UNIVERSITÄT PASSAU

Wirtschaftswissenschaftliche Fakultät

Product ban versus risk management by setting emission and technology requirements

The effect of different regulatory schemes taking the use of trichloroethylene in Sweden and Germany as an example

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Diskussionsbeitrag Nr. V-37-05

Volkswirtschaftliche Reihe ISSN 1435-3520

Oktober 2005

PASSAUER DISKUSSIONSPAPIERE

Herausgeber:
Die Gruppe der volkswirtschaftlichen Professoren
der Wirtschaftswissenschaftlichen Fakultät
der Universität Passau
94030 Passau

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Abstract

This report highlights the opportunities inherent in smart regulatory measures to effectively reduce risks related to hazardous substance emissions and exposure, and underscores the danger of simplistic and ineffective policy. The example of different regulatory approaches used in Germany and Sweden to regulate the use of trichloroethylene was taken as the basis for the study.

During the 1990s, due to environmental, health and safety considerations, the use of trichloroethylene in Europe was a subject of broad concern. As a consequence, the use of trichloroethylene became regulated through multiple approaches, such as labelling, handling regulations and performance standards.

Since that time the absolute emissions of trichloroethylene in Europe have been decreasing consistently in all member states. These results were achieved by various regulatory measures governing the use of trichloroethylene in industrial applications that have been introduced by individual Member States. However, given the implementation responsibility at Member State level not all member States have implemented the same set of regulatory measures.

In Germany, for example, the use of trichloroethylene is regulated through strict technical standards for equipment and emissions that has required companies to replace existing old machines with the state-of-the-art equipment. In Sweden a general ban on trichloroethylene use was introduced in 1996, which however eventually evolved into an exemption permit system for companies that found no alternative to degreasing with trichloroethylene.

Absolute emissions have declined in Sweden as well as in Germany. However, for the specific emission per Euro of value added in the metal industry, the difference between these countries has largely increased. Today, the specific emission of trichloroethylene per Euro of value added in the metal industry in Sweden is 90 times higher than in Germany. In 1993 it was only nine times higher.

The outcome of implementing these two very different policies clearly shows the higher effectiveness of the German risk management based regulatory approach to reduce trichloroethylene emissions and exposure in the metal industry. The difference in effectiveness is mainly due to the fact that the Swedish ban, combined with temporary exemptions, clearly disfavoured investment in state-of-the-art technology – companies would rather provisionally upgrade their old equipment – whereas the German risk management based approach encouraged such capital expenditure as the companies were secure in the knowledge that they would recoup the value of their investments. Accordingly, German machine manufacturers had an incentive to invent new technology and have become world leaders in new low emission cleaning equipment while the major Swedish producer exited the market and acts only as a retailer today.

In conclusion, the German risk management based legislative approach resulted in a higher level of worker protection and a better degree of environmental protection due to the imposed use of state-of-the-art machines while at the same time contributing to more sustainable businesses.

The proponents of banning of substances on the basis of their intrinsic hazard properties typically claim that such a regulatory measure will 1) reduce exposure to man and the environment and 2) will stimulate innovation and the development of alternative technologies. The report results clearly show how wrong this assumption can be, as demonstrated by the example of the different regulatory options chosen by Germany and Sweden in the case of trichloroethylene for metal degreasing, and that simplistic bans leading to time-limited exemptions are poor role models for the REACH authorization process. Regulation on the basis of appropriate active risk management is more likely to be successful.

Contents

1. The goal of this study

During the 1990s, due to environmental, health and safety consideration, the use of trichloroethylene in Europe was a subject of broad concern. In the European Union, on the basis of Directive 76/548/EEC the use of trichloroethylene became regulated through multiple approaches, such as labeling (e.g. R 49: "may cause cancer by inhalation"), handling regulations and performance standards (e.g. the standards for degreasing machines laid down in the German 2nd BImSchV[1]).

Figure 1 demonstrates that the total use of trichloroethylene and other chlorinated solvents has been decreasing consistently in the EU from 1990 to 2001. This result was achieved by various regulatory measures governing the use of trichloroethylene in industrial applications that have been introduced by individual Member States. However, given the implementation responsibility at Member State level not all member States have implemented the same set of regulatory measures.

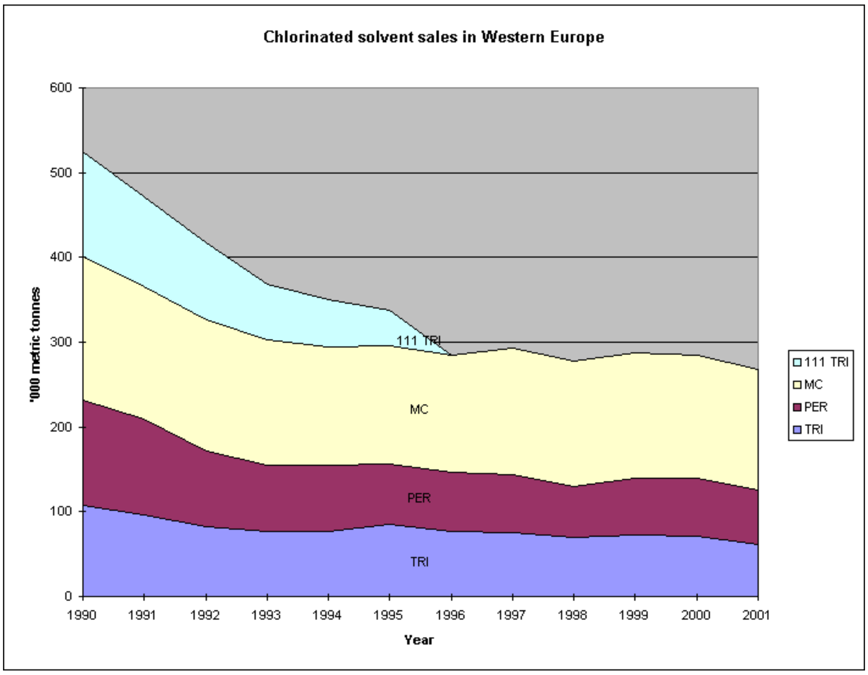

Figure 1: Sales of chlorinated solvents in Western Europe 1990-2001

In Germany, for example, the use of trichloroethylene is regulated since 1986 through ever stricter technical standards for equipment and emissions that has required companies to replace existing old machines with the state-of- the-art equipment. In Sweden a general ban on trichloroethylene use was introduced in 1996, which however eventually evolved into an exemption permit system for companies that found no alternative to degreasing with trichloroethylene.

This study aims to investigate and compare the current situation with the trichloroethylene use for degreasing applications in Sweden and Germany. The comparison includes recent trends in the amounts of trichloroethylene consumed, types of degreasing equipment used in the two countries and total emission levels of trichloroethylene in the last decade. Based on the comparison conclusions are drawn on the economic efficiency and environmental effectiveness of the chosen policy approaches on trichloroethylene use in the two countries.

To understand the difference in environmental outcome, the study will give a comparative description for Germany's and Sweden's national legislative frames, regulating the use of trichloroethylene in surface cleaning as well as compare the ability and effectiveness of the different legislative schemes to positively impact the emission situation. It will further present data on the share of substitution or the use of emission preventing technology on emission reduction (substitution or use of improved emission preventing technology are the two possibilities[2] to achieve emission reductions considered).

The core focus of the study is on investigating the quantities of trichloroethylene used for degreasing in Germany and Sweden as well as the types of degreasing equipment used by the industry. As a result we will be able to estimate emission levels in Germany and Sweden in order to demonstrate the effect of both regulatory schemes.

For Sweden, accessible authority records and customer interviews will be used. The prime sources of such information are national statistics and product registries, sales figures from the industry and material from interviews with trichloroethylene users. The information is primarily based on interviews with companies using trichloroethylene or supplying trichloroethylene-based degreasing equipment. Additional interviews were held with relevant authorities. Furthermore, published official statistics and other literature sources were reviewed. The statistical data on national trichloroethylene use and emissions were collected through interviews with companies still using trichloroethylene, the Swedish Chemicals Inspectorate (KEMI), the Swedish

[1] *"Zweite Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes"* (2nd Directive for the Implementation of the Federal Clean Air Act) or in short the 2nd *BImSchV*

[2] A third way of reducing emissions would be to change the production process. When fewer parts have to be cleaned, the use of solvents and hence the quantity of emissions will drop.

Environmental Protection Agency, chemical suppliers, manufacturers of degreasing equipment and other relevant experts.

Three major sources of statistical data have been reviewed: the Nordic registry of chemicals (the SPIN database), the Swedish Statistical Bureau (the SCB database) and the Swedish Chemicals Inspectorate, which aggregates data from the national Product Registry. The three sources provided data on the total use of trichloroethylene as well as the volumes consumed for specific applications, including the use for degreasing and the use as an additive to products.

For Germany, publications from scientists, providers of trichloroethylene, and the "Umweltbundesamt" (Federal Environmental Office) have been used to extract data about the amount of trichloroethylene in metal degreasing and other applications. The same variety of publications has been used to obtain information about the train of machines presently run in Germany.

The following key data were relevant for the investigation:

- Total annual consumption of trichloroethylene on national level and historic trends.
- Detailed information about the main types of machinery / technology used for degreasing.
- Performance characteristics of the equipment used in terms of trichloroethylene emissions to air, water and waste.
- A reference unit (functional unit) for comparing the two counties.

Recent emissions on the national level and on equipment base gave information about the technology status achieved and potential for further reduction. Swedish and German data can be compared with the help of recent emissions and achieved technology status (emissions per cleaning equipment, emissions as percentage of input over time, emissions per value added of metal-industry) or with the help of effectiveness in emission reduction.

The study was commissioned and financed by SAFECHEM Europe GmbH.

2. Trichloroethylene and problems

Trichloroethylene is believed to have been discovered in 1864 and was first commercially produced in Germany in the early 1900s. It has been commonly used for cleaning of metals and other parts since the introduction of the vapor degreasing process in the early 1930s and continues to be the standard by which other cleaning processes are compared. Today, its primary uses are as an intermediate in the production of hydro fluorocarbon refrigerants and as a cleaning agent. Trichloroethylene, a colorless, volatile liquid, is an unsaturated aliphatic halogenated hydrocarbon.[3]

In the 1970s, trichloroethylene was mainly used in metal degreasing, degreasing of textiles and the extraction of oil fruits, coffee, resins, bones, glue, tobacco pressure residues and residues of carcass.[4]

As metal degreasing is the main application in Germany as well as in Sweden, this study will only compare trichloroethylene emissions that result from metal degreasing.

2.1. Market, supply, demand and market equilibrium

A market in an economic understanding is a forum where supply and demand meet and interact. Profit-maximising suppliers calculate the total costs that result from production and extend their supply as long as the costs of producing an additional unit are lower than the price they can realise on the market for their product. Supply is therefore graphed by an inclining curve in figure 2.

On the other hand there are consumers who are maximising their individual welfare, extending their demand as long as their welfare for one additional unit of the product is greater than the price they have to pay for it. Demand is shown by the declining curve.

The intersection of the demand and the supply curve in the graph represents the market equilibrium; P_{Market} is the equilibrium-price and Q_{Market} is the quantity traded on the market for this price. The central aspect about the market-equilibrium is that in this situation the market is cleared, which means that the quantity traded is maximised. That is not to say that for a price above the equilibrium-price no trade at all would be realised. Some consumers would be willing to pay a higher price than the equilibrium-price (e.g. because they gain a lot of welfare from the consumption of the product).

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[3] HSIA (2001)

[4] Von Grote (2003), 16

The advantage of those individuals having to pay a lower price is called the consumers' rent. The value of the consumers' rent results from deducting the equilibrium-price from the price consumers would be willing to pay given a certain quantity. At the market equilibrium total consumers' rent equals the area $AP_{Market}E$.

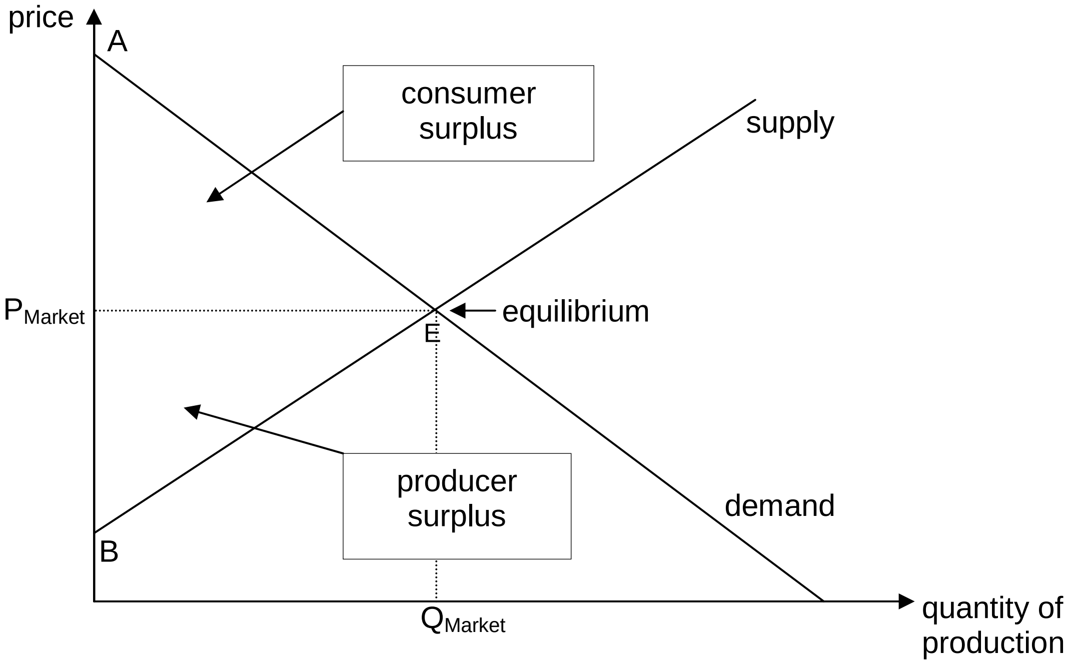

Figure 2: Market equilibrium

Similarly producers' rent results from certain producers' ability to sell for a lower price than the equilibrium-price, e.g. because they are able to produce more cheaply. Therefore, total producers' rent equals the area BEP_{Market}. The sum of consumers' and producers' rent is called social surplus. Social surplus is considered a measure for the welfare that results for the society from trading the product. A market equilibrium will result from free interaction of supply and demand.

2.2. Externalities and intervention

Externalities or external effects are positively or negatively perceived results from an activity, which are not or not fully paid for by the causing party. They are therefore not included in the trading party's considerations and the market equilibrium does not reflect the maximum social surplus possible.

In figure 3 externalities are represented by the horizontal line. As explained above, producers would realize the quantity Q_{Market}, because they do not include external costs into their individual considerations. However the state should make those externalities felt to the producer and raise total welfare. The state can achieve this internalization by means of a tax, binding laws etc. This way, producers perceive external costs. The relevant curve results from adding up external and private costs to social costs. The optimum is found in the intersection of the demand-curve and the social-cost-curve. From the reduction of the produced quantity from Q_{Market} to Q_{Opt} a plus of welfare equal to the triangular *CDE* is realised.

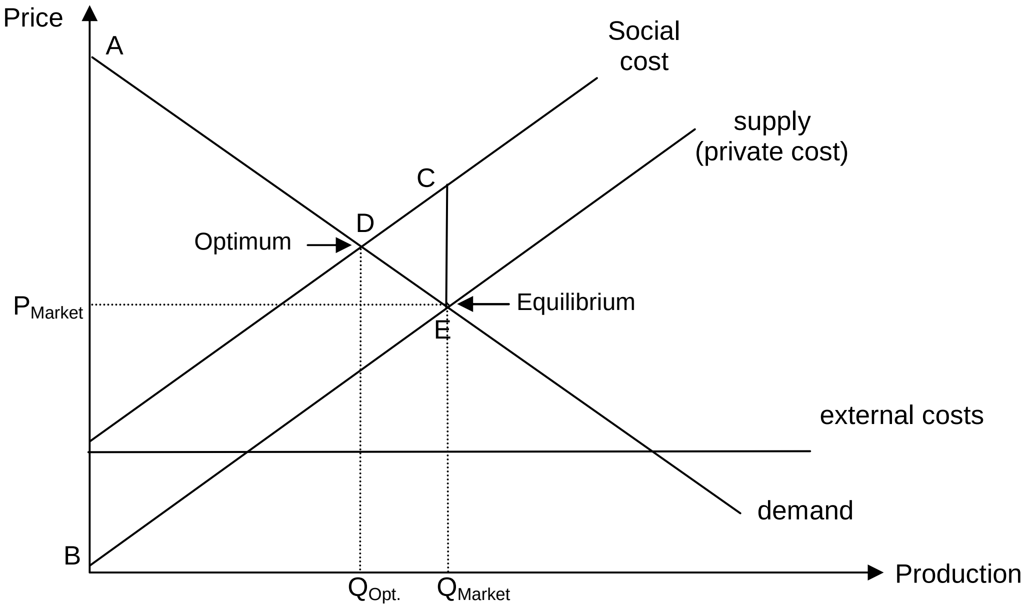

Figure 3: External costs

Since the producer now perceives the externalities as ‚real' own costs, he revises his decision and produces less. From the lower production level result less externalities and third parties' harm is reduced.

2.3. Externalities from the use of trichloroethylene

The health effects of trichloroethylene have been studied extensively. The most significant findings to come out of the many long-term animal studies of the chemical are that it has caused tumors in animals. The significance of these tumors to human health is unclear due to species differences in both trichloroethylene metabolism and reaction to the metabolites. Epidemiology studies of workers exposed to trichloroethylene have in general not indicated an overall increase in cancer risk, but controversial discussions in literature have taken place with respect to kidney cancers. Various regulatory bodies in the world have reviewed trichloroethylene and came to different conclusions: The International Agency for Research on Cancer (IARC) currently considers trichloroethylene to be "probably carcinogenic to humans" (group 2A), based on its conclusions that there is "limited" evidence of carcinogenicity in humans. The epidemiological data base for trichloroethylene is considered by the American Conference of Governmental Industrial Hygienists (ACGIH), however, to support classification in Group A5 (Not Suspected as a Human Carcinogen) "since the substance has been demonstrated by well controlled epidemiological studies not to be associated with any increased risk of cancer in exposed humans." The U.S. Environmental Protection Agency is currently conducting a reassessment of the carcinogenic potential of trichloroethylene.[5]

Trichloroethylene in Europe is classified as R 45 (may cause cancer), R 36/38 (irritating to eyes and skin), R 67 (vapours may cause drowsiness), R 52/53 (harmful to aquatic organisms, may cause long term adverse effects in the aquatic environment), R67 (vapours can cause nausea and dizziness) and R68 (possible risk for long-terms health damage) according to directive 67/548/EEC.[6]

Therefore the use of trichloroethylene seems to be linked to externalities - one person decides about the use of trichloroethylene and another person may suffer from cancer without being able to get any kind of compensation from the first. Legislation should therefore aim to internalize these external costs in order to encourage a conscious approach towards trichloroethylene. In the following, degreasing technology and German and Swedish law regarding the use of trichloroethylene will be depicted.

[5] HSIA (2001)
[6] http://www.eurochlor.org/qandatrienglish

3. Technologies used in metal degreasing

Metal degreasing is widespread in the metal processing industry, e.g. if parts are tooled metal working fluids are used to enable the tooling process or if parts need to be transported or stored, they are greased to prevent corrosion until final treatment, such as painting and coating. These oils or metal cutting fluids need to be removed for further of final treatment like tolerance measurements or application of coatings. This can be done with aqueous systems, hydrocarbons or chlorinated solvents. Chlorinated solvents are often used in degreasing equipment for difficult tasks, such as with metal parts that need to be totally dry to have highest cleanliness, are very small or temperature sensitive, are made of diverse or different metals, or have lots of cavities. Degreasing can be done by immersion in a cold or heated bath or by vapour degreasing.[7]

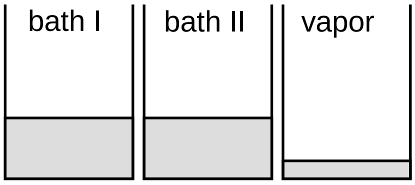

Figure 4: Machine types I and II

3.1. Machine types I and II

These types are fully emissive open-top machines in which the metal parts are brought to the solvent bath in different steps. In general there are one or two liquid pre-cleaning bathing steps in which the parts are dipped and a following vapour bath in which final cleanliness is achieved. The bathes are equipped with a suction device. Since the machine is open, vapours of the volatile solvent are strongly emitted into the surrounding air. The difference between machine type I and II is the different temperatures the solvent is cooled down to.

[7] von Grote (2003), 43 and UBA (1994) 293-295

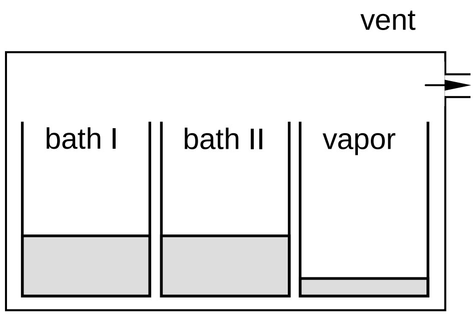

Figure 5: Machine type III

3.2. Machine type III

This type of machine encases the degreasing baths and is equipped with a suction device. Some machines of this type incorporate an activated carbon filter, over which the solvent is run after the cleaning cycle.

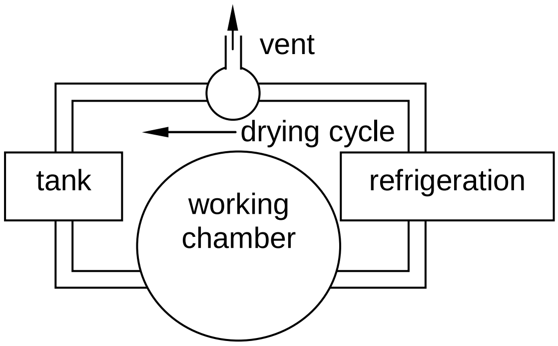

Figure 6: Machine type IV

3.3. Machine type IV

These machines use a single working-chamber for the first time to perform all cleaning steps by bringing the solvent to the metal parts and not vice versa. These standardised machines condense the solvent after vaporization cleaning and refuel it into the closed system. But as vapour rests are vented out into the atmosphere, the system is considered to be at least half-open. The parts are dried using refrigeration cooling at temperatures between -20°C to -40°C.

3.4. Machine type V

This machine type is a fully closed-looped machine with one working-chamber. Besides the drying and recycling systems and refrigeration cooling, the air is additionally directed over an activated carbon filter before re-entering the working-chamber to dry the metal parts. No exhaust air is released into the environment with this generation of equipment. Type V machines were developed in the late 1980s.[8]

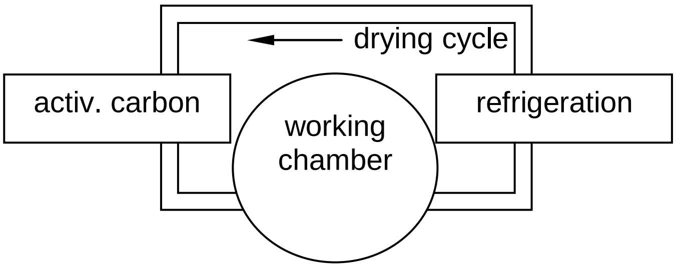

Figure 7: Machine type V

As machines differ substantially in their emissions to the environment, a clear distinction must be made when estimating noxious effects from metal degreasing. The individual emission-factors for the different types of machinery which have been in use in Germany are shown in table 1.

Type	Subtype	Characteristic	Emission-factor
I	A	fully-open; two baths	92%
I	B	fully-open; two bath and vapour degreasing	92%
II	A	fully-open; two bath	92%
II	B	fully-open; two bath and vapour degreasing	92%
III		half-open	28%
IV	A	half-open; cooling temperature -30 °C	28%
IV	B	half-open; cooling temperature -40 °C	28%
V	A	hermetically closed; no vacuum drying	1%
V	B	hermetically closed; vacuum drying	1%

Table 1: Emission-factors for machine types I to V[9]

[8] Von Grote (2003), 48
[9] Von Grote (2003), 47 and UBA (1998), Stoffband B, 41-42

4. Regulations

4.1. Possible regulations

Consequently the state should make the costs discussed in section 2 perceptible to the polluters. To this end, three basic approaches are discussed in economics:

- Fixing a technical standard connected with sanctions (allowing each company the same amount of emissions).
- Emission charges (charging all companies for every unit of emission).
- Transferable emission permits (certificates that allow emissions).

In the following the three approaches of internalizing external effects from the use of the environment are analyzed regarding ecological accuracy, cost efficiency and dynamic efficiency. In section 5.1 we will depict how the German and the Swedish regulation approaches fit into the theoretical definitions.

4.1.1. Ecological accuracy

When introducing a technical standard, the maximum national amount of emission must be well known and distributable to the single emitters accurately. Companies will not emit more than the assigned amount when offences are fined. Consequently ecological accuracy is given.

An emission charge is a fee, collected by the government and levied on each unit of pollutant emitted. Indeed, the government can set the price of emission charges, but it cannot set the resulting total amount of emission. Therefore ecological accuracy of emission charges depends heavily on the likeliness of changes in production technology.

A system of transferable emission permits is typically associated with the twin aim of attaining the centrally set nation-wide level of emissions and simultaneously achieving cost efficiency. The government must only determine the desired pollution level and distribute the total number of permits among all polluting firms. To be allowed to emit pollutants, the companies need to buy emission rights. After initial allocation of the permits, the emission rights are tradable via stock exchange. With this approach the government can set the emission amount precisely. Therefore, transferable emission permits show a high ecological accuracy.

Concerning ecological accuracy both transferable emission permits and technical standards seem to address the requirements well.

4.1.2. Cost efficiency

In figure 8 the amount of emissions is represented by the abscissa and the marginal abatement costs. The emission charges (tax) are represented by the ordinate. Two different enterprises are considered; the companies have different marginal abatement costs (MAC_1; MAC_2) which result from the consecutive avoidance of one additional emission unit. If the companies were to avoid all emission, they would have extremely high costs. If the enterprises could emit according to their own judging, they would realize the emission volume *S* which is represented by the intersection of the *MAC*-curves with the abscissa. In this case the marginal abatement costs are zero.

The technical standard is represented by the vertical line in the chart. If we suppose that both companies were realizing the emission amount *S* before the introduction of the technical standard, they now are obliged to reduce emission. Marginal abatement costs result from avoidance of emissions. The abatement costs for company *1* are represented by the area *STU* while area *STR* represents the abatement costs for company *2*. By adding up both areas one receives the total abatement costs.

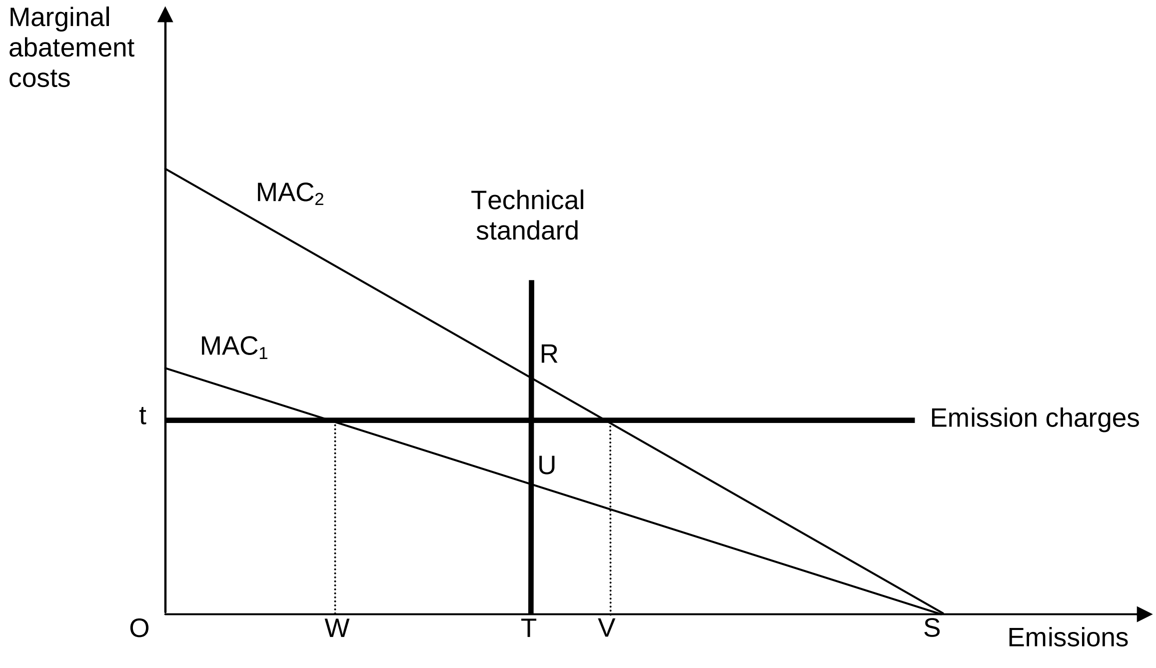

Figure 8: Static efficiency

It can easily be seen that each company's abatement cost differ for the last emitted unit – i.e. company *1* can avoid emissions cheaper than company *2*. Consequently no efficient solution can be reached by a technical standard. As long as the marginal costs differ there are potential gains from trade remaining. The environmental goal is to reduce overall emissions. It is therefore not relevant which company achieves what amount of reduction as long as the nationwide reduction is achieved.

The emission charge is represented by the horizontal line. Each of the two companies has to pay a tax *t* per emitted unit of pollutant. The enterprises will avoid emissions as long as marginal abatement costs are lower than the tax. Company *2* will reduce emission, realizing emission totalling *V* - company *1* will lower emissions to *W*. In the end the costs for the last emitted unit of pollutant are equal for both companies. Therefore cost efficiency is given.

The state can give out emission rights equalling the amount of pollution reached by the technical standard. After initial allocation the trade of these certificates is taken up between the companies. Those enterprises which need more certificates than initially granted will buy these on the stock exchange and those companies which need less emission rights will sell spare certificates. In our example, company *1* will sell certificates allowing emissions up to *WT* to company *2*. The price for one unit of emission will be equal to *t*. In this manner cost efficiency is reached. Emission charges and transferable emission permits lead to cost efficiency.

Cost efficiency is a possible criterion only if the distribution of reduction among polluters is of no interest for the environmental goal. This is true for greenhouse gasses for example. Concerning trichloroethylene, this principle does not hold. Primarily the workers in the premises suffer from trichloroethylene emissions. Therefore, cost efficiency will not be considered when comparing German and Swedish legislation.

4.1.3. Dynamic Efficiency

Dynamic efficiency refers to the incentive for technological progress. Environmental legislation is dynamically efficient, if it offers constant economic incentives to reduce emissions.

One company is now displayed in figure 9, which can lower its marginal abatement costs by means of technological innovation. Marginal abatement costs after the technological innovation are shown as MAC_{new}.

The company will in both cases, i.e. before and after the introduction of technological innovation, emit up to the maximum legal amount. The costs of emission avoidance before the technological innovation equal the area *STR.* After the innovation they equal *STU*. Therefore the total savings sum up to *RUS*. The company will only invest in technical innovation if the expected cost is less than the savings *RUS*.

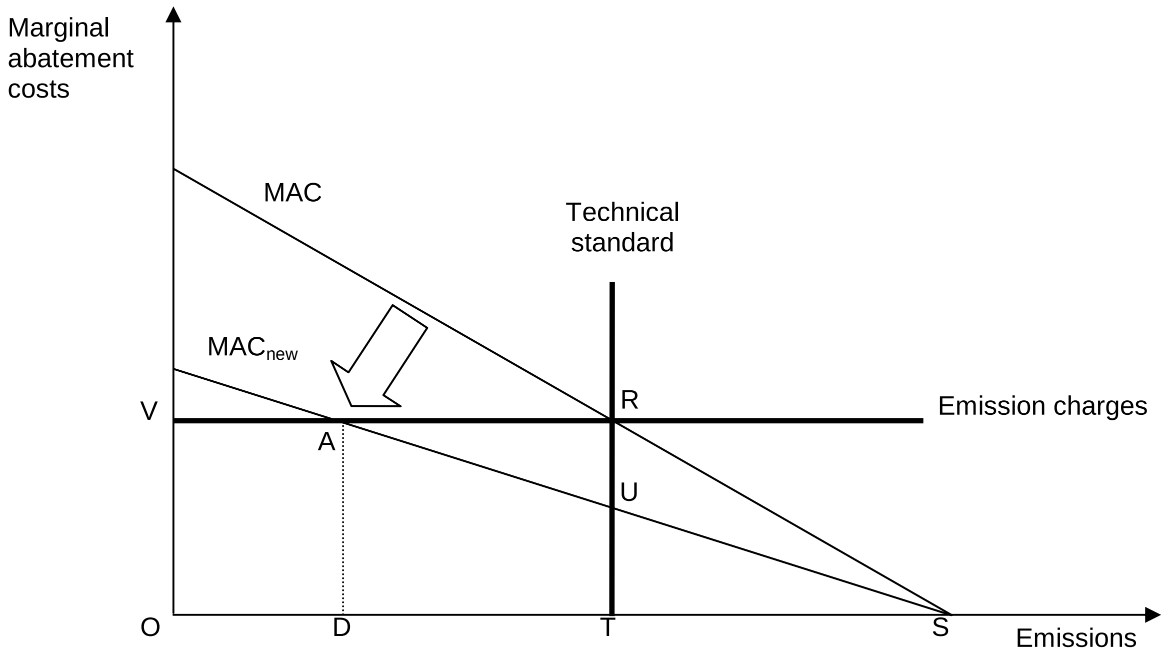

Figure 9: Dynamic efficiency

Before the introduction of the technological innovation the financial burden of the tax equalled the area *OVRT* (amount of emission times the tax), the costs of avoidance equalled *RTS*. After the innovation the burden equals the area *OVAD*, while avoidance costs equal *ADS*. Compared to the result with an environmental standard, additional savings equal to the area *AUR* are gained and emission is lowered as well. Dynamic efficiency is therefore given in the case of an environmental tax.

Assuming that before the technological innovation the price of a certificate was equal to the environmental charge per emission and that the number of certificates in trading was reflecting precisely the amount of emission in the case of regulation through an environmental standard, the price of a certificate remains the same after the introduction of a technological innovation. Companies can now sell surplus certificates at the stock market though. For the company displayed in the graph above, this means it can yield earnings from selling certificates totalling the area *ADRT*. In addition the company will be able to avoid emission at a lower cost after the innovation (area *RUS*). With dynamic efficiency in mind, certificates are very suitable.

Both taxes and certificates address dynamic efficiency better than standards.

4.2. Swedish regulations

4.2.1. Swedish restrictions and ban of trichloroethylene

In Sweden the use of chlorinated substances, such as trichloroethylene and methylene chloride (considered to be carcinogenic) has been a subject to ever increasing environmental regulations since the end of the 1970s. At the beginning most attention was given to improving the working environment by increasingly stringent emission standards and exposure limits. During 1978-1991 the use of trichloroethylene, for example, decreased from 9’000 tons per year to 3’000 tons per year (figure 10).

Many user representatives share the opinion that the ban on trichloroethylene use in Sweden was very much a political decision. The reason for the political nature of the decision was that Sweden was the first in Europe to ban freons (with Germany following shortly after). Politicians were likely to follow the tradition of being the first in the decision on banning trichloroethylene, too. Only after the ban had caused a significant uproar among the industries (some have invested into alternative systems but were dissatisfied with the quality and/or productivity, some were on the verge of closing down their activities), the system of permits was introduced.

From 1991, further reduction took place following the decision of the Swedish Parliament to support the government proposition (Ordinance 1991: 1289)[10] to introduce a ban on industrial use of chemical products that contained trichloroethylene and methylene chloride. This decision followed the demand of the Swedish Metalworkers Union on improving the working environment. The decision of the Parliament was followed by an active five-year period of companies preparing for the ban. Between 1991 and 1996, some companies made efforts to further reduce the use of trichloroethylene and emissions by increasing process efficiency and / or by finding alternatives to trichloroethylene.

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[10] Förordning (1991)

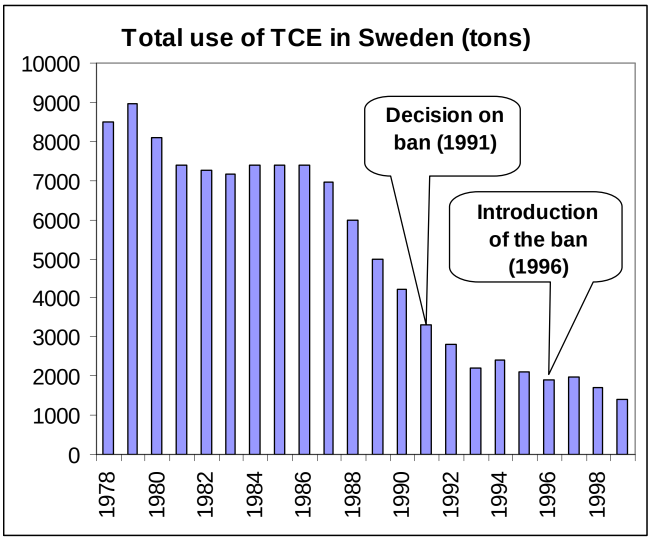

Figure 10: Use of trichloroethylene in Sweden 1978–1999[11]

In parallel, the use of trichloroethylene in consumer products was banned in 1993, prohibiting all chemical substances that contained trichloroethylene. These substances could not be sold or transferred to customers for own use. From January 1st, 1996 on, trichloroethylene and methylene chloride were no longer allowed to be offered, sold or transferred for professional use in industries either. Ordinance 1991: 1289 was later replaced by the new Ordinance 1998: 944. Thus, as seen from the text of both Ordinances, the ban was not absolute as its enforcement in 1996 also anticipated a system of permits administered by the Swedish Chemicals Inspectorate. The permits to use trichloroethylene could be issued to companies that could report difficulties with fulfilling the conditions of the ban.

Therefore, following the enacting of the ban, the Swedish Chemicals Inspectorate formulated the rules for exemptions from the trichloroethylene ban. Only companies that could show that they made serious improvements in their processes or economic efforts to substitute trichloroethylene and had a plan for future attempts would get the exemption. In 2002, the Chemicals Inspectorate increased the requirements for the exemptions triggering the companies to speed up phasing out trichloroethylene.[12]

[11] Slunge and Sterner (2001b), unofficial statistics
[12] Andersson (2003)

Ordinance 1991: 1289 on certain chlorinated solvents
1 § Chemical products that totally or partially consist of … trichloroethylene shall not be marketed or transferred to consumers for private use. The Chemicals Inspectorate may prescribe that products that contain … trichloroethylene shall not be marketed or transferred to consumers for private use.
2 § Chemical products that totally or partially consist of … trichloroethylene shall not be marketed, transferred or used for professional use.
3 § If there exist special reasons, the Chemicals Inspectorate may issue regulations about exemptions from the ban according to 1 and 2 §§. In this specific case the Chemicals Inspectorate permits the exemption from the ban according to 1 or 2 §, if there exist specific reasons. In the case the Chemicals Inspectorate via regulations or in a special case issued an exemption, it may take such a fee that is prescribed in 19 § of law (1985: 426) on chemical products.
3 a § The Chemicals Inspectorate may even take an application fee from those who apply for the exemption from the ban according to 1 and 2 §§. This fee is taken in accordance with the rate that is fixed by the Chemicals Inspectorate. Ordinance (1996: 1081).

6 § Further prescriptions on execution of this Ordinance are announced by the Chemicals Inspectorate.

Ordinance 1998: 944 on the ban etc. in certain cases in connection to handling, import and export of chemical products
5 § Chemical products that totally or partially consist of … trichloroethylene shall not be marketed or transferred to consumers for private use. The Chemicals Inspectorate may prescribe that products that contain … trichloroethylene shall not be marketed or transferred to consumers for private use.
6 § Chemical products that totally or partially consist of … trichloroethylene shall not be marketed, transferred or used for professional use.
7 § If there exist special reasons, the Chemicals Inspectorate may issue regulations about exemptions from the ban according to 5 and 6 §§. If there exist special reasons, the Chemicals Inspectorate may in this special case issue an exemption from the ban according to 5 or 6 §.

Currently the conditions for acquiring the exemption from the ban include four basic requirements:

- A proof that the company actively searches for alternatives.
- A proof that no suitable alternatives are readily accessible to the company for its applications. The company should present information about what substances and alternatives have been tested and reasons why they are not working.
- A proof that the use does not lead to an unacceptable exposure to trichloroethylene.
- Information about future plans of finding alternative solutions to trichloroethylene use.

In 1996, around 500 companies got an exemption from the trichloroethylene ban. In 1997, 283 companies applied for the exemption, but only 137 received it, which led to an appeal to court by some 60 companies. Ruled by various levels of courts the majority of the rejected companies got the exemption. In 2002, 110 companies in total got permits to use 283 tons of trichloroethylene for degreasing[13], followed by 84 companies in 2004 (permits for 157 tons). In 2005, 72 companies got an exemption until December 2006 for using 111 tons[14] (cf table 2).

Years	Nr. of exemptions[15]	Volume granted (tons)
1996	500	
1996	187 (150)[14]	
1997	220	
1998	121	
1999	150	
2002	110	283
2004	84	157
2005	72	111

Table 2: Exemptions for industrial trichloroethylene use since 1996

At some point the exemption fee was withdrawn entirely since it was considered to be "out of proportion" to the environmental damage by the EU Commission.

4.2.2. The Swedish trichloroethylene ban and the EU

The Swedish trichloroethylene ban has been tested in the European Court of Justice, when the case of one company, Toolex Alpha, was referred to by a Swedish court. The case was tried with the intention to see whether the Swedish prohibition was in accordance with the free movement of goods (case C-473/98). The Swedish trichloroethylene ban in the eyes of the European Court of Justice constitutes a measure having an effect equivalent to a quantitative restriction on imports. The general prohibition it lays down and the obligation laid on economic operators to apply for an exemption constitute measures liable to bring about a reduction in the volume of imports of trichloroethylene into Sweden. However, the Court held, such a restriction is compatible with the Treaty if it seeks to protect the health and safety of humans.

Sweden has presented scientific evidence that trichloroethylene is a carcinogen. In 2001, a group of scientific experts together with representatives from EU member

[13] Slunge and Sterner (2001a)
[14] Personal communication with representative of the Chemicals Inspectorate Inger Lindqvist

countries recommended a strengthening of the classification for trichloroethylene, regarding it as a carcinogenic substance. In that case, the European Court of Justice has ruled that a chemical substance, which can be legally marketed and sold on the Internal Market under Community Law, may be banned by a Member State if there is an exemption procedure. The exemption procedure must be appropriate, proportionate and the exempted user continuously has to investigate feasible alternatives, there must be no practicable alternative and the use must not entail unacceptable exposure.[16]

The jury of the European Commission found that the industrial use of trichloroethylene, which is subject to the Community rules for dangerous substances of the "classification Directive"[17], the "marketing Directive"[18], and the "risks evaluation regulation"[19] is not regulated in such a way on the Community level that the Member States are prevented from regulating the industrial use of trichloroethylene themselves. Consequently, the Court has considered that the Swedish measure should be examined in the light of the Maastricht Treaty, Articles 28-30.[20] The Court established that the Swedish ban in principle conflicts with Article 28. However, taking into consideration the presented scientific evidence, which indicated that trichloroethylene might be dangerous to human health, the Court concluded that the measure to ban trichloroethylene is justified according to Article 30. Therefore, the Court concluded that national legislation which lays down a general prohibition on the use of trichloroethylene for industrial purposes and establishes a system of individual exemptions, granted subject to conditions, is justified under Article 36 of the EC Treaty (now, after amendment, Article 30 EC) on grounds of the protection of health of humans. The individual requirements to obtain an exemption were also said to be compatible with the Substitution Principle, which emerges from Council Directives 89/391 and 90/394 concerning workers protection.

According to a Swedish member of the European Parliament[21], the trichloroethylene ban could serve as a source of ideas for the EU authorisation system for chemicals

[15] Slunge and Sterner (2001a) and Andersson (2003)
[16] Court of Justice and Court of First Instance (2000) Judgment of 11/07/2000, Toolex (Rec.2000, p.I-5681) http://curia.eu.int/en/index.htm
[17] European Commission Council (1967) Directive 67/548 EEC
[18] European Commission Council (1976) Directive 76/769 EEC
[19] European Commission Council (1979) Directive 793/93 EEC
[20] Maastricht Treaty is the Treaty establishing the European Community. Article 28 and 30 can be found in Part Three on Community Policies, Title 1 on Free Movement of Goods, Chapter 2 on Prohibition of quantitative restrictions between Member States.
[21] Wijkmann (2005)

proposed in the REACH Directive. That is, it would be compatible with the substitution principle already in European law to

- consider authorisations only for uses where exposure is at acceptable level,
- limit the potential authorisations for such uses to where no safer replacement products is available, and
- to include in the conditions for such authorisations a continuous search for alternative solutions.[22]

However, the substitution principle is not a perfect solution for each case. Several drawbacks of the principle per se and of its application can be mentioned. The application of the principle to a great degree depends on many factors. The complexity of the substitution of a chemical or the phasing-out of a substance might lead to certain problems[23]:

- One problem might arise if hazardous chemicals are substituted with alternatives, which are not adequately analysed or if there is insufficient scientific evidence that alternatives are less environmentally harmful.
- Sometimes, substitution of a chemical can be beneficial from the point of view of a certain production stage. However, if looked at from the entire process perspective, these alternatives might create problems in other stages or adversely affect the environmental profile of the entire production process.
- A choice of chemicals is a complex procedure with many parameters to be taken into account. It may sometimes require thorough evaluation of environmental impacts, which might require a life cycle assessment (LCA) to be conducted. The LCA is a time-consuming and expensive procedure, in which the final result to a great degree depends on subjective judgment of the experts.
- Finally, existing systems of infrastructure and networks should be taken into consideration. Sometimes a more toxic substance should be preferred to an alternative, when there are processes and technologies already in place for treating it, whereas such process might be still lacking or not developed yet for new substances.

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[22] Wijkman (2005)
[23] Mont (2001)

4.3. German regulations

4.3.1. Development of German regulations

2nd BImSchV of 1986

The *"Zweite Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes"* (2nd Directive for the Implementation of the Federal Clean Air Act) or in short the 2nd *BImSchV* was enacted on April 21st, 1986. It regulated all surface-treatments, dry cleaning, textile finishing, and extraction equipment using halogenated solvents or mixtures of solvents containing more than 1% of halogenated solvents that are classified as either R 45 (may cause cancer), R 46 (may cause heritable genetic damage), R 49 (may cause cancer by inhalation), R 60 (may impair fertility) or R 61 (may cause harm to the unborn child) according to directive 67/548/EEC and that according to § 4 BImSchG (Federal Clean Air Act) require no permit.[24] In this directive, emissions were regulated for the first time.

Discrimination was made between surface-treatment equipment (cleaning, greasing and degreasing, coating and coating removal, and surface drying) with and without exhaust systems. Trichloroethylene was only permitted if it was used in closed machines with an exhaust system. Machines with an exhaust air volume up to 500 m^3/h must have a concentration of trichloroethylene in the undiluted air of 200 mg/m^3 or below, for machines with an exhaust air volume of more than 500 m^3/h the limit is 100 mg/m^3.

Upgraded type-III- and type-IV-machines fulfilled these requirements.

2nd BImSchV of 1990

The revised 2nd BImSchV of 1990 requires for all applications that loading and unloading of tanks be done according to state-of-the-art and that chlorinated solvents and waste be transported and stored in closed containers with safety collection trays. The use of trichloroethylene is still forbidden in dry-cleaning, textile-finishing, and extraction equipments. Trichloroethylene may only be used in enclosed machines (in general machines of type V).

[24] 4th BImSchV, Nr. 5.1: Equipment working with less than 25 kg/hour and less then 15 tons/year does not require special permit.

Amendment of 2nd BImSchV 1990 in 2001

According to an amendment of 2nd BImSchV 1990 in 2001 trichloroethylene is only allowed in surface treatment equipments with hermetically-closed solvent tanks and pipes, which are operated under vacuum and for which the consumption is less than 1 metric ton per year. The second generation of type V machines fulfils these requests.

4.3.2. Current German regulations

In general, companies operating such equipment are obliged to reduce the use of the above substances or to substitute them by less harmful substances as soon as possible. Trichloroethylene is allowed for use in surface-treatment equipment only.

Surface-treatment equipment operating with trichloroethylene has to meet several specifications:

- Machines must be hermetically-closed.
- Airborne concentration in the undiluted exhaust air is limited to 2 mg/m^3.
- A self-acting locking mechanism has to make sure, that cleaned parts cannot be taken from the machine unless the concentration in the undiluted air is below 1 g/m^3.
- Equipment must be of best available technology.

Breach of the above specifications is an administrative offence.

5. Comparison of regulation

A closer analysis of Swedish and German legislation leads to the perception, that the German legislator has put his emphasis on the protection of the employee. In German law, there are exact directions on machines to be employed and on the maximum airborne concentration of trichloroethylene. In the economic sense, the legislator directly interferes with the enterprises' production functions and thereby the noxious effect[25] of trichloroethylene on workers (cf. section 2) is reduced. There has to be considered though, that today a health-based exposure limit is not jet fixed.

Swedish law primarily aims at the regulation and reduction of the overall emission level. By means of a general ban, a complete reduction of emissions is accomplished and in the next step, the desired amount of emissions is achieved by providing exemptions from this ban. With this approach however, the employee, who is exposed directly to the emissions at his workplace is less protected, since there are no regulations concerning technology. Under this legislation, some employees might suffer from very high exposure, while the overall emission level is rather low.

Companies maintained in interviews that "*any measure could provide good results if it is done carefully. It would be much better if when introducing the ban, the authorities gave us time to adjust and to find new alternatives, study the market of alternative chemicals and to reconsider processes and products*". According to companies, the problem in Sweden was that companies had to change rather fast and many companies made necessary investments. Unfortunately, they realised with time that alternatives did not work in all applications, and for many companies and their customers this created severe problems. Companies conclude that more consideration should be given to how businesses may adjust and how this should be done in the most effective way. On the other hand, looking at the time frame of introducing the trichloroethylene ban in Sweden, companies had five years to study the market and to find and test alternatives. Some companies have used this time for finding substitutions and increasing the efficiency of their processes.

When trying to classify both legislations concerning the basic instruments of environmental policy (cf. section 4.1) one finds that an exact subsumption is impossible. Both laws rather constitute a combination of different instruments which in the following will at first be explained and then analysed regarding ecological accuracy and dynamic efficiency.

5.1. Categorization of Swedish and German legislation

As Swedish legislation fundamentally bans the use of trichloroethylene, it can be described as a technical standard where the maximum national amount of emissions is zero. Additional to the fundamental ban however, exemptions are granted to enterprises on a two-year cycle which legitimate selected companies to employ a definite amount of trichloroethylene. The interaction of ban and exemptions can therefore by described as an “alleviated ban”, a special type of technical standard.

The absolute ban creates opposition of companies who use trichloroethylene either because they are having difficulties with finding alternatives and substituting trichloroethylene, or they disapprove the timing of the ban or how it has been introduced. Many companies spent a lot of time and effort on appealing and lobbying against the ban, threatening to move out of Sweden and arguing that their competitiveness is affected. One company appealed against the ban to the European Court of Justice, which ruled against.[26] An important motive for this was the possibility to get an exemption where (still) no alternatives were available.

Theoretically, a technical standard specifies an exact legal maximum amount of emissions. Severe fines are imposed on companies which exceed this level. However, it is not the exact amount of emissions that is regulated in Germany. In fact, German law demands the use of state-of-the-art machinery and the observance of certain threshold values. Thus, relatively low concentrations at the working place are achieved as well as a rather low overall emission level. Therefore, we shall speak of a “restrictive technical standard” in Germany.

5.2. Comparison in respect to ecological accuracy

The particular goal in consideration of ecological accuracy is the exact determination of the emission level. By means of an alleviated ban, the desired amount of emission is reached by banning the product generally and allowing enterprises to apply for exemptions afterwards. The number of exemptions and their extent can be fixed by the

[25] DFG (2005), 197 and 202
[26] European Court (2000)

state and distributed among the applying companies. Producers obtain the right to use a certain amount of trichloroethylene in the production process. With the aid of the emission factor of 75 % that was identified for one of the large manufacturing companies in the Swedish machine building sector, the maximum resulting emission level can easily be calculated. (Cf. section 6.1.2) As the desired amount of emissions can be realised under Swedish legislation, ecological accuracy is given.

There are detailed instructions on the applicable technology in Germany. Only hermetically closed machines with a consumption of less than 26 kg/h and less than 15 tons/year may be employed without special permit.[27] In connection with the empirically identified emission-factor of 1 % this rule allows the determination of the maximum amount of emissions for each machine. Since there is no regulation on the maximum amount of machines – neither on the company level, nor nationwide – it is impossible to achieve a desired overall amount of emissions. Thus, ecological accuracy is only partially given with German legislation.

It must be observed however, that the consideration of emissions in the premises is more important than the overall emissions. According to studies, trichloroethylene emissions at the working place are more dangerous than emissions into air outside the premises where the substance is further diluted and dispersed and molecules are destroyed by sunlight.[28]

5.3. Comparison in respect to dynamic efficiency

Swedish exemptions from the ban are granted for a two-year time. Furthermore, there is no direction about the equipment, which has to be employed when dealing with trichloroethylene. Since Swedish companies cannot rely on obtaining another exemption after the end of the two-year period, they hardly have any incentive to invest into more efficient and less emissive technology.

Results in terms of applied technology are less encouraging than in terms of reduced trichloroethylene use and emissions. Not many companies have closed-loop systems for degreasing. At the same time, none of the companies operating on the exemption have totally open degreasing systems (open baths). Most of the companies have rather old equipment, from end 1970s to mid-1980s to which several modifications were made.

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[27] 4th BImSchV, Nr. 5.1

[28] Von Grote (2003), 12-13

The most frequent modifications are covers for the baths, additional ventilation to reduce trichloroethylene concentration in the premises as well as in some cases vapour recuperation systems with cooling zones and active carbon filters. A handful of companies also practice an on-site recycling of carbon filters and recirculation of trichloroethylene back into the process. Nevertheless, even with these improvements, trichloroethylene is in direct contact with the working environment. The add-ons are not fully effective in reducing workers' exposure to trichloroethylene vapours, especially during (re)loading operations as well as partly during idle times.

Comparing technical progress of degreasing machines using trichloroethylene in Sweden and Germany over the last 30 years shows a huge gap. This demonstrates the poor incentives from Swedish legislation for modernizing trichloroethylene-equipment.

Some companies shared in interviews that providers and suppliers were or are helping them with finding alternatives and even with testing them in various applications. One German supplier had even redesigned a degreasing machine to suit the needs of the Swedish customer. However, not much help was received from the Chemicals Inspectorate or from branch organisations in terms of finding alternatives.

There is of course an incentive to change the production process to non-trichloroethylene cleaning techniques. This incentive is further augmented by the decreasing extent of exemptions granted (cf. table 2). The incentive to search for substitutes might therefore be rather strong in Sweden, depending on the level of generosity at issuing exemptions.

Finding and substituting for alternatives is a costly and time-consuming activity – if possible at all. The companies that still use trichloroethylene have not found an alternative, even ten years after the introduction of the ban. For the other companies the time from when they found an alternative to the time of the actual substitution was about or more than one year. A management problem that companies reported is that for self-employed entrepreneurs running tests with potential trichloroethylene alternatives is unfeasible due to overload, lack of time and in some cases absence of own products on which to make tests.

In Germany, the employed technology must be state-of-the-art (2nd BImSchV). This provides some kind of guaranteed sales for producers whenever an improved machine is developed and provides incentives for further - long-time - research.

	ecological accuracy	dynamic efficiency	
		„substitutes“	„technology"
Alleviated ban (Sweden)	✓✓	✓	--
Restrictive technical standard (Germany)	✓	-	✓✓

Table 3: Comparison of legislation

Regarding the incentive to find substitutes for trichloroethylene, the situation is different. After it was codified in the 2nd BImSchV of 1990, that only type V B machines may be employed in the production process, companies had to decide whether to upgrade their train of machines or to switch to substitutes. In case they opted for new machinery, incentives to simultaneously search for substitutes are rather low. Only at the point of time, when producers of cleaning equipment offer yet less emissive machinery will the degreasing companies have to think again about substituting trichloroethylene or investing in such machinery. The incentive to search for substitutes is therefore weaker in Germany compared to Sweden.

5.4. Swedish companies' reactions to the ban

From the interviews and the survey on the use of trichloroethylene in Sweden it became apparent, that ten years after the ban was introduced, the majority of trichloroethylene users is formed by rather small enterprises. Where trichloroethylene is still used this is done due to two major causes:

- Small enterprises cannot afford developing alternatives (i.e. from small enterprises authorities accept the argument, that the use of alternatives is not feasible from the economic point of view).
- There are special applications, which require the use of trichloroethylene due to quality reasons (i.e. alternatives which lead to comparable results do not exist).

Responding to the early announcement in 1991 by the government on the decision to impose the ban, a large number of companies have substituted trichloroethylene in most parts of their production by alternative products or technologies.

At the same time, it was not possible to find suitable alternatives in some smaller segments of the production. In such cases, companies either had to close down certain operations using trichloroethylene, outsource trichloroethylene-related activities or rely on the exemption system. In the latter case, among other issues, the regulations require that companies motivate their applications. Most of the motivations rest on technological and economic reasoning.

Technological aspects

The most frequently mentioned technical problems reported by the interviewed companies were following:

- High customers' demands for surface cleanliness which are impossible to reach with alternative chemicals or technologies. The examples mentioned include highly polished aluminium surfaces, bio-medical equipment, high precision and/or military equipment.
- The limited substitutability of trichloroethylene is especially apparent among enterprises degreasing small objects or complex shape objects.
- Often alternatives, such as water-based degreasing systems, cause problems with rust, for instance, spots from drying on highly glossy non-corrosive surfaces.
- Polishing waxes with metal particles are also difficult to remove with alternative solvents.
- Water-based chemicals are reported to work slower, but the equipment is cheaper. In addition to the fact that water-based alternatives cannot replace trichloroethylene in all instances, the equipment is usually larger, which was reported to be a problem for small companies, some of whom rent their production facilities and do not have the possibility to extend the rented space.
- Existing alternatives require more time and more employees. For self-employed entrepreneurs this may mean 20 hours more per week of work, which customers cannot afford.
- Some companies have special needs for trichloroethylene equipment and are less flexible in choosing alternatives, e.g. the continuous process of degreasing wire or cleaning over-dimensioned objects that do not fit into standard alternative equipment.
- In many cases alternatives lead to more waste. For example, alkali alternatives require more rinsing steps, which leads to considerably higher water consumption than in the case of trichloroethylene use.

Economic aspects

The majority of degreasers in Sweden operating within the permit system are small enterprises, for which investments into alternative degreasing solutions are prohibitively expensive. According to the information form the Swedish Chemicals Inspectorate, finding alternatives to or reducing the emissions of trichloroethylene, require substantial investments. The typical cost examples indicated were:[29]

- Trichloroethylene substitution to alkali treatment requires new equipment with an average investment rate of around 500’000 SEK (ca. € 45’000).
- The costs for upgrading of the old open-loop equipment by means of hermetical enclosure and installation of vapour recuperation systems based on active carbon filters is in the area of 400’000 SEK (ca. € 40’000).
- Totally closed (hermetic) systems, such as e.g. produced by the German company PERO and in Sweden traded by Agaria Trading AB, cost approx. 1.5 million SEK (€135’000).

Therefore, some companies put forward arguments that a change of equipment is not feasible due to economic reasons. In marginal cases, some Swedish companies did invest into closed-cycle trichloroethylene degreasing technologies, which makes it difficult to economically justify equipment decommissioning in a short run and may force companies to find different excuses for a permit.

From the other side, the current system of ban and permits by no means encourages new investments into state-of-the-art low emission equipment. The sheer cost of the new closed-loop systems is too high, especially considering risks linked to the two year exemption period. This is especially true for small and medium-size companies, which constitute about 90% of all companies currently operating within the permit system.

Environmental aspects

In Sweden, spent trichloroethylene solvents (sludge of trichloroethylene and oils) are classified as hazardous waste and must undergo special treatment, e.g. destruction or recycling with trichloroethylene recuperation. Today the costs of destruction in Sweden are around 50 SEK/kg (ca. 4 €/kg).[30]

[29] Personal communication with representative of the Chemicals Inspectorate Inger Lindqvist
[30] Personal communication (2005-08-19) with Mr. Håkan Gustavsson, Akso Nobel AB, marketing of base chemicals, tel.: +46-(0)54-511 000

Before and shortly after the ban, when trichloroethylene consumption in Sweden was in the range of 2'000-3'000 tons/year and recycling made economic sense, large chemical suppliers used to collect the sludge from their customers for re-processing. For instance, Akso Nobel AB used to collect the sludge in fairly large quantities for recycling to be re-sold as raw chemicals and the oils incinerated for heat recovery. After the ban, the use of trichloroethylene dropped by an order of magnitude (e.g. today Sweden uses less than 200 tons/year), which resulted in declining collection and recycling. Today, waste management companies favour thermal destruction.[30]

Recently the role of the ban in reducing the total use of trichloroethylene is somewhat decreasing. The list of companies receiving the permits is decreasing slowly, suggesting that the rate of improvements has reached saturation point (cf. table 2). Therefore, the effective role of the ban is more prominent in improving internal environment and working conditions.

A few interviewees, especially from small companies, acknowledged that with years applying for an extension of their trichloroethylene permit has become a routine, provided that they can argument having no better alternative or face too high costs of substitution. Some companies indicated that they would rather keep using outdated equipment and avoid significant investment in process innovation.

At the same time companies argue that *restrictions on trichloroethylene emission levels* in the working environment would be much more welcome and effective than the ban. Regarding the trichloroethylene emissions to the outer environment, there is no final evidence to suggest that trichloroethylene emissions are worse than emissions of CFCs, which are not banned.

From the interviews with the companies and some experts it became apparent that after the ban a number of large companies prefer outsourcing the "dirty job" to small industries. It is likely that it is a strategic move to avoid environmental pressures form social groups and authorities. The smaller companies having fewer means to invest into alternative equipment are likely to be less exposed to these pressures. The result is that smaller companies are working with inferior outdated equipment.

Type V B machines are also available in Sweden at a typical price of 1-1.5 MSEK (€ 90'000-135'000) per unit, which is prohibitively expensive for some small companies. On the other hand, installing an active carbon filter for trichloroethylene recuperation over the old equipment costs about 100'000-150'000 SEK (€ 11'000-

16'000), which is thought to be affordable even for small companies. Such filters normally ensure emission concentrations within the 20 mg/m^3 limit.

An interesting finding was that although some companies have found trichloroethylene alternatives or eliminated or outsourced degreasing operations, they still apply for an exemption "just in case".

A few indicative quotations from the interviews are provided below.

"It is always better with a carrot than with a stick. Under the ban, companies are looking for an easy way out, while with standards companies would have searched for most economically and environmentally effective solutions. The goal now is anyway to get an exemption, while of course companies are trying to find alternatives and reduce trichloroethylene use, but the incentive structure is totally different. It was a purely political decision to ban trichloroethylene use, while it might not be the most dangerous chemical that is in use in industry."

"The ban is inhibiting for Swedish companies and affects their competitiveness. All companies in EU should work within the same conditions. This company market is 80% outside Sweden. They saw that their products were more expensive than for instance German products, even though it is of course not possible to allocate higher prices to trichloroethylene issue only."

"Both approaches have their pluses and minuses. The ban in itself is not the issue, the issue is how it is used and whether KEMI through the exemption procedure can trigger continuous and real improvement or change for better equipment and alternative chemicals. The company sells their products all over the world and so far it did not see that the product price was considerably affected by the trichloroethylene ban."

"Companies maintain their old equipment for the time being, while big investments are considered not viable with the ban."

"No one expects trichloroethylene to stay forever. The company did what it could, bought masks and gloves to protect the workers and is continuously looking for alternatives, but it would probably make more sense to introduce the strict standards. Now, if the company cannot get the exemption they will have to buy these services from bigger companies which invested into closed-loop equipment and can prove that there are no trichloroethylene emissions to the Chemical Inspectorate. On the other hand, there are also requirements from big customers, such as Volvo, that no trichloroethylene-containing products or processes are used in materials and semi-products that are supplied to them. This creates a business pressure on companies, which for some customers is even more stringent than the ban."

"If we will not get exemption, we will have to move the production line to another country, which has a different production culture (like China), or to a country where investments into closed-loop systems are encouraged."

"Strict standards are good; one can invest and reduce the emissions, while with the ban and exemptions one does not know what will happen in the future."

"Trichloroethylene is expensive, so companies try to reduce their costs of trichloroethylene. That is why even before the ban the company reduced trichloroethylene use as much as possible."

"Ban is bad for competition. Setting emission limits for inner and external environment is necessary, no one is opposing it, but to ban trichloroethylene was totally unnecessary. Companies after the ban started to invest money and time into finding alternatives and after one year there was a decision about exemptions, so the companies that invested lost to their competitors who did not jump into adjusting to new rules."

"Ban is maybe good for big facilities who can invest into new solutions and equipment, but small companies are on the verge of closing down. Plus with such a short exemption period (1-2 years) there is no incentive whatsoever to invest into new equipment."

"It is clear that often companies have to invest into new equipment simply to confirm to a purely political decision, which is not always backed up by scientific knowledge. In this case, trichloroethylene is perhaps not the most dangerous substance, but companies have to spend their time and resources on finding alternative, while it is not always clear that alternatives are better."

6. Empirical data

To enable a meaningful comparison of Swedish and German legislation the reduction in emissions of trichloroethylene that was due to legislation must be distinguished from the one that might have happened due to a possible decline of the metal-industry.

The choice of the functional unit had to be based on a measurable relevant performance parameter and be common for both countries. Choosing a unit based on physical characteristics such as product area cleaned in degreasing was not possible due to the great variety of products treated and the impossibility to account for the area.

It was decided that an economic functional unit would reflect the performance of the industry (efficiency of degreasing) in terms of emissions generated. The most relevant unit in this case was the value added of the metal-industry (cf. table 4) for the entire sectors of machine building and metal parts processing, “because metal-degreasing machines are used all over in the metal-processing industries”[31] and machine building. This will allow a cross-country comparison as well as a look at the response of German metal-industry to the tightening of regulation over time.

Year	Sweden	Germany
1991		120,455
1992		114,693
1993	7,652	103,838
1994	8,990	106,312
1995	10,204	110,863
1996	9,963	107,021
1997	10,376	108,514
1998	10,493	113,441
1999	10,652	108,952
2000	11,502	113,691
2001	11,556	115,372
2002	11,607	116,384

Table 4: Value-added for Swedish and German metal-industry[32]

Reduction is possible in two ways. On the one hand, a company can invest in newer more efficient equipment with a closed material cycle, i.e. emit less trichloroethylene from the same amount of solvent used. On the other hand, the company can substitute trichloroethylene for other solvents, provided that the substitution is technically and

[31] von Grote (2003), 56. Cf. also Werner (2004) and TÜV (1992), chapter 3

[32] Eurostat. Value-added in million euros at factor costs in constant-prices. Prices and exchange-rates of 1995. We are using metal-industry as a whole (Eurostat’s NACE-classification DJ and DK), assuming that metal degreasing is done in all sub-sectors of the metal-industry at more or less the same level.

economically feasible and that an appropriate license will be acquired from the authorities. Both actions lead towards the same ecological goal.

Reduction that is due to an economic downturn of the metal industry must not be mistaken as success of environmental legislation.

6.1. Empirical data for Sweden

6.1.1. Trichloroethylene consumption in Sweden

Statistics on total use of trichloroethylene and trichloroethylene use for degreasing in Sweden is rather ambiguous. Since 1995, trichloroethylene was no longer produced in Sweden implying that the total trichloroethylene consumption can only be determined from the balance between the imports and the exports. However, the data on trichloroethylene use obtained from KEMI is rather inconsistent.

	trichloroethylene imported as raw material [t]		trichloroethylene exported as raw material [t]		Used for degreasing (estimate) [t]
	KEMI[33]	SCB[34]	KEMI	SCB	KEMI & SCB
1993	1,335 ..(*)	2,647 ..(*)		1,655 ..(*)	
1994	654 ..(*)	2,704 ..(*)		2,827 ..(*)	
1995	555 3,122 (*)		.. 1,552 (**)		.. 2,125 (***)
1996	2,324	2,694	..	1,278	ca. 1,770
1997	1,883	..	2	..	ca. 1,880
1998	1,249	..	<1	..	ca. 1,250
1999	1,030	193	<1	8	ca. 1,035
2000	486	147		18	ca. 400
2001	367	346		22	ca. 350
2002	285	254		12	ca. 250
2003	228	216		36	ca. 200
2004	(157)[35] (133)[36]				
.. – missing data; (*) – amount produced as degreasing agent; (**) – amount exported as degreasing agent; (***) – as balance of produced and imported/exported as degreasing agent.					

Table 5: Material flow of trichloroethylene in Sweden

Table 5 shows trichloroethylene material flow for the period 1993-2004 indicating total imports and exports and approximate amounts used for degreasing. Although a gradual reduction in volumes is apparent, the inconsistency of data between the two sources for

33 KEMI (2005). http://apps.kemi.se/flodessok/floden/_flodenbild/floden.cfm?ID=211

34 Data of SCB quoted by KEMI (2005)

35 Preliminary unofficial data from Inger Lindqvist (KEMI)

the period 1993-2000 puts the reliability of data in question. Unfortunately, during the time of the study it was impossible to establish clear background and sources of these statistical data.

The national accounts on commodity trading (imports and exports) collected from SCB databases are rather ambiguous, too (table 6). For example, no explanation could be found on considerable fluctuations of trichloroethylene use during 1995-1997.

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Imports [t]	1,884	2,694	95	197	193	147	346	254	216
Exports [t]	1,466	1,277	51	2	8	17	22	11	36
Balance (consumption)	418	1,417	44	195	185	130	324	243	180

Table 6: Swedish total import and export of trichloroethylene[37]

The data on commodity trading are based on customs' information, assuming accurate and complete registration of all materials crossing the borders. One could speculate that this may not be the case. Also some Swedish companies using trichloroethylene do not have to apply for the exemption if they use trichloroethylene is used for R&D, analytical purposes or when it is produces as a by-product. However, according to KEMI[38], this consumption is negligible in comparison to degreasing. Other application of trichloroethylene, for example in glues and similar products (cf. table 7), is relatively small, too. Finally, it could be that, the use of trichloroethylene in the period 1996-1997 indeed dropped from 1'417 to 44 tons per year due to the introduction of the ban. Nevertheless, the explanations are rather speculative and require a more objective investigation.

The third source of statistics, the Nordic chemical register (SPIN) provides data on trichloroethylene volumes consumed for degreasing and as ingredient in adhesives, which also shows that degreasing is the major use of trichloroethylene (table 7). Unfortunately, this data is highly inconsistent with the previous two sources, where in some cases the annual use differs by the several factors and only in the resent years the figures are somewhat closer.

In spite of the questionable quality of statistics, all three sources indicate, that since the introduction of ban in 1996 the use of trichloroethylene in Sweden has been falling.

[36] Preliminary unofficial data from Margareta Östman (KEMI)
[37] SCB (2005). Statistics Sweden, import-export databases for the commodity KN-nr. 29032200 (trichloroethylene). URL: http://www.ssd.scb.se/ Data extracted 2005-08
[38] Personal communication (2005-09-12) with Mrs. Inge Lindqvist at National Chemicals Inspectorate

	Total use[39] [t]	Use for degreasing, cleaning or washing [t]	Used as adhesives, binding agents [t]
1999	1036 (41)	1022	8
2000	504 (38)	485	10
2001	381 (36)	365	12
2002	347 (30)	333	..
2003	270 (28)	261	7

Table 7: Use of trichloroethylene in Sweden in different applications

The empirical data on the equipment, trichloroethylene consumption and emissions were collected by interviewing 72 companies that still use trichloroethylene in their degreasing processes. The names of the companies were obtained from the list of companies which received exemption from the trichloroethylene ban from the Swedish Chemicals Inspectorate for the period 2005-2006 (cf. section 9.3 on page VII). The data were collected following a specifically developed questionnaire (cf. section 9.4 on page IX). Complementary interviews were held with other stakeholders, such as officials at the Swedish Chemicals Inspectorate, equipment manufacturers, experts in trichloroethylene use and equipment, and Consultants.

The survey of the equipment showed that among the 72 companies having a permit to use trichloroethylene, 11 companies are less relevant for the study (either stopped using trichloroethylene, use it in very small quantities, or use it as an ingredient in products, e.g. adhesives). Furthermore, 14 companies were unavailable for contact or simply refused to respond. The list of companies with a short description of equipment is provided in section 9.6 on page XI.

Among the interviewed companies in Sweden the following types of equipment for trichloroethylene degreasing could be observed (here, they will be labelled using the typology described in chapter 3):

Type I or II:

- “An open bath” – an open bath where work pieces are dipped into liquid trichloroethylene solvent in a basket. Such systems are totally open as all solvent vapours are vented directly into the working place without prior treatment/recuperation. In Sweden the use of this technology has been practically eliminated due to strict regulations on work environment and worker health and safety.

[39] SPIN (2005). In brackets: number of preparations, i.e. the total registered count of preparations containing the substance

Type III:

- “An open bath with ventilation hood” – similar to Type I and II with addition of extensive ventilation systems to vent out untreated vapours of trichloroethylene. The ventilation systems are typically overdimensioned in order to comply with the governmental requirements of 10 ppm limit concentration (8-hour limit) in the working premises. This type of equipment clearly dominates among small companies in Sweden.

Type IV A or B:

- “A half-open vapour degreaser” – a half-open system for vapour degreasing, where solvent vapour is condensed on work pieces placed into a condensation chamber and the rests is vented out into the air with (Type IV B) or without (Type IV A) vapour recuperation with e.g. active carbon filters. Such systems are considered half-open, since even with the use of carbon filters, there are significant material losses through ventilation. This is the second largest group of equipment currently used in Sweden. Most companies do have carbon filters in place for further on-site or off-site recuperation of trichloroethylene.

Type V:

- “Closed system” – the modern type of equipment with minimum losses to the atmosphere. The equipment in principle being similar to Type IV has advanced solvent vapour recovery systems and effective hermetisation to prevent solvent releases into the atmosphere. Only three companies were found to be using this type of equipment.

In total 47 companies provided information. About 85-90% of the companies use rather old equipment of the first type dated from 1970-1985. It has also been apparent that many interviewees could not provide specific information about the equipment, such as the model number, and could only indicate the approximate age and/or the name of the manufacturer.

Among the 47 companies, three use closed degreasing systems, 24 use open system equipment manufactured by Uddeholm AB, which in 1970-1980s was the dominant equipment provider in Sweden (further in the text referred as the “Uddeholm type” equipment) and 17 use open systems from other producers.

In many cases the interviewees stated that the equipment was running as a “closed system” pointing out that the open baths were closed during idling and off work modes.

In addition, many companies have made a number of add-ons, such as ventilation hoods to vent the vapours outside the premises and to protect the working environment. Follow up questions, however, revealed that in most cases the systems were not closed in a true sense, i.e. open baths were often exposed during loading/re-loading operations. Furthermore, the vapours were vented out into the air outside the buildings.

6.1.2. Illustrations of typical emissions for generic equipment types

In order to illustrate the ratios of emissions to air and other media from the two generic types of equipment, which are most prevailing in Sweden, two scenarios are made for the equipment Type III and Type IV B. Equipment Type V (closed systems) Which is similar to the typical equipment used in Germany it was not considered as a scenario. Only three companies use totally closed trichloroethylene degreasing systems (section 9.6) with the total consumption of less than one ton per year

Scenario I – open system, no recuperation of trichloroethylene vapours

This type of equipment operates on the principle of open degreasing cycle without filters and trichloroethylene vapour recuperation. These are the dominant systems produced by Uddeholm AB between 1960 and 1985. This scenario prevails among the majority of manufacturers. It was assumed that companies, which were not able to provide any data about the type or make of their equipment, were using open systems.

The typical trichloroethylene emission factor to air for the dominant type of equipment is 0.5-1.0 kg/m^2*hour under normal production conditions. Losses in the stand-by mode are significantly smaller.[40] If the baths in this equipment are not protected with lids during idling time and no vapour recuperation system is in place, the typical estimated components of trichloroethylene losses are the following:

[40] Personal communication (2005-08-31) with Mr. Anders Holm, retail, TEIJO AB, tel. 054-85 01 38

- 75% vented into air during operation.
- 5% vented into air during idling mode (the upper end of the range is for the not covered baths).
- 20% sent for destruction in form of spent solvent (trichloroethylene and oil) or in form of a mixture of trichloroethylene and oils. [41]

The idling mode is the time when equipment is not used (nights, weekends, etc.). The 5% losses in this mode may seem overrated knowing that in most cases the interviewed companies do close the baths (typically self-made lids with sealants). However, according to an expert[42], this type of prevention being not hermetic is not fully effective and trichloroethylene escapes due to cracks in old sealants, vapour pressure as well as during loading operations. Furthermore, in order to ensure the required limit of 10 ppm trichloroethylene in the premises, companies often add over-dimensioned ventilation equipment, which increases the losses. Also, in some cases the idling mode means that trichloroethylene solvent is kept just below the boiling point of 87^{o}C, which facilitates higher evaporation rates.[43] It could be assumed that in cases of very infrequent use (e.g. small companies using trichloroethylene machinery a few days per year) the loss of around 5% in idling is fairly likely.

With the typical emission rate of 0.5-1.0 kg/m^2*hour for the Uddeholm type of equipment, the evaporation rates further depend on the surface area of the baths. The surface area varies among the companies and data is largely unavailable. Typical surface area of 2 m^2 could be assumed for the Uddeholm type of machines.[44]

Scenario II – open system with recuperation of trichloroethylene vapours

This type of equipment operates on the principle of open degreasing cycle with active carbon filters to capture trichloroethylene vapours. The filters are later treated with steam or hot water to recuperate and re-distil captured trichloroethylene. In all cases observed companies have their own on-site recuperation systems and are able to re-circulate trichloroethylene for the same application.

[41] Personal communication (2005-08-31) with Mr. Anders Holm, retail, TEIJO AB, tel. 054-85 01 38
[42] Personal communication (2005-08-31) with Mr. Anders Holm, retail, TEIJO AB, tel. 054-85 01 38
[43] In these conditions "thermo wind" losses take place – when the lids are being opened to dip the pieces, it creates a micro-wind, estimated at double evaporation rate to 10% as compared to the "passive" evaporation of 5% under closed conditions giving an average concentration of 0.5 g/m^3.
[44] Personal communication (2005-08-31) with Mr. Anders Holm, retail, TEIJO AB, tel. 054-85 01 38

A fairly good information was obtained from the largest trichloroethylene consumer in Sweden.[45] This case is used as representative for scenario II. The information was obtained from interviews with company representatives.[46]

In 1990 this company had 18 operations using trichloroethylene with the total amount of around 100 tons/year. Already in 1990 they knew about the upcoming ban on trichloroethylene and started to phase it out by commencing a successful programme. At first they managed to reduce the need for trichloroethylene rather drastically, but later fewer and fewer improvements could be made. Today the company is close to the limit of what is possible to do to eliminate trichloroethylene use.

The main improvements since 1990 were of three kinds:

- Preventative – eliminating the need for trichloroethylene treatment, e.g. requesting deliveries of metal parts protected in other ways than oils (mainly powder protection).
- Alternative technologies - increasing the utilisation of the existing water-based degreasing and introducing three new water cleaning systems.
- Increasing the efficiency – improving degreasing operation using trichloroethylene.

Today trichloroethylene is used to degrease different products for civilian and military purposes. Interestingly no trichloroethylene-related operation has been outsourced. It did outsource the production of some products however, where trichloroethylene could be used by their suppliers, but this was not due to the ban.

For 2004-2005 this company has a permit to use 20 tons of trichloroethylene per year. In 2004 the company used 12.9 tons. Today three machines are in operation; all operated manually. In two of them trichloroethylene is heated by steam and in the third one – by electricity:

Machine 1 (bath 1.5 x 2.5 m):	"Perstorp AB" (1981)
Machine 2 (bath 1 x 4 m):	"Interkemek AB" (1981)
Machine 3 (?)	"Bycosin Teknik AB" (1984)

The mass balance of trichloroethylene consumption is calculated based on the total annual consumption of 12.9 tons in 2004. The losses of trichloroethylene take place due to the emissions into air, water and liquid waste (oil sludge).

[45] Company name is omitted for confidentiality reasons
[46] Personal Communication with chief machinery maintenance engineer and chief environmental officer of the company

Trichloroethylene losses to air in filter regeneration systems

All machines are fitted with active carbon filters and have trichloroethylene vapour recuperation systems, which are operating at 97-98% efficiency. Trichloroethylene vapours are captured, regenerated from filters and re-circulated back into degreasing operations. This allows reducing the use of virgin trichloroethylene. The total flow of circulated trichloroethylene is calculated from water re-circulation rates registered in process logs.

	No. of recirculation cycles	Amount re-circulated [kg/cycle]	Total [t]
M1	199	19.11	3.80
M2	2'644	5.88	15.55
M3	642	3.01	1.93
		Sum:	21.28

Table 8: The total flow of circulated trichloroethylene in 2004

Trichloroethylene losses are to air (open vent), water (filter regeneration) and sludge (spent trichloroethylene solvent with oils). At 97% recuperation efficiency the losses of trichloroethylene are 0.64 ton/year (3% of the 21.28 tons circulated).

Trichloroethylene losses to water in filter regeneration systems.

Some trichloroethylene is lost with the steam used for filter regeneration. Trichloroethylene emissions into water are based on the amount of water/steam pumped through the filters to regenerate and the average concentrations of trichloroethylene in the water.[47]

	Water volume [m^3]	concentration in water [g/ m^3]	losses with water [kg]
M1	147.50	30	4.43
M2	186.70	46	8.58
M3	161.00	56	9.02
		Sum:	22.03

Table 9: Trichloroethylene losses to water in filter regeneration systems

Trichloroethylene losses with the oil sludge

The losses of trichloroethylene with the sludge are estimated based on typical oil content in spent trichloroethylene solvent. At the boiling point of 87°C trichloroethylene is 100% pure. The solvent is changed at 90°C (maximum allowed is 92°C), which corresponds to 30% oil contamination in the spent solvent. The total weight of sludge

[47] Note: the water solubility of trichloroethylene at 25°C is 1.1 g/l. The concentrations indicated in the table are much smaller, which is perhaps due to possible reduction by e.g. air-stripping, coal filters with absorption or other similar technology practiced at the company. During the time of the study the authors did not have the possibility to verify this issue.

produced is 3.4 tons/year. The total weight of oils in the sludge is 1.02 ton (30% of the 3.4 ton oils). The rest is the amount of trichloroethylene in the sludge - 2.38 ton. The total trichloroethylene mass balance is presented in the table below.

Input [kg]		Output [kg]	% of input
12,900	Air	9’855.6	76.40%
	Water	25.9	0.20%
	Sludge (recycled) 30% oil concentration	2’380.0	18.45%
	Vapour recovery losses to air (at 97% recovery efficiency)	638.5	4.95%

Table 10: The total trichloroethylene mass balance

The case of this large manufacturing company in the Swedish machine building sector indicates that even in the second type of equipment the bulk of trichloroethylene losses (75-80%) are to the air and the rest is liquid waste, which potentially is possible to recycle. Whether recycling takes place or not depends on recycling costs versus destruction costs. The choice of treatment alternative depends on the total volume of liquid waste.

6.1.3. Alternatives solutions to trichloroethylene use in Sweden

From the interviews with the Swedish companies it also became apparent that the main information channels for finding trichloroethylene alternatives are chemical suppliers and equipment providers, while information from authorities is almost non-existent.

In the aftermath of the ban, a large number of companies phased out trichloroethylene completely, outsourced trichloroethylene-dependant operations abroad or found substitute chemicals and technologies. In cases where no alternatives could be found (to be proven to the Chemicals Inspectorate), companies applied to permits. In response to the requirement to show progress in phasing out trichloroethylene, some companies increased the efficiency of trichloroethylene use or installed closed-loop systems for trichloroethylene vapour recuperation and sometimes on-site or off-site sludge recycling. In Sweden a fair portion of trichloroethylene goes to destruction by waste management companies.

The reduction of trichloroethylene use was achieved by almost all large companies and a fair number of small enterprises. Larger industries either made adjustments in process or product design that reduce or eliminate the need for trichloroethylene use or found alternative degreasing methods. For example, the strategy of the company described in Scenario II was to phase out trichloroethylene long before the introduction of the ban by means of substitution, efficiency improvements and technology innovation. The estimated R & D costs incurred by the company were about € 1.1 million.

The alternatives to trichloroethylene could be found among water-based solvents, low-, middle- and high-alkali solvents, low-aromatic carbon-hydrogen, ethyl lactate and glycol ether. Some companies could switch from greasing with hard grease types to more liquid oils that do not need trichloroethylene for degreasing. It is considered technically feasible to degrease with propylenglycolethers, which have a degreasing effect (quality) similar to trichloroethylene. However, these technologies often prove to be too expensive.

Because of quality requirements it is not possible today to phase out trichloroethylene completely. Trichloroethylene is often the only chemical delivering high quality degreasing with feasible costs. Alternative products often are not able to achieve high performance, which is typical when treating small work pieces with complicated shapes and cavities or when work pieces must be glued together, which requires totally oil-free surfaces.

Finally, many companies, which could consider investments in new technologies, are afraid to do so, because there is a shared fear that substance regulations similar to the ban will be proliferated to other chemicals. The mere words “solvent-based degreasing technologies”, irrespective which solvent is used, raise doubts and uncertainty to many Swedish manufacturers.[48]

[48] Personal communication (2005-10-07) with Mr. Anders Holm, retail, TEIJO AB, tel. 054-85 01 38

6.2. Empirical data for Germany

Year	Consumption of trichloroethylene [t]	Consumption of trichloroethylene in metal-degreasing [t]	Fraction used in metal-degreasing	Emission-factor
1982	42'000[49,50]			90%[51]
1983	39'000[49,50]			
1984	43'000[49,50]			
1985	34'000[49,50]			
1986	30'000[49,52 ,50]		90%[53]	
1987	25'000[49,50]			
1988	22'000[49,50]			90%[54]
1989	18'000[49,50]			90%[54]
1990	14'000[49,52,55]			
1991	10'500[49]			
1992	10'000[49, 52]	7'100[56]	66%[57]	
1993	8'500[49] 9'000[55]			
1994	7'000[49,55]	5'216[59]	68%[58]	39%[59]
1995	5'000[52] 7'000[49,55]			
1996	6'700[49] 8'200[55]	7'000[59]	45%[60]	1%[59]
1997	6'000[49]	7'000[59]		1%[59]
1998	4'500[49]			
1999	5'000[49]		16%[61]	
2000	5'000[49, 52]			
2001	4'400[49, 52]			
2002	4'200[52]		36%[62]	
2003	4'000[52]		38%[62]	
2004			39%[62]	
2010 (est.)	4'000[52]			

Table 11: Consumption and emission of trichloroethylene in Germany

Table 11 gives an overview of the amounts for trichloroethylene consumption and emission from different sources. The data in columns two and three can easily be identified from sales figures, column four is the ratio derived from column two and

[49] Von Grote (2003), 19
[50] BUA (1993), 31
[51] Fachgruppe (1987)
[52] Fax from Safechem Europe GmbH on August 2nd 2005
[53] BUA (1993)
[54] BUA (1993), 42
[55] UBA (1998) Stoffband B, 10
[56] UBA (1998) Stoffband B, 11
[57] BUA (1999)
[58] Scholl et. al. (1996)
[59] UBA (1998) Stoffband B, 42
[60] Adams (1997)
[61] Nader (2001)

column three. The fifth column shows the emission-factor, i.e. how much of the trichloroethylene that is used in metal-degreasing evaporates into the atmosphere. These average emission-factors can be calculated from the train of machines (section 9.5 on page X).

The large reduction in the use of trichloroethylene in metal-degreasing was mainly caused by two factors. On the one hand, several smaller degreasing machines were sometimes substituted by one new machine after the introduction of the 2nd BImSchV which also lead to fewer emissions. On the other hand, the substitution of halogenated solvents for aqueous cleaning systems turned out to be the cheaper solution in most cases.[63]

Size	Length [mm]	Breadth [mm]	Height [mm]	Volume [m³]	Load [kg]
1	370	220	200	0.016	45
2	530	320	200	0.034	55
3	660	480	300	0.095	135
4	1’200	850	500	0.510	600
5	3’000	1’000	1’000	3.000	1’000

Table 12: Dimensions of machines[64]

To calculate the emission-factor for e.g. 1985, a weighted average - regarding the different loads the machines can handle - must be calculated. The emission-factor will be higher if the older machines in use have bigger loads than the new ones and vice versa. There were - among others – 1’133 machines of type I A (cf. section 9.5) with a maximum load of 45 kg (cf. table 12) and one machine of type IV B with a maximum load of 135 kg active in 1985. Altogether the machines had a load of 731’550 kg[65] in that year.

The emission-factor for the year 1985 can be calculated as:

$$\frac{1'133 \cdot 45kg \cdot 92\% + ... + 1 \cdot 135kg \cdot 28\%}{731'550kg} = 88.86\%$$

Average emission-factors for the other years can be calculated in the same way. Results are shown in table 13.

[62] Own calculation from a survey among 29 German merchants (9 replies for 2002, 15 for 2003, and 16 for 2004)
[63] Jacob (1999), 27
[64] Von Grote (2003), 156
[65] If all machines are used for one cleaning process, 731’550 kg of greasy metal-parts could be cleaned. It is not important to know, how often the machines were running in 1985 in order to calculate an average emission-factor, as long as the presumption holds that they were all more or less working to the same capacity. The factor may be overestimated: If machines are run at different intensity, it will surely be the newer machines that are used more frequently.

From 1990 on, only type V machines were allowed. The emission-factors for 1991 and 1994 are way greater then 1 % because German authorities had not insistently enforced the new rule.[66]

	Average emission-factor
1982	90%[51]
1985	89%[67]
1988	90%[54]
1989	90%[54]
1991	41%[67]
1994	39%[59]
1996	6%[67] 1%[59]
1997	1%[59]
1999	1%[67]

Table 13: Average emission-factors for Germany

From 1999 on, the average emission-factor is assumed 1 %. Further improvements in machine technology might lead to further reduction.

[66] UBA (1998), Stoffband B, 41-42
[67] Own calculations

7. Conclusion

Situation 1993

In 1993, a total amount of 9’000 tons of trichloroethylene was used for various purposes in Germany. From this quantity, about 6’120 tons were used for degreasing in Germany. In Sweden, around 2’125 tons were used, but statistics on the use of trichloroethylene in Sweden are rather ambiguous and there is no earlier data available.

The train of machines in use for metal-degreasing in Germany in 1993 caused emissions of about 41 % of the solvent used whereas the average emission-factor for Sweden is still above 75 % today. The scenario for Sweden was estimated for one of the large manufacturing companies in the Swedish machine building sector, whose newest machine dates from 1984. Other Swedish enterprises are mostly working with older and less effective equipment. Therefore, one can take an emission-factor of 90 % as the maximum limit.

The emissions of trichloroethylene which result from metal-degreasing amount to 2’510 tons in Germany and something between 1’600 and 1’900 tons in Sweden, depending on the average emission-factor.

In Germany, the added value of the metal-industry in 1993 amounted to € 103’838 million. In contrast, Sweden’s metal-industry was almost 14-times smaller with a value added of € 7’652 million in 1993. Germany’s metal-industry produced 24 tons of emission for every billion Euro of value-added and Sweden’s metal-industry emitted at least 209 tons of trichloroethylene respectively.

Hypothetically setting equal the value added in the metal-industry in Germany and Sweden, Swedish legislation in 1993 – before the ban – led to almost nine times higher emission of trichloroethylene.

Situation 2003

In 2003, about 1’500 tons of trichloroethylene have been used for degreasing in Germany and up to 260 tons have been used for degreasing in Sweden. The train of machines that is in use for metal-degreasing in Germany today causes emissions of about 1 %.

The emissions of trichloroethylene which result from metal-degreasing amount to 15 tons in Germany and something between 135 and 234 tons in Sweden.[68]

In Germany, the value added of the metal-industry in 2002 amounted to € 116'384 million. Swedish metal-industry produced a value added of € 11'607 million in 2002. Assuming that this relation has not changed significantly, German metal-industry now produced 0.13 tons of emission for every billion Euro of value-added and Swedish metal-industry emitted at least 11.6 tons of trichloroethylene for every billion Euro of value-added.

Again setting equal the value added in the metal-industry in Germany and Sweden, Swedish legislation today leads to a 90 times higher emission of trichloroethylene. Out of these, 83 % are due to outdated equipment, the remaining difference results from greater use of trichloroethylene per Euro of value-added.

The reduction of emissions per value added in the metal-industry within ten years has been about 90 % in Germany, whereas the Swedish ban has only lead to a reduction of about 35 % in the best case. So the regulatory instruments have led to a different response than might have been anticipated.

For the emissions inside the premises which are considered more relevant for the health of the workers who are most exposed than the exhaust emissions into open air a quantitative comparison of Germany and Sweden is hardly possible, again due to meagre Swedish data.

Most of the - overall rather low - emissions in Germany are diffuse emissions at the working place, a minor part stems from recycling.[69]

Estimates for Sweden are rather difficult as old machines have been upgraded with lids and ventilation systems. Empirical studies however have shown that the workers' risk of high exposure to trichloroethylene is clearly linked to the equipment in use. The effectiveness and efficiency improvements in risk management when substituting outdated type III and type IV machines – which are common in Sweden today – with modern type V machines is enormous,[65] but of course requires a sound basis to bear the economic risks.[70]

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[68] 135 tons of emissions stem from the assumption that only 180 tons of solvent had been applied and that the emission-factor is 75 %. 234 tons of emissions stem from the assumption that 260 tons had been used and that the emission-factor is 90 %.

[69] UBA (1998) Stoffband B, 41

[70] Von Grote (2003), 57-65, especially figures 4.9 and 4.11

A ban clearly impairs this economic incentive. To still observe Swedish working place emission limits, Swedish companies installed additional ventilation systems, which in turn increase the draft of the vapours to the environment. Primarily, emissions inside the premises are substituted for emissions into open air, which clearly is not the most effective way to reduce possible noxious effects of trichloroethylene on both workers and the environment.

Furthermore, these ventilation systems lead to an increase in trichloroethylene consumption, which might be a reason that Swedish companies argue that restrictions on emission levels of trichloroethylene in the working environment would be much more welcome and effective than the ban, which takes away the economic sustainability of investing in equipment substitution.

Of the two legislative approaches analysed in this study, German law leads to more favourable ecological results and has at the same time effectively and efficiently reduced workplace exposure. This case study suggests, that the Germany legislation regulating the use of trichloroethylene which uses a consistent set of regulatory instruments including, as appropriate, standards for best available technologies and techniques to stimulate an active, adequate risk management and the willingness to invest, should be considered as an example for future European legislation for comparable cases.

8. References

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9. Appendices

9.1. List of figures

9.2. List of tables

9.3. Companies with exception from the trichloroethylene ban

	Period	Company	Telephone nr	Location
1.	2005-12-31	GMK AB	0980-617 14	KIRUNA
2.	2005-12-31	Metso Minerals (Kiruna) AB	040-24 32 84	STAFFANSTORP
3.	2005-12-31	MIP Technologies AB	046-286 37 80	LUND
4.	2005-12-31	Metso Minerals (Sweden) AB	040-24 32 84	STAFFANSTORP
5.	2005-12-31	Transportbandföretagens Riksförbund (TBR)	08-440 11 70	STOCKHOLM
6.	2006-12-31	Ulvsunda Industrilackering AB	08-26 01 37	BROMMA
7.	2005-12-31	SSAB Oxelösund AB	0155-25 56 69	OXELÖSUND
8.	2005-12-31	Guson Industri AB	031-14 44 45	GÖTEBORG
9.	2005-12-31	Industripolyuretan AB	0501-279440	MARIESTAD
10.	2005-12-31	Opcon AB	0532-611 27	ÅMÅL
11.	2005-12-31	S.I.G AB	031-44 44 85	PARTILLE
12.	2005-04-30	Henrikssons Lackcenter AB	0243-181 21	BORLÄNGE
13.	2006-12-31	Danielsson Sverige AB	0498-20 54 24	VISBY
14.	2006-12-31	Bendiro i Falkenberg AB	0346-71 43 40	FALKENBERG
15.	2006-12-31	PIAB AB	0684-155 61	HEDE
16.	2006-12-31	Olsbergs Hydraulics AB	0381-150 75	EKSJÖ
17.	2006-12-31	Weland AB	0371-344 00	SMÅLANDSSTENAR
18.	2006-12-31	Leba Industriservice AB	0370-37 32 00	HILLERSTORP
19.	2006-12-31	Hagab Industri AB	036-36 30 90	TABERG
20.	2006-12-31	Prinsfors Metallfabrik AB	036-37 10 80	BANKERYD
21.	2006-12-31	Westal AB	036-37 71 90	BANKERYD
22.	2006-12-31	Anti-Corr i Sävsjö AB	0382-61 380	SÄVSJÖ
23.	2005-12-31	AB Tranås Skinnberedning	0140-100 50	TRANÅS
24.	2005-12-31	Bjädes Mekaniska AB	0383-349 98	EKENÄSSJÖN
25.	2006-12-31	Ramos Snickeri AB	0480-155 10	KALMAR
26.	2006-12-31	Lectus Office AB	0499-448 40	MÖNSTERÅS
27.	2005-12-31	Ankarsrum Die Casting AB	0490-533 60	ANKARSRUM
28.	2006-12-31	Backer BHV AB	0451-662 73	SÖSDALA
29.	2006-12-31	Bjärnums Stålprodukter AB	0451-77 58 50	BJÄRNUM
30.	2006-12-31	Jensens Svartoxidering KB	040-18 18 78	MALMÖ
31.	2006-12-31	Löfa, AB	08-580 311 60	JÄRFÄLLA
32.	2006-12-31	Saab Tech Electronics AB	08-580 840 00	JÄRFÄLLA
33.	2006-12-31	Combi-Lack AB	08-647 60 03	BANDHAGEN
34.	2006-12-31	Edquist Lack AB	08-361 756	SPÅNGA
35.	2006-12-31	AB Stockholms Industrilack	08-749 10 55	BANDHAGEN
36.	2005-12-31	S-E-G Instrument AB	08-764 74 00	BROMMA
37.	2005-12-31	Dentatus AB	08-546 509 32	HÄGERSTEN
38.	2005-09-08	JH Automatlådor	08-668 33 11	STOCKHOLM
39.	2005-12-31	AGA Gas AB	08-706 95 49	SUNDBYBERG
40.	2005-12-31	Ställspecialisten HSH AB	08-97 68 00	TUMBA
41.	2006-12-31	Calibra AB	08-404 14 80	BROMMA
42.	2006-12-31	Väsby Ytförädling AB	08-590 875 05	UPPLANDS VÄSBY
43.	2006-12-31	ALAB Anders Johanssons Lack AB	08-511 729 30	VALLENTUNA
44.	2006-12-31	PIAB Sweden AB	08-540 839 00	ÅKERSBERGA
45.	2006-12-31	AB Fas Låsfabrik	016-17 02 10	ESKILSTUNA
46.	2005-12-31	Preciform AB	016-10 80 70	ESKILSTUNA

47.	2006-12-31	G G Widlund AB	016-130 736	ESKILSTUNA
48.	2005-12-31	Silver & Stål i Vingåker AB	0151-511576	VINGÅKER
49.	2006-12-31	Robust Ståldörrar AB	0590-187 00	NYKROPPA
50.	2006-03-30	Harry Holms AB	0563-533 50	MUNKFORS
51.	2006-12-31	Assa Industri AB	0950-231 32	LYCKSELE
52.	2006-05-31	BEGAB Ångpannerengöring AB	070-727 21 80	SKARA
53.	2006-12-31	Formgummi i Ramvik, AB	0612-408 80	RAMVIK
54.	2005-12-31	Kanthal AB	0220-210 00	HALLSTAHAMMAR
55.	2006-12-31	SGV, Skultuna Gnosjö Verkstads AB	021-783 53	SKULTUNA
56.	2006-12-31	Elenco Lighting AB	033-10 24 65	BORÅS
57.	2006-12-31	Svenska Rakbladsfabriken AB	0514-100 68	GRÄSTORP
58.	2006-12-31	Avancerad Industrilackering i Göteborg AB	031-54 20 35	GÖTEBORG
59.	2006-12-31	Mekosmos AB	031-87 65 25	KÅLLERED
60.	2005-12-31	SYART	070-645 78 49	LÄNGHEM
61.	2006-12-31	N-Products AB	0586-450 00	DEGERFORS
62.	2006-12-31	Nammo LIAB AB	0581-871 98	LINDESBERG
63.	2005-12-31	Saab Bofors Dynamics AB	0586-830 55	KARLSKOGA
64.	2006-12-31	Metallfabriken Ljunghäll AB	0492-166 95	SÖDRA VI
65.	2006-12-31	Aerotech Telub AB	013-23 14 02	LINKÖPING
66.	2006-12-31	Korroterm, AB	031-742 54 03	LINGHEM
67.	2006-12-31	Lundberg, AB Kurt	013-10 31 80	LINKÖPING
68.	2005-12-31	Saab AB	013-18 22 73	LINKÖPING
69.	2006-12-31	Galfa AB	0141-20 95 70	MOTALA
70.	2005-12-31	Electrolux Home Products Operation (Sweden)	0141-23 80 00	MOTALA
71.	2006-12-31	Förnicklingsfabriken A. Brink AB	011-21 96 90	NORRKÖPING
72.	2005-12-31	Holmbo Production AB	0123-29 550	VALDEMARSVIK

Source: KEMI (2005)
Internet: URL: http://www.kemi.se/upload/Företag/Docs/DispenserTri_Metylenklorid200506.xls

9.4. Questionnaire used in the interviews.

1. What are the consequences of the ban for your company (in terms of costs and technology changes)?
2. How much trichloroethylene do you purchase every year?
3. What is the actual annual use of trichloroethylene (purchased minus emitted and wasted)?
4. In what processes or equipment do you use trichloroethylene? Which one is the largest trichloroethylene user?
5. What kind of equipment is used in these processes? How old is it?
6. Do you measure the efficiency of trichloroethylene use? How? (e.g. per unit operation, per product)
7. What is the typical rate of trichloroethylene consumption in this equipment (e.g. kg/hour)?
8. How much of trichloroethylene is emitted to air/water per year in the company as a whole and from individual equipment?
9. How much of trichloroethylene is left over every year and do you have to dispose it off? If yes, how?
10. Could you compare trichloroethylene consumption before and after the ban? How did you reduce it?
11. Has your company phased out trichloroethylene from some of the processes already? How? (e.g. new equipment bought or new chemical substitutes found)
12. Are there alternative materials or technologies to trichloroethylene that is still used in your company? What are they? What are the reason(s) for not using them?
13. Are you planning to phase out trichloroethylene in the near future? How?
14. Would it be better for your company, if the ban was substituted with strict trichloroethylene air emission standards and requirements for trichloroethylene recuperation and recycling schemes?

9.5. Degreasing equipment using trichloroethylene in Germany

		Number of machines			
Machine type	**Sizes**	**1985**[71]	**1991**[72]	**1996**[73]	**1999**[74]
IA	1	1'133	342		
	2	117	35		
	3	96	29		
	4	39	12		
	5	5	2		
IB	1	1'133	343		
	2	117	35		
	3	95	29		
	4	38	12		
	5	4	1		
IIA	1	0	5		
	2	354	19		
	3	298	23		
	4	268	8		
	5	30	1		
IIB	1	0	5		
	2	354	19		
	3	297	23		
	4	268	8		
	5	29	1		
III	1	14	46		
	2	57	188		
	3	71	234		
	4	25	82		
	5	3	10		
IVA	1	10	14		
	2	41	56		
	3	10	70		
	4	0	25		
	5	0	3		
IVB	1	1	14	15	
	2	5	56	59	
	3	1	70	74	
	4		25	26	
	5		3	3	
VA	1		23	45	17
	2		93	179	67
	3		117	223	83
	4		41	79	30
	5		5	10	4
VB	1			15	8
	2			59	33
	3			74	42
	4			26	15
	5			3	2
		4'913	2'127	890	301

[71] Adams, Jeker (1986), 1-12. Only West Germany
[72] Adams (1993). Only West Germany
[73] Adams (1997), 1-17
[74] von Grote (2003), 168

9.6. Degreasing equipment in the interviewed Swedish companies

Nr	Company code*	Use [kg/year]	Comment	Equipment description	Equipment maker/make	# of machines	Type[75]
1	A.	0	No, trichloroethylene, an alternative found		n.a.	0	n.a.
2	B.	0	No degreasing, gluing		n.a.	0	n.a.
3	C.	0	<1 litre/year		n.a.	0	n.a.
4	D.	0	No degreasing, gluing		n.a.	0	n.a.
5	E.	0	No, trichloroethylene, an alternative found		n.a.	0	n.a.
6	F.	3'000		Uddeholm type produced in the early 1980s	Uddeholm AB	1	Type III
7	G.	0	No, trichloroethylene, an alternative found		n. a.	0	n.a.
8	H.		*No information*		?	?	
9	I.		*No information*		?	?	
10	J.	1'500		Uddeholm type from 1980s, encapsulated, semi-open, ventilation	Uddeholm AB	1	Type IV A
11	K.	0	No degreasing, gluing		n.a.	0	n.a.
12	L.	800		One semi-open bath with lock from late 1980s	Interkemek AB	1	Type IV A
13	M.		*No information*		?	?	
14	N.	200		Closed system from 1980s, large modifications, with "only 0.1% emissions"	*Unknown*	1	Type V
15	O.	0	No degreasing, gluing		n.a.	0	n.a.
16	P.	?		Closed system with chemical management services contracted	*Unknown*	1	Type V
17	Q.	500		No information	*Unknown*	1	*unknown*
18	R.		*No information*		?	?	
19	S.		*No information*		?	?	
20	T.	250		Uddeholm type machine from late 1980s with 3 baths, "special ventilation systems added"	Uddeholm AB	1 with 3 baths	Type III

[75] The type is placed to a large degree arbitrarily by the authors, owing to the lack of more detailed description of the existing equipment.

Nr	Company code*	Use [kg/year]	Comment	Equipment description	Equipment maker/make	# of machines	Type[75]
21	U.	1’500		Uddeholm type from late 1970s early 1980s	Uddeholm AB	1	Type ?
22	V.		*No information*		?	?	
23	W.	0	No trichloroethylene, but PER		n.a.	0	n.a.
24	X.	400		Uddeholm type from late 1980s, “semi-open” with modifications to close open baths	Uddeholm AB	1	Type III
25	Y.		*No information*		?	?	
26	Z.	2’000		Unkown type equipment from 1980s, from Uppsala, semi-open system with ventilation	*unknown*	1	Type III
27	AA.	2’000		Unknown type from 1970s by Tigerström, with coal filters and vapour recuperation at 85% efficiency rates	*Unknown*	1	Type IV B
28	BB.	4’500		Uddeholm type, late 1970s, 2 semi-open baths with lock and ventilation system	Uddeholm AB	2	Type III
29	CC.	1’000		Uddeholm type from late 1970s, open bath, no changes, all to air	Uddeholm AB	1	Type I-II
30	DD.	1’500		Uddeholm type from 1950s, steam degreasing, bath 5m^2, ventilation system	Uddeholm AB	1	Type IV A
31	EE.	500		Uddeholm type from the late 1970s	Uddeholm AB	1	Type ?
32	FF.	160		Unkown type, one semi-open machine from the mid-1990s	*Unknown*	1	Type ?
33	GG.	1’000		Unkown type, Swedish machine, 10 year old, with TCE vapour recuperation system	*Unknown*	1	Type IV A
34	HH.	1’500		Unkown type, one 10 years old machine with semi-open bath and a lid	*Unknown*	1	Type III
35	II.	1’500		Unkown typ, semi-open machine from 1990s, bath with added lid	*Unknown*	1	Type III
36	JJ.	50		Uddeholm type, 15 years old, semi-open with lid, encased for vacuum conditions	Uddeholm AB	1	Type III
37	KK.	300		Uddeholm 1972	Uddeholm AB	1	Type I-II
38	LL.	350		Uddeholm 1962	Uddeholm AB	1	Type I-II
39	MM.	0	No, trichloroethylene, alternative found		n.a.	0	n.a.
40	NN.	300		Unknown type from 1970s open bath with lids	*Unknown*	1	Type III

Nr	Company code*	Use [kg/year]	Comment	Equipment description	Equipment maker/make	# of machines	Type[75]
41	OO.	500		Uddeholm 1977 /no more details/	Uddeholm AB	1	Type ?
42	*PP.*		*Refused to talk*		?	?	
43	QQ.	1’500		Open cycle machine from 1985-86 manufactured by Swedish company	Interkemek AB	1	Type IV A
44	RR.	200		Unknown type "very old" open cycle machine	*Unknown*	1	Type ?
45	SS.	800		Uddeholm type form 1970s	Uddeholm AB	1	Type
46	TT.	880		Uddeholm type from 1980s (Apoca 18kW 70-150 08.2000) open system, air cooled vapour condenser and vapour recuperation	Uddeholm AB	1	Type IV B
47	UU.	900		Unknown type, "one very old open bath produced in Sweden"	*Unknown*	1	Type III?
48	VV.	3’000		Uddeholm type from 1973, model (UHB 321985), open bath with lids	Uddeholm AB	1	Type III?
49	WW.		*No information*		?	?	
50	XX.	0	No degreasing, additive to plastics		n.a.	0	n.a.
51	YY.	1’500		Uddeholm type, unknown age, one machine, open system with three heating elements, one of them keeps the idling mode (constant evapouration)	Uddeholm AB	1	Type IV A
52	ZZ.	600		Unknown type, self-produced open system	*Unknown*	1	Type I-II
53	AAA.	800		No machine just bath even without heating	n.a.	n.a.	Type I
54	BBB.	500		Uddeholm type from 1970s, “semi-closed” (open baths with lids and vapour recuperation)	Uddeholm AB	1, ? baths	Type IV A
55	CCC.		*No information*		?	?	
56	DDD.		*Refused to talk*		?	?	
57	EEE.	440		Uddeholm type from 1975 with lids, no vapour recuperation, no filters	Uddeholm AB	1, Baths?	Type IV
58	FFF.	400		Uddeholm type, unknown age ("very old"),open bath with lids	Uddeholm AB	1	Type III
59	GGG.	100		TEIJO machine (Germany) from 1995, closed	TEIJO AB	1	Type V
60	HHH.	500		Uddeholm type form 1977, model Nr. 010596 (15kW volume 1,165 litres)	Uddeholm AB	1	Type III
61	III.	300		Unknown type, open system, "very old"	*Unknown*	1	Type ?

Nr	Company code*	Use [kg/year]	Comment	Equipment description	Equipment maker/make	# of machines	Type[75]
62	JJJ.		*No information*		?		
63	KKK.	0	No degreasing, additive		n.a.	0	n.a.
64	LLL.	2’500		BEKOSIN machine (Sweden) "generation III" from 1982-84, filters and vapour recuperation	BEKOSIN	1	Type IV B
65	MMM.	3’500		Unknown type, unknown age, machine with vapour recuperation system	*Unknown*	1	Type IV B
66	NNN.	1’000		Uddeholm type from 1984, semi-closed system with hoods for venting out, coal filters and vapour recuperation	Uddeholm AB	1	Type III
67	OOO.	200		Uddeholm type from 1977, standard, no filters, no vapour recuperation	Uddeholm AB	1	Type III
68	PPP.	12’900	3 machines:	Perrstorp, Interkemek (Uddeholm), Bycosin Teknik AB, 2 open (1981), 1 semi-open (1984)	Uddeholm AB	3	Type IV B
69	QQQ.			Interkemek Teknik AB (Sweden) 10-15 years, semi-closed, rebuilt	Interkemek AB	1	Type IV A/B?
70	RRR.	0	No, trichloroethylene, alternative found		n.a.	0	n.a.
71	SSS.	0	No degreasing, sales of trichloroethylene		n.a.	0	n.a.
72	TTT.		*No information*		?	?	
Sum:		57’380					

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V-22-00 Carsten Eckel - Labor Market Adjustments to Globalization: Unemployment versus Relative Wages

V-23-00 Klaus Beckmann - Tax Competition through Tax Evasion

V-24-01 Klaus Beckmann - Steuerhinterziehung, begrenzte Rationalität und Referenzabhängigkeit: Theorie und experimentelle Evidenz

V-25-01 Klaus Beckmann - Solidarity, Democracy, and Tax Evasion: an Experimental Study

V-26-04 Michael Fritsch, Udo Brixy und Oliver Falck - The Effect of Industry, Region and Time on New Business Survival - A Multi-Dimensional Analysis

V-27-04 Gerhard D. Kleinhenz, Bevölkerung und Wachstum - Die Bevölkerungsentwicklung in Deutschland als Herausforderung für Wirtschafts- und Sozialpolitik

V-28-04 Johann Graf Lambsdorff - The Puzzle with Increasing Money Demand - Evidence from a Cross-Section of Countries

V-29-04 Frauke David, Oliver Falck, Stephan Heblich und Christoph Kneiding - Generationsgerechtigkeit und Unternehmen

V-30-04 Roland Engels† - Zur mikroökonomischen Fundierung der Geldnachfrage in allgemeinen Gleichgewichtsmodellen

V-31-05 Johann Graf Lambsdorff - Between Two Evils – Investors Prefer Grand Corruption!

V-32-05 Oliver Falck - Das Scheitern junger Betriebe – Ein Überlebensdauermodell auf Basis des IAB-Betriebspanels

V-33-05 Raphaela Seubert – On the Nature of the Corrupt Firm: Where to Situate Liability?

V-34-05 Johann Graf Lambsdorff – Consequences and Causes of Corruption – What do We Know from a Cross-Section of Countries?

V-35-05 Stephan Heblich - Arbeitszeitflexibilisierung Revisited

V-36-05 Oliver Falck und Stephan Heblich - Das Konzept der eigenverantwortlichen Generation zur Bewältigung des demographischen Wandels