Transition to chlorine free pulp!

Experiences from the Swedish pulp and paper industry in contrast to the U.S.

Ann-Kristin Bergquist, department of Geography and Economic History, Umeå University, Sweden

Kristina Söderholm, department of Business Administration, Technology and Social Sciences, Luleå university of technology, Sweden

Abstract

In 1985, the U.S. Environmental Protection Agency (EPA) detected low concentrations of dioxins in fish caught downstream a few paper mills. It was not previously known that those extremely toxic highly chlorinated hydrocarbons could be formed in the manufacturing of paper. In both the U.S. and in Sweden the pulp and paper industry together with environmental authorities immediately started to investigate the formation of dioxins in pulp mills. Two years later, in September in 1987, the US EPA announced the results of the investigation to the public, i.e., dioxins had been detected in pulp mill effluents, in fish caught downstream from the pulp mills, and in various bleached paper products. The EPA report raised the issue of bleached pulp on public and governmental agendas throughout the world and consumers began to ask for chlorine-free paper.

Although both North American and Swedish firms were exposed to the dioxin alarm simultaneously, Swedish (and Scandinavian) firms would lead and move ahead U.S. firms in the transition towards chlorine-free pulp bleaching. Oxygen delignification, the core technology to implement elementary chlorine free bleaching, was first developed and commercially operative in Sweden. It was also Swedish mills that developed and commercialized total chlorine free bleached pulp. According to previous research, this was mainly due to a new green (primarily German) market for the Scandinavian firms in the late 1980s, for chlorine-free pulp. In this paper, we argue that the explanation behind why Swedish companies were at the forefront in the production of chlorine-free paper must be sought deeper than in changing market demands in the late 1980s. By focusing on the pollution control strategies of Swedish pulp and paper firms in the 1970s, and by contrasting them to U.S. strategies, we will try to show how the regulatory framework, in tandem with business strategies, came to foster initial knowledge development and technological approaches that had implications for the potential to respond to the dioxin alarm and subsequent regulatory measures in the late 1980s.

1. INTRODUCTION

In 1985, the US Environmental Protection Agency (EPA) detected dioxins in fish caught downstream a few paper mills. The concentrations were low, but dioxins, which are the name of a group of highly chlorinated hydrocarbons, are extremely toxic. It was previously known that dioxins could be formed. That dioxins could be formed in the manufacturing of paper was however a novelty. The U.S. paper industry immediately started up further investigations together with the US EPA. At the same time in Sweden, both industry and authorities started to study the formation of dioxins in pulp mills. The results were unambiguous. In the sewage from factories producing bleached chemical pulp – but not unbleached – dioxins were found in measurable levels.[1] Finally, in September in 1987, the US EPA announced public that dioxins had been detected in pulp mill effluents, in fish caught downstream from the pulp mills as well as in various bleached paper products such as diapers, coffee filters and milk cartons.[2] Because of the high toxicity of dioxins, the EPA report raised the issue of bleached pulp on both public and governmental agendas throughout the world. Regulatory processes were initiated in pulp producing countries and consumers, essentially the European market, began to ask for chlorine-free paper.

Prior studies noticed that Sweden came to lead the way in the new green market for non-chlorine pulp that emerged after the dioxin alarm in the late 1980s.[3] Two alternative bleaching technologies – where chlorine (Cl_2) was replaced as bleaching agent – entered the market: elemental chlorine free (EFC) and total chlorine free (TCF).[4] Oxygen delignification, the core technology to implement the alternative bleaching technologies was first developed and commercially operative in Sweden. It was also Swedish mills that developed and commercialized TCF-pulp. Moreover, the replacement of chlorine-based bleaching was very fast in the Scandinavian countries while it was rather slow in North America.[5] This paper deals with the question why Swedish firms came to lead the way in the transition to alternative bleaching processes and production of chlorine-free pulp and paper and we will contrast the Swedish development with experiences from the U.S. Unlike prior studies we will seek more historical explanations to why Swedish firm came to move ahead U.S. firms in the transition towards chlorine-free bleaching, even though the dioxin alarm affected both countries simultaneously. We will specifically study the pre-conditions for the rapid technological transformation within the Swedish pulp industry, a knowledge development that was initiated much earlier than previous studies has revealed. By using a unique archive source material that includes the Swedish pulp- and paper

[1] Jerkeman (2007).
[2] Norberg-Boom & Rossi (1998).
[3] Smith and Rajotte (2001).
[4] Popp et al. (2011).
[5] Reinstaller (2005), (2008); Popp et al. (2011).

industries environmental R&D projects since the 1970s, we will be able to study the underlying motives for technological change in-depth. Both industry level- and firm level motives for advancing alternative bleaching processes will be explored.

Differences in the regulatory approaches between the countries and a stronger market pressure for the Nordic pulp producers have been highlighted as major explanations to why Swedish firms moved faster towards chlorine-free pulp production compared to the industry in North America.[6] Essentially, events on the German market have been regarded as very important for how Nordic pulp and paper producers reacted on the dioxin alarm. In 1991 the Greenpeace magazine “Das Plagiat” was published in Germany and was outwardly a copy of Der Spiegel. The magazine was printed on chlorine-free paper and contained a series of articles on the risks of using substances containing chlorine in the manufacture of paper. Das Plagiat had great impact on the German public and the German pulp and paper buyers, and the Swedish pulp and paper producers could not ignore the development on their main export markets.[7]

However, as argued by Reinstaller (2005), the series of events in the late 1980s and the rise of “green consumerism” in the key markets for the Nordic producers cannot explain the divergences in diffusion patterns of the alternative bleaching processes. Instead, Reinstaller stresses the importance of differences in the regulatory approaches as well as deviating perceptions and interpretations of the dioxin threat by firms and consumers in the two countries.[8] Moreover, the technology for pulp and paper production is known for being a mature technology and the chlorine-based bleaching process had been the dominant bleaching technology since the 1950s.[9] Thus it could not possibly change overnight albeit demand for chlorine-free products came to be very strong in the late 1980s and the early 1990s. By focusing on initial pollution control strategies in the Swedish pulp and paper industry in contrast to the U.S., this paper highlights circumstances that fostered initial technological approaches that had implications for the potential to respond to the dioxin alarm and subsequent regulatory measures. By doing so, we will shed new light on the critical importance of how events in the past may influence firms’ ability to respond to sudden and unexpected challenges stemming from environmental regulation and ‘greener’ market demand and requiring rapid technological changes. These events particularly include R&D strategies undertaken by firms in the past and the extent firm-activities interplayed with the national strategies for environmental regulation under which the firms operate.

[6] Harrison (2002); Reinstaller (2005), (2009).
[7] Jerkeman (2007); Popp (2011); Reinstaller (2009).
[8] Reinstaller (2005).
[9] Norberg-Boom and Rossi (1998).

2. THE PULP AND PAPER INDUSTRY AND THE CHLORINE ISSUE: A SHORT BACKGROUND

Sweden and U.S. are key players in the ensemble of pulp and paper producing countries. Today, U.S. is the second largest producer of paper after China, while Sweden is the sixth largest. Moreover, U.S. is the world's largest producer of pulp while Sweden is the fourth largest.[10] Additionally, U.S. is the second largest exporter of paper in the world and the biggest exporter of pulp, while Sweden is the sixth largest exporter of paper and the fourth largest exporter of pulp. Swedish pulp and paper production is however far more dependent on exports than the U.S. – about 50 percent of the Swedish paper production is exported.

As mentioned in the introduction, the dioxin issue was raised on the global agenda after the US EPA announcement in 1987 that dioxins had been detected in pulp mill effluents and in various paper products. At the time, the volume of imports of pulp and paper was larger in U.S. than its exports. Despite the globalization of the U.S. economy, exports in pulp and paper was only around 6 percent in the early 1970s and had increased only slightly up to the mid 1990s – to about 10 percent.[11] The inverse relationship was true for Sweden. In 1984, imports of pulp and paper were negligent.[12] In 1986, the German market accounted for 24 percent of the Swedish pulp export followed by Italy, UK and France. Germany was also the largest export market for newsprint, closely followed by UK which was the largest export market for other publication paper than newsprint.[13]

The chlorine used in bleaching not only affects the mill's wastewater but also persist in the final paper product. Removing elemental chlorine from the production process thus not only prevents pollution stemming from the production process but also such pollution diffused in society by paper products. The manufacturing process for producing bleached chemical pulp consists of two main processes, boiling and bleaching, where bleaching is one of the most environmentally intensive aspects of paper production. The aim with chemical pulp production is to extract fibres for paper production from wood, where they are imbedded in lignin. To break down wood into lignin and fibres, wood chips are boiled in a digester with either alkaline sulphate (i.e. the Kraft process) or acid liquor. The bleaching occurs in stages, generally alternating between acid and alkaline stages. The acid stages increase the whiteness of the pulp while the alkaline stages remove any residual lignin and alkali from the pulping

[10] Swedish Forest Industry Federation (2011).
[11] Norberg-Bohm & Rossi (1998).
[12] Skogsstatistisk Årsbok 1986, tab. 15.9.
[13] Skogstatistisk Årsbok, 1989, Foregin trade, tab. 10.3.

stage.[14] The use of elemental chlorine (Cl_2) as bleaching agent became dominant in the 1950s.[15]

Previous research has reported that two alternative bleaching technologies, elemental chlorine free (EFC) and total chlorine free (TCF), were developed and diffused as a response to the dioxin alarm.[16] A complete replace of chlorine (Cl_2) with chlorine dioxide gas (ClO_2) is known as the ECF-process. By replacing Cl_2 with ClO_2 the levels of absorbable organic halogens (AOX) are greatly reduced. The TCF-process in turn completely eliminates the use of both Cl_2 and ClO_2 and instead typically Hydrogen peroxide (H_2O_2) and/or ozone (O_3) is used as substitute bleaching agent.[17] The development of ECF and TCF was aided by improvements in oxygen delignification in a pre-bleaching stage.

The direction of technological development is affected by decisions taken in the past and influenced by society's institutions. Therefore – to understand why Swedish mills developed oxygen delignification and made it commercially operative as well as were the first to develop and commercialize TCF – it becomes important to understand the framing of the environmental regulatory approach and the establishment of technological trajectories. Drawing on the literature of path dependency, we will give a brief overview of the institutional context in Sweden and the U.S. in terms of environmental regulatory approaches and technological strategies. In the following section we will deal with the chlorine issue and in the last section we will sum up and discuss our results.

3. TECHNOLOGY DEVELOPMENT, ENVIRONMENTAL POLICY, AND FIRM STRATEGIES

3.1. Environmental regulation and technological change

It has been suggested that environmental regulations can substantially determine the direction of technology development[18] and they are moreover seen as the primary driver for innovation.[19] Previous research has noticed different regulatory approaches and modes of corporate response and compliance strategies between Sweden and the U.S.[20] The reason why these different pathways can be noticed is an empirical question and has to do with different national contexts in terms of political culture, institutions, knowledge, direction of R&D, including also, the national environmental regulatory

[14] www.skogsindustrierna.se [Swedish Forest Industry Federation, approached July 4 2013]; Popp et al. (2011).
[15] Norberg-Bohm & Rossi (1998).
[16] Popp et al. (2011).
[17] Popp et al. (2011); Reinstaller (2005).
[18] See e.g. Yarime (2007).
[19] Popp et al. (2011) p 1253.
[20] Lundqvist (1980); Auer (1996); Harrison (2002).

framework and associated relations between the regulators and polluters. Both countries were (together with Japan) early adopters of environmental regulation, where Sweden was the first country in the world to establish an environmental protection agency in 1967. Sweden developed a cooperative mode of the environmental protection system[21] based on flexibility in compliance measures and a functioning dialogue between regulators and industry[22], while the U.S. practiced a legalistic style and a political toughness with poorer relations between the policy makers and industry.[23] In contrast to the U.S., Swedish firms invested predominantly in pollution prevention and internal process control technologies[24] while U.S. firms invested heavily in end-of-pipe facilities.[25]

The literature on technological path dependency assumes that historical events that seem minor at the time can be amplified by positive feedback in ways that drive the selection of technology down an unanticipated trajectory.[26] Modern and more complex technologies often display 'increasing returns' to adoption; the more experience that is gained with them, the more they are improved. When a new technology begins to emerge it becomes progressively more 'locked in' by 'chance' or 'historical events' forming an outcome not necessarily the best alternatives, easily altered or totally predictable in advance.[27] The Swedish pulp and paper industry and the Swedish regulatory approach early on came to favor internal- (in-plant) over end-of-pipe measures and performance standards[28] – a strategy that stands in contrast to the U.S. where the regulatory approach became heavily reliant on the design (Best Available Technology, BAT) or specification standards that preferably could be met by end-of-pipe abatement measures.[29] Literature on technological path dependency has noted that once a pathway is established, the technology development is driven along a certain direction even though more superior routes are available.[30] Initial technological strategies to deal with pollution can therefore have serious implication for firms' options and ability to adapt process technology to deal with new, uprising environmental problems. This since technological development requires much information, and the acquisition of information is a costly activity.[31]

Apart from that firms are restricted by high development costs in advancing new technologies, technology innovations are moreover intertwined with cultural evolutionary processes that may

[21] Lundqvist (1980); Rotstein (1994); Karlsson (2012).
[22] Lundqvist (1971); Bergquist et al. (2012).
[23] Wallace (1995).
[24] Söderholm & Bergquist (2012).
[25] Harrison (2002).
[26] See e.g. Arthur (1989); Rosenberg (1994); Liebowitz and Margolis (1995).
[27] Arthur (1989).
[28] Söderholm and Bergquist (2012).
[29] Norberg-Boom & Rossi (1998).
[30] See e.g. Rosenberg (1994).
[31] Rosenberg (1994) p 14.

emerge at the sub-national, national and transnational levels.[32] Rycroft & Kash (2002) state the link between culture and institutions and technological innovations is most clearly distinguished at the national level. The influence of culture and institutions on path dependence is however important also at other levels. At the national level, distinct national institutions (e.g. firms, government laboratories and universities) have evolved into sophisticated national innovations systems (NIS) where cultural norms and culturally based institutions contribute the context within which the previously distinct institutions continuously create and integrate the knowledge that makes it possible to repeatedly develop new and enhanced complex technologies.[33] From this perspective, the development of environmental technology cannot only bee seen as a lengthy process of trial and errors and 'historical events' that eventually results in a technology entering the market. Since national cultures and institutions tend to be deeply embedded[34] they are hard to modify, even when new technological opportunities appear.[35] Dosi (1982) uses the term "technological paradigm" to refer to the presence of technological trajectories. The origin of the technological paradigm stems from the interplay between scientific advances, economic factors, institutional variables and unsolved difficulties on established technological paths. Within this context, public policies plays on important role related to the search of new technological paths. The regulatory approach of a country influences the technology strategy chosen and has implications for firms' willingness to innovate.[36]

3.2. Regulatory frameworks in Sweden vs. U.S.: a brief overview

The Swedish Environmental Protection Act was implemented in 1969, and it represented the first uniform framework for regulation of emissions to air, water pollution, noise and other disturbing activities from industrial plants in Sweden. The Act had a pre-history that dates back to the *Public Health Act of 1874* and the *Water Rights Ordinance of 1880*. After step-wise additions of the regulatory frameworks, the Swedish government in 1963 appointed an expert committee assigned to investigate the issue of all interference from stationary plants. A proposal was presented in 1966[37] which came to form the basis for the *Environmental Protection Act* (hereafter EPAct) passed by Parliament in 1969. In the years before the final bill was passed, the construction of a modern system for environmental protection began in Sweden. Thus, in 1967 the *National Environmental Protection Agency*, a unified body for almost the entire area covered by the EPAct, was founded. The

[32] Rycroft & Kash (2002).
[33] Freeman (1995).
[34] e.g. North (1993).
[35] Rycroft & Kash (2002).
[36] Dosi (1982).
[37] SOU 1966:65

Environmental Protection Agency was an amalgamation of several existing agencies including the Water Inspection (1957) and the Air Pollution Control Board (1963).[38]

The EPAct was based on plant-by-plant licensing; firms had to have their plans for construction or alteration of production plants assessed according to several criteria specified in the Act. The so-called Franchise Board of Environmental Protection (hereafter FBEP), administrated the licensing system and was in practice a court, with experts from both industry and the Swedish EPA. Unlike the U.S., Sweden came to regulate both water and air pollution under the same Act and the licensing process thereby integrated. Moreover, the regulatory approach was in practice based on performance (emission level values) rather than on technology-based standards, and these were negotiated with each plant owner, sometimes over ex-tended periods of time.[39] The licenses had to be reassessed and renewed every 10 years on the basis of what was considered Best Available Technology (BAT) at the time. As a general rule, the industrial polluters were required to take all precautionary measures, and tolerate such restrictions on their activities as could be reasonably demanded. In practice BAT referred to the least polluting technologies that proved practicable in other industrial plants of the same type, either in Sweden or in other countries.[40] BAT was used as a reference for achievable emission level values, where emission levels normally set the target for the licence (not prescriptions of using a certain method). As the system also aimed at favoring internal (pollution prevention) process changes the system needed to be flexible in terms of compliance strategies.[41]

In the U.S., modern environmental regulation dates back to the 1960s, which is when the first major federal legislation was enacted and the EPA was shaped. Three years after the Swedish Environmental Protection Agency was established, the US EPA began its operations with the responsibility of maintaining and enforcing national standards under a variety of environmental laws. The laws of importance to industry include the Clean Air Act (CAA), which passed in 1963 but really took shape first in the reauthorization and amendments of 1970, and the Water Pollution Control Act of 1972, later called the Clean Water Act, CWA. Of importance to the U.S. pulp and paper industry, due to its particular problems with water pollution, is the CWA. The CWA regulates the pulp and paper mills' discharges by using a two-pronged approach. First, the EPA issues uniform technology-based guidelines for comparable sources, which in the next stage are incorporated (typically by state governments) in individual facilities permits. In 1992 however, the EPA merged development of air, water, and sludge regulations for the pulp and paper industry under the 'cluster rule'.[42]

---

[38] Westerlund (1971); Lundqvist (1971).
[39] Bergquist et al. (2012).
[40] Lundqvist (1980).
[41] Harrison (2002).
[42] Harrisson (2002) p 71.

In contrast to Sweden, heavy reliance has generally placed on the design (Best Available Technology, BAT) or specification standards (which stipulate duty holders exactly what measures to take) rather than on performance (emission level) standards.[43] The North American system also relied on air and water quality standards, allowing certain concentration of pollution in the surrounding air and water with respect to health aspects.[44] Legally, the environmental quality standards dominate the technology-based standards, but in practice, technology based standards have been emphasized.[45] It has also been viewed that the emphasis on technology-based standards avoids the potentially greater time and cost associated with developing, administrating, and complying with different geographically-specific pollutant discharge limits that must be tailored to meet ambient water quality standards.[46]

The North American paradigm for pollution control contrasts to the Swedish regime that instead has emphasized internal process changes, based on plant-by-plant judgments and plant negotiated performance standard.[47] The U.S. system also represented a much stricter command-and-control regime compared to the Scandinavian countries including Sweden. It was a direct regulation that permitted little flexibility in terms of compliance measures.[48] American environmental regulatory rules are generally far more detailed and are enforced more legalistically resulting in more frequent and much lager regulatory sanctions than in countries with a more cooperative regulatory style.[49] It is also obvious that the regulatory frameworks have been embedded differently in Sweden and the U.S., essentially with respect to the influence given to the States in the U.S. regulatory enforcement. Compared to Sweden, it is clear that U.S. environmental policy had a more difficult birth than the Swedish, with generally adversarial legislative approach and practices.[50]

The regulatory history and past compliance strategies of industries and government has had, as we will see, important implications for how regulations have been approached. Not the least inter-firm and state-firm collaborations in R&D formed the basis for the early regulatory response to the dioxin alarm in Sweden. In the U.S., the policy process proceeded slower and was more incremental, formed by scientific uncertainties, problems for the EPA to define the technology based standard and by industry interest to avoid costs from implementing more radical technologies.

[43] Gunningham (2009).
[44] Lundqvist (1980).
[45] Powell (1997) p 3.
[46] Powell (1997).
[47] Harrison (2002).
[48] Gunningham (2009) p 4.
[49] Gunningham et al. (2003) p 80.
[50] For instance, the Clean Air Act set ambitious national goals for air quality, and in order to guard against "agency capture" of the American EPA, the congress used the "hammer clause" which gave the EPA a strict compliance deadline for its implementation, a strategy that industry considered to be unreasonable. Wallace (1995) p 114.

4. THE PROCESS OF TRANSITION TO CHLORINE-FREE PULP AND PAPER

Dioxins were already prior to the mid-1980s known as a highly toxic, carcinogenic substance, but it was not known that dioxin was formed in the production of bleached pulp. This was discovered when the US EPA in 1983 initiated a national survey that in 1985 detected dioxins down streams from pulp and paper mills. To determine the specific cause of dioxins in pulp and paper manufacture, the US EPA, the American Paper Institute (API) and the NCASI (National Concil of the Paper Industry for Air and Stream Improvement) thereafter, in 1986, agreed to undertake the "5 Mills Study". The study was released in 1987 and concluded that bleaching was the primary source of dioxins in pulp and paper mills.[51] Environmentalists learned about the agreement and in December 1986, Greenpeace initiated a Freedom of Information Act request seeking all available information on the pulp mill dioxin problem. Information leaked to Greenpeace which, in 1987, released a report alleging an EPA cover-up. Only a month later, the New York Times ran a front-page story reporting that traces of dioxins had been detected in paper products.[52] And in 1988, the "104 mill studies" in turn was initiated. By that time, the Swedish authorities had already begun regulatory action.[53]

4.1 The Swedish technological pathway: internal process changes through collaborative R&D platforms

The Swedish strategy for dealing with pollution problems was to accomplish emission reductions through internal process changes – an approach that contrasted to the U.S. What concerns the Swedish pulp and paper industry, this concept can be traced back to the 1940s and 50s and the pioneering R&D activities then taking place in collaborative platforms established jointly by the Swedish pulp and paper producers. Previous studies have shown that industry collaboration in environmental R&D as such became a key feature in the Swedish pulp and paper industry's green reconstruction, and a number of green R&D platforms were gradually established during the 1900s.[54] While the first collaborative initiatives of the industry sector to deal with pollution problems actually took place already at the turn of the 20th century, as a response to local pollution resistance (especially the odor problems), the R&D activities thereafter increased in tandem with the development of environmental policy up to the 1960s. During this novel period, attention was foremost directed towards improved

[51] Norberg-Bohm & Rossi (1998), Powell (1997).
[52] Powell (1997), p 23 ff.
[53] Powell (1997) p 34.
[54] Söderholm and Bergquist (2012), Bergquist and Söderholm (2011).

efficiency and reduced fiber emissions, while more resolute efforts aiming for decreased discharges began in the 1960s. At the time of the enforcement of the EPAct, collaborative environmental R&D efforts were further accomplished in cooperation with environmental authorities.[55]

Important collaborative platforms for the greening of the Swedish pulp and paper industry in the 1960s were: a) the *Swedish Pulp and Paper Research Institute*[56] (STFI), founded by the forest industry in collaboration with the state already in the mid-1940s; b) the state-industry funded *Institute for water and air protection* (IVL), founded in 1966; and c) the *Forest Industries' Water and Air Pollution Research Foundation* (SSVL), founded by the forest industry in 1963. Both STFI and IVL have their background in the Swedish system of collective research institutes in order to strengthen the Swedish industrial competitiveness, where the financial framework was determined by multi-year contracts between the state and a foundation formed by the industries concerned.[57] While the original idea of STFI was to pursue research on forest products in close cooperation with the Royal Institute of Technology in Stockholm, and to advance methods for their rational refinement and exploitation, the motive for establishing the two latter platforms in the 1960s was the recognized need for effective collaborative efforts in environmental R&D to manage costs and risks related to emerging stricter environmental requirements.[58]

Even though STFI was not established to address pollution issues, it ended up doing so as improved material utilization and process control became important strategies to combine production expansion with pollution prevention from the late 1960s and onwards. And from the mid-1970s to the 1990s, research in the field of pulp bleaching was carried out with high intensity at STFI. This was linked to the fact that the bleaching process was the point of the pulp mill where the material that could not be brought to the chemical recovery or over to the paper production, left the factory as bleach plant wastewater.[59] It was known already in the 1970s that the bleaching process accounted for a very high percentage of total emissions of oxygen-consuming substances, as well as that the bleach plant emissions contained toxic substances.[60]

The state-industry funded IVL, and a related consulting company, the IVL-company, was founded in 1966 and reflects an on-going mobilization, both within the government and the industry, to enhance knowledge on the relation between industrial production and environmental problems and to identify effective solutions. By engaging in basic and applied research on the quantity, content, and

---

[55] Söderholm and Bergquist (2012).
[56] Today *Innventia AB*.
[57] Sörlin, Sverker. 2006. *En ny institutssektor. En analys av industriforskningsinstitutens villkor och framtid ur ett närings- och innovationspolitiskt perspektiv*. Näringsdepartementet.
[58] Bergquist & Söderholm (2011); Söderholm & Bergquist (2012).
[59] Eriksson, Lennart (2010) *STFIs öden och äventyr 1942-2010: fakta-minnen-reflexioner*, Spearhead production AB: p 272.
[60] See e.g., *Klorid i återvinningssystem*, 1974-76, Stockholm: SSVL (1977), p 23.

environmental impact of emissions, which was knowledge equally important to industry representatives and environmental authorities for the development of both efficient pollution-abatement technology and efficient environmental legislation, IVL came to underpin the greening of the Swedish industry in the 1960s and 70s.[61]

SSVL was formed already in 1963 by the Swedish Pulp and Paper Association (SCPF) – past professional body for parts of the pulp and paper industry, now the *Forest Industries* – but expanded operations considerably at the beginning of the 1970s when it stood clear that the industry-specific problems faced by the pulp and paper industry were to big to be handled merely within IVL. A wide project organization was built up under SSVL with representatives from a number of private companies, research institutions, such as IVL and STFI, consultants, equipment suppliers and industry interest groups. The purpose of the wide project organization was to "get together" both research results and technological achievements, to get them assessed and evaluated properly in order to lower the risks for the individual mill. Problem-/project areas were selected by the SSVL-board (key industry representatives such as CEOs and technical managers) and involved what various plants had identified as important but which was not yet fully covered. A majority of the pulp and paper companies were generally represented in each of the different projects. Individual firms in turn supplemented the projects on a large scale and, together with equipment suppliers, provided access to factory floors, machinery, and personnel.[62]

The SSVL-projects primarily aimed at preparing background material and evaluate available environmental technologies, but also supporting the introduction of new technology.[63] Findings spread through a wide variety of reports which, according to a person with central insight and abundant participation in the SSVL-projects of the period (Hans Norrström, he was engaged by both IVL, STFI and the largest consulting firm of the pulp and paper industry) were well distributed to and utilized by the individual mills.[64] According to Norrström the pulp and paper industry took the projects very seriously as there was a concern over what the economic impact of the EPAct would be: for most, production went up steeply towards the end of the 1960s while emissions were large and in many cases increased. Thus: "We needed to get this to work."[65] In sum, the collaborative R&D platforms STFI, IVL and, not the least, SSVL, formed the basis of a major part of the green technology development undertaken by the Swedish pulp and paper industry from the late 1960s to the 1990s.

4.2. R&D and the bleaching process

[61] Bergquist & Söderholm (2011)
[62] Interview with Norrström, 8 June 2010, Stockholm.
[63] *Miljö 90*, Final report, Stockholm: SSVL (1991):15.
[64] Interview with Norrström, 8 June 2010, Stockholm.
[65] Ibid.

From the mid-1970s, also the SSVL projects, as the STFI activities, focused largely on the field of pulp bleaching.[66] Process technically it was, of both cost and environmental reasons, about doing as much delignification work as possible in the boiler and in the subsequent oxygen delignification, and to adapt the subsequent bleaching after this. The large number of chlorine-based and non-chlorine based bleaching agents contributed to the area's major research width. The gradual removal of elemental chlorine (chlorine gas) as bleaching agent implied significant research efforts, as well as, finally, the issue of bleaching without chlorine.[67] In this context, the small Swedish company ASPA was a pioneer.

Already in the SSVL-project *Chlorides in recovery system* (1974-76), different ways to reduce the environmental impact of bleach plant wastewater were recommended although the main focus was the impact of chlorides in the recovery system. First recommended was to try to achieve as much delignification work as possible in the boiler and in the subsequent oxygen delignification, and secondly, to try to use as large proportion of chlorine dioxide in the bleaching process as possible.[68] Efforts to bleach pulp with chlorine dioxide had of economic reasons been initiated in Sweden decades before, such as in MoDo's laboratories and mills in the 1940s.[69] Thus, when the use of chlorine dioxide in the Swedish and Finnish production of bleached kraft pulp was mapped within the project in 1974, it was found that while Swedish mills usually used chlorine dioxide, Finnish mills did not.[70] Total project cost was 4 MSEK and it resulted in 37 interim reports and a final report in 1977. Apart from SSVL, among others STFI, the *Board for Technical Development* (STU) and *the Nordic Industrial Fund* contributed funds.[71]

In parallel was also the SSVL-project *Nordmiljö 80* (Nord Environment 80, 1975-78), which aimed to find ways for the rational observation of the forest industry with relevant and modern control methods. The project focused on pollution control, measurement and sampling appliances, as well as on system

[66] When the basic research of IVL and STFI primarily aimed at clarifying the biological effects and chemical composition of the bleach plant wastewater, SSVL had greater focus on process technologies for reducing emissions, although these areas of knowledge – which not least the organization of the SSVL projects bear witness of – are strongly connected with each other.

[67] *Klorid i återvinningssystem*, 1974-76, Stockholm: SSVL (1977); *Miljövänlig tillverkning av blekt massa*, 1977-81, Final report, Stockholm: SSVL (1982); *Miljö 90*, Final report, Stockholm: SSVL (1991). See also Eriksson, Lennart (2010): 272.

[68] *Klorid i återvinningssystem*, 1974-76, Stockholm: SSVL (1977): p 13.

[69] Söderholm K. and Bergquist A-K. (2013) "Growing Green and Competitive – a Case Study of a Swedish Pulp Mill", *Sustainability*, 2013 5(5), pp 1789-1805.

[70] G. Annergren, E. Jansson, H. Makkonen H. Norrström och R. Rasimus (1974) *Kartläggning av svenska och finska blekerier*, Interim Report No. 10 within the project "Klorid i återvinningssystem" (1974-76), Stockholm: SSVL (1974).

[71] Klorid i återvinningssystem, 1974-76, Stockholm: SSVL (1977), p 112.

design for data collection.[72] Before the completion of this project completed, SSVL initiated a vastly larger project on bleach plants' actual environmental impact, *Environmentally harmonized production of bleached pulp* (1977-81). The project, which resulted in over 100 reports, was mainly funded by the pulp- and paper industry but also by contributions from IVL, STFI and STU. Government grants (through such organizations) amounted to about 13 of the total of 40 MSEK of the project cost.[73] In the foreword to the final report for this project, the proactive approach of the industry in this context is justified:

"Water protection in the Swedish pulp and paper industry has so far largely focused on reducing emissions of biochemically readily biodegradable and suspended material. [...] With the high environmental standards achieved by the vast majority of Swedish mills, a continued decrease in these parameters would only give a marginal improvement of the environment to a high specific charge. [...] Given the pulp and paper industry's economic importance and the residual emissions size, environmental work should, however, continue and focus on investigating the industry's emissions, other environmental impacts, and if so, find effective and economical methods to counteract it."[74]

In the final report (1982) for the project it was found that of the 21 mills in Sweden at the time producing bleached chemical pulp, 10 had already installed or committed to install oxygen delignification plants. Only a total of 15 additional oxygen delignification plants were put in operation outside Sweden. Of the 27 mills for bleached chemical pulp outside Sweden in Scandinavia, only two Norwegian mills had oxygen delignification plants and two Finnish mills had aerated ponds.[75] By 1985, five U.S. mills had installed oxygen delignification system.[76] In this context it is justified to mention that the Swedish company MoDo already in the early 1970s constructed a pilot plant for oxygen delignification.[77] This technology was in turn established in Sweden soon thereafter which is mirrored in the numbers above.

The attention paid to the bleaching process continued in several SSVL projects of the 1980s, and in the sub-project "Discharges from the bleaching of chemical pulp" within *SSVL 85* (1981-85) it was established that mills with bleaching sequences containing oxygen and a high percentage of chlorine dioxides in pre-bleaching, or oxygen bleaching with treatment of bleach plant wastewater in aerated ponds, responded to "highest environmental standards".[78] In the final SSVL-project of the 1980s, *Miljö 90* (Environment 90), as many as 200 pages are devoted to the bleaching process while the remaining three sub-projects only take up about 10-40 pages each.[79] *Miljö 90* started after a review

[72] *Nordmiljö 80*, Final report, Stockholm: SSVL (1981). See also *Miljö 90*, Final report, Stockholm: SSVL (1991): 41.
[73] *Miljövänlig tillverkning av blekt massa*, 1977-81, slutrapport (1982), Stockholm: SSVL, p 5.
[74] *Miljövänlig tillverkning av blekt massa*, 1977-81, slutrapport (1982), Stockholm: SSVL, p 5.
[75] *Miljövänlig tillverkning av blekt massa*, 1977-81, slutrapport (1982), Stockholm: SSVL, p 7.
[76] Norberg-Bohm and Rossi (1998).
[77] Jerkeman (2007), p 13.
[78] *SSVL 85*, Final report, Stockholm: SSVL (1986).
[79] *Miljö 90*, Final report, Stockholm: SSVL (1991).

and prioritization of current environmental issues in July 1985, i.e., a few months before the US EPA in the autumn of 1985 reported that dioxins had been detected in fish caught near pulp and paper mills. The risks of dioxins however came to be a high priority in the Swedish and European environmental debate in the late 1980s. Hence, the content of dioxins in products and emissions were questions that came to be incorporated into the project.[80] IVL was very well represented also in this project as well as, in fact, the Swedish EPA with a few individuals.[81] In the next section follows examples of how this involvement of Swedish authorities in the SSVL projects, through the semi-governmental IVL and SEPA, provided policy-makers with necessary tools for the gradual tightening of ELVs and for sometimes stipulating ELVs based on novel process-internal technology not yet fully developed. SEPA further compiled several own reports in the 1980s and early 90s on the composition and effects of bleached pulp mill effluents.[82]

4.3 Dioxins and intense pressures for technological change? Sweden vs. the US

The risks of dioxin became a high priority issue in the European environmental debate in which a key question was whether the small residue of polychlorinated dioxins that could be traced in products based on bleached pulp could leak when exposed to moisture, such as a wet baby diaper. Another to the pulp industry related environmental issue which came to be debated simultaneously in Sweden, was the emission of pollutants in the Baltic Sea, where especially the emissions of the bleaching pulp industry were in focus.[83] FBEP took a first clear standpoint in the dioxin issue already in 1986 when delivering final conditions for a sulphate pulp mill, establishing that wastewater from the bleaching process caused significant local damage to water based organisms. An unusually high proportion of representatives from the industry sector, several of which were in the midst of their own licensing processes, were present as well as chlorine producers, consultants, equipment suppliers, research institutions and an additional number of SEPA representatives. FBEP established that:

”significant progress has been made in recent years in terms of different measures to reduce the emissions of chlorinated organic matter, including increasing the share of chlorine dioxide in the first bleaching stage as well as through improved process equipment and process control.”[84]

FBEP however at the same time announced that it expected even more R&D on the matter, especially on how to increase delignification in the cooking- and bleaching stages as well as on the possibilities

[80] *Miljö 90*, Final report, Stockholm: SSVL (1991).
[81] *Miljö 90*, Final report, Stockholm: SSVL (1991): pp 327ff.
[82] See e.g., *Biologiska effekter av blekeriavlopp*, Anders Södergren (Ed.), Report, Solna: Naturvårdsverket (1988), 134 pp.
[83] Waluszewski, Alexandra and Håkansson, Håkan (2004) “Das Plagiat” in Widmalm, Sven (Ed.) *Artefakter*, pp 219-244: 223.
[84] Documentation from the licensing of the Norrsundet mill in 1981-1987, Decision 1986-12-09, p. 44f, National Archive of Arninge, E1:817-819, Sweden: Stockholm.

to switch to other bleaching chemicals. In this particular licensing process the FBEP actually advocated a specific abatement technology. The Board however at the same time emphasized that it should not be stipulated in the final conditions as the firm had both the right and the duty to use other methods if any shortcomings could be proved with this particular technology and/or if more effective methods were developed. In this way the Board maintained the regulatory strategy to permit flexibility in compliance strategies while at the same time requiring emissions to comply with the performance of state-of-the-art (BAT) technology.[85]

At the same time in the U.S., the policy process moved slower and the US EPA worked on defining the standard setting. Following a series news reports about EPA's cooperation with industry in 1987, the US EPA signed a decree to perform a comprehensive risk assessment of dioxins and furans considering sludge, water effluents and products made from pulp produced at 104 pulp mills. The agreement also required the EPA to propose regulation before 1993.[86] Interesting to notice is that the Office of Technology Assessment (OTA) in 1989 reported about the Swedish pulp mills compliance with more stringent standards when it comes to the emissions of chlorinated organics.[87]

By this time in Sweden, an emotional public debate on dioxins were in full swing. In 1987, Sweden's largest and oldest environmental organization, the Nature Conservation (SSNC), recommended consumers to choose unbleached products upon which the producers and distributors of a range of unbleached products, such as packaging- and tissue paper, began to provide them with SSNC's signature. In 1989, the association further launched two environmental classes (a low chlorine- and a chlorine free[88] level) for chlorine bleached paper qualities where brightness was important, such as magazine paper. In the absence of any national or international (at EU level) official emission limit that was considered harmless to the environment, the SSNC criterion got major impact.[89] In fact, the issue of chlorine free paper and unbleached products in this way became the issue that finally came to seriously initiate the environmental issue as a marketing issue for the Swedish pulp and paper industry.[90]

Also Green Peace had many members in Sweden (if not quite as many as SSNC), and in their "Pulp and Paper Campaign" during the second half of the 1980s, there was a major focus on Sweden, where the Swedish pulp bleach plants according to Green Peace accounted for about 99 % of the country's total emissions of chlorinated organics. As an activity within the campaign, Green Peace in 1986

---

85 Ibid.

86 For a detailed accounting, see Powell (1997).

87 Powell (2007) p 12.

88 The "chlorine-free" level was in fact allowed to contain 0.5 kg AOX/tonnage of pulp (Waluszewski and Håkansson, 2004, p 224).

89 Waluszewski and Håkansson (2004), p 224.

90 Eva Bingel, Claes Sjöberg och Charlotte Sjöquist (2002). *Från defensiv till proaktiv. Drivkrafterna bakom hållbar tillväxt*, Rapport, Stockholm: Svenskt näringsliv.

dumped 1.5 tonnages of dead fish in front of an office entrance to one of the largest producers of bleached pulp in Sweden. And a few years later Green Peace conducted yet another action against the use of chlorine as a bleaching agent in the production of white paper products when, in collaboration with the small pulp-producing Swedish mill ASPA, producing an exact copy of the weekly *Der Spiegel* printed on paper containing no shred of chlorine-bleached pulp.[91]

When the citizens of Sweden during the summer of 1988 also came to experience severe algal blooms, as well as an excess mortality of an already endangered seal population, the chlorine issue became an even hotter topic of debate, not least in media.[92] One article by the chief physician at a regional hospital was published in Sweden's largest daily newspaper, *Dagens Nyheter*, on August 2 in 1988, entitled "Dioxins are a likely cause of the seal death and the disease process resembles AIDS". The article states that it is found that the seal death is "likely" to be due to the contamination of dioxins where pulp bleaching constitutes "one of the now largest known" dioxin sources in Sweden. The article further states that "it is well known that Swedish children during breastfeeding far exceed tolerable daily intake [of dioxins]".[93]

The dioxin issue together with the pollution of the Baltic Sea and the big seal death in the summer of 1988 in fact constitute key explanatory factors behind the fact that environmental issues in general got their big break among Swedish citizens during the second half of the 1980s, which not least the "Environmental election" to the Swedish Parliament in 1988 bear witness of.[94] The environmental debate and mobilization of the environmental movement after the mid 1980s was much stronger than what Sweden had experienced in the 1960s. At the same time in the U.S., the absence of both a green market demand and a pronounced anti-dioxin mood in the public induced a different perception of the problem within industry. Gaining knowledge to the problem through scientific research into what would be the best technology was one mean to influence EPA's decision, but also a way to explore possible solutions on the basis of the established technological paradigm.[95]

When it comes to regulation the Swedish parliament in 1988 adopted a proposal which stipulated that industrial emissions of chlorinated organic compounds must be reduced to 1.5 kg AOX/tonnage of pulp (normal emission level was about 4 kg/tonnage of pulp at this time).[96] The FBEP had however chosen to stipulate this level (with effect from January 1 1992) in the final conditions for a mill already in 1987, although it was based on a technology that was not yet developed. Still, the FBEP

---

[91] Waluszewski and Håkansson (2004).
[92] Waluszewski and Håkansson (2004) p 223.
[93] Hardell, Lennart "Säldöden liknar aids : Dioxiner är trolig orsak till säldöden och sjukdomsförloppet påminner om aids", *Dagens Nyheter* (DN), 1988-08-02.
[94] About the "Environmental election" in 1988, see e.g. Giljam, Mikael and Holmerg, Sören (1990), *Rött blått grönt*, Stockholm: Bonniers.
[95] Reinstaller (2005) p 1380.
[96] Waluszewski and Håkansson (2004) p 223.

“expected” the technology[97] to be developed within a relatively short time and SEPA in turn confirmed it was already “about to be implemented” at a number of Swedish mills.[98] The example reflects the great insight of the environmental authorities in the industry’s on-going environmental development and investment projects, but also how the environmental authorities in fact stipulated technology development. This is also confirmed by an anonymous FBEP official with direct experiences of pulp and paper licensing processes in the late 1980s:

“The Board listened eagerly to the results of the investigations made by both the authorities and the industry and if we could identify prospects for a certain technological development, we granted probation periods and stipulated [performance standards] based on expected technological development and thus in fact stipulated technological development.”[99]

Fact is the same year (1988) the Swedish Parliament adopted a proposal which stipulated that industrial emissions of chlorinated organic compounds must be reduced to 1.5 kg AOX/tonnage of pulp, the Swedish government imposed the most stringent requirements on emissions from bleaching ever been presented, a maximum of 0.5 kg AOX/tonnage, on one of Sweden’s smallest producers of market pulp, Aspa. In 1987, Aspa had submitted a license application to expand capacity, and the mill’s sensitive location on a lake that served as drinking water for several communities had contributed in referring the question to the government.[100] The method which already in the spring of 1989 would allow such low emissions, and the fact is – after further development work at Aspa and only a year after (in 1990) – a pulp bleached without chlorine, was the so-called Lignox process.[101] The process was based on knowledge of the use of oxygen, hydrogen peroxide and chlorine dioxide in the bleaching process, developed within SSVL-projects since the 1970s (and partly within even earlier collaborative platforms).[102] ASPA was thus the first mill to develop and commercialize TCF-pulp, however, on the basis of decade-long efforts within collaborative semi-governmental R&D platforms (of which the company had taken part) to achieve environmentally friendlier bleaching methods through increased efficiency and reduced use of chemicals by internal process changes.[103] ASPA was further not the only Swedish mill to produce chlorine-free pulp in 1990: the MoDo mill Domsjö soon followed with the so-called MoDo Crown product, also based on the increased use of oxygen and

---

97 The new technology involved a combination of oxygen and chlorine dioxide in the bleaching process.

98 Kinneryd (2010) Ch. 10.

99 Personal interview with anonymous Franchise board official with experiences of pulp and paper licensing processes of the late 1980s and onwards, Stockholm, 8 June 2010.

100 Waluszewski and Håkansson (2004).

101 The Lignox process: oxygen-bleached pulp is treated with hydrogen peroxide at high temperature after the removal of heavy metals with a complexing agent. Subsequent final bleaching takes place with peroxide and chlorine dioxide.

102 See e.g. *Miljövänlig tillverkning av blekt massa*, 1977-81, Final report, Stockholm: SSVL (1982). See also Waluszewski and Håkansson (2004).

103 This was initially, already in the 1940s, motivated by economic reasons but soon also environmental.

peroxide in the bleaching process.[104] The Lignox process was in turn explained and evaluated in the final report for *Miljö 90* (1991) whereupon knowledge of the process spread to the entire industry as well as to environmental authorities.[105] In the same report it was further established that: "In short, all Swedish pulp mills will have introduced oxygen delignification". [106]

Meanwhile, in 1993 the US EPA announced a proposal based on a technology-based approach that involved: 1) substituting elemental chlorine with chlorine dioxide or other bleaching agents (e.g., peroxide or ozone) and 2) reducing the extent of chlorine bleaching required to achieve a given quality of product through alternative means of pulp delignification (i.e., extended cooking or oxygen delignification prior to chlorine bleaching).[107] The U.S. pulp and paper industry strongly opposed the proposal and after receiving critical comments from both industry and environmental groups, the EPA released further revisions. The new standard was proposed in 1996 and the regulation was eventually finalized in 1997.[108] Studies report that the US EPA deliberately chose a standard which could be met by employing only full substitution for chlorine gas with oxygen gas, but no oxygen delignification. U.S. mills thus didn't have to incur the expense of installing oxygen delignification like their Swedish competitors which, according to Harrison (2002), saved the U.S. industry 1 billion U.S. dollars.[109] Noteworthy is though that when the US EPA determined the standard, one third of the U.S. Kraft mills had already installed oxygen delignification.[110] Only two U.S. mills had pursued more radical innovations. The first one was Louisiana Pacific, who adopted TCF in 1995, and did so to comply with the CWA. The Louisiana Pacific mill was one of few Kraft pulp mills that hade never installed secondary waste water treatment. Thus, when faced with the demand to reduce emissions, TCF appeared more attractive here than at mills which had already installed end-of pipe technology.[111]

In this regard, it is important to acknowledge that the lifetime for equipment in the pulp and paper industry is 15-30 years. As the prior U.S. strategy had been to invest in end-of-pipe, it fundamentally affected the assessment and costs of different technologies to reduce the discharges of dioxins or other effluents. Mills that had not installed secondary treatment plants thus found it more attractive to invest in TCF.[112] According to Norberg-Boom and Rossi (1998), the regulation proposed by the EPA in 1997 thus only required incremental innovation rather than moving industry to new technological

[104] Söderholm and Bergquist (2013).
[105] *Miljö 90*, Final report, Stockholm: SSVL (1991): see e.g. section 5.3.
[106] *Miljö 90*, Final report, Stockholm: SSVL (1991):19.
[107] Powell (2007) p 4.
[108] Norberg-Bohm and Rossi (1998) p 231.
[109] Harrison (2002) p 73.
[110] Harrison (2002) p 73.
[111] Norberg-Bohm and Rossi (1998) p 235.
[112] Norberg-Bohm and Rossi (1998) p 239.

trajectories.[113]

Quite a few Swedish mills however produced TCF bleached pulp already by 1994[114], and the remaining mills so-called elementary chlorine free (ECF) bleached pulp. And this development put Swedish pulp and paper mills in the forefront internationally.[115] The long term collaborative R&D efforts within platforms like STFI, IVL and, not the least, SSVL, were of central importance to this development. The knowledge development and -diffusion taking place here formed the basis for a major part of the green technology development undertaken by the Swedish pulp and paper industry from the late 1960s to the 1990s. Important prerequisites for Swedish mills to make the final steps towards EFC and TFC were further the early choice of the Swedish pulp and paper industry and Swedish government to try to achieve reduced emissions from the bleaching process through internal process changes as well as industry's early choice to focus on reducing the use of chlorine gas as bleaching agent.

5. DISCUSSION

Oxygen delignification, the core technology to implement alternative bleaching technologies (where chlorine is replaced as bleaching agent) was first developed and commercially operative in Sweden. It was also Swedish mills that developed and commercialized total chlorine free (TCF) bleached pulp. This paper has shown that it was no coincidence that this development took place among Swedish pulp and paper producers. Long before environmental authorities begun suspect that pulp bleaching was a considerable source for dioxins, the Swedish pulp industry was well aware that the bleaching process accounted for a very high percentage of total emissions of oxygen-consuming as well as toxic substances. This is one of the reasons why Swedish pulp mills usually had chlorine dioxide implemented in the bleaching process already in the early 1970s.

The technology evolution towards ECF and TCF can be traced back to the proactive collaborative green R&D activities initiated by the Swedish pulp and paper industry even before modern environmental regulation was implemented in Sweden in 1969. These activities were, as we have shown, related to the industry (as well as the authorities') early strategy to focus on reducing the environmental impacts through internal process changes, which guided the development into certain technological development path. In the same token, the U.S. development followed a different

[113] Norberg-Bohm and Rossi (1998) p 230.
[114] The majority of the Nordic mills that had switched to TCF in 1994 were of Swedish origin. Only two mills in Finland and two mills in the U.S. had then opted for TCF (Reinstaller, 2005, p 1373).
[115] Reinstaller (2008).

technological trajectory since the U.S. regulatory approach fostered more of end-of-pipe solutions compared to the Swedish approach.

Previous research has emphasized the importance of the strict environmental regulation implemented in Sweden in the early 1990s, as well as the corporative, plant-by-plant regulatory style. According to Popp et al. (2011), competition among major industry players to satisfy consumer demand for chlorine free paper further played a vital role in the initial development of chlorine-free technologies. We have shown in this paper that the Swedish authorities required the Swedish pulp and paper producers to push the technology development beyond 'of the shelf' (BAT) technology already from the mid-1980s, which is earlier than noticed in previous studies.[116] This was possible since the Swedish EPA through the collaborative R&D platforms had knowledge of "around the corner" technology. Because of this, the ECF and TCF technology was principally already developed when Swedish consumers and the German export market started to ask for chlorine-free paper. Knowledge on alternative bleaching processes was spurred by both a strong regulatory action and proactive firm-collaborative R&D initiatives, which fundamentally aided the transition to TCF and ECF in Sweden. The public debate and demand for chlorine-free paper however played a vital role for the swift adoption and fast diffusion of the technology when it was at hand.

As much as the Swedish trajectory was influenced by its' technological paradigm to focus on internal process changes, the U.S. regulatory approach was consistent with the dominant abatement technology in the U.S. pulp and paper industry. Moreover, the absence of a wide public debate in conjunction with the institutional regulatory style considerably delayed the process of substituting chlorine in the U.S. industry. The U.S. pulp and paper industry strongly opposed the regulation proposed by the EPA in 1993, and a less stringent rule was announced in 1997, excluding the oxygen delignification stage.

This paper has highlighted the critical importance of events in the past in explaining firms' ability to respond to sudden and unexpected challenges requiring rapid technological changes, stemming from environmental regulation and/or 'green' market demand. These events include firms'/industry sectors' R&D strategies undertaken in the past and how these have interplayed with national strategies for environmental regulation. It is perhaps no news that the U.S. and Sweden approached industrial pollution issues differently already in the 1ate 1960s, or that development subsequently has differed between the countries. The great influence of initial corporative and authoratitive approaches on long-term technology development trajectories is however not as well known.

[116] See e.g. Reinstaller (2005) and Popp et al (2011).

REFERENCES

Arthur, Brian W. (1989) “Competing Technologies, Increasing Returns, and Historical Lock-In by Historical Events”, *Economic Journal*, 99, p 116-131.

Bergquist, Ann-Kristin, Söderholm, Kristina, Kinneryd, Hanna, Söderholm, Patrik, Lindmark, Magnus. (2013) “Command-and-Control revisited: Environmental Compliance and Technological Development in Swedish industry 1970-1990”, *Ecological Economics*, 85, January: 6-19.

Bergquist, Ann-Kristin and Söderholm, Kristina (2011). “Green Innovation Systems in Swedish Industry 1960-1989”, *Business History Review,* Winter, 85: 677-98.

Bergquist Ann-Kristin and Söderholm Kristina, “Institutes for the Diffusion of Green Knowledge”, forthcoming chapter (2014) in *Institutes and new roles in science, technology and innovation,* Katarina Larsen (Ed.).

Bingel, Eva, Sjöberg Claes and Sjöquist, Charlotte (2002). *Från defensiv till proaktiv. Drivkrafterna bakom hållbar tillväxt*, Rapport, Stockholm: Svenskt näringsliv.

Dosi, Giovanni. (1982) “Technological Paradigms and Technological Trajectories”, *Research Policy*, 11, 147-162.

Eriksson, Lennart. (2010) *STFIs öden och äventyr 1942-2010: fakta-minnen-reflexioner,* Spearhead production AB.

Freeman, Chris. (1995) ”The ’National System of Innovation’ in historical perspective”, *Cambridge Journal of Economics*, 19, 5-24.

Gunningham, Neil. (2009) “Environmental Law, Regulation and Governance: Shifting Architectures”, *Journal of International Law*, :1-34.

Gunningham, Neil., Kagan, Robert A, and Thorthon, Dorthy. (2003) *Different Shades of Green. Business, Regulation, and Environment.* Standford University Press, California.

Harrison, Kathryn. (2002) “Ideas and Environmental Standard Setting: A Comparative Study of Regulation of Pulp and Paper Industry”, *Governance*, 15 (1): 65-96.

Interview with anonymous Franchise board official with experiences of licensing processes of the late 1980s and onwards, Stockholm, 8 June 2010.

Interview with Hans Norrström, (engaged by both IVL, STFI and the largest consulting firm of the pulp and paper industry) Stockholm, 8 June, 2010.

Jerkeman, Per. (2007) *Bokslut. Några lönsamma forskningsresultat*, Skogsindustrins Forskningsstiftelse: Stockholm.

Jänicke, Martin. (1992) “Conditions for Environmental Policy Success: An international Comparision”. *The Environmentalist*, 12 (1); 47-58.

Kinneryd, Hanna. (2010) ”Så Länge Det är Tekniskt Möjligt, Ekonomiskt Rimligt och Miljömässigt Motiverat: en studie av det tidiga svenska miljöskyddssystemet med fokus på teknisk utveckling inom svensk pappers och massaindustri’, Research Report, Luleå University of Technology.

Liebowitz, S.J. and Margolis, Stephen E. (1995) “Path Dependence, Lock-in and History”, Journal of Law, Economics, & Organiszation, 11 (1), 205-226.

Lundqvist, Lennart J. (1980). The Hare and the Tortoise: Clean Air Policies in the United States and Sweden. Ann Arbor: The University of Michigan Univ. Press

Magnusson, Lars. (2002). *Sveriges ekonomiska historia.* Stockholm: Norstedts.

Norberg-Bohm, Vicki and Rossi, Mark. (1998). ”The Power of Incrementalism: Environmental Regulation and Technological Change in Pulp and Paper Bleaching in the US”, *Technology Analysis & Strategic Management*, 10 (2): 225-245.

Popp, David, Hafner, Tamara and Johnstone, Nick. (2011) “Environmental policy vs. public preassure: Innovation and diffusion of alternative bleaching technologies in the pulp industry”, *Research Policy*, 40, 1253-1268.

Powell, Mark R. (1997) *Control of Dioxins (and other Organochlorines) from the Pulp and Paper industry under the Clean Water Act and Lead in Soil at Superfund Mining Sites: Two Case Studies in the EPA’s Use of Science,* Discussion Paper 97-08, Washington DC.

Reinstaller, Andreas. (2008) “The technological transition to chlorine free pulp bleaching technologies: lessons for transition policies”, *Journal of Cleaner Production*, 16 (1): 133-147.
Reinstaller, Andreas. (2005) “Policy entrepreneurship in the co-evolution of institutions, preferences and technology. Comparing the diffusion of totally chlorine free pulp bleaching technologies in the US and Sweden”, Research Policy, 34, 1366-1384.
Rajotte, Alain (2003) ”Paper Production Technology and Environmental Performance in Sweden and Finland: Policy, Science and Market Share”, *Society and Natural Resources*, 16, :719-728.
Rosenberg, Nathan. (1994) *Exploring the Black Box: Technology, Economics and History*, Cambridge University Press: New York.
Rothstein, Bo (1992), *Den korporativa staten – Intresseorganisationer och statsförvaltning i svensk politik.* Stockholm.
Rycroft, Roberg W. and Kash, Done E. (2002) ”Path Dependence in the Innovation of Complex Technologies, *Technology Analysis & Strategic Management*, 14 (1) 21-35.
SSVL (Swedish Forest Industries’ Water and Air Pollution Research Foundation) (1991). ‘Miljö 90’, Final report, Stockholm.
SSVL (Swedish Forest Industries’ Water and Air Pollution Research Foundation) (1997). *Klorid i återvinningssystem*, Final report, Stockholm.
SSVL, (Swedish Forest Industries’ Water and Air Pollution Research Foundation) (1974). Interim Report No. 10 within the project ”Klorid i återvinningssystem” (1974-76), Stockholm.
SSVL (Swedish Forest Industries’ Water and Air Pollution Research Foundation) (1982). *Miljövänlig tillverkning av blekt massa*, Final report, Stockholm.
SSVL (Swedish Forest Industries’ Water and Air Pollution Research Foundation) (1981). *Nordmiljö 80*, Final report, Stockholm.
Swedish Forest Industry Federation (2011). Faktasamling, 2011 år branschstatistik.
Södergren, Anders. (1998) *Biologiska effekter av blekeriavlopp*. Naturvårdsverket: Solna.
Söderholm, Kristina., Bergquist, Ann-Kristin. (2012). ”Firm-collaboration and environmental adaptation: the case of the Swedish pulp and paper industry 1900–1990”. *Scandinavian Economic History Review* 60 (2): 183–211.
Söderholm K. and Bergquist A-K. (2013)”Growing Green and Competitive – a Case Study of a Swedish Pulp Mill”, *Sustainability*, 2013 5(5),1789-1805
Sörlin, Sverker (2006). *En ny institutssektor. En analys av industriforskningsinstitutens villkor och framtid ur ett närings- och innovationspolitiskt perspektiv*. Näringsdepartementet.
Wallace, David. (1995). *Environmental Policy and Industrial Innovation. Strategies in Europe, the US and Japan*. Earthscan, London.
Waluszewski, Alexandra and Håkansson, Håkan (2004) “Das Plagiat” in Widmalm, Sven (Ed.) *Artefakter*, pp 219-244: 223.
Westerlund, Staffan (1971), *Miljöskyddslagstiftning och välfärden*, Stockholm: Natur och Kultur.