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Decentralized Regulation, Environmental Efficiency and Productivity

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Decentralized Regulation, Environmental Efficiency and Productivity

Vivek Ghosal[1], Andreas Stephan[2] and Jan Weiss[3]

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Abstract

Using a unique plant-level dataset we examine green productivity growth in Sweden's heavily regulated pulp and paper industry, which has historically been a significant contributor to air and water pollution. Our exercise is interesting as Sweden has a unique regulatory structure where plants have to comply with national environmental regulatory standards and enforcement, along with decentralised plant-specific regulations. In our analysis, we use the sequential Malmquist-Luenberger productivity index which accounts for air and water pollutants as undesirable outputs. Some of our key findings are: (1) regulation has stimulated technical change related to pollution control, and has induced plants to catch up with the best-practice technology frontier with regard to effluent abatement; (2) large plants are more heavily regulated than small plants; (3) plants in environmentally less sensitive areas or those with local importance as employer face relatively lenient regulatory constraints; (4) environmental regulations trigger localized knowledge spillovers between nearby plants, boosting their green TFP growth.

Keywords: TFP, DEA, Sequential Malmquist-Luenberger productivity index, pulp and paper industry, pollution, environmental regulations, enforcement, plant-specific regulation, productivity, Porter hypothesis.

JEL classification: D24; L51; L60; Q52; Q53; Q58

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1. Introduction

The literature examining the impact of environmental regulations has hightlighted the negative link between the regulatory standards and manufacturing industries' productivity growth (Gray 1987, Jaffe, Peterson et al. 1995). As environmental compliance forces firms to reallocate real resources to pollution abatement and control activities, costs increase and productivity growth declines (Repetto, Rothman et al. 1997). However, pollution control measures might have productivity enhancing effects as well; they curb the production of negative externalities or "undesirable" outputs, such as air emissions and water effluents, which are created along with the production of the conventional "desirable" output (final goods production).[4]

While a significant literature has examined the broader effects of environmental regulations, there is less research on the effects of decentralized standards. The debate on decentralized environmental policymaking is fragmented (Oates 1999, 2002). One body of this literature argues that decentralized regulations result in an environmental race-to-the-bottom, whereas other researchers deem that homogenous jurisdictions' decentralized

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[4] The Porter hypothesis notes potential regulation-induced innovation which may trigger longer term enhancements in technology and productivity (Porter and van der Linde 1995a, 1995b). Further, Ghosal and Nair-Reichert find that pulp and paper firms in Scandinavia, Europe and North America undertook significant investments in information and digital technologies to enhance process control to reduce pollution and increase environmental efficiency They find that these investments also markedly improved the firms' productivity (Ghosal and Nair-Reichert 2009).

policies are socially optimal because environmental standards are designed to equate marginal benefits and costs (Oates and Schwab 1988).

In this paper we study the impact of environmental regulations on the efficiency of Swedish pulp and paper manufacturing plants. As we detail in section 2, the unique feature of the Swedish environmental regulatory structure is the layering of a strong degree of decentralization in setting of standards, monitoring and enforcement on top of national standards and controls. This implies that when we examine the impact of regulations on the manufacturing plants' efficiency, we have to assess both the broader regulatory standards which all plants have to comply with, but also the highly decentralized local controls which individual plants are often confronted with.

Our work is related to several previous studies. From an environmental policy point of view, it extends studies by Brännlund, Färe et al. (1995) and SEPA (2002). With regard to the methodology applied, it refines work by Managi, Opaluch et al. (2005) and Telle and Larsson (2007). Brännlund, Färe et al. (1995) examine the effect of environmental regulation on profits of Swedish pulp plants in 1989-90. The authors first apply a nonparametric programing model to calculate the plant-specific costs of regulation, which in turn are regressed on plant-level characteristics to determine drivers of regulatory cost. Their results indicate substantial variations in plants' regulatory cost burden, with large plants more affected than smaller ones.

SEPA (2002) evaluates the effects of Sweden's individual permit system on air and water emissions from Swedish sulfate pulp plants during 1981-2000. A panel regression is run to test the effect of changes in plants' permit conditions regarding emissions per ton on the change in plants' actual relative emissions of that pollutant. Their findings suggest that case-by-case permitting contributed significantly to emissions reductions over the sample period. In addition, the study contains descriptive results for the year 2000 which indicate that inland plants and large plants are subject to stricter emission limits relative to production than coastal and small plants. The authors view this as being supportive of the permit system's environmental efficiency.

Telle and Larsson (2007) use plant-level data to study the effects of Norway's plant-specific regulations on environmentally-adjusted TFP growth in the country's most energy-intensive manufacturing during 1993-2002. They compute their green TFP measure using an environmental Malmquist productivity index. The index is used to empirically test the effects of regulatory stringency on conventional and green TFP growth. They find a positive and significant effect of regulatory stringency on the index. The authors conclude that excluding environmental considerations when measuring TFP growth can lead to misguided conclusions.

Finally, Managi, Opaluch et al. (2005) use Data Envelopment Analysis to measure growth in environmentally-adjusted TFP and its constituents in the Gulf of Mexico offshore oil and gas industry during 1968-1998. To test the Porter hypothesis and a recast variant of it, they use regression analysis to explore the link between environmental regulation and change in standard TFP and green TFP. They find evidence in favor of the modified Porter hypothesis, suggesting a positive link between the stringency of environmental regulation and the joint productivity of market and non-market outputs.

As we detail in section 3, to examine the impact of environmental regulations on the productivity of Swedish paper plants, we use an extension of the Malmquist-Luenberger productivity index which has recently been proposed as sequential Malmquist-Luenberger productivity index (Oh and Heshmati 2010). The latter index has a conceptual advantage in that technical regression of the green technology frontier cannot occur. First, we obtain the sequential Malmquist-Luenberger index for each plant. Second, we examine which potential drivers of bias in environmental regulatory stringency are related to the observed heterogeneity of environmental efficiency across plants. We also present baseline regression results using the standard Malmquist index to assess whether Swedish regulations affect conventional TFP growth in this industry.

The paper is organized as follows. Section 2 provides background on the Swedish 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 describes our hypotheses and the methodology used in our empirical analysis. In section 4 we present the data and descriptive statistics. Section 5 presents the results and concluding comments appear in section 6.

2. Emissions, Environmental Standards and Decentralized Permitting

Against the backdrop of increasingly stringent environmental regulations and rapidly changing global markets, the pulp and paper industry in Europe and North America has been undergoing a fundamental transformation since the 1980s.[5] From an economic standpoint, the paper industry 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).[6]

The paper industry, 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 ongoing environmental scrutiny. In this section we briefly detail the industry's emissions and trends, and the process of environmental standards and permitting in Sweden.

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

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

2.1. Air and Water Emissions

The paper industry is one of the most polluting in manufacturing, generating multiple air and water pollutants. Air emissions result primarily from plants' energy-intensive production processes, which require the combustion of fossil fuels. Even though there has been a considerable reduction in emissions over several years, the industry still accounted for 35 percent of Swedish manufacturing industry's emissions of sulfur dioxide (SO2) in 2010 (Statistics Sweden 2013) Another important air pollutant is nitrogen oxide (NOx). Between 1993 and 2010, the paper industry's share in Swedish manufacturing industry's NOx emissions has grown from 42 percent to over 46 percent (Statistics Sweden 2013) largely due to substituting fossil fuels with biofuels (Sterner and Turnheim 2009).

Significant amounts of water pollutants are contained in the paper plants' wastewater effluents. The pollutants include halogenated organic compounds (AOX), biochemical oxygen demand (BOD5 or 7), chemical oxygen demand (COD), total nitrogen (N), and total phosphorus (P). While the paper industry has been a major emitter of AOX (European Commission 2001), they have declined significantly since the 1990s (SEPA 2002). Historically, the Swedish paper industry has also been a major emitter of COD and BOD with more than half 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 the paper production have resulted in an ever increasing regulatory pressure on the part of the

Swedish environmental protection authorities (Lönnroth 2010). These measures have caused the paper industry to reallocate considerable amounts of resources to pollution containment.

Regarding pollution control expenditures and trends in emissions, data from Statistics Sweden (2013) show that between 2001 and 2011 the paper industry, 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 here]

The industry's resource allocations to pollution mitigation are mirrored by favorable emission trends. Between 1993 and 2010, NOx emissions decreased by 1.6 percent, whereas total SO2 reduction was 68 percent (Statistics Sweden 2013). 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).

[Figure 2 here]

2.2. Environmental Permiting Process

Sweden's polluting industries are subject to general principles stipulated in the Swedish Environmental Code (Swedish Code of Statutes 1998a). First, they face common environmental standards in the form of various economic instruments, such as taxes and charges (Swedish Code of Statutes 1990a, 1990b, 1990c). Second, and the cornerstone of Sweden's environmental regulatory structure, is 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.[7]

The setting of environmental standards, permitting and enforcement, therefore, follows a complex and creative pattern. Depending on the perceived environmental risk they pose, paper manufacturing 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

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

environmentally most relevant, pulp and paper 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, 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 involves taking into account plant-specific environmental impacts and economic feasibility (Swedish Code of Statutes 1998a, SEPA 2002, OECD 2007).

In general, a joint evaluation of a plant's impacts on land, air and water is undertaken in the permit-issuing process. Permits issued are temporary; they are revised when an operator gets the approval to change operations (e.g. increase production) or when the permit is older than ten years. In that latter case, the authorities have the right to review licenses and impose new conditions. Licenses may also be updated as a result of involved parties appealing a court permit decision, with the Environmental Court of Appeal acting as supreme instance (Swedish Code of Statutes 1998a).[8]

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[8] The right to appeal is granted both to SEPA and to people affected by the court decision (e.g the permit applicant, local trade union associations and residents). The operative enforcement and inspection work is in principle conducted at the regional-district level by the 21 County Administrative Boards or the 290 municipalities. These bodies—of which the former is a Swedish government agency and the latter a political assembly elected by the municipal residents—also independently define environmental standards for their counties or municipalities, using fifteen national environmental quality objectives as guideline (Swedish Code of Statutes 1998a). Moreover, the plants themselves are expected to monitor environmental compliance, with SEPA focusing on evaluating operators' self-monitoring (Swedish Code of Statutes 1998c). This includes the annual submission of an environmental report to the authorities (Swedish Code of Statutes 1998d).

This regulatory structure results in a relatively flexible case-by-case approach to the exact standard a plant may have to meet. First, technological change causes BAT-levels to advance over time. At a given point in time this may result in plant A's recently obtained permit to reflect a more recent BAT standard (and thus stricter emission limits) than plant B's older permit (based on older BAT levels). Second, regulators can impose more stringent conditions on plants with more severe local environmental impact (SEPA 2002). A realization of the "Polluter Pays Principle," this implies, for example, that some 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 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 economies within Sweden, respectively (Lönnroth 2010). This has manifested itself in emphasis on internal process changes – or 'cleaner production' – to foster pollution prevention. On that basis, it is reasonable to assume that larger plants will be subject to more stringent phase-in periods of BAT on the part of the regulators (and thus lower ELVs) than smaller plants.[9]

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[9] 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, on the other, of politically motivated discrimination of certain plants, which would be similar in all other aspects

2.3. Taxes and Emissions Trading Schemes

The complementary regulatory constraint affecting the paper industry involves economic instruments: taxes, subsidies, charges and emissions trading schemes. These instruments have been increasingly used in Swedish environmental policy since the beginning of the 1990s. In 1991, carbon dioxide and sulfur taxes were introduced (Swedish Code of Statutes 1990a, 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 supposed 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. Introduction of a charge on NOx emissions from energy production occurred in 1992 (Swedish Code of Statutes 1990c).[10]

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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). Also, plants located close to each other might engage in collective action with the aim of, again, obtaining more favorable ELVs than under the status quo. Politically-conditioned unequal treatment of otherwise identical plants may occur, in particular, when municipalities are involved in the operative enforcement work. (Sjöberg 2012) 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] 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).

Under these schemes, plants for which emission reduction is more expensive will 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 have to incur lower pollution abatement costs per unit emissions than smaller plants due to economies of scale. Therefore, they will tend to proportionately reallocate more inputs to emission abatement than smaller plants.

3. Hypotheses and Empirical Methodology continue here

3.1. Hypotheses

Based on the foregoing discussion, we formulate four testable hypotheses:

- First, a stricter environmental regulation will induce a positive effect on plants' green TFP growth. Since regulation's primary objective is to induce plants to adopt BAT standards, that green TFP growth will be dominated by changes of technical efficiency as opposed to movements in the frontier itself.
- Second, 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, decentralized regulation is subject to bias: it may trigger a discriminatory treatment of plants with otherwise similar characteristics (e.g. regarding size and production process). This bias can be due to local environmental arguments in line with the Swedish Environmental Code or local politico-economic considerations (e.g. a plant's importance as local employer or a stronger bargaining position of large plants) Thus, the more important the plant is as a local employer or the less sensitive plant's surrounding environment, ceteris paribus, the less strict it is regulated.
- Fourth, environmental regulation gives rise to localized knowledge spillovers between plants, entailing higher green TFP growth in nearby plants relative to more dispersed plants.

3.2. Methodology

A major reason why conventional productivity indexes, such as the Törnqvist and Fisher indexes, exclude bad outputs is that they require prices – which, unless emission trading schemes or taxes are part of a regulatory regime, do not exist for bad outputs (Färe, Grosskopf et al. 2001). One recent development to overcome this restriction has been the development of productivity indexes which do not need information on prices, and which can include good and bad outputs simultaneously, using observed data on input and output quantities. The Malmquist-Luenberger (ML) productivity index has been widely used in this context (Chung, Färe et al. 1997). Based on nonparametric data envelopment analysis (DEA) techniques, it allows a decomposition of productivity growth in change in technical efficiency (catching up to the best practice-frontier) and technical change (shifting the best practice-frontier) for each observed DMU.

Our paper applies a recently developed methodological improvement to the ML productivity index: the sequential Malmquist-Luenberger (SML) productivity index (Oh and Heshmati 2010).[11] The SML index's major benefit is its ability to capture the progressive nature of technology, avoiding technical regress in the best-practice frontier—an unrealistic, and hence unfavorable, side-effect when measuring environmentally-adjusted productivity growth using the conventional ML index.

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 possibilty set (PPS) is expressed as

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

We assume that inputs are strongly disposable, so that

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

Furthermore, we assume null-jointness which implies

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[11] The sequential model dates back to (Diewert 1980).

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

meaning that the desirable output is not produced when the undesirable output is not. In addition, weak disposibility is imposed of the form

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

which means that a proportional contraction of both desirable and undesirable outputs is feasible in PPS. Finally, we assume strong disposability of desirable outputs, denoted as follows

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

which means that some of the desirable output can be disposed of without cost in the PPS. The original Malmquist index uses Shephard output distance functions to represent technology, defined as

$$\vec{D}_o(\mathbf{x},\mathbf{y},\mathbf{b}) = \inf\{\theta : \left((\mathbf{y},\mathbf{b})/\theta\right) \in P(\mathbf{x})\}$$

As suggested by (Chung, Färe et al. 1997) and (Oh and Heshmati 2010), for computational implementation we introduce the notation of directional output distance functions (DDF) instead of the Shephard output distance function to represent technology. The corresponding DDF to the PPS defined above is denoted

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

where $\mathbf{g} = (\mathbf{g}_y, \mathbf{g}_b)$ is a direction vector, in this case $\mathbf{g} = (1, -1)$, meaning that desirable outputs are maximized while simultaneously minimizing undesirable outputs. Figure 3 illustrates these assumptions.The PPS is represented by the inner area of the solid line. The direction vector and the DDF are depicted for a DMU *F*. The direction of the DDF of the DMU *F* is constructed as an arrow, *β*, from the origin in northwest direction.

[Figure 3 here]

(Färe, Grosskopf et al. 1989) defined a productivity index based on Shephard's output distance function. Their index is the geometric mean of two Malmquist productivity indices, which were introduced by (Caves, Christensen et al. 1982). Its nice feature is that it is a total factor productivity index. Following this line, the ML productivity change is defined as geometric mean $ML^{t,t+1} = \left[ML^t \cdot ML^{t+1} \right]^{1/2}$ with

$$ML^t = \frac{\left(1 + \vec{D}_o^t(\mathbf{x}^t, \mathbf{y}^t, \mathbf{b}^t; \mathbf{g})\right)}{\left(1 + \vec{D}_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{b}^{t+1}; \mathbf{g})\right)} \text{ and } ML^{t+1} = \frac{\left(1 + \vec{D}_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t, \mathbf{b}^t; \mathbf{g})\right)}{\left(1 + \vec{D}_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{b}^{t+1}; \mathbf{g})\right)}.$$

Furthermore, one can decompose ML productivity change into efficiency change, $EC^{t,t+1}$, and technical change, $TC^{t,t+1}$. It holds that $ML^{t,t+1} = EC^{t,t+1} \cdot TC^{t,t+1}$. If $EC^{t,t+1} > 1$ then there has been a movement of a DMU towards the best practice frontier between $t+1$ and t. If $TC^{t,t+1} > 1$ then there has been a shift of the best practice frontier towards higher productivity between $t+1$ and t.

In order to express the progressiveness of technology, we define a sequential PPS as: $P_q^t(\mathbf{x}^t) = P_1^1(\mathbf{x}^1) \cup P_2^2(\mathbf{x}^2) \cup \cdots \cup P_t^t(\mathbf{x}^t)$, where $1 \le t \le T$ (Oh and Heshmati 2010). This establishes a benchmark technology for the frontier using the observations from time point *1* to *t*. Again, using directional distance functions we can now define a sequential ML (SML) productivity index as

$$SML^{t,t+1} = \left[\frac{\left(1+\vec{D}_q^t(\mathbf{x}^t,\mathbf{y}^t,\mathbf{b}^t;\mathbf{g})\right)}{\left(1+\vec{D}_q^t(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})\right)} \cdot \frac{\left(1+\vec{D}_q^{t+1}(\mathbf{x}^t,\mathbf{y}^t,\mathbf{b}^t;\mathbf{g})\right)}{\left(1+\vec{D}_q^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})\right)} \right]^{1/2}$$

where $\vec{D}_q^s$ are sequential directional distance functions based on $P_q^t(\mathbf{x}^t)$.

Finally, in order to calculate $\vec{D}_q^t$, we define the following LP problem

$$\begin{aligned}
&\vec{D}_q^t(\mathbf{x}^t,\mathbf{y}^t,\mathbf{b}^t;\mathbf{g}) = \max\beta \\
&s.t. \sum_{\tau=1}^{t} \mathbf{Y}^\tau \mathbf{z}^\tau \ge (1+\beta)\mathbf{y}_k^t \\
&\sum_{\tau=1}^{t} \mathbf{B}^\tau \mathbf{z}^\tau = (1-\beta)\mathbf{b}_k^t \\
&\sum_{\tau=1}^{t} \mathbf{X}^\tau \mathbf{z}^\tau \le \mathbf{x}_k^t \\
&\mathbf{z}^\tau \ge 0.
\end{aligned}$$

For computing the four required directional distance functions, the linear programming problem described above is solved four times. In addition to $\vec{D}_q^t(\mathbf{x}^t,\mathbf{y}^t,\mathbf{b}^t;\mathbf{g})$, the linear programming problem is modified so that $\vec{D}_q^t(\mathbf{x}^t, \mathbf{y}^t, \mathbf{b}^t; \mathbf{g})$, $\vec{D}_q^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{b}^{t+1}; \mathbf{g})$, $\vec{D}_q^{t+1}(\mathbf{x}^t, \mathbf{y}^t, \mathbf{b}^t; \mathbf{g})$ and $\vec{D}_q^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{b}^{t+1}; \mathbf{g})$ are determined in a similar fashion.

4. Data and Descriptive Statistics

4.1. Data Sources

In our empirical analysis, we employ data from different sources. The SML indexes are constructed using annual input-output data on the population of the larger pulp and paper plants in Sweden between 1996 and 2011. Data on these A-plants (see Section 2) 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 2001-2011 retrieved from an online database maintained by Swedish Forest Industries.[12]

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. Yest 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).

Due to missing values regarding employees and capacity in these publications, however, we also had to directly retrieve firms' annual reports, both through their

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[12] Swedish Forest Industries (2013). "Environmental Database." Retrieved January 4, 2013, from http://miljodatabas.skogsindustrierna.org.

respective website and through Retriever Business, a Swedish online business database.[13] Moreover, for the period 2007-2011 we were able to make use of yet another online database – the Swedish Pollutant Release and Transfer Register (PRTR).[14] PRTR lists emissions from the 1,000 largest companies in Sweden that are involved in activities considered ‘environmentally hazardous’ by the Environmental Code. It therefore also includes our pulp and paper A-plants that matter for our study. PRTR has helped us verify, during 2007-2011, that the Swedish Forest Industries emission data are consistent (and vice versa).[15] The firms’ environmental or sustainability reports were themselves 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 (see Section 4.2 for more detailed information).

4.2. Variables and Predicted Effects

Table 1 lists the variables used for deriving the productivity growth measures. Both for our M and SML productivity measures, we use plants’ pulp and paper production

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[13] Retriever Business (2013). “Online Database on Swedish Businesses.” Retrieved January 21, 2013, from http://www.retriever-info.com.

[14] SEPA (2013). “Swedish Pollutant Release and Transfer Register (PRTR).” Retrieved January 5, 2013, from http://utslappisiffror.naturvardsverket.se.

[15] 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.

quantities for desirable output, y_1 and y_2. As bad outputs in the area of air pollution, we selected a plant's sulfur (ap_1) and NOx emissions (ap_2). We abstained from including CO2 emissions due to lack of data.[16] The water pollutants we include are Phosphorus effluents (wp_1), AOX effluents (wp_2), and COD effluents (wp_3). These emerged as our most implementable choices given data availability and environmental impact (see Section 2). We do not expand the list of pollutants to a larger array in order to reduce the number of infeasible solutions in the linear programming problem (Yörük and Zaim 2005).

[Table 1]

In terms of plant-level inputs, we chose process water (x_1), net electricity use (x_2), number of employees (x_3), and capacity for pulp and paper production (x_4). Capacity does not reflect what machines in a given plant are technically able to produce but maximum allowable output as stipulated in the plants' operating permits. For integrated plants, we sum up pulp and paper production capacities as they determined total output, inputs used, and pollutants generated. Table 2 provides summary statistics for the plant-specific inputs and outputs used in constructing the SML indexes.

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[16] These data are not included in the SEPA emission publications noted in Section 4.1, and only a few firms have published environmental reports with CO2 emission data on that period. Computing CO2 emissions via emission factors is also difficult because there is no detailed information available on plants' fuel consumption – a requirement for producing reliable emission values.

[Table 2]

As indicated in Section 4.1, the variables used in the second-stage regression, where we incorporate the effect on our SML measure of Swedish case-by-case environmental regulation, are obtained from Statistics Sweden and PRTR. *Mu_PLALAR* measures, for year *t*, the ratio between the protected and the total land area in municipality *m* in which pulp and paper plant *i* is located (Statistics Sweden 2013). Information on a plant's home municipality was obtained from PRTR.[17]

We expect *Mu_PLALAR* to reflect two opposing effects on a plant's environmentally-adjusted TFP growth of Swedish case-by-case regulation. On the one hand, there should be a positive effect because environmental courts, in accordance with the Environmental Code's general rules of consideration, will find it reasonable to impose stricter ELVs on plants located close to such areas, which then will be credited by the SML measure. On the other hand, this type of regulation might entail lower maximum production limits compared to plants outside environmentally-sensitive areas—which

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[17] The protected land area adds up a municipality's areas declared as national park, nature reserve, nature management areas, wildlife sanctuaries, and habitat protection areas. Decisions regarding the establishment of national parks are made by the Swedish government. and the Parliament. The other types of protected area are all established either by the Country Administrative Boards or the Municipalities.

would imply an adverse effect on the SML index. Provided that we obtain significant results, we will derive the net effect by benchmarking our SML measure against one obtained by regressing a standard Malmquist index (Färe, Grosskopf et al. 1994) without bad outputs on our regulation proxies.

LA_nomills counts the number of plants *i* located in year *t* within a Swedish functional labor market area *f*. Labor market areas (LMAs) are time-varying integrated housing and working areas within which commuting is common. They are adaptions to existing administrative demarcations (municipalities and counties), which are less suitable to delimit such an area. Information on the Swedish LMAs was obtained from Statistics Sweden's register over local labor markets (Statistics Sweden 2013). *LA_nomills* is supposed to capture two effects: First, based on collective action theory (Marwell, Oliver et al. 1988), we expect that the higher the number of plants within an LMA, the more effective will plant owners be in lobbying for more favorable permit and operative enforcement conditions. In the SML measure, this would then be reflected by a lower SML growth relative to those plants with less plants in their LMA. Second, in line with regional science theory (Duranton and Puga 2003), the higher the number of plants within an LMA, the more regulation will indirectly be able to push them to engage in an informal or formal dialogue on how to continuously improve on environmental parameters in their production process. This would then result in higher SML growth relative to those benefitting less from those productive “face-to-face” interactions. Therefore, the net effect in terms of green TFP growth is uncertain.

Sh_MIMUEMP denotes plant *i*’s share, in year *t*, in municipality *m*’s total employment.[18] Indicating a plant’s relevance for the local economy, this variable is meant to capture the potential for lobbying—and thus a possible environmental efficiency loss implied by decentralized case-by-case regulation: If a plant has a significant economic importance for the municipality in which it is located, both local politicians and plant owners may, all else equal, have an interest in more lenient, and thus less costly, regulatory standards compared to a municipality where a plant would matter less in economic terms: The former in order to save jobs and become re-elected, and the latter because they are aware of the municipality being dependent on the plant as a local employer. This may ultimately result in lobbying, on the part of the municipality, for more favorable regulatory enforcement and inspections or even less strict conditions in a plant’s operating permit (if regional environmental courts are prone to lobbying). We conjecture, therefore, that an increase in *Sh_MIMUEMP*, all else equal, will have an adverse impact on green TFP growth.

MCE_ShGreen measures the Green Party’s share in the Municipal Council Election in plant *i*’s municipality *m* in year *t*.[19] This variable tests Sjöberg’s finding that

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[18] Data on municipal employment were taken from Statistics Sweden (2013).

[19] The data are were obtained from Statistics Sweden (2013).

municipal differences in the enforcement of the Environmental Code can be explained by Green Party representation in a municipality's ruling coalition (Sjöberg 2012). We hypothesize that, all else equal, an increase in *MCE_ShGreen* will cause an increase in a plant's green TFP growth—which would signal a politically-motivated unequal treatment of plants not in line with environmental efficiency.

Mu_popden indicates municipality *m*'s population density in year *t* (Statistics Sweden 2013). Just like *Mu_PLALAR*, it is meant to capture variation in regulatory enforcement due to differences in the sensitivity of the local environment. The lower a municipality's population density, the more vegetation and ecosystems are available for protection per inhabitant—that is, the higher the relative sensitivity of the environment.[20] We therefore expect plants located in relatively more sensitive environments to be regulated more strictly in accordance with the Environmental Code's rules of consideration (Swedish Code of Statutes 1998a). This should should then result in a higher green TFP growth.

LOC_coast and *LOC_town* are also expected to proxy variation in the regulatory stringency due to differing sensitivity of the local environment.[21] *LOC_coast* is a dummy variable taking the value of 1 if plant *i* is located by the coast, and 0 otherwise. It is assumed

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[20] This conjecture is supported by two ordinances on Environmental Quality Standards. They stipulate distinct SO2 and NOx ELVs to protect human health within agglomerations, and vegetation outside agglomerations. Comparing the ELVs reveals that ELVs with regard to nature conservation tend to be lower than those concerning human health protection (Swedish Code of Statutes 1998e, 2001).

[21] Both variables were constructed by means of cartographic data found in PRTR.

to reflect the conjecture that coast location tends to constitute a less environmentally sensitive area than inland location, for example, because effluents can be released in the sea, instead of into more sensitive inland waters (SEPA 2002). *LOC_town* is yet another dummy, taking on 1 if plant *i* is located within an agglomeration, and taking on 0 if not.[22]

In line with our discussion of the Swedish Environmental Quality Standards in the context of the *Mu_popden* variable, *LOC_town* has exactly the same interpretation: populated areas should be interpreted as being less environmentally sensitive by the regulatory authorities than vegetation and ecosystems. If this is true, regulators will impose more lenient standards on plants that are located nearby the coast and within agglomerations compared with those that are not. As a result, the green TFP growth for the “coastline” and “agglomeration” plants should be lower than that of the reference plants for which neither category applies.

Finally, we used *y*, a plant’s combined pulp and paper output in year *t*, as proxy for plant size. For reasons outlined in Section 2, we expect large plants to display larger green TFP growth than smaller ones. First, the regulators will tend to enforce the Polluter Pays Principle, forcing larger plants to internalize their larger environmental footprint. Second, since economic feasibility matters to the Swedish BAT principle, the fact that it will be less expensive for larger plants to reduce emissions per ton output may imply that it is

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[22] An agglomeration is defined as a place with more than 200 inhabitants where the distance between houses does not exceed 200 m (Statistics Sweden 2010).

them who face more stringent regulatory conditions. Due to their ability to reduce emissions more cost-efficiently than smaller plants, the larger plants may also have a higher incentive to avoid paying the green taxes discussed in Section 2—which would be captured by our *y* variable as well. The only factor that might lead to a reduction in plants' green TFP growth would be lobbying: due to larger plants' stronger bargaining position vis-a-vis the authorities. Yet we expect the net effect still to be positive. The variables employed in the second stage regression are again reported in Table 3.

[Table 3]

Descriptive statistics for the varuables employed in the second-stage regression analysis are provided in Table 4.

[Table 4]

5. Results

Table 5 exhibits the descriptive results for the various productivity growth measures. The conventional Malmquist TFP index excluding bad output yields an average growth rate across plants of 1.57 percent per year during 1996-2011, with the main source of growth being technical change. This indicates that traditional TFP in the Swedish pulp and paper industry has rebounded after featuring negative growth between 1989 and 1999 (Brännlund 2008). Growth rates are still higher when we apply the SML index, which is in line with our expectations: Firms reallocate productive resources to pollution abatement which, in contrast to the standard Malmquist index, is acknowledged by the SML measure. We find annual average growth of 2.72% for the SML index air and 3.23% for the SML index water. In both cases, technical change is the dominant source of growth, which confirms Chung et al.'s findings for the period 1986-1990 (Chung, Färe et al. 1997). However, the heterogeneity of this growth rate is notable, as highlighted both by the high standard deviation as well as the 10% and 90% percentile values. Interestingly, technical change as a dominant source of green TFP growth is only partly confirmed when we explicitly examine the effect of environmental regulation on green TFP growth (see below).

[Table 5]

Table 6 presents the results of our baseline regression, where we test the effect of Sweden's decentralized environmental regulation on a standard Malmquist TFP measure excluding undesirable outputs. We find virtually no statistically significant relationships between our regulation proxies and conventional TFP growth, the only exception being a positive and statistically significant effect, although weak, of plant size on conventional efficiency change (EC). The existence of such a catching-up effect to the best-practice frontier in the case of large plants may be due to more stringent environmental regulation. The estimation results become more significant when we replace the conventional Malmquist measure excluding bad outputs with the SML index as dependent variable. This is shown in Tables 7 and 8.

[Table 6]

Table 7 reports results when including air emissions along with the desirable output pulp and paper, revealing an interesting pattern: While the coefficients have the expected sign, confirming the hypothesized positive effect of regulatory stringency on green TFP growth, the statistically significant relationships found all concern the technical change (TC) component of the SML air measure. The results, at the same time, provide evidence of a systematic bias of Sweden's decentralized regulatory approach. We find a negative effect of *Sh_MIMUEMP* on the SMLTC-Air index at the 5% level, suggesting that the less important plants are as local employer, the higher, on average, is their growth in the SMLTC-Air frontier. In other words, the regulative authorities, by means of stricter permit conditions and operative enforcement, appear to be able to stimulate pulp and paper firms to develop air pollution control technologies: an empirical support to the notion that Sweden's environmental regulation creates "maximum opportunity for innovation" (Porter and van der Linde 1995a). Yet at the same time, the result provides evidence for the regulatory bias arising from the trade-off between economic and environmental interests: Increased local economic importance of plants, ceteris paribus, decreases regulatory stringency, which makes regulators fail to induce the technical change noted above.

The negative coefficients of *LOC_coast* and *LOC_town* have similar implications: They signal a significantly lower growth in the SMLTC-Air frontier for plants located in less sensitive areas (coastline or town). We interpret this as further evidence that stricter regulation succeeds in inducing technical change in the field of air pollution control, whereas more lenient does not. In this case, however, the regulatory bias against inland plants and plants located outside agglomerated areas is less due to a trade-off between economic and environmental interests but more the result of regulators considering the coastline and agglomerations less environmentally-sensitive areas.[23]

The positive and statistically significant effect of our *y* variable on the SMLTC-Air index provides yet another empirical evidence to the conjecture that the Swedish authorities have had the ability to induce green technical change within the pulp and paper industry by means of reasonably strict regulations: the SMLTC-Air frontier of large plants, which we expected to be subject to more stringent regulatory standards, on average, has higher growth rates than that of smaller plants. This implies that we do not find support to the notion that the larger plants' stronger bargaining position vis-à-vis the authorities might cause regulatory bias in their favor. In other words, we interpret the stricter regulatory treatment of larger plants as confirmation that the regulators have succeeded in

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[23] Note that, in particular, *LOC_town* could be interpreted differently, if the standard Malmquist regression results were significant. According to them, plants located within agglomerations have lower conventional TFP growth than those outside agglomerations, probably due to output restrictions (the coefficient for *LOC_town* is -0.326). Now if we add sulfur and NOx as bad outputs, *LOC_town* continues to be negative, but the coefficient of -0.139 indicates that technical change has improved relative to the Malmqiust baseline case. This would imply that plants within agglomerations, on average, are more induced by regulation to introduce technical innovations in air pollution control than those located outside towns—turning towns into the sensitive area. However, the Malmquist regressions' insignificance prevents us from drawing this conclusion.

maintaining economic and environmental efficiency by inducing technical change: On the one hand, because the Polluter Pays Principle is implemented, and, on the other, since, in line with BAT considerations, economic feasibility is ensured (more cost-efficient emission reductions for larger plants).

The positive and significant effect of our *y* variable on SMLTC-Air may even confirm the effectiveness of Sweden's sulfur tax and NOx charge: Larger plants' ability to reduce emissions more cost-efficiently than smaller plants, on average, seems to have induced them more to avoid paying the sulfur tax and the NOx charge than smaller plants, by instead finding technical innovations that reduce their environmental impact in terms of SO2 and NOx emissions.

[Table 7]

Table 8 presents the estimation results from regressing SML water productivity growth (SMLPC-Water) on our regulatory stringency proxies. Here we observe a slightly different pattern compared to the results from Table 7. Judging from the significance levels as well as the coefficient signs, one can discern that stricter environmental regulation tends to go along with plants' overall green TFP growth. As predicted, this in turn, tends to be steered by improvements in technical efficiency, and less by technical change as in the case of SML-Air. In general, these results lend less support to the hypothesis of there being a regulatory bias leading to economic or environmental efficiency losses—which puts our findings from Table 7 into perspective. In particular, we find negative effects of

Mu_popden and *LOC_coast* on SMLPC-Water, of which the former is highly significant. This suggests that plants located in environmentally less sensitive areas, on average, have lower effluent-adjusted TFP growth (and vice versa). The TFP growth in turn appears to be determined by improvements in technical efficiency (this is less clear, though, for *LOC_coast* due to insignificance). Because we equate more environmentally-sensitive areas with an increase in regulatory stringency, we claim to have found evidence that plants exposed to stricter effluent-related regulation, on average, have been induced by the authorities to catch-up to the best-practice frontier by adopting existing effluent abatement technology or by decreasing effluent discharges via continuous improvement processes.

Moreover, we now obtain a positive, though weakly significant, relationship between our *LA_nomills* variable and SMLPC-Water. The positive coefficient implies that the higher the number of plants in a Swedish functional labor market area, the higher, on average, their effluent-adjusted TFP growth. We discern that growth tends to be determined by efficiency improvements toward the best-practice frontier (albeit the effect is insignificant). We therefore believe to have found some evidence for our conjecture that the presence of environmental regulation triggers a positive externality in the form of localized information and knowledge spillovers: it tends to foster a face-to-face dialogue on the part of nearby plants on how to realize effluent-related environmental efficiency improvements in their production processes.[24]

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[24] Hence, we can reject the hypothesis that an increase in the number of plants in an LMA gives rise to

[Table 8]

Finally, the y variable denotes a highly significant effect of plant size on our effluent-adjusted TFP measure. However, in contrast to the other significant variables in Table 8, TFP growth is determined not by a catching-up effect to the best-practice frontier but by a change in the frontier. This resembles indeed the relationship between y and SMLTC-Air in Table 7. Based on our hypothesis that larger plants will be subject to stricter environmental regulation, we again take the positive coefficient for y as evidence that regulation has induced more technical innovations in effluent abatement in larger plants than in smaller plants. Moreover, just like in Table 7, the positive coefficient for y confirms that economic and environmental efficiency appears to have been maintained on the part of the regulators (see reasoning above).

6. 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

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lobbying for more favorable permit and enforcement conditions; that is, we have not found evidence of efficiency distortions due to collective action in the case of effluent-related regulation.

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 size and production process). This bias can be due to local environmental arguments in line with the Swedish Environmental Code or local politico-economic considerations (e.g. a plant's importance as local employer).

Against this backdrop, we examined the effects of environmental regulations in general, and Swedish decentralized and plant-specific regulatory structure in particular, on environmentally-adjusted total factor productivity growth and its components for the Swedish pulp and paper industry. We analyzed the productivity effects by applying the recently proposed sequential Malmquist-Luenberger (SML) productivity index, which is an extension to the traditional Malmquist-Luenberger index. In our regressions, we also applied a traditional Malmquist index as the benchmark. We tested two propositions that are scarcely examined formally in the empirical literature: hypothesizing that an increase in regulatory stringency will co-move with a rise in plants' green TFP growth, whereas the more leniently regulated plants will feature lower green TFP growth due to different types of regulatory bias.

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 TFP growth, and its components. It appears to have been particularly successful in stimulating technical change related to air pollution control, and it induced the manufacturing plants to catch up with the best-practice technology frontier with regard to effluent abatement. Therefore, we find considerable evidence of a variant of the Porter hypothesis. By contrast, regulation was found not to affect conventional TFP growth, which lets us reject the classical Porter hypothesis (Porter and van der Linde 1995a).

Our results moreover reveal sources of regulatory bias. We find that plants of importance for local employment, as well as those located in environmentally less sensitive areas tend to have had lower green TFP growth than those that are not. By contrast, larger plants have, in line with economic and environmental efficiency considerations on the part of the regulators, diverted more inputs to pollution abatement than smaller plants, resulting in a higher green TFP growth. Finally, we find some support to our conjecture that environmental regulation triggers localized knowledge spillovers between plants, finding higher efficiency growth with regard to effluent treatment in nearby plants.

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A Appendix Tables and Figures

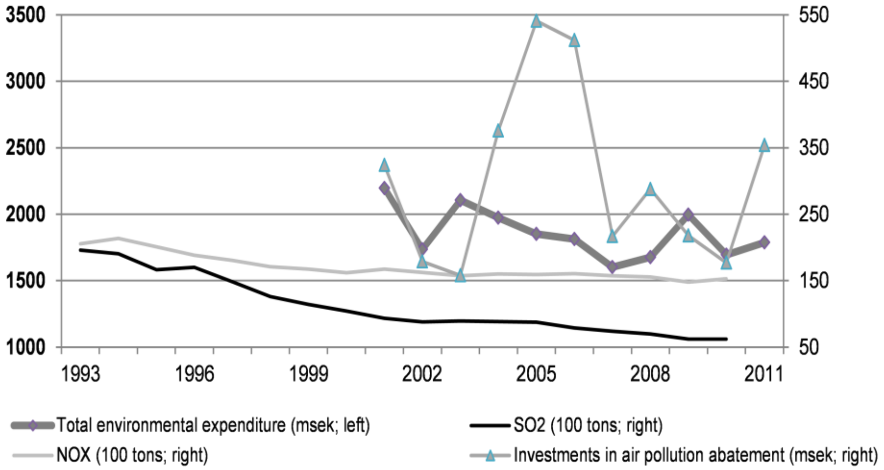

Figure 1: Air emissions and environmental expenditures in the Swedish pulp and paper industry, Source: Statistics Sweden (2013), and authors' calculations

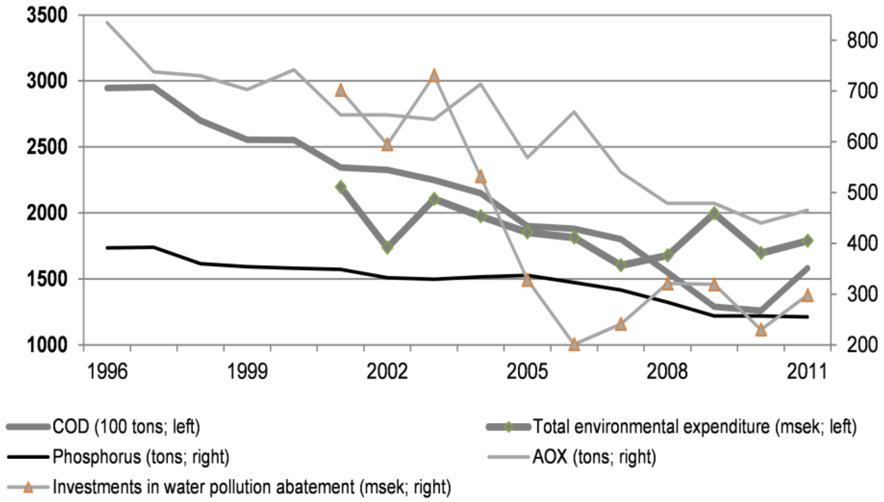

Figure 2: Water pollution and environmental expenditures in the Swedish pulp and paper industry, Source: Swedish Forest Industries (2013), PRTR, Retriever Business (2013), and authors' calculations

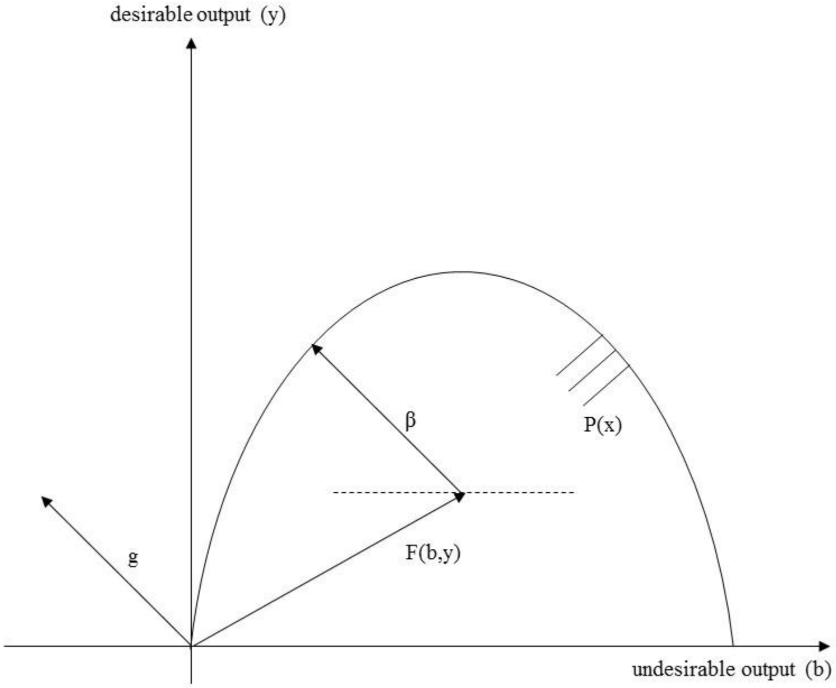

Figure 3: Directional distance function and the ML index

Table 1: Variables used for constructing the productivity indices

Symbol	**Variable description**	**Units**
	Desirable Outputs	
y_1	Total production of paper	tons
y_2	Total production of pulp	tons
	Undesirable Outputs	
ap_1	Sulfur emissions (air)	tons
ap_2	NOx emissions (air)	tons
aw_1	Phosphorus effluents (water)	tons
aw_2	AOX effluents (water)	tons
aw_3	COD effluents (water)	tons
	Inputs	
x_1	Process water	1000 m3
x_2	Net electricity use	GWh
x_3	Number of employees	persons
x_4	Total production capacity of pulp and paper	tons

Notes: The data were obtained from Swedish Forest Industries (2013), the Swedish EPA (SEPA 1997-2001), the Nordic Paper and Pulp Makers' Directory (Nordisk Papperskalender 1996-2010), and Retriever Business (2013).

Table 2: Descriptive Statistics for Variables Used in Productivity Index Calculation

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
y_1	907	251.1	237.4	1	885
y_2	907	211.2	251.4	1	919
ap_1	839	87.3	106.0	0.005	658.1
ap_2	874	279.1	299.3	0.1	1441
aw_1	898	6.3	8.1	0.007	40
aw_2	870	12.3	28.6	0.0003	215
aw_3	904	4124.3	4773.4	11	27200
x_1	906	10966.6	12490.3	52	64080
x_2	903	423.6	496.8	0.1	2492.7
x_3	907	473.5	326.9	26	1921.2
x_4	907	514123.1	498488.4	7000	1940000

Table 3: Determinants of Productivity Growth: Variable Description

Variable	**Definition**	**Exp. sign**
Mu_PLALAR	Ratio between the protected and the total land area in P&P plant *i*'s municipality in year *t*	+/-
LA_nomills	Number of P&P plants *i* located, in year *t*, within a Swedish functional labor market area *f*	+/-
Sh_MIMUEMP	P&P plant *i*'s share, in year *t*, in municipality *m*'s total employment	-
MCE_ShGreen	Green Party's share in the Municipal Council Election in P&P plant *i*'s municipality *m* in year *t*	+
Mu_popden	Municipality *m*'s population density in year *t*	-
LOC_coast	Dummy with value 1 if plant *i* is located by the coast; 0 otherwise	-
LOC_town	Dummy with value 1 if plant *i* is located within an agglomeration; 0 otherwise	-
y	Plant *i*'s total output in year *t* (proxy for plant size)	+

Table 4: Descriptive Statistics for Determinants of Productivity Growth

Variable	**mean**	**sd**	**min**	**p50**	**max**
Mu_PLALAR	0.02	0.02	0.000	0.014	0.255
LA_nomills	2.23	1.15	1	2	5
Sh_MIMUEMP	0.06	0.06	0.001	0.035	0.336
MCE_ShGreen	4.22	3.54	0.4	3.8	43.7
Mu_popden	43.91	62.30	8.4	24.4	396.7
LOC_coast	0.37	0.48	0	0	1
LOC_town	0.82	0.39	0	1	1

Table 5: Results for standard Malmquist and Sequential Malmquist-Luenberger (SML) Productivity Growth (%)**Error! Bookmark not defined.**

Productivity Index	**mean**	**std.dev**	**p10**	**p50**	**p90**
Malmquist (n=834)					
PC	1.574	20.38	-10.10	0.744	11.66
TE	0.617	9.85	-9.04	0.000	10.99
TC	0.970	15.61	-5.43	0.370	6.63
Air SML (n=770)					
PC	2.717	12.09	-7.61	1.162	12.46
TE	0.198	9.20	-8.49	0.000	7.56
TC	2.507	7.60	0.00	0.445	5.79
Water SML (n=787)					
PC	3.230	12.36	-6.56	1.700	13.29
TE	0.074	9.70	-7.51	0.000	6.24
TC	3.143	7.18	0.00	0.488	8.01

Notes: PC=productivity change, EC=efficiency change, TC=technology change

Table 6: Determinants of standard Malmquist Productivity Growth (%)

	PC	**EC**	**TC**
Mu_PLALAR	-7.907	-8.875	-2.646
	(11.60)	(9.092)	(4.276)
LA_nomills	0.178	0.0911	0.0842
	(0.225)	(0.173)	(0.102)
Sh_MIMUEMP	-0.183	0.767	-2.348
	(3.688)	(3.848)	(1.682)
MCE_ShGreen	0.0173	0.117	0.000164
	(0.107)	(0.198)	(0.0171)
Mu_popden	-0.00590	-0.00754	0.000884
	(0.00769)	(0.00598)	(0.00174)
LOC_coast	0.180	-0.225	0.157
	(0.520)	(0.449)	(0.260)
LOC_town	-0.588	-0.0396	-0.326
	(0.553)	(0.370)	(0.297)
y	0.000498	0.000820*	0.000111
	(0.000528)	(0.000457)	(0.000246)
Constant	0.365	-0.685	0.503
	(1.155)	(1.185)	(0.614)
Observations	834	834	834
R-squared	0.193	0.122	0.466

Notes: Result from Robust MM Regression Estimation, breakdown point 50%, efficiency 85%, robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 7: Determinants of SML Air Productivity Growth (%)

	PC	**EC**	**TC**
Mu_PLALAR	-8.848	-1.556	-1.168
	(8.979)	(3.762)	(0.825)
LA_nomills	0.156	0.137	0.0251
	(0.204)	(0.0962)	(0.0232)
Sh_MIMUEMP	-4.801	0.680	-1.056**
	(4.879)	(2.435)	(0.513)
MCE_ShGreen	0.111	0.000485	0.00565
	(0.402)	(0.0682)	(0.00393)
Mu_popden	0.00276	-0.000758	6.70e-05
	(0.00502)	(0.00175)	(0.000300)
LOC_coast	-0.826	0.216	-0.141**
	(0.542)	(0.296)	(0.0595)
LOC_town	-0.751	0.139	-0.139*
	(0.487)	(0.267)	(0.0793)
y	0.000634	0.000174	0.000165**
	(0.000460)	(0.000287)	(7.44e-05)
Constant	1.108	0.223	0.250**
	(2.270)	(0.634)	(0.120)
Observations	770	770	770
R-squared	0.0987	0.0826	0.143

Notes: Result from Robust MM Regression Estimation, breakdown point 50%, efficiency 85%, robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 8: Determinants of SML Water Productivity Growth (%)

	PC	**EC**	**TC**
Mu_PLALAR	-11.10	-2.172	0.997
	(8.519)	(3.979)	(0.747)
LA_nomills	0.299*	0.0303	-0.0211
	(0.181)	(0.0754)	(0.0178)
Sh_MIMUEMP	-0.524	-0.599	-0.0484
	(3.621)	(1.814)	(0.345)
MCE_ShGreen	0.123	0.0184	-0.00165
	(0.153)	(0.0315)	(0.00467)
Mu_popden	-0.0118***	-0.00433*	-1.94e-05
	(0.00346)	(0.00235)	(0.000294)
LOC_coast	-0.885*	-0.227	0.0174
	(0.535)	(0.202)	(0.0511)
LOC_town	-0.446	-0.0294	-0.0680
	(0.442)	(0.185)	(0.0602)
y	0.00132***	0.000192	0.000101**
	(0.000495)	(0.000231)	(5.03e-05)
Constant	0.750	0.943**	0.152*
	(1.297)	(0.476)	(0.0907)
Observations	787	787	787
R-squared	0.138	0.0737	0.111

Notes: Result from Robust MM Regression Estimation, breakdown point 50%, efficiency 85%, robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1