition to functional equivalence, the following factors will usually play a role in the realisation and outcome of a substitution process:

- The availability of the substitute (i.e. it should be developed and tested to a sufficient extent);
- Availability of information on the substitute and its consequences (including risks and uncertainties, as well as gaps in knowledge);
- Awareness in the organisation of the problems related to the currently used substance, and preparedness to change;
- The (investment and operational) costs of the substitute (these should be affordable and acceptable for the innovating firm, even though they do not necessarily have to be lower than the costs of the current practice: considerations such as better product quality, consumer demand, anticipated regulation or a 'green' company image may justify higher costs);
- Environmental performance of the substitute (obviously, for a substition to be environmentally desirable this performance should be unequivocally better than the current practice; tools such as life cycle analysis or substance flow analysis may be needed to determine this);
- The risk of other negative (side) effects, both for the firm itself and for others (these may include indirect, cumulative and long term effects).

Policies aimed at stimulating the substitution of hazardous chemicals will have to address these factors so as to make them favourable for the substitution to take place. This means that different cases may call for different policy instruments, depending on the state of the factors without the policy intervention. For example, if the costs of the sub-

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1 A number of other ways to reduce risks from chemicals are included in the principles of 'Green Chemistry' as developed by the US Environmental Protection Agency (http://www.epa.gov/greenchemistry/pubs/principles.html, accessed 21 July 2006).

2 In Lohse *et al.*the words 'or by' are used instead of the term 'whilst'.

stitute are the main barrier to substitution, a charge on the hazardous chemical could be a useful policy instrument. If a lack of awareness or knowledge is the most important factor, information provision might be the the right instrument.

Voluntary substitution of hazardous substances is not yet common practice in European business.[3] An important issue in the current discussions on the REACH proposal is therefore the extent to which substitution should be compulsory. In the present case study, we will look at some examples of mandatory chemicals substitution legislation, and assess to what extent such legislation affects innovative behaviour in industry. On the one hand, the influence on actual substitutions is addressed; on the other hand, the impact of mandatory substitution on the general innovation performance of the chemical industry receives attention.

This case study focuses on policies that have substitution as their primary objective. Obviously, substitution can also occur as a side effect of other policies. An example is the phase out of leaded petrol due to the introduction of the catalytic converter. Substitution of hazardous chemicals may also take place as a result of (commercially motivated) innovations in which environmental concerns or policy measures do not play a significant role. However, the borderline between substitutions induced by environmental policy and other substitutions is a grey area: it may be commercially attractive to substitute, for example, because environmental concerns create demand for a product containing (or made with) less hazardous chemicals.

The structure of this case study report is as follows. Chapter 1 deals with the dynamics of chemicals substitution as an innovation process, addressing its complexity, learning curve effects, and the influence of public policy. In Chapter 2, substitution policies in some countries and their effects are compared, with specific emphasis on chlorinated solvents. Chapter 3 discusses the general impact of substitution policy on the chemical industry's innovative activity. Chapter 4 summarizes and concludes.

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3 For example, a recent study by EIRIS (2006) revealed that only two out of seven large chemical producers have a commitment to phase-out and/or substitute chemicals of concern where feasible as well as to avoid them in the development of new products where possible.

1. Innovation dynamics of chemicals substitution

1.1 A complex process

Substitution usually pertains to more than just replacing one chemical by another one. The difference in properties between the two substances may create the need for other changes (technical, but possibly also organisational) as well. Moreover, the hazardous substance does not necessarily have to be replaced by another substance. It can also be substituted by other means of fulfilling the function it had. Thus, a hazardous cleaning agent (e.g. a chlorinated solvent) can be replaced by a less harmful one, but is also conceivable that the product or the production process is redesigned in such a way that the cleaning step can be omitted.

The necessity and desirability of substitution will not only depend on the availability, feasibility and costs of the alternative, but also on the function of the hazardous substance in the production chain. If the substance is only being used by specific firms under controlled circumstances, and the risks for the employees can be minimized by taking appropriate measures (e.g. using a closed system), the need for substitution may be relatively low. On the other hand, if the substance is incorporated in final products and/or is being used by a large number of relatively uninformed end users, the risks will be much higher and substitution will therefore be more appropriate.

More generally, cases of chemical substitution can display a wide range of complexity. The larger the number of users and applications of a substance and the broader the scope of changes involved in the substitution, the more difficult the substitution will be. At the same time, however, as noticed in the preceding paragraph, especially these complex cases call for substitution, because effective control mechanisms for safe use of the hazardous substance are much more complicated in such cases.

1.2 Development of costs and prices

Empirical evidence on the dynamics of costs and prices in the innovation of chemical substances appears to be scarce. The main source that could be found is more than 20 years old, but it may still have relevance as far as the general patterns are concerned.

Lieberman (1984) studied the development of production costs and prices for 37 chemical substances during a period from around 1960 until 1972. He found that learning curves are a function of cumulated output and cumulated investment rather than calendar time. Learning curve effects appeared to be much more important than standard economies of scale, even though the latter play a major role in the chemical industry. For more than half of the sample, the estimated 'learning curve slope' was between 70 and 80%, i.e. the production costs decreased by 20 to 30% for each doubling of cumulated output. The individual learning curves for the 37 substances were remarkably uniform, although there were some small but significant differences. In particular, R&D expenditures (or the underlying technological opportunities) appeared to steepen the learning curve. For the overall sample, prices declined at an average rate of 5.5% per year. In the long term, prices of chemicals closely followed the learning curve, but in the short term market power led to a slow-down in price decreases, as might be expected.

To the extent that substitution involves the replacement of hazardous chemicals by less hazardous ones, the evidence on learning curve effects suggests that it may be a self-reinforcing process: growth in production of the alternative implies cost and price reductions, making it more attractive for an increasing number of actors.

1.3 The role of public policy in relation to other factors

In the past, government policies did not seem to be an important driving force behind innovations in the chemical industry. For example, Achilladelis *et al.* (1990) found that for a sample of 203 radical innovations in the chemical industry, only in 12 cases was government legislation considered to be the most important or the only driving force. Meanwhile, this situation seems to have changed due to the increasing involvement of public policy in the production and use of chemical substances. As far as environmental policy is concerned, the phase-out of ozone depleting CFCs is probably the best known example of regulation-induced chemicals substitution (see e.g. Vanner, 2006). Obviously, this regulation (the Montreal protocol and its corollaries) could only be introduced after a major player in the chemical industry (DuPont) had developed promising substitutes. This implies the importance of harnessing diversity in industry: some producers stood to gain more from the envisioned regulations than others. Such industry heterogeneity may provide opportunities for coalitions of ‘the green and the greedy’ (Maxwell and Briscoe, 1997).

Verschoor and Reijnders (2001) investigated five cases in which companies had applied process modifications to reduce toxic chemicals. All of the companies mentioned environmental legislation as a reason for process modification, although they all had a (voluntary) toxics use reduction strategy.[4]

Lohse *et al.* (2003) also conclude (on the basis of ten case studies) that legislation is one of the most powerful drivers, often inducing substitution as a side-effect even where it is not explicitly addressed as the main goal.

Monßen (2005) has investigated a number of environmentally relevant innovations at the German chemical company Bayer. Her case studies showed that Bayer’s motivation to undertake environmental innovations were primarily determined by external factors: environmental policy regulation, competitive factors, market demand, or social awareness of the need for clean production. In the specific case involving the development of a substitute chemical (IDS, a biodegradable and less harmful substitute for EDTA as a complexing agent) the main driver was the expected market demand. The large R&D investment (EUR 25 million between 1992 and 1997) could only be justified from a global market perspective.

In the EIM (2006) study it was found that for the so called SME ‘formulators’ (small and medium sized enterprises making intermediate products from chemicals, for professional use) legislation and regulation is by far the most important factor behind chemical substi-

[4] The environmental legislation involved mainly related to emissions and waste. In one case mandatory substitution played a role (ban on the use of carbon tetrachloride).

tution. The influence of legislation (in force or anticipated) can be either direct or via suppliers or major corporate clients. The SMEs are very dependent on their suppliers of basic chemicals. They are usually short term oriented and risk-averse. Therefore, they will usually not be the initiators of a substitution process.

2. Policy instruments for substitution and their effectiveness in selected countries

2.1 Introduction

The substitution principle is already incorporated in EU occupational health and safety legislation. Directive 98/24/EC (article 6) requires employers to ensure that the risk from a hazardous chemical agent to the safety and health of workers at work is eliminated or reduced to a minimum. In doing so, substitution should by preference be undertaken, whereby the employer should avoid the use of a hazardous chemical agent by replacing it with a chemical agent or process which, under its condition of use, is not hazardous or less hazardous to workers' safety and health.

A similar general substitution requirement is presently not in force for environmental protection against hazardous chemicals. However, some member states (notably Sweden en Denmark) have introduced an 'environmental' substitution obligation in their legislation. In this chapter the application of the substitution principle in these two countries is discussed, alongside with an example from the USA. For comparison, the situation in Germany is also addressed. The substitution of chlorinated solvents in these countries is used as an exemplary case.

2.2 Sweden

In Sweden, the substitution principle became part of chemicals legislation already in 1973 (Löfstedt, 2003). Since 1999 it is known as the 'product choice principle', one of the cornerstones of the Swedish Environmental Code. Chapter 2, Section 6 of the Environmental Code says: "Persons who pursue an activity or take a measure, or intend to do so, shall avoid using or selling chemical products or biotechnical organisms that may involve risks to human health or the environment if products or organisms that are assumed to be less dangerous can be used instead. The same requirement shall apply to goods that contain or are treated with a chemical product or a biotechnical organism." Applying the substitution principle is facilitated by the Swedish government, for instance by means of a database (PRIO) which companies can use to assess their use of hazardous substances and possible substitutes.[5]

A famous example of the application of the substitution principle in Sweden is the ban on trichloroethylene (tri) which was introduced in 1996. The European Court of Justice found this ban to be in agreement with EU law (case C-473/98). Nevertheless, the ban has met with a lot of opposition, on the one hand because a total ban was considered to be disproportional given the relatively minor harmful properties of tri, and on the other hand because many industries argued they had no substitute for tri. As a matter of fact, exemptions from the ban were made possible for the latter cases.

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[5] http://www.kemi.se/templates/PRIOEngframes____4144.aspx. (accessed 21 July 2006).

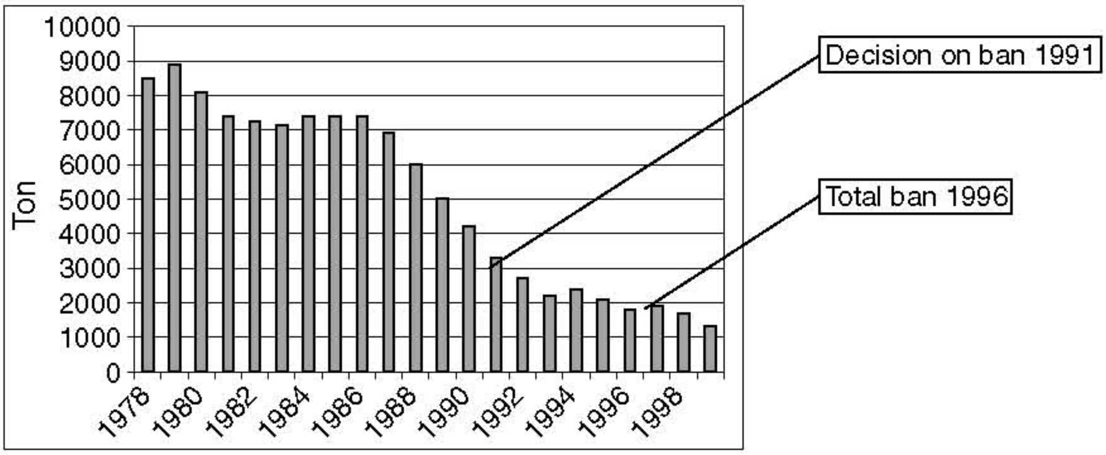

Figure 3.1 Use of trichloroethylene in Sweden, 1978-1999 (source: Slunge and Sterner, 2001).

Figure 3.1 shows the development of the use of tri in Sweden before and after the introduction of the ban. According to Slunge and Sterner (2001) the ban as such has not caused the phase-out of tri but might perhaps be considered as the logical last step in a phase-out, or it might be thought of as the only instrument capable of stopping the last residual uses after other policies have been used (such as emission standards and exposure limits).

Compared to the approaches in other countries, the Swedish tri ban may not have been very effective, as a large number of exemptions to the ban were granted (see Figure 3.2).[6] In Germany, where the emphasis was on technical standards for equipment and emissions, industry has invested in modern, 'closed' systems for tri use. As a result, the specific emissions of tri per euro of value added in the metal industry in Sweden is 90 times higher than in Germany, whereas in 1993 it was only 9 times higher (Birkenfeld *et al.*, 2005). Major reductions in tri use have also been achieved in Norway, where a tax on tri and other chlorinated solvents was introduced in 2000. Purchases of tri in Norway fell from more than 500 tonnes in 1999 to 82 tonnes in 2000 and 139 in 2001 (Sterner, 2004). This reduction is thought to have been driven by efforts to cut leakage and boost recycling, as well as through substitution (ENDS, 2003).

The tri example from Sweden thus seems to suggest that *imposing* chemical substitution by means of a general ban with exemptions may lead to less environmental innovation than *stimulating* substitution by means of financial incentives or regulations aimed at limiting exposure and emissions. However, this may be more a matter of instrument design and implementation than of instrument choice. A ban with exemptions could in principle be (cost-)effective if the exemptions are granted selectively, using objective criteria, on a temporary basis (possibly with the obligation to investigate alternatives), and with efficiency considerations in mind.

[6] Nevertheless, the volume of tri use granted under the exemptions has decreased in recent years. In 2005, only 111 tons were granted (Birkenfeld *et al.*, 2005). Firms that receive an exemption have to search actively for alternatives.

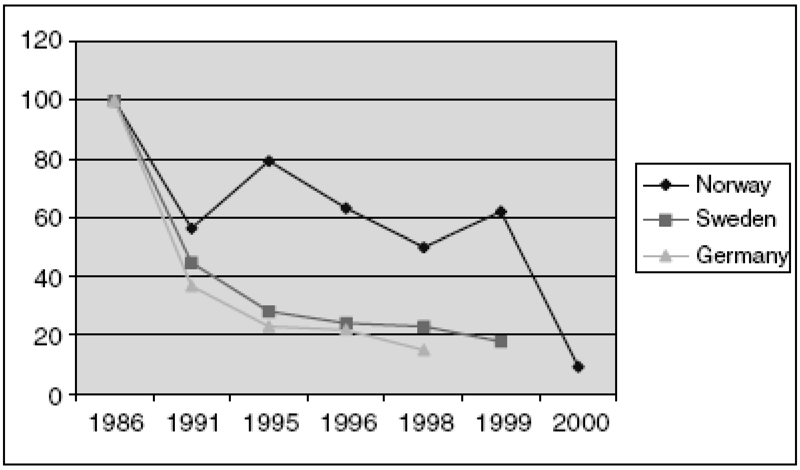

Figure 3.2 Relative rates of reduction in tri use in Sweden, Norway and Germany (1986 = 100) (source:Slunge and Sterner, 2001).

2.3 Denmark

Danish occupational health and safety legislation requires the replacement of hazardous substances or materials by less hazardous ones.[7] This substitution is compulsory even if the effects of the hazardous substances are insignificant. The law provides for exemptions if substitution is technically impossible or prohibitively expensive.

In addition, the Danish Environmental Protection Agency has published a 'List of Undesirable Substances'. These substances (more than 8,000) are not banned, but their substitution is being encouraged. In 2003, a website was launched containing more than 200 examples of substitutions in different companies.[8]

Substitution of hazardous chemicals in Denmark is also promoted by means of economic instruments. For example, environmental taxes are levied on pesticides, chlorinated solvents, CFCs, nickel-cadmium batteries, soft PVC and phthalates. There is some evidence for the effectiveness of these taxes (Ecological Council, 2002). According to a Danish cable producer, which has replaced PVC with phthalates by halogen-free polymers in part of its products, the taxes on PVC and phthalates have helped to lessen the price difference (Ecological Council, 2006). The tax on chlorinated solvents, though much lower than the Norwegian tax on the same substances, contributed to a decrease in the use of these substances by 60% (Sterner, 2004).

In general, the reasons for companies in Denmark to engage in substitution processes, as well as their experiences with it, show a wide variety, as the Ecological Council (2006) report reveals.

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7 Executive order 292 of April 26, 2001 on Work with Substances and Materials (quoted in Ecological Council, 2006).

8 www.catsub.dk (accessed 21 July 2006).

2.4 USA: The Massachusetts Toxics Use Reduction Program

The Massachusetts Toxics Use Reduction Act (TURA) of 1989 requires that manufacturing firms using specific quantities of some 900 industrial chemicals undergo a biyearly process to identify alternatives to reduce waste and the use of those chemicals.[9] Through the toxics use reduction planning process firms understand why they use a specific chemical (what 'service' it provides), and how it is used in the production process. They also conduct a systematic search for and comprehensive financial, technical, environmental, and occupational health and safety analysis of viable alternatives. The act instructs firms to identify ways to redesign production processes and products and provides six different methods that 'count' as toxics use reduction (including chemical substitution, for example replacement of a chlorinated solvent with an aqueous one; process change, for example use of high pressure paint applicators; product change, for example using a different plastic to avoid the use of phthalates; and improved management, for example upgrading equipment and procedures to more effectively manage chemical flows) (Tickner *et al.,* 2005).

Between 1990 and 2000, some 550 firms that have continuously participated in the program have reduced the use of the targeted toxic chemicals by 40% (Tickner and Geiser, 2004, Appendix A). According to O'Rourke and Lee (2004), mandatory planning, new mechanisms of accountability and improved processes of learning have all been critical to TURA's success in motivating firms to innovate for the environment.

The Massachusetts TUR program has designated tri as one of five high priority substances that are to receive special attention, with the aim of attaining significant reduction in use. In 2004 a project was started, targeted at smaller businesses using tri, who do not have direct access to pollution prevention information and resources (TURI, 2006).

2.5 Germany

The German Ordinance on dangerous substances (*Gefahrstoffverordnung*) states (in § 9(1)) that employers should undo or minimize the dangers for the health and safety of their employees caused by hazardous substances, preferably by performing a substitution. A decision not to substitute has to be motivated. The German substitution principle is thus primarily based on occupational health and safety considerations.

There are doubts about the effectiveness of this general substitution clause. Especially in SMEs the substitution principle is hardly turned into own initiatives (SubChem, 2004).

As indicated in the preceding sections, the German approach to chlorinated solvents has differed from the approach taken in Sweden (a ban with exemptions) and Norway and Denmark (taxation). The German approach focused on risk reduction through the introduction of 'closed' systems for the use of chlorinated solvents. As a result of this policy, Germany did not only achieve substantial decreases in solvent use, but also became a leading exporter of high-quality closed-loop degreasing equipment (Sterner, 2004). This

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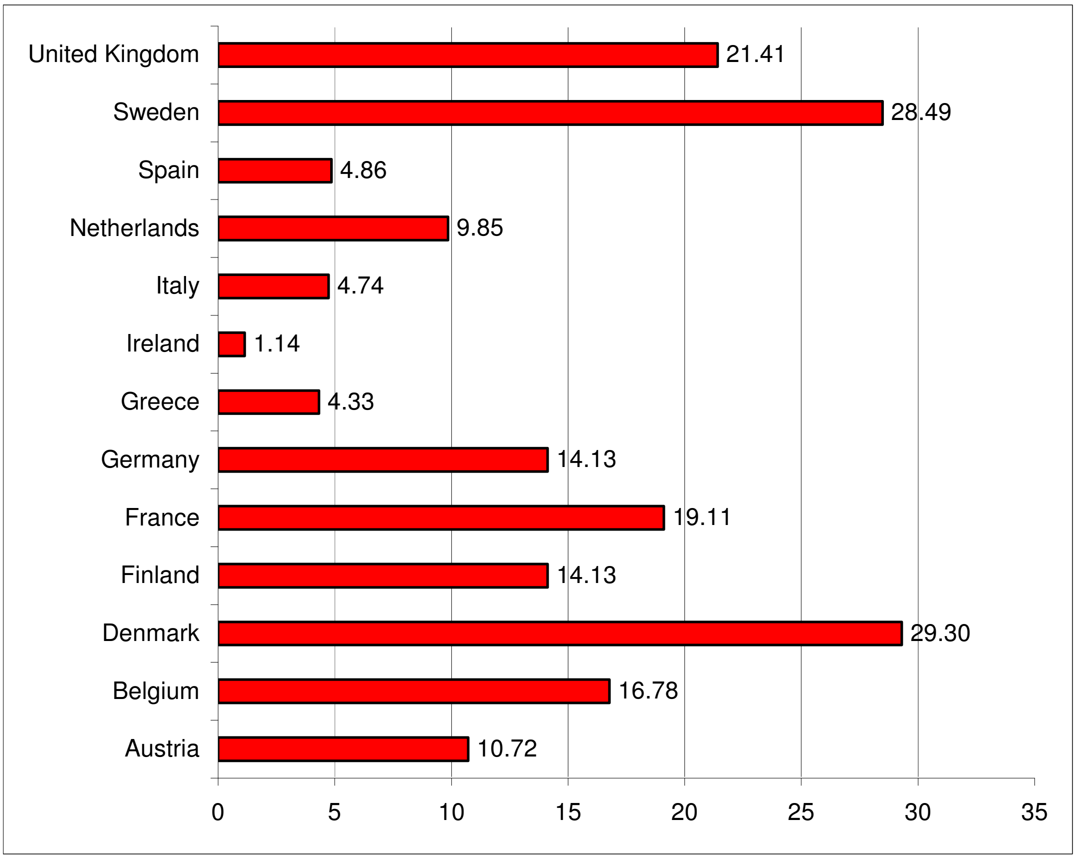
9 Tickner and Geiser (2004, Appendix A) mention a number of 190 chemicals.

can be seen as an illustration of 'first mover advantages' and the famous 'Porter hypothesis' (Porter and Van der Linde, 1995).

3. Chemicals substitution and aggregate innovation activity

Within the framework of the present study it is of course impossible to make a profound analysis of the relationship between mandatory substitution of hazardous chemicals and innovative activity. Nevertheless, we can tentatively look for some evidence, for instance by measuring the difference in R&D activity between EU countries with an explicit (environmentally motivated) substitution policy and those without. As Table 4.1 shows, the innovative activity in the chemical industry in Denmark and Sweden (the two EU countries having a mandatory chemicals substitution policy on environmental grounds, as we have seen in Chapter 3) is substantially higher than in other EU countries.



Source: Own calculations based on OECD (R&D data) and Eurostat (value added data).

Figure 4.1 Own (intramural) expenditure on R&D by the chemical industry in 13 'old' EU countries, in % of gross value added (average of years in 2000-2003 for which data are available).

Obviously, the reasons for the high R&D level in Denmark and Sweden can be manifold. Labour market conditions, dominance of specialty rather than bulk chemicals, and the general innovative climate probably make these countries relatively attractive for R&D activities. Nevertheless, it can be concluded that the substitution policy they pursue at least does not seem to deter innovation in the chemical industry.

In a global perspective, Mahdi *et al.* (2002) found that there is no unambiguous evidence that the innovation performance of the European chemical industry is significantly below that in the USA, despite the fact that European regulation is more stringent and less flexible. The introduction of new regulations can cause an initial 'innovation-shock' to the industry which decreases the rate of innovation, but competitive and innovative firms survive through creative substitution and by moving into higher value markets.

One should keep in mind that it is not only the chemical industry that is involved in innovations regarding chemicals substitution. In particular, companies using hazardous chemicals in their processes or in the products they make will be affected by substitution policies. Such companies are spread over a wide range of industries, and they are often SMEs. An analysis of the innovative performance of these industries and companies in relation to chemicals substitution policies is beyond the scope of this study.

4. Summary and conclusions

Substitution of hazardous chemicals occurs in a wide variety of forms and for a wide variety of reasons. Therefore it is impossible to formulate general statements or conclusions about the typical course of a substitution process, or on how it can be stimulated. Nevertheless, it may be possible to identify some features that many substitution cases seem to share.

Substitution is a complex process. It usually pertains to more than just replacing one chemical by another one: other changes (technical, but possibly also organisational) may be involved as well.

Learning curve effects are quite important in the development of chemical substances. Typically, production costs decrease by 20 to 30% for each doubling of cumulated output. This means that substitution may be a self-reinforcing process: growth in production of the alternative implies cost and price reductions, making it more attractive for an increasing number of actors.

Despite the large diversity of substitution processes, motives and actors involved, it is obvious that public policy is a major driver to bring about environmentally benign innovations in the production and use of chemicals. Instrument choice seems to affect the (cost-)effectiveness of the policy. Banning a substance while allowing exemptions will often be less cost-effective than a tax (as the Swedish tri case shows, in comparison with Norway). But even if the policymaker prefers direct regulation, differences in instrument design can lead to quite different results. Obligations for a firm to meet certain emission or exposure standards (as in Germany) or to search for alternatives (as in Massachusetts) may be more effective in terms of achieving substitution than an outright ban on the hazardous substance (with exemptions, as in Sweden). In any case, exemptions to a ban should be granted selectively, using objective criteria, on a temporary basis (possibly with the obligation to investigate alternatives), and with efficiency considerations in mind. In short, the design and implementation of a policy instrument may be at least as important as the choice of instrument type.

The available evidence does not reveal a conflict between stringent environmental requirements (including mandatory substitution of hazardous chemicals) and the rate of innovation in the chemical industry. There are even indications that in countries pursuing an active environmentally motivated substitution policy (Sweden, Denmark) the innovation activity in the chemical industry is higher than elsewhere. Obviously, however, the nature and direction of innovation will be affected as companies are confronted with the need to search for creative solutions to reduce the use of harmful chemicals.

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