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Decentralized Environmental Regulations and Plant-Level Productivity

Abstract

Using a unique plant-level dataset we examine total factor productivity (TFP) growth and its components, related to efficiency change and technical change. The data we use is from Sweden and for their pulp and paper industry, which is heavily regulated due to its historically large contribution to air and water pollution. Our paper contributes to the broader empirical literature on the Porter Hypothesis, which posits a positive relationship between environmental regulation and "green" TFP growth of firms. Our exercise is innovative as Sweden has a unique regulatory structure where the manufacturing plants have to comply with plant-specific regulatory standards stipulated at the national level, as well as decentralized local supervision and enforcement. Our key findings are: (1) prudential regulation limits expansion of plants with high initial pollution; (2) regulation, however, is not conducive to plants' "green" technical change, which provides evidence against the recast version of the Porter Hypothesis; (3) decentralized command-and-control regulation is prone to regulatory bias, entailing politically motivated discriminatory treatment of plants with otherwise equal characteristics.

JEL-Codes: D240, L510, L600, Q520, Q530, Q580.

Keywords: pollution, environmental regulations, plant-specific regulation, decentralized regulation, enforcement, political-economy, Porter Hypothesis, TFP, productivity, efficiency, technical change, pulp and paper industry.

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1. Introduction

The more traditional literature examining the impact of environmental regulations highlighted a negative link between the stringency of regulatory standards and manufacturing industries' total factor productivity (TFP) growth (e.g., Gray 1987, Jaffe, Peterson et al. 1995). The conventional logic is that as environmental compliance forces firms to reallocate real resources to pollution abatement and control activities, costs increase and TFP growth declines (Repetto, Rothman et al. 1997).

This conventional view was questioned in a series of articles by Michael Porter (Porter, 1991; Porter and Van der Linde 1995a, 1995b). In the widely debated "Porter Hypothesis", a case was made that regulation-induced innovation and efficiency gains may actually trigger longer-term enhancements in technology and productivity. Pollution control measures might also have productivity enhancing effects simply because they curb the production of 'undesirable' (or bad) outputs, such as toxic air emissions and water effluents, which are created along with the production of conventional 'desirable' (or good) output (e.g., Chung, Färe et al. 1997).

The Porter Hypothesis has generated much empirical research in the Economics, Management, and environmental studies literatures. Ambec et. al. (2013), Cohen and Tubb (2018), for example, provide excellent overviews of the conceptual issues, and the empirical evidence to date. Many articles, including numerous examples presented in Porter and Linde (1995a), provide evidence on instances where environmental regulations stimulate new innovation, as measured by product or process innovations. These have occurred in industries such as automotive, plastics, various agricultural products, chemicals, among others.

A secondary channel to show the effects of the Porter Hypothesis has been, for example, via analysis of productivity. Empirical tests of the impact of environmental regulation on TFP growth measures able to capture the multi-output nature (including bad outputs) of technology are known as tests of a recast version of the Porter Hypothesis (Managi, Opaluch et al. 2005).

This paper contributes to empirical literature on the Porter Hypothesis's recast version. At the same time, it provides an empirical test to the 'original' Porter Hypothesis and its posited positive link between environmental regulation and conventional TFP growth of regulated firms.

As we detail in section 3, in our paper we utilize a non-parametric approach to examine issues related to productivity, efficiency and technical change due the methodological advantages relative to the more conventional econometric techniques involving fixed functional forms. The non-parametric methods we use offer benefits due to their ability to model multi-output technologies.

When modeling the activities of polluting firms, this approach allows for firms' 'undesirable' or 'bad' outputs related to air and water emissions to be included in the production technology. This is useful from the perspective of analyzing productivity as polluting firms typically have to allocate substantial resources to reduce bad outputs without being compensated for these measures on the output side – because the conventional productivity measures only consider 'good' (i.e. conventional) output, alongside conventional inputs. Thus, standard TFP indexes tend to underestimate firms' TFP growth since they do not consider the fact that pollution abatement has led to positive effects on the output side in the form of reduced bad outputs. This bias is eliminated by the so-called environmentally-adjusted performance measures.

With regard to the Porter Hypothesis in particular, a second key argument in favor of non-parametric methods such as data envelopment analysis is that they allow for potential 'win-win' or 'double dividend' effects from regulation; the Porter Hypothesis's key message. This is because of the fact that firms are allowed be below the production possibility frontier; a departure from the neoclassical assumption of profit-maximizing firms in line with the Porter Hypothesis's postulations. The 'Porter effects' can hence be achieved via an increased static efficiency, whereby firms catch up to the frontier.

In a dynamic data envelopment analysis setting, the Porter effects can materialize through an enhanced dynamic efficiency which is related the shift of the frontier via technology development.[4] Hence, our overall approach is appealing as we gain improved insight into the effect of environmental regulations on firm performance.

In this paper we argue that the regulator is concerned with pushing polluting firms to the efficiency frontier: that is, regulation leads to a positive efficiency change, and we argue that the Porter Hypothesis side effect of a shift of the technology frontier materializes as positive technical change.

In our empirical analysis we follow a two-step procedure. In the first step, we use the data envelopment approach to calculate environmentally-adjusted TFP growth for the plants, including air and water pollutants and poisonous landfill waste.[5] We compute our green TFP

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[4] See Chung, Färe et al. (1997), Marklund (2003), and Brännlund and Lundgren (2009).

[5] A comprehensive literature review of non-parametric energy and environmental modeling approaches is provided by Zhang and Choi (2014).

growth measure employing the Malmquist-Luenberger (ML) productivity index (e.g., Chung, Färe et al. 1997, Oh and Heshmati 2010). In the second stage, we use the environmentally sensitive TFP measure as dependent variable in a parametric dynamic panel regression model built to explain to what extent the variation in plants' environmentally sensitive TFP growth is explained by environmental regulation.

Aside from providing evidence on productivity, efficiency and technical change, we focus on the challenges of coordinating environmental policy in decentralized systems of environmental governance. The medium to long-term dynamic efficiency and 'win-win' goals of national environmental legislation need to be aligned with goals pursued by more decentralized (regional, local) levels of government – which might be more of a short-term nature and at odds with the longer-term dynamic national objectives.

This conjecture has been confirmed by some recent findings in the literature suggesting that decentralized environmental governance may lead to regulatory bias and efficiency losses (Oates and Schwab 1988, Oates 1999, Oates 2002). Sjöberg (2012), for example, reports anecdotal evidence of political pressure on environmental inspectors in Swedish municipalities for the purpose of appearing more business friendly. We expect likelihood of regulatory bias in a decentralized system – which can be interpreted as flawed coordination between different regulatory levels – to be detrimental to inducing green TFP growth at regulated firms.

Overall, our empirical results lend some support to our conjecture that regulatory stringency positively affects pulp and paper plants' environmentally-adjusted TFP growth and its components (efficiency change and technical change), respectively. In particular, we find that Swedish regulation has induced environmentally-adjusted efficiency change of plants, which suggests that the authorities have been be able to stimulate plants to develop new pollution control technologies to reduce their comparatively large environmental footprint. Also, we find that decentralized Swedish command-and-control regulation might be subject to regulatory bias, entailing a politically motivated discriminatory treatment of plants with otherwise equal characteristics, which suggests a coordination failure of Sweden's decentralized regulatory system.

The paper is organized as follows. Section 2 provides a background on the Sweden's pulp and paper industry's air emissions and water pollutants, their trends over time, and the structure of national and local regulatory standards. Section 3 notes our main hypotheses, and in section 4 we present the methodology used in our empirical analysis. In section 5 we present the data and descriptive statistics. Section 6 presents the results, and concluding comments appear in section 7.

2. Emissions, Environmental Standards, and Decentralized Permitting in Sweden

Against the backdrop of increasingly stringent environmental regulations and rapidly changing global markets, the pulp and paper industry (**PPI**) in Europe and North America has been undergoing a fundamental transformation since the 1980s.[6] From an economic standpoint, the PPI has been one of the more important industries in Sweden and other Nordic countries. Nearly 31,000 persons were employed in Sweden in the industry in 2011, with its share in overall industry employment remaining steady at 5-6 percent since 1993. Also, the industry has been a major contributor to Sweden's trade balance over the last 20 years, accounting for over 12 percent of total Swedish exports in 1993, and for over 8 percent in 2011 (Statistics Sweden 2013).[7]

The PPI, however, is a source of considerable environmental pollution. Due to its production technology – which involves converting wood to pulp, bleaching, processing the bleached pulp to paper, and application of chemical coatings to finish the papermaking process – the industry significantly contributes to air and water pollution. This has resulted in the firms being subject to significant ongoing environmental scrutiny.[8] In this section we briefly detail the industry's emissions and emission trends, and the process of environmental standards and permitting in Sweden.

2.1. Air and Water Emissions

The PPI is one of the most polluting manufacturing industries, generating multiple air and water pollutants. Air emissions result primarily from plants' energy-intensive production processes, which require the combustion of fossil fuels as well as biofuels. Even though there has been a considerable reduction in emissions over the years, the industry still accounted for a substantial 35 percent of Swedish manufacturing industry's emissions of sulfur dioxide (SO2) in 2010 (Statistics Sweden 2013). Another important air pollutant is nitrogen oxides (NOx): Between 1993 and 2010, the PPI's share in Swedish manufacturing industry's NOx emissions increased from 42 percent to over 46 percent (Statistics Sweden 2013).

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[6] For an overview over the global market issues, see Ghosal (2003) and Ghosal (2013).

[7] Statistics Sweden (2013). "Statistical Database." Retrieved January 22, 2013, from http://www.scb.se.

[8] Ghosal and Nair-Reichert (2009) and Ghosal (2015). Provide details for some of the findings.

Significant amounts of water pollutants are contained in plants' wastewater effluents. The pollutants include halogenated organic compounds (AOX), biochemical oxygen demand (BOD5, BOD7), chemical oxygen demand (COD), total nitrogen (N), and total phosphorus (P). While the PPI long has been a major emitter of AOX (European Commission 2001), these pollutants have declined significantly since the 1990s (SEPA 2002). Historically, the Swedish PPI has also been a major emitter of COD and BOD, accounting, for example, for more than 50 percent of the total discharge of BOD in Sweden in the beginning of the 1990s (Brännlund, Färe et al. 1995).

These environmentally harmful by-products from pulp and paper production have resulted in an ever increasing regulatory pressure on the part of the Swedish environmental protection authorities which, in turn, has induced the PPI to invest considerable amounts of resources to pollution containment (Lönnroth 2010).

Regarding pollution control expenditures and trends in emissions, data from Statistics Sweden (2013) show that between 2001 and 2011 the PPI, on average, accounted for 20 percent of the combined total environmental expenditures by Swedish industry and the energy sector. Amounting to annual average expenditures of 1.9 billion SEK during that period, those costs were in part incurred for environmental investments (45 percent on average), which in turn were used for water pollution abatement (47 percent on average) and air pollution abatement (38 percent on average). Particularly noteworthy are the industry's abatement efforts in the area of water pollution. During 2001-2011, its share in total water-related environmental investments by Swedish industry and the energy sector together, on average, was 39 percent - compared with a share of just 19 percent for air-related environmental investments (Statistics Sweden 2013).

[Figure 1 about here]

The industry's resource allocations to pollution mitigation are mirrored by favorable emission trends. Between 1993 and 2010, NOx emissions decreased by around 25 percent, whereas total SO2 reduction was 68 percent (Statistics Sweden 2013). **Figure 1** illustrates air emission and corresponding environmental expenditure trends in the PPI once more.
The water pollution data show that the most pronounced reductions were accomplished for COD (annual average decrease of 3.8 percent), and AOX (annual average decrease of 3.5 percent) – with annual average decreases in Phosphorus and Nitrogen discharges being

slightly lower at 2.6 percent and 2 percent, respectively. **Figure 2** illustrates water emissions and corresponding environmental expenditure trends in the PPI once more.

[Figure 2 about here]

2.2. Environmental Permitting Process

Sweden's polluting industries are subject to several layers of regulatory constraints under the general principles stipulated in the Swedish Environmental Code (Swedish Code of Statutes 1998a). *First*, they face common national environmental standards in the form of various economic incentive instruments, such as taxes and charges (Swedish Code of Statutes 1990a, Swedish Code of Statutes 1990b, Swedish Code of Statutes 1990c). *Second*, they face stringent CAC regulation in the form of a plant-specific operating permit issued by regional environmental courts on a case-by-case basis. The permits contain emission standards specific to the plant to which it must comply.[9] *Third*, they are exposed to decentralized local monitoring and enforcement (Swedish Code of Statutes 1998a).

The setting of environmental standards, permitting and enforcement, therefore, follows a complex and creative pattern. Depending on the perceived environmental risk they pose, pulp and paper plant permits are issued either by the municipal authorities ('C-plants' or lowest risk), the county administrative boards ('B-plants' or moderate risk) or by regional environmental courts ('A-plants' or highest risk). The larger, and environmentally most damaging, plants are all classified as 'A-plants,' putting them under the supervision of one, out of five, regional environmental courts (Swedish Code of Statutes 1989, Swedish Code of Statutes 1998a). When issuing a permit, the environmental court stipulates plant-specific "emission limit values" (ELV). The ELVs are determined based on "best available technology" (BAT) considerations, which take into account plant-specific environmental impacts and economic feasibility (Swedish Code of Statutes 1998a, SEPA 2002, OECD 2007). For example, regulators can impose more stringent conditions on plants with more severe local environmental impact (SEPA 2002). A realization of the 'Polluter Pays Principle,' this can imply that large plants may be obliged to divert more resources to pollution abatement—in order to internalize their larger environmental footprint—than smaller ones. Analogously, plants located close to environmentally-sensitive areas (e.g. nature

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[9] Prior to 1999, the Franchise Board for Environmental Protection was the regulatory authority for the pulp and paper industry (Swedish Code of Statutes 1969, Swedish Code of Statutes 1988, Swedish Code of Statutes 1989).

reserve, inland water) can be subject to stricter regulation than, for instance, those located by the sea. Third, the regulatory authorities aim to strike a balance between environmental concerns and national economic welfare, aiming not to harm the international competitiveness of Swedish industry and industry's importance for local and regional Swedish economies, respectively (Lönnroth 2010).

From a political economy perspective, the efficiency benefits of a plant-specific permit system have to be weighed against the risk, on the one hand, of lobbying on the part of the industry and firms, and, on the other, of politically motivated discrimination of certain plants, which would be similar in all other aspects discussed above. Such an efficiency-distorting scenario is not unrealistic, not least due to the fact that the operative enforcement takes place at the regional-municipal level. Lobbying, for example, may be likely in the case of large plants, who have a stronger bargaining position vis-à-vis the authorities—and thus could achieve more favorable conditions (SEPA 2002).

Politically-conditioned unequal treatment of otherwise identical plants may occur, in particular, when municipalities are involved in the operative enforcement work. (Sjöberg 2012), for instance, shows that municipal differences in the enforcement of the Swedish Environmental Code can be explained by Green Party representation in a municipality's ruling coalition.[10]

2.3. Taxes and Emissions Trading Schemes

The complementary regulatory constraints affecting the PPI involve a mix of economic incentive instruments: taxes, subsidies, charges and emissions trading schemes. These instruments have been increasingly used in Swedish environmental policy since the beginning of the 1990s.[11] In 1991, carbon dioxide and sulfur taxes were introduced (Swedish Code of Statutes 1990a, Swedish Code of Statutes 1990b). Intending to curb CO2 and SO2 emissions, the taxes are levied on fossil fuels consumed, with fuels having the highest carbon and sulfur content taxed the highest. Making fossil fuel consumption more expensive is designed to induce plants to improve energy efficiency and to substitute away from 'dirty' fuels to 'cleaner' fuels, such as biofuels—whose combustion is less emission-intensive.

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[10] For a more detailed analysis of Swedish CAC regulation, see Weiss (2015).

[11] A comprehensive review of Swedish economic incentive instruments in the context of regulating polluting industries is provided by Weiss (2015).

Introduction of a charge on NOx emissions from energy production occurred in 1992 (Swedish Code of Statutes 1990c).[12]

Under these schemes, plants for which emission reduction is more expensive will tend to pay the tax or acquire emission rights from plants for which curbing emissions is less expensive. Those plants for which emission reductions are cheaper will tend to avoid green tax payments. As in the case of the plant-specific permit regulation, large plants, all else equal, will likely incur lower pollution abatement costs per unit emissions than smaller plants due to economies of scale that arise from the typically high fixed costs involved in abatement investments that firms have to incur. Therefore, large plants will tend to proportionately reallocate more.

3. Hypotheses

Based on our discussions in Sections 1 and 2, we formulate the following main hypotheses of this paper.

First, the traditional (neoclassical) assumption is that that regulation imposes additional costs on firms and therefore hampers productivity growth. However, according to the strong version of the Porter hypothesis, prudential regulation that creates incentives for plants to improve induces product and process innovations, may beneficially affect firms' resource allocation and increase productivity.

> ***H1****: Stricter environmental regulation will, in line with the original Porter Hypothesis, induce a positive effect on Swedish pulp and paper plants' environmentally-adjusted TFP growth and its components.*

Second, the regulatory intensity of a plant should be a function of a plant's pollution level. The more inefficient a plant, the stricter should be the regulation that it faces. To capture the effects from these two variables on productivity growth, we regress the lagged distance to the frontier as a measure of inefficiency and the lagged plant's overall pollution contribution on a plant's TFP growth. We expect that both variables are positively related to TFP growth.

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[12] This action had a large impact on the pulp and paper industry, which is the largest industrial energy producer and consumer in Sweden (SEPA 2007). The charge tackles electricity and heat production from boilers with a useful energy production of at least 25 gigawatt hours (GWh) a year—and is levied regardless of the type of fuel employed. The NOx charge is a refund-based system, implying that all revenue net of administration cost is returned to the plants involved, in proportion to the amount of clean energy they produce. Boilers producing energy output with low NOx emissions are net recipients, whereas boilers with emission-intensive energy production are net payers to the system. In this way, an incentive is created for participating plants to minimize NOx emissions per unit of energy produced (SEPA 2006).

> ***H2**: In line with environmental and economic efficiency considerations, the larger a plant in terms of its pollution, the more stringent it is regulated, and thus the higher is its green TFP growth.*

Third, as discussed in section 2, there might be political influences on regulatory stringency. While, according to the Porter Hypothesis, prudential regulation can improve a plant's productivity growth according to our main hypothesis, there might be political influences that hamper the productivity improvement of the manufacturing plants. One such political influence could be the strength of the green party in the region where the plant is located. While environmental concerns on the one hand would lead to stricter environmental regulation (and thus to higher productivity growth, if regulation is prudential, according to our hypothesis), it might be that those concerns are so strong that the plant has to reduce output in order to meet political-economy influences.

> ***H3**: Decentralized regulation is subject to bias: it triggers a politically motivated discriminatory treatment of plants with otherwise similar characteristics (e.g. regarding size and production process).*

4. Methodology

The literature on the Porter Hypothesis's recast version harnesses non-parametric methods and their methodological advantages relative to pure econometric techniques involving fixed functional forms. A major benefit of non-parametric approaches is their ability to model multi-output technologies. When modeling the activities of polluting firms, this implies that firms' 'undesirable' or 'bad' outputs (e.g. air and water emissions) can be included in the production technology. This makes sense from a productivity perspective because polluting firms often allocate substantial productive resources to reduce bad outputs without being compensated for these measures on the output side - because conventional productivity measures only consider 'good' (i.e. conventional) output, alongside conventional inputs.

This implies that the standard TFP indexes tend to underestimate firms' TFP growth since they do not consider the fact that pollution abatement has led to positive effects on the output side in the form of reduced bad output. This bias is eliminated by so-called environmentally-adjusted performance measures (Chung, Färe et al. 1997).

A non-parametric approach that has been used in this context is data envelopment analysis (DEA), in connection with a so-called directional distance function (DDF).[13] Based on the underlying multi-output technology, the DEA procedure constructs a technology frontier consisting of the best-performing firms in the sample. Lower-performing firms are clustered below the frontier.

With regard to the Porter Hypothesis, a second key argument in favor of non-parametric methods such as DEA is that they allow for potential 'win-win' or 'double dividend' effects from regulation – the Porter Hypothesis's key message. This is because of the fact that firms are allowed be below the production possibility frontier, which is a departure from the neoclassical assumption of profit-maximizing firms in line with the Porter Hypothesis's postulations.

The above 'Porter effects' can hence be achieved via an increased static efficiency, whereby firms catch up to the frontier. In a dynamic DEA setting, the Porter effects can materialize through an enhanced dynamic efficiency – a shift of the frontier via technology development.[14] Hence, the DEA-DDF approach is appealing to gain improved insight into the effect of environmental regulation on firm performance. In this paper we argue that the regulator is concerned with pushing polluting firms to the efficiency frontier. That is, regulation leads to a positive efficiency change. We argue that the Porter Hypothesis's side effect of a shift of the technology frontier materializes as positive technical change.

One way of analyzing this link is to regress the environmentally-adjusted performance variable, obtained using the DEA-DDF approach, on proxy variables that might influence environmental regulation. Those regulatory proxies are examples of so-called uncontrollable variables: explanatory variables that are assumed to affect the environmentally-adjusted performance measure while being beyond the plant manager's control. Referred to as a two-stage model, this approach has certain advantages over other techniques (Yang and Pollitt 2009). It is this approach that we chose in the empirical analysis of this paper.

Our empirical study are for the most pollution-intensive Swedish pulp and paper plants ('A-Plants'), which we observe during 2001-2014. The two-stage model involves, in a first step, the use of the DEA-DDF approach to calculate environmentally-adjusted TFP

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[13] See (Chung, Färe et al. 1997).

[14] See Chung, Färe et al. (1997), Marklund (2003), and Brännlund and Lundgren (2009).

growth for these plants, including air and water pollutants and poisonous landfill waste.[15] We compute our green TFP growth measure employing the Malmquist-Luenberger (ML) productivity index (Chung, Färe et al. 1997, Oh and Heshmati 2010). The second stage of our modeling approach involves using the environmentally sensitive TFP measure as dependent variable in a parametric dynamic panel regression model built to explain to what extent the variation in plants' environmentally sensitive TFP growth is explained by environmental regulation.

Following the approaches of Färe, Grosskopf et al. (2012) and Kumar (2006), we compute the Luenberger total factor productivity indicator ML. The assumptions of the approach are as follows. DMUs produce M desirable outputs, $\mathbf{y} \in R_+^M$, and J undesirable outputs, $\mathbf{b} \in R_+^J$, jointly from N inputs, $\mathbf{x} \in R_+^N$. The production possibility set is expressed as:

$$P(\mathbf{x}) = \{(\mathbf{y},\mathbf{b}) \mid \mathbf{x} \,\text{can produce}\, (\mathbf{y},\mathbf{b})\}$$

Regarding underlying assumptions for this (need to spell out the "three types" very clearly to avoid any productivity measure, we assume that inputs to production are strongly disposable, which is:

$$x' \geq x \text{ then } \mathrm{P}(\mathbf{x}') \supseteq \mathrm{P}(\mathbf{x}).$$

This means that a plant can produce the same output using more inputs. The models also assume strong disposability of desirable outputs, denoted as:

$$\mathbf{y} \in P(\mathbf{x}) \text{ and } \mathbf{y} \geq \mathbf{y}', \text{ then } \mathbf{y}' \in \mathrm{P}(\mathbf{x}) \ .$$

Some of the desirable output can be disposed of in the production possibility set, meaning that it is possible – at a given amount of inputs – to produce less output without cost.

The ML approach uses an assumption related to the undesirable output, which is called null-jointness and can be written as:

$$(\mathbf{y},\mathbf{b}) \in P(\mathbf{x}) \text{ and } \mathbf{b} = \mathbf{0}, \text{ then } \mathbf{y} = \mathbf{0}.$$

Furthermore, the ML model uses the assumption of weak disposability for the bad output which can be formalized as:

$$(\mathbf{y},\mathbf{b}) \in P(\mathbf{x}) \text{ and } 0 \leq \theta \leq 1, \text{ then } (\theta\mathbf{y},\theta\mathbf{b}) \in \mathrm{P}(\mathbf{x}).$$

This means that a proportional contraction of both desirable and undesirable outputs is feasible in the production possibility set. The approach uses the notation of directional

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[15] A comprehensive literature review of non-parametric energy and environmental modeling approaches is provided by Zhang and Choi (2014).

output distance functions (**DDF**) to represent technology, which is also called additive-DEA model in contrast to the traditional multiplicative-Shepard distance function (see Cooper 2007).

For the ML index, the DDF can be written as:

$$\vec{D}_o(\mathbf{x},\mathbf{y},\mathbf{b};\mathbf{g}_y,\mathbf{g}_b)=\max\{\beta:\left(\mathbf{y}+\beta\mathbf{g}_y,\mathbf{b}-\beta\mathbf{g}_b\right)\in P(\mathbf{x})\},$$

where $\mathbf{g}=(\mathbf{g}_y,\mathbf{g}_b)$ is a direction vector. Following the literature, we assume in our empirical application $\mathbf{g}=(1,-1)$, which means that we try to find an efficiency measure β which expresses the distance of current output to the maximum feasible output (frontier) while simultaneously considering the maximum feasible reduction of undesirable outputs defined by the best available technology.

[Figure 3 about here]

Figure 3 illustrates these assumptions. The production possibility set is represented by the inner area of the solid line. The direction vector and the DDF are depicted for a plant *F*. The direction of the DDF of the plant *F* is constructed as an arrow, *β,* from the origin in northwest direction.

The measure of main interest for our study is the environmentally adjusted total factor productivity growth of plant i, tfp. In our case we want to analyze annual tfp changes. This is denoted by $tfp_i^{t,t+1}$ and can be obtained from:

$$\begin{aligned} tfp^{t,t+1}=\frac{1}{2}\Big[&\vec{D}_o^{t+1}(\mathbf{x}^t,\mathbf{y}^t,\mathbf{b}^t;\mathbf{g})-\vec{D}_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g}) \\ &+\vec{D}_o^{t}(\mathbf{x}^t,\mathbf{y}^t,\mathbf{b}^t;\mathbf{g})-\vec{D}_o^{t}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})\Big] \end{aligned} \quad (1)$$

where $\vec{D}_o$ refers to distance of plant i to the frontier (subscript i is omitted in the following for the sake of notational simplicity). Notation $\vec{D}_o^{t+1}$ indicates that the reference technology is constructed from period $(t+1)$ data, and inputs and outputs $(x^\tau,y^\tau,b^\tau),\tau\in\{t,t+1\}$ are then compared to that technology in $(t+1)$. The reference technology constructed from period t is denoted as $\vec{D}_o^t$. If there is no tfp change between periods t and $(t+1)$ then $tfp^{t,t+1}=0$. Productivity growth or regress are indicated by $tfp^{t,t+1}>0$, or $tfp^{t,t+1}<0$ respectively.

Another interesting feature of environmentally adjusted tfpindex is that it can be decomposed into two parts, which are: (a) *"efficiency change"*

$ec^{t,t+1} = \vec{D}_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g}) - \vec{D}_o^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})$;

And (b) *"technical change"*:

$$tc^{t,t+1} = \frac{1}{2}\begin{bmatrix} \vec{D}_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g}) - \vec{D}_o^{t}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g}) \\ +\vec{D}_o^{t+1}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g}) - \vec{D}_o^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g}) \end{bmatrix}.$$

Given these definitions it follows that: $tfp^{t,t+1} = ec^{t,t+1} + tc^{t,t+1}$.

The interpretation of efficiency change and technical change are as follows. If $ec^{t,t+1} > 1$ then there has been a movement of a plant towards the best practice frontier between *t+1* and *t*. If $tc^{t,t+1} > 1$ then there has been a shift of the plant's technology towards higher productivity between *t+1* and *t*.

Critical to examining the linkages between environmental regulations and productivity and efficiency improvements, are the interpretation of $ec^{t,t+1}$ and $tc^{t,t+1}$. Our basic assumption is that the regulator imposes efficiency improvements on plants, thus consequently $ec^{t,t+1}$ should be higher the stronger the regulation impacts the plants. (what does it mean if the plants do not or are unable to comply with the same set of regulations? Briefly spell it out). A byproduct of a strict regulation according to the Porter Hypothesis is that technical efficiency of plants improves; therefore, we should find that $tc^{t,t+1}$ is higher for the more regulated plants.

To obtain the tfp measure described above, we need to calculate the four distances, $\vec{D}_0^{\tau}(\mathbf{x}^{\tau},\mathbf{y}^{\tau},\mathbf{b}^{\tau};\mathbf{g})$, $\tau \in \{t, t+1\}$. For doing so, the following linear programming (LP) models are specified. The four distances that define tfp according to equation (1) are obtained from the LP problem:

$$\begin{aligned} &\vec{D}_0^{\tau}\left(\mathbf{x}_i^{\tau},\mathbf{y}_i^{\tau},\mathbf{b}_i^{\tau};\mathbf{g}_{y,b} = [1,-1]\right) = \max \beta \\ &s.t.\, \mathbf{Y}^{\tau}\mathbf{z}^{\tau} \geq (1+\beta)\mathbf{y}_i^{\tau} \\ &\mathbf{B}^{\tau}\mathbf{z}^{\tau} = (1-\beta)\mathbf{b}_i^{\tau} \\ &\mathbf{X}^{\tau}\mathbf{z}^{\tau} \leq \mathbf{x}_i^{\tau} \\ &\mathbf{z}^{\tau} \geq 0. \end{aligned}$$

In a second step we regress the obtained productivity growth measures on regulatory proxy variables to test the effect of 'well-designed' environmental regulation on environmentally-adjusted tfp growth at Swedish pulp and paper plants. Referred to as a two-stage model, this approach has certain advantages over other techniques in incorporating 'uncontrollables' into DEA.[16] These include the possibility of considering both continuous and categorical uncontrollable variables without risking a rise in the number of efficient plants. Moreover, no previous expectation is required as to how (positive or negative) an uncontrollable effects efficiency is needed (Battese and Coelli 1995, Coelli, Rao et al. 2005, Simar and Wilson 2007).

Next, we formulate a fixed effects panel data model as follows:

$$y_{it} = \boldsymbol{\beta}_k \mathbf{x}_{kit} + \mu_i + \theta_t + \varepsilon_{it} \qquad (0.1)$$

$i = 1, \ldots, \mathrm{N}$, $t = 1, \ldots, T$, $\mathbf{x}_{kit}$ is a matrix of k exogenous variables which are assumed to have an impact on a plant's productivity change according to our hypotheses, , μ_i denotes the plant's fixed effect, and θ_t denotes a time effect which capture common productivity trends across plants.

We also compute so-called counterfactual measures of tfp growth. For first counterfactual measure, we keep bad outputs at the year 2001 level and therefore this measure of tfp$^{(1)}$ growth is only determined by changes in outputs, inputs and technology. For the second measure we keep output at the 2001 level and let only bad outputs change over years 2001- 2014. Therefore, for this counterfactual measure, tfp$^{(2)}$ growth is driven entirely by changes of bads, inputs and technology. These measures help us to address what-if type of questions. We can for instance look at regulatory influences on the tfp$^{(2)}$ measure that only captures improvements in terms of bad output reduction.

5. Data and Variables

5.1. Data Sources

In our empirical analysis, we employ data from different sources. The environmentally adjusted productivity change measure is based on the ML index and is constructed using annual input-output data on the population of the larger pulp and paper plants in Sweden between 2001 and 2014. Data on these 'A-plants' (see Section 3) are published by The Swedish Forest Industries Federation and the Swedish EPA (SEPA), with the period 1996-2000 covered by SEPA (SEPA 1997-2001), and with the period 2001-2014 retrieved from an online database maintained by Swedish Forest Industries.[17]

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[16] The DEA literature refers to regulatory proxies as 'uncontrollables,' because they lie outside the influence of a DMU's management but a DMU's performance. For further approaches to include uncontrollable variables in a DEA framework, see Yang and Pollitt (2009).

[17] Swedish Forest Industries (2014). "Environmental Database." Web: http://miljodatabas.skogsindustrierna.org.

The data include plants' good outputs (pulp and paper quantities), the major bad output quantities regarding air and water pollution, as well as inputs such as water and energy. However, these sources lack data on plants' number of employees, and production capacity – information relevant to our analysis, which we partly found in the Nordic Paper and Pulp Makers' Directory (Nordisk Papperskalender 1996-2010).

We obtained data on employees and capacity from firms' annual reports from their respective websites and through Retriever Business (a Swedish online business database).[18] In addition, for the period 2007-2014, we were able to make use of yet another online database – the Swedish Pollutant Release and Transfer Register (**PRTR**).[19] PRTR lists emissions from the 1,000 largest companies in Sweden involved in activities considered 'environmentally hazardous' by the Environmental Code. This database includes our pulp and paper A-plants that matter for our study. PRTR helped us verify, during 2007-2014, that the Swedish Forest Industries emission data are consistent (and vice versa).[20] The firms' environmental or sustainability reports were yet another valuable source for us to verify the environmental data's consistency.

Finally, for the second-stage regression analysis, we merged our plant-level dataset with regional variables generated based on data from Statistics Sweden and PRTR, with the aim of constructing proxies designed to capture the varying regulatory stringency standards faced by Swedish pulp and paper plants.

In computing the environmentally adjusted tfp for each plant, we benchmark only against the balanced sample but use all plants for measuring plant-level productivity growth, and from this we get an unbalanced sample of 569 plant-year observations. The balanced sample should consist of 35 plants observed over 2001-2014, which is 490 observations.

5.2. Variables and Predicted Effects

Table 1 lists the variables used for deriving the productivity growth measures. For our environmentally adjusted tfp measure, we use plants' pulp production quantities for desirable output, denoted y. The bad outputs are in the areas of air and water pollution. Consistent with the pollutants that are considered harmful (see section 3), and the

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[18] Retriever Business (2014). "Online Database on Swedish Businesses." Web: http://www.retriever-info.com.

[19] SEPA (2014). "Swedish Pollutant Release and Transfer Register (PRTR)." Web: http://utslappisiffror.naturvardsverket.se.

[20] It must be noted that both online databases in principle use the same data source: the environmental reports that all companies submit to their supervisory authority.

availability of data, we consider the following measures. For air pollution, we use a plant's sulfur (ap_1), NOx emissions (ap_2), and CO2 emissions (ap_3). The water pollutants we include are COD effluents (wp_1), AOX (wp_2), phosphorus effluents (wp_3), nitrogen effluents (wp_4), and suspended organic materials (wp_5).

[Table 1 about here]

In terms of plant-level inputs, we chose total installed capacity for pulp and paper production (x_1), number of employees (x_2), net electricity use (x_3), and process water (x_4).

Following Färe, Grosskopf et al. (2012), and due to the fact that directional distance functions are sensitive to the scaling of the underlying variables, we normalize all inputs and outputs by dividing with the respective variable mean across all plants. Furthermore, in order to reduce the dimensionality problem of DEA[21], we average the four normalized inputs into an aggregate input index, **x**, and all normalized undesirable outputs are averaged into an aggregate indicator, denoted **b**.

Table 2 provides summary statistics for the plant-specific inputs and outputs used in constructing environmentally adjusted tfp growth.

[Table 2 about here]

The covariates employed in the second-stage regression including their expected effects are reported in **Table 3**. The variables are obtained from Statistics Sweden and PRTR.

[Table 3 about here]

The first variable, *pollution* measures the overall level of a plant's pollution relative to the average plant. We assume that the higher the current pollution level of a plant, the stricter it will be regulated and thus, productivity change of the respective plant will be lower. This is because the regulations limit the output of those plants and therefore the

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[21] The larger the number of inputs/outputs, and the smaller the number of plants to construct the efficient frontier, the higher the fraction of efficient plants. As an example, in our case with about 35 plants and defining 2 outputs, 1 bad with 3 inputs will render about one-third of the plants as 100 percent efficient, which is implausibly high.

relationship between current year's pollution level and productivity change should be negative.

The second variable of the model is plant size, *empl*, measured by the plant's number of employees. As implementing environmentally friendly technologies is costly, we assume that larger plants will have an advantage given the fixed cost nature of those investments. Furthermore, according to H2, larger plants are expected to be more regulated compared to smaller ones.

Our political variables are defined as follows. The Green party's share in the Municipal Council Election in plant *i*'s municipality *m* in year *t* is denoted *green*[22] This variable tests Sjöberg's (2012) finding that municipal differences in the enforcement of the Environmental Code can be explained by Green Party representation in a municipality's ruling coalition. *Green* is meant to proxy efficiency losses through regulatory bias due to decentralized elements in Swedish CAC regulation. As argued above, decentralized environmental governance may enhance the risk for coordination failures between decentralized branches of governance and its centralized national counterpart, thereby entailing a discriminatory treatment of plants with otherwise equal characteristics (e.g. size)..

Descriptive statistics of the variables that are used as explanatory variables in the second-stage are provided in **3Error! Reference source not found.**. Note that plant size, measured by the plant's number of employees, is normalized by dividing employees by the average number of employees over all plants.

[Table 4 about here]

6. TFP Growth Estimates

This section presents the estimates for the TFP growth measures over the sample period 2001-2014.

6.1. Environmentally-adjusted TFP Growth

Table 4 presents the results for *environmentally-adjusted* annual tfp growth at Swedish pulp and paper plants computed by model (1) as described in Section 5.[23] Overall,

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[22] The data were obtained from Statistics Sweden (2014).

[23] The computations have been performed using the package nonparaeff in R, version 0.5-8, written by Dong-hyun Oh and Dukrok Suh.

the results show that tfp growth in the pulp and paper industry is only modest with annual rates slightly above 1 percent. This holds both for the environmentally-adjusted tfp and the first counterfactual measure. This implies that tfp growth is mainly driven by output expansion or input reduction, and not by reduction of bad outputs.

The second counterfactual measure reflecting only the improvements in pollution reduction shows an even lower rate with 0.6%. This result is surprisingly low but can be explained by the fact that the biggest reduction in pollutants of Swedish PP plants was achieved in the 1990s and further reductions were costlier compared to initial reductions.

[Table 5 about here]

Table 5 shows that plants that were more distant to the frontier have experienced higher tfp growth, thus inefficient plants are catching up. In contrast to H2 plants with overall high pollution did not experience higher environmentally adjusted tfp growth. On the other hand, we find that larger plants have higher tfp growth, which could be due to economies of scale effects. The last column of Table 5 shows however no impact of plant size on counterfactual tfp growth that is only determined by pollution reduction. This shows that the advantage of larger plants in mainly due higher output growth, which is also shown by column 4. The green party share and also green party in government hampers the development of tfp. Thus, H3 is confirmed. We find that there is no significant impact from green party on bad ouput reduction (column) but a negative impact on tfp growth when bads are held constant (column 4). This means that a high share of the green party in last electionin the municipality where the plant is located reduces further expansion of PP plants.

Figure 4 shows the distribution of tfp, ec and tc across plants. One can see a considerable heterogeneity across plants. While efficiency change is negatively skewed, technical change is slightly positively skewed. This corresponds to a positive overall mean for technical change, whereas the overall mean for efficiency change is smaller (Table 4). These tests confirm that tfp$^{(1)}$, which reflects the recast Porter Hypothesis, outperforms the original tfp measure. Thus, pure output related tfp growth is higher compared to tfp growth when also bad reductions are considered. This is a finding in contrast to previous studies.

Error! Reference source not found. tests for determinants of ec and tc. We find that inefficient plants with high distance to frontier catch up, while at the same time they experience lower tc. Bigger plants have higher efficiency changes while again tc is lower.

The green party share hampers efficiency change of plants, but is conducive to environmentally adjusted technical change. This is in line with our hypothesis H3.

[Table 6 about here]

7. Conclusions

In contrast to many other countries, Sweden's emission standards are plant-specific and part of an operating permit issued by regional environmental courts on a case-by-case basis. The enforcement of these standards, in turn, occurs at the local level. This flexible approach has been noted by some to contribute to the dual goals of environmental protection and maintaining the competitiveness of Swedish manufacturing industry (Porter and van der Linde 1995a, Lönnroth 2010). A potential downside of such a regulatory regime is that it may trigger a discriminatory treatment of plants with otherwise similar characteristics (e.g. regarding plant size, politics, and local importance). This bias can be due to local environmental arguments in line with the Swedish Environmental Code or local political-economy considerations.

Against this backdrop, we examined the effect of environmental regulations in general, and Swedish decentralized and plant-specific regulatory structure in particular, on environmentally-adjusted TFP growth and its components for the Swedish pulp and paper industry. This approach allows us to empirically test some of the predictions of the Porter Hypothesis, which posits a positive relationship between environmental regulation and polluting firms' TFP growth (Porter and van der Linde 1995a). Moreover, we were able to analyze a less studied recast version of the Porter Hypothesis, which suggests that environmental regulation stimulates plants' environmentally-adjusted technical change.

Our findings suggest that Sweden's decentralized and plant-specific environmental regulation has had a positive effect on the pulp and paper industry's green efficiency change, though it has a negative effect on green TFP. Therefore, we find evidence in favor of the original version of the Porter Hypothesis. By contrast, regulation was found not to affect technical change of plants, which lets us reject the recast version of the Porter Hypothesis. Also, we find that decentralized Swedish command-and-control regulation might be subject to regulatory bias, entailing a politically motivated discriminatory treatment of plants with otherwise equal characteristics, which suggests a coordination failure of Sweden's decentralized regulatory system.

Our findings provide at least two valuable policy implications. First, our evidence is in favor of the classical Porter Hypothesis, but against the recast version of the Porter Hypothesis. This suggests that harmonizing the dual goals of environmental protection and economic growth continues to be a major challenge for environmental policy. Second, the fact that the achievement or non-achievement of these goals is usually judged using standard measures of productivity growth might miss the point. This is because these measures do not reflect polluting agents' true productivity improvements, suppressing the fact that they allocate productive resources to pollution abatement. Recently developed environmentally-sensitive TFP growth measures such as the Malmquist-Luenberger index represent promising steps towards correcting the alleged contradiction between environmental regulation and productivity growth.

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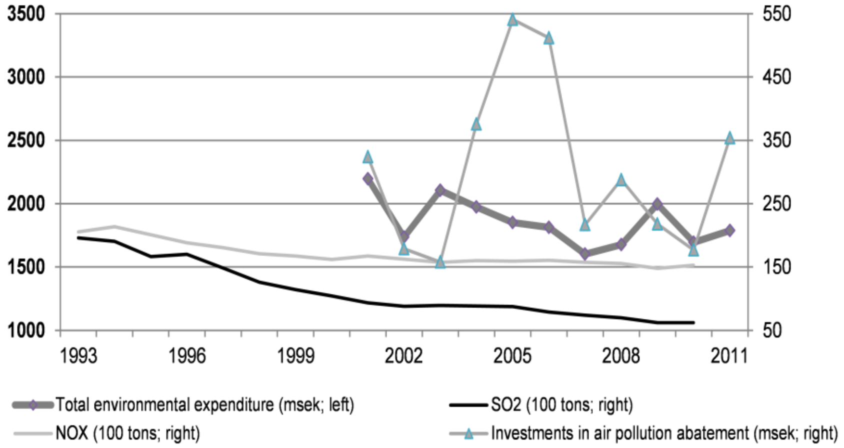
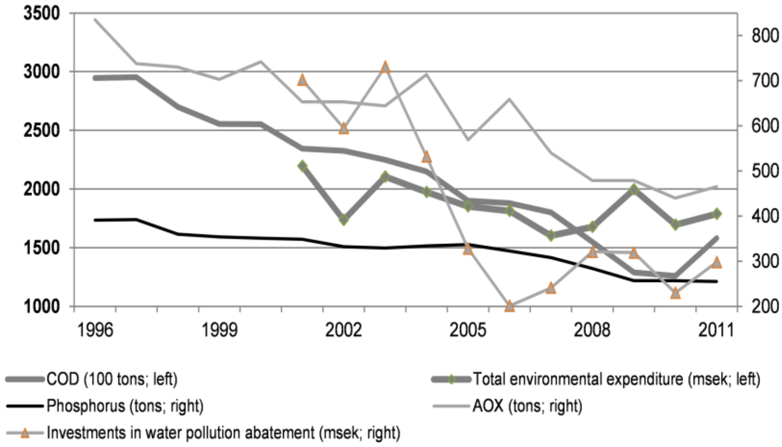
Figures

Figure 1. Air emissions and environmental expenditures



Source: Statistics Sweden (2013), and authors' calculations

Figure 2. Water pollution and environmental expenditures



Source: Swedish Forest Industries (2013), Swedish Pollutant Release and Transfer Register, Retriever Business (2013), and authors' calculations

Figure 3. Directional distance function and the ML index

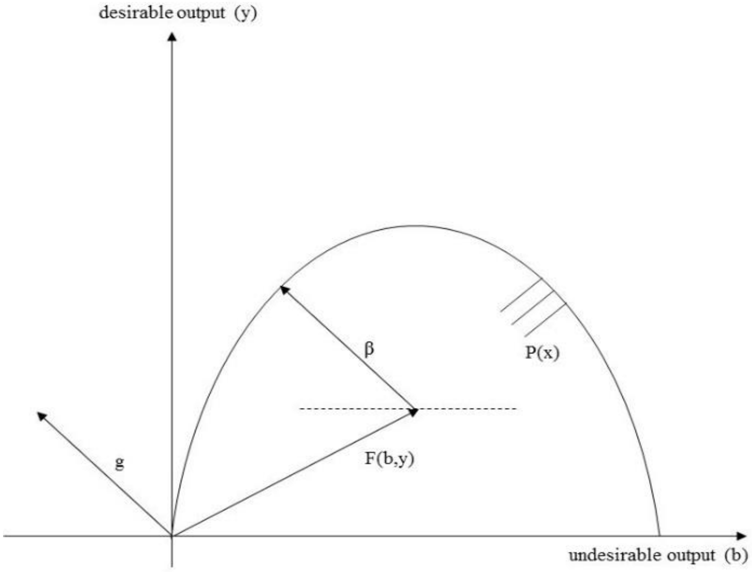
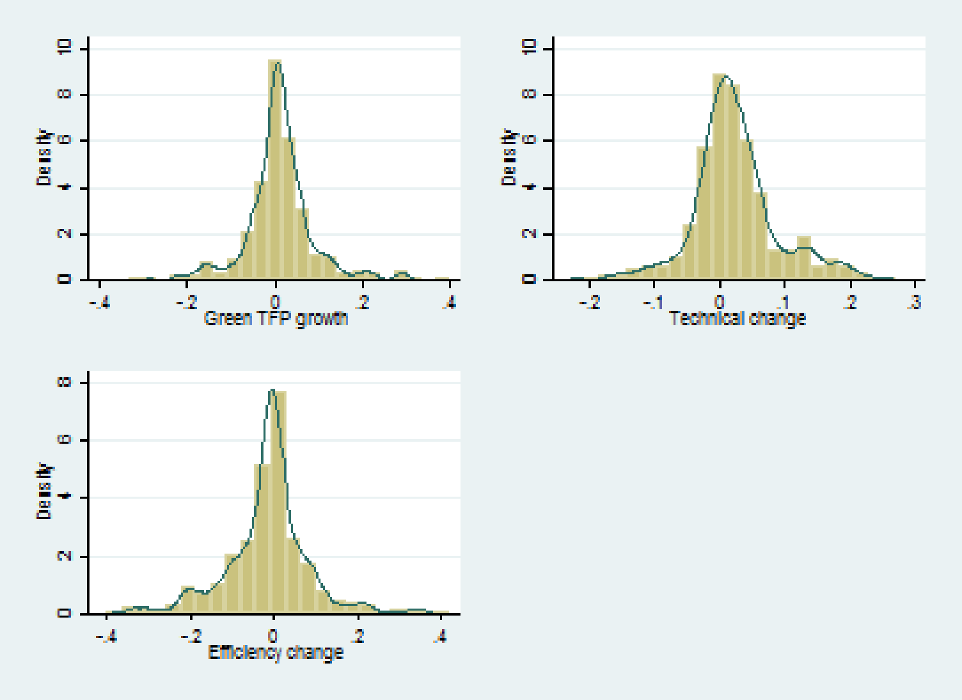


Figure 4. Distribution of green TFP growth and its decomposition components efficiency change and technical change over the pulp and paper plants 2001-2014



Tables

Table 1. Variables used for constructing the productivity indices

Symbol	**Variable description**	**Units**
Desirable Outputs		
Y_1	Total production of paper	1,000 tons
y_2	Total production of pulp	1,000 tons
Undesirable Outputs		
ap_1	Sulfur emissions (air)	tons
ap_2	NOx emissions (air)	tons
ap_3	CO2 emissions (air)	tons
wp_1	COD effluents (water)	tons
wp_2	AOX effluents (water)	tons
wp_3	Phosphorus effluents (water)	tons
wp4	Nitrogen effluents (water)	tons
wp5	Suspended materials (water)	tons
fp1	Poisonous waste (land-fill)	tons
Inputs		
x_1	Production capacity of pulp and paper	1,000 tons
x_2	Number of employees	persons
x_3	Net electricity use	GWh
x_4	Process water	1,000 m3

Note: The data were obtained from Swedish Forest Industries (2015), the Swedish EPA (SEPA 1997-2001), the Nordic Paper and Pulp Makers' Directory (Nordisk Papperskalender 1996-2010), and Retriever Business (2015).

Table 2. Descriptive statistics
Variables used in the environmentally adjusted tfp growth

Variable	Mean	Std. Dev.	Min	Max
Y_1	330.5	221.3	5	762
y_2	316.4	265.3	6	919
x_1	558.1	495.7	7	1610.5
x_2	460.1	304.3	30	1487
x_3	473.3	527.1	9.4	2492.7
x_4	11330.6	12146.3	0	61900
wp_1	3865.5	3989.0	1	24375
wp_2	12.1	25.6	0.01	215
wp_3	6.3	7.7	0	40
wp_4	58.4	58.6	0	325
wp_5	487.0	639.9	0.7	4161
ap_1	74.9	86.6	0	417
ap_2	305.1	308.9	0	1441
ap_3	538679.5	539332.1	145	2173011
fp_1	179.2	328.5	0.34	3812
Aggregate indices of inputs and outputs used in the computation of tfp measures				
y	1.0	0.8	0.02	2.69
bad	0.9	1.0	0.02	5.55
x	1.1	0.9	0.06	3.23

Table 3. Regulation and tfp growth
Variable description and expected effect in second-stage regression

Variable	Definition	Exp. Sign
Distance	Distance to frontier in the previous year, a measure of a plant's inefficiency	+
Pollution	Pollution level of plant *i* in the previous year	+
Employment	Number of employees of plant *i* in year *t*	+
Green party's share	Green party's lagged vote share in the last election of municipal council	-
Green party in govt.	Lagged dummy indicating that the Green party is member of the municipal government	-

Notes: For definitions see section 3.2 for description of models.

Table 4. Descriptive statistics
Variables in second-stage regression

Variable	mean	sd	min	max
Δtfp	0.0114	0.0818	-0.33058	0.3985
Δtfp$^{(1)}$	0.0118	0.0817	-0.33108	0.3981
Δtfp$^{(2)}$	0.0063	0.0684	-0.28514	0.3012
Δ*efficiency change (ec)*	-0.0127	0.1066	-0.39981	0.4238
Δ*technical change (tc)*	0.0240	0.0692	-0.22843	0.2719
Distance to frontier	0.4603	0.2953	-0.07083	0.9516
Bad output (normalized)	0.9423	0.9821	0.016773	5.5470
Employment (normalized)	1.0718	0.6966	0.069263	3.0199
Green party's share in last election	0.0422	0.0401	0	0.4146
Green party in municipal government(=1)	0.2926	0.4553	0	1.0000

Notes: tfp $^{(1)}$ counterfactual, bad is held constant at 2001 level, tfp$^{(2)}$ counterfactual, output is held constant at 2001 level.

Table 5. Determinants of environmentally adjusted “green”tfp growth
Fixed effects estimation

Models	(1) Δtfp	(2) Δtfp	(3) Δtfp	(4) $\Delta tfp^{(1)}$	(5) $\Delta tfp^{(2)}$
Distance to frontier (t-1)	0.423***	0.426***	0.488***	0.417***	0.266***
	(0.0552)	(0.0626)	(0.0728)	(0.0560)	(0.0495)
Pollution level (t-1)	-0.0169	-0.0275*	-0.0431**	-0.0161	0.00905
	(0.0131)	(0.0139)	(0.0184)	(0.0129)	(0.0104)
Plant employment (t-1)	0.0519*	0.0970***	0.108***	0.0502*	0.0122
	(0.0263)	(0.0325)	(0.0362)	(0.0261)	(0.0222)
Green party share (t-1)	-0.176*	----	----	-0.177*	-0.145
	(0.0984)			(0.101)	(0.135)
Green party govt. (t-1)	----	-0.0134*	-0.0155*	----	----
		(0.00737)	(0.00787)		
Year 2003 dummy	-0.0400**	----	----	-0.0395**	-0.0224
	(0.0186)			(0.0187)	(0.0166)
Year 2004	0.00805	0.0480**	0.0492**	0.00796	0.000466
	(0.0147)	(0.0184)	(0.0223)	(0.0146)	(0.0138)
Year 2005	-0.0193	0.0219	0.00951	-0.0186	-0.00435
	(0.0161)	(0.0158)	(0.0167)	(0.0161)	(0.0153)
Year 2006	-0.0216	0.0205	0.0134	-0.0215	-0.00199
	(0.0159)	(0.0153)	(0.0159)	(0.0158)	(0.0122)
Year 2007	-0.0111	0.0353**	0.0259	-0.0109	0.0143
	(0.0143)	(0.0173)	(0.0165)	(0.0142)	(0.0128)
Year 2008	-0.0677***	-0.0201	-0.0263	-0.0667***	-0.0152
	(0.0131)	(0.0184)	(0.0205)	(0.0130)	(0.0104)
Year 2009	-0.0798***	-0.0312*	-0.0430**	-0.0725***	-0.00936
	(0.0164)	(0.0180)	(0.0199)	(0.0170)	(0.0131)
Year 2010	-0.0236	0.0279	0.0240	-0.0234	-0.0190
	(0.0197)	(0.0196)	(0.0149)	(0.0197)	(0.0137)
Year 2011	-0.0839***	-0.0334*	-0.0479***	-0.0833***	-0.0365***
	(0.0168)	(0.0168)	(0.0168)	(0.0168)	(0.0127)
Year 2012	-0.0755***	-0.0254	-0.0398**	-0.0749***	-0.0344*
	(0.0188)	(0.0195)	(0.0185)	(0.0189)	(0.0175)
Year 2013	-0.0506***	0.00192	-0.0118	-0.0501***	0.000988
	(0.0178)	(0.0185)	(0.0179)	(0.0179)	(0.0145)
Year 2014	-0.0586***	-0.00434	-0.0220	-0.0582***	-0.0132
	(0.0182)	(0.0185)	(0.0173)	(0.0181)	(0.0151)
Constant	-0.178***	-0.270***	-0.309***	-0.175***	-0.122***
	(0.0468)	(0.0548)	(0.0597)	(0.0468)	(0.0383)
Fixed effects	yes***	yes***	yes***	yes***	yes***
Observations	564	514	417	564	563
R-squared	0.260	0.267	0.307	0.251	0.156
Number of plants	53	51	35	53	52

Notes: (1) all plants 2002-2014, (2) all plants 2003-2014, (3) balanced sample, 2003-2014, (4) $\Delta TFP^{(1)}$ counterfactual TFP 2002-2014, bad level constant at 2002 value, (5) $\Delta TFP^{(2)}$ counterfactual TFP growth 2002-2014, output level constant at 2002 value, cluster robust standard errors (by plant) in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 6. Determinants of efficiency and technical change
Fixed effects estimation

Models	(1) ec	(2) tc
Distance to frontier (t-1)	0.581***	-0.158***
	(0.0687)	(0.0298)
Pollution level (t-1)	-0.0288	0.0118
	(0.0179)	(0.00864)
Plant employment (t-1)	0.0800**	-0.0281*
	(0.0312)	(0.0147)
Green party share (t-1)	-0.296**	0.120**
	(0.141)	(0.0548)
Year 2003	0.127***	-0.167***
	(0.0246)	(0.0134)
Year 2004	0.0806***	-0.0726***
	(0.0144)	(0.0126)
Year 2005	0.103***	-0.122***
	(0.0169)	(0.00683)
Year 2006	0.0739***	-0.0955***
	(0.0162)	(0.00704)
Year 2007	0.0427**	-0.0538***
	(0.0161)	(0.0105)
Year 2008	0.0283*	-0.0960***
	(0.0154)	(0.0105)
Year 2009	0.0762***	-0.156***
	(0.0205)	(0.0141)
Year 2010	-0.000533	-0.0231**
	(0.0224)	(0.00963)
Year 2011	0.0205	-0.104***
	(0.0185)	(0.00987)
Year 2012	0.0409*	-0.116***
	(0.0227)	(0.0120)
Year 2013	0.0392**	-0.0899***
	(0.0189)	(0.0109)
Year 2014	0.0485**	-0.107***
	(0.0217)	(0.0111)
Constant	-0.381***	0.203***
	(0.0563)	(0.0208)
Fixed effects	yes***	yes***
Observations	564	564
R-squared	0.447	0.597
Number of plants	53	53

Notes: see previous Table, cluster robust standard errors (by plant) in parentheses,
*** p<0.01, ** p<0.05, * p<0.1