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The transition to cleaner technologies: the Swedish pulp and paper industry in a comparative perspective

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1. Introduction

Over the past five decades modern environmental regulation has greatly altered the commercial conditions for most industries in the Western world. Market pressure has moreover interplayed with regulation as a driver towards greener production processes and products. The pulp and paper industry (PPI) is known as one of the biggest polluters in the world. Since the expansion of chemical pulp in the late 19th century, the industry has been associated with odorous gases and the emission of fibers and other substances into waterways, and has peaked environmental agendas in virtually every nation with such production after the 1960s. Thus the PPI was an obvious target when stricter regulations to control industrial pollution started to get implemented in the 1970s, in Finland, Sweden, Canada, the United States, Australia, New Zeeland and other countries (Gunningham et al. 2003; Bergquist & Söderholm, 2015a).

For any polluting industry, technology is at the very core of the challenge of reducing the environmental impact, and indeed this has been the case for the PPI. Technological strategies and timing for investments have differed between countries and regions depending on the different national jurisdictions, organizational solutions and demand characteristics. The literature on corporate environmentalism, which stresses the mode of response to environmental issues, has generally identified a movement along an evolutionary adaptive learning process forming specific attitudes or modes of response during certain periods. An important conclusion from this research is that before 1990, firms typically employed end-of-pipe approaches to achieve regulatory compliance, which practically means external treatment of effluents after they have left the plant (Lee and Rhee, 2005; Frondel et al. 2007; Hoffman, 1997). The alternative technological approach, internal process changes (e.g., in-plant measures that prevent or reduce effluents before they leave the plant, sometimes also referred to as 'cleaner production technologies'), has subsequently been acknowledged a more advantageous strategy (Sinclair, 1990). Still, the Swedish PPI do not follow the text book example of the learning process from end-of-pipe technology to 'cleaner' production processes, but already in the 1970s embarked on internal process changes as the main technological strategy to control pollution.

In this paper, we examine innovation and technological shifts in cleaner production technologies in the Swedish PPI in an international context. We cover the period from the late 1960s until today, and discuss how the importance of regulatory- and market/opinion pressure, technological strategies and environmental performance has evolved. We will also include the development of energy efficient technology in our analysis as the phasing-out of oil in the Swedish PPI in the 1970s meant several environmental problems could be addressed simultaneously.[1] Still, before the 1990s energy use was not distinctly connected to environmental concerns. The Swedish development will be partly contrasted to the parallel Finnish and North American experience, focusing on different technological strategies to control pollution. While the Swedish PPI early on embarked on internal process changes as the main technological strategy to control pollution, the Finnish and the US PPI became more focused on end-of-pipe technologies (Harrison, 2001; Bergquist and Söderholm, 2015).

Section 2. Background

Serious pressure on the PPI to reduce emissions started in Sweden in the late 1960s (slightly later in Finland and North America), and was driven by new regulatory frameworks, public debates and eventually changing market preferences, such as a new demand in the 1990s for chlorine free paper products on the European market. In parallel to the 'greening' of the industry also energy prices have put strong pressure on the PPI to transform. Thus, serious concerns about the energy use were driven by increasing energy prices in the wake of the Oil crisis in the 1970s, and later, in the 1990s, the energy use became interrelated with concerns about climate change and CO_2 emissions.

Although the Swedish PPI had been mobilizing recourses to assess various aspects of the environment ever since the early 20th century (Söderholm and Bergquist, 2012), the enforcement of the Environmental Protection Act in 1969 pushed the whole industry to boost their R&D efforts and investments in environmental technology. Efforts paid off and between 1970 and the mid 1990s, the emissions of Chemical Oxygen Demand (COD) were reduced by 85 percent, Chlorinated Organic Compounds (AOX) by 90 percent, and sulfur by 90 percent

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[1] Oil was substituted in the Swedish PPI in the 1970s mainly by biofuels in terms of rest products from the pulp manufacturing process. This illustrates a dynamic nexus between energy and environmental challenges as increased energy efficiency meant a parallel disposal of waste (bark and newspaper) and emissions (e.g., CO2, organic substances and elemental chlorine) (Bergquist and Söderholm 2015b)

from the Swedish PPI (Skogsindustrierna, 1995:74, 90). The decoupling between pulp production and the different emissions typically occurred a few years later in Finland and North America than in Sweden (Hilden, 2002; Bergquist and Söderholm, 2015). In parallel to the 'greening' of the Swedish PPI, its' energy mix has changed substantially, with oil being replaced by biofuels. Between 1973 and 1990, the use of oil was reduced by more than 80 percent (Bergquist & Söderholm, 2015b). As an effect, also the emission of CO_2 from the Swedish PPI was reduced by more than 80 percent (Lindmark et. al., 2011). Today the Swedish PPI is a world leader in terms of CO_2 efficiency (IEA, 2007). Together with the Finnish PPI, the Swedish PPI further has a more efficient energy use than other major pulp producing countries, including the USA, Canada and Brazil (Fracoro et el. 2012). All in all, the emission reductions and switch in energy carriers indicate major technological shifts carried out in interrelation to the overall development of the global PPI since the 1960s. Figure 1, 2 and 3 in our Appendix illustrates the reduction of sulfur, AOX respectively COD from the Swedish PPI. Figure 4 illustrates the Swedish pulp production and Figure 5, 6 and 7 shows the production of ECF and TCF bleached pulp. Table 1 and 2 in turn lists major environmental impacts of pulp and paper production respectively technological strategies of the Swedish PPI to control pollution.

Drawing on the Introduction and Background above (***section 1 and 2***), the following sections of this chapter will cover how the Swedish PPI built up its technological capacity to control pollution. In this context it is necessary to cover both the main environmentally related problems caused by pulp and paper production, and the role of environmental regulation. In the wake of the environmental revolution in the 1960s, countries developed very different regulatory styles to control industrial pollution, with implications for how the PPI of the different countries developed their environmental strategies. Sweden and the US approached industrial pollution differently already in the late 1960s, which enforced not only different relations between the firms and the environmental authorities but also divergent technological paths (Bergquist & Söderholm, 2015b).

Section 3 provides a short overview of the main environmentally related problems caused by the PPI. These problems are common for the whole industry globally, and have no national characteristics. Table 1 illustrates the main pollution problems and shortly explains the processes which cause the problems. This section will be descriptive.

Section 4 will cover the development of the 'infrastructure' for environmentally related R&D in the Swedish PPI and how it evolved in tandem with stricter environmental regulations from the 1960s until the mid-1980s. In this section we will also discuss the reason why the Swedish PPI, in contrast to their Finish and US counterparts, came to focus on internal process changes rather than end-of pipe technologies. As has been showed by previous research covering the Swedish PPI, there has been a distinctive feature of collaboration between the state and the industry sector in both environmentally related and energy related R&D (Bergquist & Söderholm, 2011; Bergquist and Söderholm, 2015a). This characteristic relates to a broader literature that suggests that the Swedish PPI formed a nation-based business system with specific characteristics that include collaboration between firms (Hellgren and Melin, 1994; Melander, 1997). Section 4 provides a table (Table 1) with major technological strategies to control pollution in the Swedish PPI. The section concludes that environmental technology has typically been developed incrementally and strongly underpinned by jointly (sector-wide) financed R&D. However, in the 1980s, there was a major eruption in the public debate targeting the PPI, which will be discussed in the section below.

Section 5 will focus on what is known as the most controversial environmentally related technological shift in the PPI worldwide, i.e., the transition from bleaching pulp by elemental chlorine to elemental chlorine free (ECF) or total chlorine free (TCF) bleaching technologies. The transition started in the late 1980s, after the US EPA had discovered concentrations of dioxins in the waterways connected to pulp mills producing bleached pulp. When it was confirmed that dioxins was formed during the manufacturing of bleached pulp, the issue was raised globally. Here, Swedish firms took the technological lead in commercializing TCF, and was early with the adoption of ECF (Smith, 1997; Reinstaller, 2008). Scandinavian firms today dominate the market for TCF pulp, and the reasons will be explained in this section. Figure 5, 6 and 7 shows the production of ECF and TCF bleached pulp in 1990-2012, in the World, Scandinavia and in North America respectively.

Section 6 covers the energy issue, starting with the increase in oil prices in the 1970s. The PPI is heavily energy intensive. Thus, the rise in oil prices in 1973 implied strong pressure on the Swedish PPI to reduce the use of oil and to improve energy efficiency (Lindmark et al.). This occurred in parallel to the first wave of greening and heavy investment in pollution control technologies and related R&D in the Swedish PPI after the enforcement of the Swedish Environmental Protection Act in 1969. The section provides an overview of the ‘infrastructure’ for energy related R&D, which was similar to how the Swedish PPI organised for environmentally related R&D. The section further covers the transition, when oil was replaced with bio fuels (e.g. black liquor, bark and chips), meaning lower emissions of sulfur and CO_2. Today, craft pulp mills are self-sufficient when it comes to energy, and the PPI is increasingly acknowledged as an industry of great importance to the transition to an energy system based on renewable resources.

Section 7. In this section we sum up the main features of the strategy towards more sustainable production processes in the PPI since the 1960s. We will argue that environmentally related issues have played a central role for the overall transformation of the Swedish PPI in the second half of the 20^{th} century, essentially because new or altered technologies were required to comply with tightening environmental regulation. The development after the 1980s further illustrates how the emergence of green consumerism came to play an important role as driver towards TCF production in the Swedish and Finnish PPI, however not to the same extent in other pulp producing countries. We will further point to the fact that the PPI has developed from being considered as one of the greatest polluters of the 20^{th} century, to an industry considered as essential in the transition towards a more sustainable (bio-based) economy. The PPI produces original bio-based products using wood, a renewable material, and paper for recycling. In EU today the PPI constitute the biggest single industrial producer and user of renewable energy: 56 % of the industry's primary annual energy consumption is biomass-based (CEPI, 2013:50).

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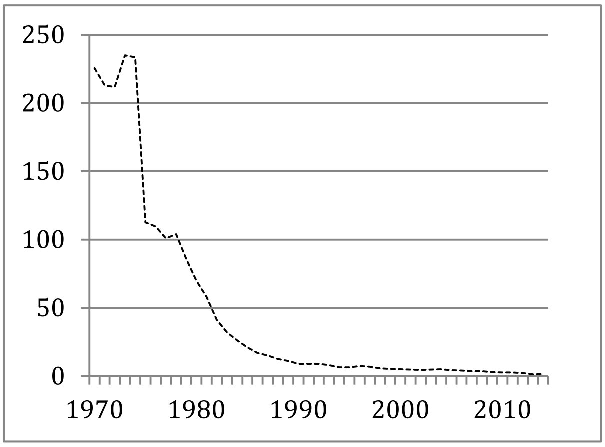
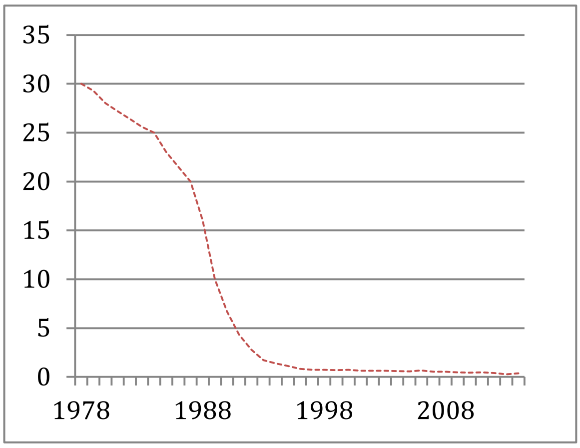
Appendix

Figure 1. Emissions of sulfur 1970-2014 (metric tons)



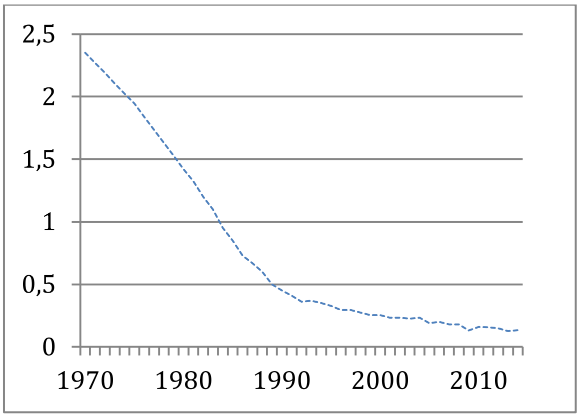
Source: Skogsindustriernas miljödatabas

Figure 2. Emissions of AOX 1978-2014 (metric tons)



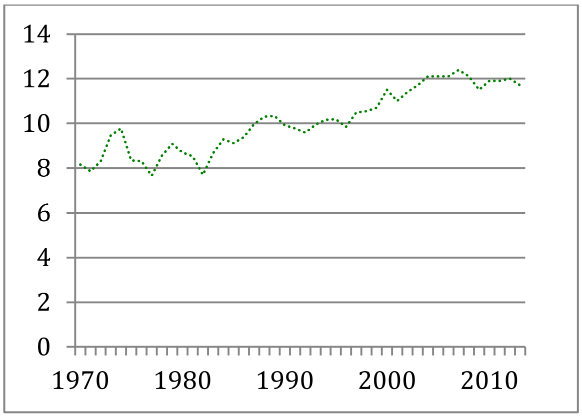
Source: Skogsindustriernas miljödatabas

Figure 3. Emissions of COD 1970-2014 (million tons)



Source: Skogsindustriernas miljödatabas

Figure 4. Swedish pulp production 1970-2013 (million tons)



Source: Swedish Forest Industry Statistics

Figure 5. Bleached chemical pulp production in the world 1990-2010 (million tons)

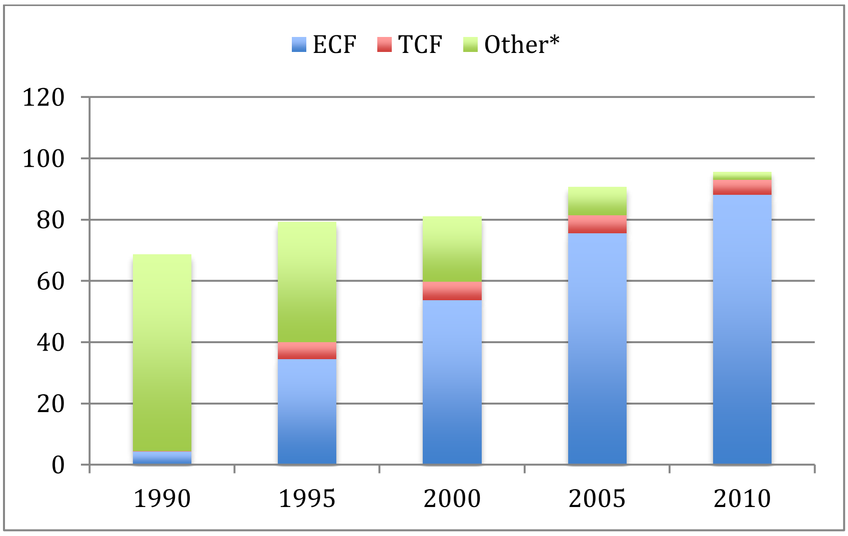
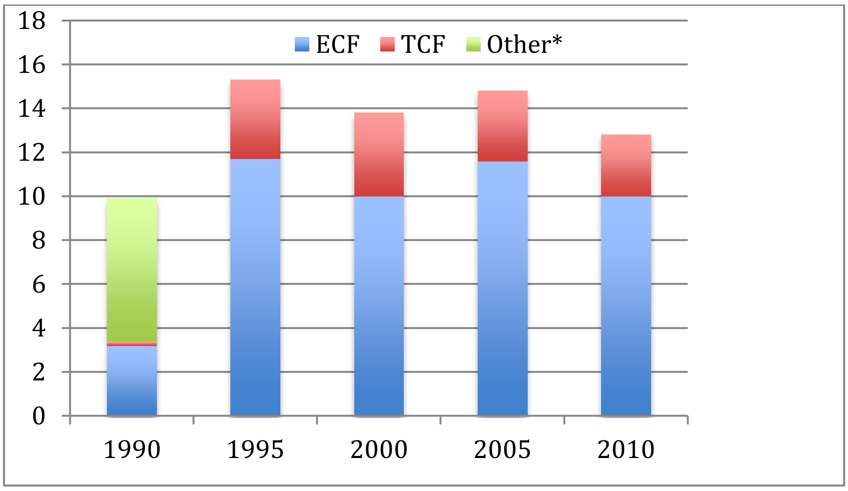


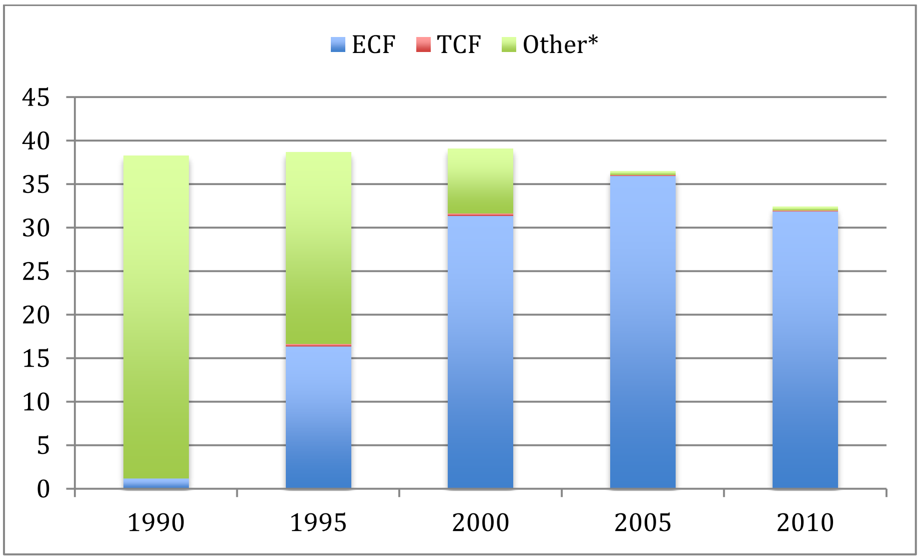
Figure 6. Bleached chemical pulp production in Scandinavia 1990-2010 (million tons)



*Pulp bleached with some molecular chlorine

Source: Alliance for Environmental Technology (2012)

Figure 7. Bleached chemical pulp production in North America 1990-2010 (million tons)



*Pulp bleached with some molecular chlorine

Source: Alliance for Environmental Technology (2012)

Table 1. Major environmental impacts of pulp and paper production

Suspended solids (SS)	Have its origins in bark, pieces of fiber and filling and coating agents. Consumes oxygen when decaying and can be carriers of poisonous substances.
Organic matter in general (BOD and COD)	Uses oxygen from water. May cause oxygen deficiency in waterways, which leads to death of i.e. fish and severe damage to the ecosystem.
Chlorinated organic compounds (AOX)	From mills using elemental chlorine in their bleaching sequence. Waste water that contain organic products formed by elemental chlorine reacting with wood products to form absorbable organic halide (AOX). AOX has become an accepted measure of chlorinated organic material, and is used to monitor and regulate bleached Kraft pulp mill effluents. AOX is used as a surrogate parameter of dioxins in wastewater (and stack gas) from pulp mills.
Water consumption	Pulp mills are big water users. Consumption of fresh water can seriously harm habitats near mills, recduce water levels, necessary for fish, and change water temperature, a ritical enviornmental factor for fish.
Sulfur dioxide (SO_2) and reduced sulfur compounds	Leads to acid rain and causes soil degeneration.
Nitrogen oxides (NOx)	Gases composed of nitrogen and oxygen formed during combustion. In moist air, the substances are converted into nitrogen oxides and then nitric acid, which creates acid rain. Orginates from recovery boilers in the Kraft pulp process.
Smell	

Source: Ince, B.K., Cetecioglu, Z. & Ince, O. (2011). "Pollution Prevention in the Pulp and Paper Industries", in *Environmental Management in Practice,* edited by Broniewicz. INTECH. Skogsindustrierna (1995). *MiljöInfo från Skogsindustrierna*, Stockholm: Skogsindustrierna; Nilsson, N. (2007); "Cleaner Production: technologies and tools for resource efficient production. Baltic University Press.

Table 2 illustrates how the Swedish PPI, both when it comes to water- and air pollution, controlled pollution foremost by internal strategies. (Table 2 is a work in progress).

Table 2. Major technological strategies of the Swedish PPI in the 1970s to the 1990s to control pollution

Technological measures	**Water internal**	**Water end of pipe**	**Air internal**	**Air end of pipe**
Modified boiling and bleaching	Prolonged cooking Oxygen delignification Bleaching with ozone			
Stepwise closure of the water systems	Reduced discharges (of fibres and chemicals) and consumption of water through: -Separated and closed sewers -Closed water systems in screening- and bleaching plants -Closed water systems in paper mills			
Increased recovery of chemicals	Improved pulp washing			
Treatment of condensates.	Separation of condensates			
Measures against temporary discharges.	Embankment of tanks and other equipment Monitoring of emissions and chemical consumption Monitoring of process equipment Staff training			
Mechanical, ***biological and*** ***chemical treatment.***		Sedimentation and flotation Aerated pond, Activated sludge method and Aerob- and Anaerob purification Chemical precipitation		
Improved combustion			In recovery boilers, bark boilers and lime kilns	
Process changes			Increased temperature, liquor solids and load, and other process engineering measures in recovery boilers Control of bleaching to minimize the surplus of bleaching chemicals	
Cyclones, electrical filters/precipitators and scrubbers				Gas purification and separation of particulates.