sustainability

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Effect of Environmental Regulation Stringency on the Pulp and Paper Industry

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Received: 21 November 2017; Accepted: 11 December 2017; Published: 13 December 2017

Abstract: The article investigates whether environmental regulations have affected productivity development and technological change in the European pulp and paper industry. A dynamic panel data approach is selected for analyzing a sample consisting of the pulp and paper industries in eight European countries. Industry total factor productivity for the period 1993–2009 is used as the dependent variable; it is explained by the intensities of environmental regulations for various types of pollutants, as well as by a number of other independent variables. The econometric results indicate that the regulation of nitrogen oxides is associated with productivity improvements with a one-year lag, whereas regulations regarding sulphur dioxide and carbon dioxide have not had any statistically significant impact. In line with the a priori expectations, the price of pulp is connected to a negative effect, while lagged R&D expenditures have had corresponding positive impacts. However, since stationary tests are asymptotic and the data series are quite short, strong conclusions regarding the actual causal effect of environmental policy could not be drawn. The results could therefore not be viewed as a proof of the so-called strong Porter hypothesis postulating that stringent well-designed environmental regulations increase productivity growth compared to a no-policy scenario.

Keywords: environmental regulation; sustainability; productivity; cross-country; Europe; pulp and paper industry

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1. Introduction

Apart from delivering useful goods to society, industrial activity also brings about a certain amount of bad outputs, i.e., industrial waste, which for a long time could be unrestrictedly emitted into the sea or into the earth's atmosphere. But since the second half of the 1960s, an increasing concern has emerged regarding environmental pollution and, consequently, a large number of regulations restricting the emissions have been imposed. However, during the 1970s, the ascending regulatory stringency coincided with a number of recessions, stagflation, and a general slowdown in the rate of productivity increase, which inevitably led to a heated debate on whether these regulatory schemes were the actual cause behind this problematic economic development [1,2].

Since the 1980s, an extensive body of empirical literature on the economic effects of environmental regulation has been produced, but there is still no ultimate consensus on whether the economic effects are positive or negative [3]. One plausible reason for the ambiguous results is that empirical investigations with observational data usually only cover a selected subset of the overall industrial population and thus produce results that may be highly context specific. Perhaps it is a fair conclusion that the effects of environmental policy indeed are context specific and that the expected impact of an environmental regulation must be seen in the light of the circumstances that surround the regulated industry. Moreover, apart from the very existence and intensity of environmental regulations, it has also been remarked that the regulative design is important for its productivity impacts [4]. The discussion also has an important part in the so-called Porter hypothesis; if the effects of regulation had traditionally been thought of as something that must lower the level of productivity, this view was questioned and eventually explicitly challenged at the beginning of the 1990s [5]. The main argument of the Porter hypothesis is that environmental regulation, if properly designed, actually could improve the productivity or profitability of a firm. Since technological change is an important determinant of productivity improvements, it is in itself an important variable to understand, especially in terms of how it is affected by environmental regulation. However, technological change cannot be observed directly; instead, it must be quantified by statistical or mathematical techniques. But even though an estimate of the impact of environmental regulations on technological change would be useful, the potentially heterogeneous effects and restrictions also set boundaries for empirical investigations.

The pulp and paper industry, being a large-scale process industry, has traditionally been a heavy emitter of pollutants and has consequently been the target of many environmental regulations since the 1970s [6–8]. This makes it an interesting industry to study. For instance, in the European Union, the pulp and paper industry has been one of the main industrial sectors targeted by the 1996 Intergovernmental Panel on Climate Change (IPPC) directive, as well as the succeeding Industrial Emission directive (IED), which have been the major frameworks for the control of industrial pollution during the last 20 years [9,10]. The practical implementation of environmental regulation could be of both a quantitative and a qualitative nature, i.e., performance standards, taxes, or tradable permits, as well as detailed prescriptions of mandated technology or production processes.

The objective in this study is to empirically analyse the effect of environmental regulations on technological change in the European pulp and paper industry. A dynamic panel data approach will be used to analyse air pollutant regulations for a sample of the pulp and paper industry in eight European countries over the time period 1993–2009. Technological change is disentangled using industry total factor productivity (TFP) as the dependent variable and environmental regulation stringency quantified by a synthetic proxy variable. Three pollutants are addressed, i.e., nitrogen oxides (NOx), sulphur dioxide (SOx), and carbon dioxide (CO_2). In addition, a number of control variables such as capacity utilisation, output prices, total output, and R&D expenditures are included. However, it is outside the scope of this study to analyse the impact of regulatory policy designs since the regulatory proxy variable is not able to distinguish between them.

Previous Research

Previous empirical studies on the economic effects of environmental regulation can be categorised along several dimensions. In terms of the methods employed, the previous literature exhibits a wide range of choices. Some studies use partial equilibrium models for selected industries in single countries. Some studies employ a general equilibrium framework where total production in the economy is modelled with and without the restriction imposed by environmental regulations, e.g., [11]. In addition, many studies are conducted in an output-input distance function framework. This strand of the literature embraces methods such as Data Envelopment Analysis (DEA), which measures the relative efficiency and the impact of environmental regulations on productivity [12–17]. DEA has also been used to obtain explicit shadow prices of regulation [7]. Another strand of studies in the distance function framework is stochastic production frontier analysis (SFA), which includes a stochastic error term in the computation of the production possibility frontier, e.g., [8,18]. Finally, total factor productivity (TFP) is used in numerous studies [2,6,19–29]. The literature on TFP measurements has lately incorporated bad outputs. That is, to the extent that undesired outputs are ineluctably linked with the production of goods, resources used for the disposal of the bad outputs should also be included as an input to the production [12,29–35]. Moreover, under the assumption that abatement is mandatory, even a traditional productivity measure should include pollutants since the effectiveness by which emissions are reduced is also a part of total productivity.

An important issue when evaluating the impact of environmental policy is the dynamic dimension [8,15,26–28]. It is not evident that a regulation should only have contemporaneous effects, or maybe not even a contemporaneous effect at all, but the response could come with a certain lag (or even prior to the date of policy enforcement if it is credibly and transparently announced). However, the empirical results are ambiguous. For instance, Managi [15] and Lanoie [27] show that environmental regulations have a negative contemporaneous effect but a positive effect on productivity in the medium to long-term. In the latter study, the positive long-term effect outweighs the initial negative effect. In contrast, Broberg [8] identified a long-term negative effect.

In the earliest studies of environmental regulation, that almost exclusively analyse the productivity slowdown in the United States during the 1970s, a negative effect on productivity is found [1,2,6,11,19,21,36]. A negative effect is also found in some of the more contemporary studies [8,16,22,23,37,38]. However, regarding the studies conducted during the last 20 years, the results are somewhat ambiguous. There are cases where no statistically significant effect on productivity by environmental regulation can be found in [20,24], while some studies find positive effects [12,15,18,26–28,39].

There are still areas sparsely studied and issues not fully addressed in many of the earlier studies on the effects of environmental regulation. A first issue is the generality of studies made on single firms or industries in a specific (small) geographical area. These results should be regarded as context specific and are only applicable under similar conditions as those which surround the subjects under investigation. A second issue is the quite short timeframe used which excludes the dynamic non-contemporaneous effects of regulation. Finally, many studies employ a static view of technology. That assumption implies that the estimated cost of regulation gets higher since all forms of endogenous technological response are overlooked.

Studies analysing the pulp and paper industry include case studies of individual companies [5], industry-scale studies [7,22], and cross-country studies comparing effects on the manufacturing sector or general macroeconomic performance [14,16,25,40,41]. In addition to the studies focusing directly on the impact of environmental regulations on productivity and technical change, there are studies analysing the effects of environmental regulations on labour and capital productivity [6,38,42]; on investments and age of the capital stock [43,44]; and on industry profitability [7,30,45]. Thus, the pulp and paper industry is fairly well scrutinised with regard to the impact of environmental regulation on production, profitability, productivity, and market equilibria. The majority of studies found negative regulatory effects on profits and productivity [6–8,22,29,46–48]. Other studies found none or a positive effect [12,26,37,49–51]. Interestingly, in a study of several American industrial sectors, Shadbegian and Grey [37] found that the economic returns on investments in abatement capital, on average, are lower than investments made on an exclusively commercial basis. However, investments in abatement capital, specifically in the pulp and paper industry, have been shown to give returns close to the ones for commercial investments. This is in contradiction to Broberg [8], who found that investments in pollution abatement are particularly detrimental to the (Swedish) pulp and paper industry. Boyd and McClelland [12] used DEA to investigate the effects of environmental regulation on technical efficiency and the allocation of capital, respectively, in the American pulp and paper industry. They found that environmental regulations have positive effects on the efficiency and that the potential reductions in emissions and input use ranged between 2% and 8%.

An influential segment of the studies analysing the pulp and paper industry consists of a strand of literature that empirically tests the implications of the inclusion of bad outputs in the construction of productivity indexes [12,29–31,33–35]. The general conclusion is that such inclusion will reveal that productivity development is higher than what would be the case if the indexes were computed by traditional methods. In another study, contradicting results are found [29]. A possible explanation could be that a large number of observations get omitted due to infeasible solutions in the estimation when a bad output is included.

There are thus numerous studies analysing the impact of environmental regulations on both productivity development and technological change for the pulp and paper industry. However, the results could not easily be generalised. Analyses using industry-wide and cross-country perspectives have rarely been done, and therefore it is of great interest to see whether the impact of environmental regulations on the pulp and paper industry differs when examined in a cross-section of countries instead of a single-country setting. Using this approach, an estimation of the impact of environmental regulation on the pulp and paper industry on a more general level is possible. The result would summarise the average outcome of the different strategies used to implement environmental regulation, and is less sensitive to the specific effect of the regulative mechanism used in each country.

2. Materials and Methods

2.1. Total Factor Productivity as a Measurement of Technological Change

Since technological change is an abstract, intangible concept, it must be measured using a proxy. There are various approaches which could be employed, for example, different engineering-based measurements such as the amount of energy used per unit of output. These proxies are accurate but target technological change in a one-dimensional way, which leaves the question regarding the general impact on technology unanswered. Another commonly used method is so-called growth accounting. In growth accounting, technological change is measured through its impact on productivity growth, which is defined as the residual that results when output growth exceeds factor input growth. The residual has also been known as the Solow residual due to the influential contribution to the theoretical field of growth accounting made by Solow [52]. Further important developments of the growth accounting methodology have been made by Jorgenson and Griliches [53] and their theoretical framework constitutes the baseline for the construction of the productivity measure used in this study [54,55].

The Solow residual is related to total factor productivity (TFP), which is a measure of the relation between the level of output and inputs needed in the production. Total factor productivity calculated by growth accounting is a non-parametric index number, which indicates that no specific assumptions on the underlying production function are needed. TFP can be seen as a Hicksian neutral shift parameter of the production function and the difference in the parameter between two time-periods corresponds to a shift of the production possibility frontier. Accordingly, the residual should be equal to the change in the shift parameter. However, being a residual measure, the growth in TFP also comprises other factors than technological change which affect the amount of output per unit of input. For example, scale effects pass undetected by the residual and will be confounded with technological change. Moreover, changes in TFP only capture technological change which originates from costless improvements of the production process. For example, R&D expenditures are sometimes used as an input factor but will only capture the technological change if the returns to the R&D expenditures are greater than the average return of the other inputs. Contrarily, if there are positive externalities from R&D in other firms, industries, or governmental organizations, they will show up in the residual as a productivity gain.

In the case of technological change embodied in new capital goods, the extent to which this will end up in the residual (when examining a partial sector or industry in the economy) depends on whether the achieved productivity improvements will be fully paid for by the purchasers of such goods. If the productivity rise given by new capital is greater than the corresponding price increase, the resulting productivity gain in the industry examined will end up in the residual for that sector. Moreover, if the price indexes used in order to transform nominal capital prices into real prices do not quantify price increases given by quality improvements correctly, the resulting mismeasurement of capital quantities will also affect measured productivity (and accordingly the residual). A related problem is if quality increases of the output are not taken into account, which implies that actual production is underestimated, as is the change in TFP.

Another imperfection of the residual measure of technological change is the assumption of a symmetric increase in the productivity of all inputs. It is likely that technological change could be biased towards a smaller number of the inputs, something which is termed Hicks-biased technological change. In that instance, productivity improvements will also depend on the magnitude of the input shares, as well as on technological change. Equally problematic is the assumption of marginal cost pricing. If the price paid to each production factor does not coincide with marginal productivity due to, e.g., imperfect competition, the residual will give a biased estimate of the shift parameter. This is an inherited problem in the non-parametric index approach estimating productivity directly from prices and quantities. Finally, productivity will also change if the labour force alters its work effort or in the case of successful (or unsuccessful) institutional reorganization. This last factor could perhaps be defined as soft technological change.

2.2. Environmental Regulation and Productivity

There are a number of theoretical mechanisms through which environmental regulation could affect productivity. A direct effect can be derived from the fact that environmental regulations impose a restriction on firms' production decisions, which forces the firms to allocate inputs to abatement activities. If there are no, or limited, substitution possibilities amongst the inputs, the regulation would cause a reduction of output since the firms need to reallocate their productive input factors. The alteration of the production process will cause a one-time shift in the production function to a new lower level of produced output per unit of input, which inevitably lowers productivity. These implications of environmental regulations are most relevant when emission reductions are achieved by various types of end-of-pipe measures, which do not give any opportunities for productivity improvements by rearrangements of the actual production process. However, the change in productivity due to regulation can also be seen as a consequence of the omission of environmental services in the traditional modeling of the production process [56]. On the other hand, if firms can substitute among inputs, either by changing the mix of inputs or by employing new factors, the direct effects of the regulation will increase.

The substitution of input also creates a second indirect effect aside from the direct effect of the reallocation of inputs to abatement, which could have a positive or negative effect [6]. If new inputs are entering the production process and if they consist of new capital, improved fuels, or materials already existing in the market, the indirect effect could be thought of as the diffusion of new technology rather than representing genuine technological change since the production possibility frontier is unaffected [57]. It could be questioned whether the capital investments would not have taken place anyway in the absence of mandated abatement expenses, and thus there is also a possible foregone opportunity to invest in updated capital contained in the direct effect [12].

Finally, there could be an endogenous technological response to imposed environmental regulations, either by pure technological change or learning (or both). The existence of such an effect depends on the notion that an increase in the price of a production factor (environmental services) induces innovation in order to economize with this factor now being relatively more expensive. If successful, this innovative activity creates technological change which raises the overall productivity of the input factors. On the other hand, an innovation effort also comes at a cost, particularity when there is an inelastic supply of R&D inputs. Research efforts that potentially could have increased productivity in the production must instead be allocated towards research and learning about the mitigation of pollution [57]. Thus it is an empirical question whether the net effect of an environmental regulation will decrease or increase the productivity [5].

A question closely related to the discussion regarding induced innovation is whether environmental regulation will induce a permanent change in productivity growth. If environmental regulation might cause a one-time shift in the production possibility frontier implying a new lower level of productivity, the question of whether the long-run rate of change is affected is still unanswered. Given a certain mandated amount of abatement, the rate of change in productivity can, after the possible initial transition to a new lower level of productivity, be affected in two ways: (1) productivity in abatement activities increases (or decreases) or; (2) the rate of productivity change in the production of normal goods changes due to the regulation. Productivity gains in abatement also merit the production of normal goods since less input has to be engaged in order to comply with given permission levels. For environmental regulation to permanently affect productivity growth, it must alter the determinants of long-run technological change such as the amount and quality of innovation. R&D is an important input in the innovation process, so if research and development is permanently affected by environmental regulation, the rate of technological change will also be influenced.

2.3. Model Specification

In order to analyze the impact of environmental regulation on technological change for the pulp and paper industry, an econometric approach is employed. An index on total factor productivity (TFP) is used as a dependent variable in a panel data regression, including a proxy for regulative stringency and a number of control variables. The control variables include the property of the capital used in the pulp and paper industry, which to a large extent is constituted by heavy machinery resulting from big long-term investments. Capital could therefore be considered as a quasi-fixed production factor impossible to dismantle in the short run with the consequence that the industry might temporarily be outside long-term static equilibrium. To control for such short-term disequilibria, total capacity utilization is included in the model. Moreover, output prices could be hypothesized as a determinant of the aggregated industry's productivity. Theoretically, an increasing output price will attract new producers with higher breakeven due to the lower productivity than already existing producers. Another side is the possibility that producers that would otherwise have been on the way out of the market will instead be able to stay in business. Growth in productivity could also be a consequence of the elimination of low productivity mills even at constant prices. This results in a decrease in total industrial production and may also be part of a development where firms move their production to other countries with less stringent environmental regulations (i.e., the pollution haven hypothesis). Total annual production of pulp and paper is therefore included to control for such an effect. Furthermore, the sum of output could also be seen as a coarse indicator of possible non-constant returns to scale effects on TFP [27].

Since R&D expenditures often are included as conventional production inputs, and not explicitly taken into account as a driver of productivity growth, the innovation effort they represent will constitute a part of the observed increase in TFP. To control for the effect on technological change constituted by research activities, the total amount of resources devoted to R&D in each country is included in the model. In addition, TFP does not only depend on research efforts made within an industry or a country, but also, to some extent, on research made in other countries. These spill-over effects will be specifically significant in countries starting from a low level of development that are catching-up towards the technology frontier. Accordingly, it will give them a higher growth in TFP just because their initial level of productivity is low [54]. The point of departure, with respect to the productivity of each country at the beginning of the time period studied, is controlled by panel fixed effects, which also control for other time invariant properties of the included countries.

In order to control for time-dependent effects of regulation stringency, a lagged dependent variable is included. Furthermore, it could be argued that the current level of productivity within an industry depends not only on research and learning performed during the same year, but also on efforts to improve productivity in all time periods before. The current level of productivity and the potential for further improvements in productivity is a function of the knowledge stock accumulated during all previous time periods [58]. Therefore, the initial level of TFP in each time period is used as a proxy for the knowledge stock. However, this measure also contains noise due to, e.g., fluctuations in capacity usage. Finally, time itself is also a factor for technological change. Common productivity shocks for all countries in the panel are taken into account by including a time dummy.

In sum, the TFP is assumed to be a linear function of the regulatory measure and the control variables:

$$TFP_{i,t} = \alpha + \beta_1 TFP_{i,t-1} + \beta_2 R_{i,t-k} + \beta_3 C_{i,t-k} + \beta_4 \delta_i + \beta_5 \gamma_t + \epsilon_{i,t}, \quad (1)$$

The specification indicates that total factor productivity $(TFP_{i,t})$ in the pulp and paper industry in country i and year t can be explained by relevant knowledge accumulated during earlier time periods $(TFP_{i,t-1})$, a vector of regulation stringency measures $(R_{i,t-k})$, and a vector of control variables $(C_{i,t-k})$

containing total capacity utilisation, output prices, total yearly production, R&D expenses, a time dummy, and country fixed effects. In order to capture possible dynamic effects of environmental regulation, R&D expenses, and output prices, lagged specifications of these variables are also included. Finally, δ_i represents the country fixed effects, γ_t represents the time dummies, β_i represents the coefficients to be estimated, and $\epsilon_{i,t}$ is the error term.

Three alternative specifications are estimated to analyze the robustness of the model. First, in order to study the effect of mitigation if made in conjunction with important European regulative events, a number of year dummies and interaction variables are constructed and included in the model instead of the time dummy. Second, an alternative method to capture the impact of time is applied to include a linear time trend. Long-term productivity is hypothesized to trend upwards due to continuous improvements in the production process given by learning effects and general increases in knowledge. Accordingly, a specification using such a trend instead of the time dummy is also tested. Third, all time determinants are removed from the model.

2.4. The Regulation Measure

One commonly used proxy for environmental regulation is pollution and abatement control expenditures (PACE), where higher expenditures signify more intense regulation. However, there is reason to believe that using PACE can cause a bias towards a negative impact of regulations since the measure contains a certain amount of selection bias; plants and companies performing badly in their effort to comply with regulation will have higher costs and expenditures than those being efficient in the reduction of a given amount of emissions [59]. Instead, the methodology developed by Gollop and Roberts [2] is chosen. This approach has been evaluated by Brunel and Levinson [60], who conclude that finding an easy-to-use measure of environmental stringency is problematic, where compromises are needed from what can be deemed as ideal. In addition, a similar measure is constructed by Cao et al. [61], where an output capacity change rate of pollutants per unit is calculated as an indirect measure of environmental regulation intensity.

The regulatory stringency measure (R) is defined in Equation (2), where e^* represents the desired (or unconstrained) emission level, e represents the actual emissions, and s_t is the country specific emission standard. As suggested by the equation, the regulatory stringency measure consists of two parts. The first term on the right-hand-side of Equation (2) is the proportional reduction in unconstrained emission required by the emission standard and captures the extent to which the emission standard constrains the firm [2]. The first term in Equation (2) has an upper bound of one, which would occur if the emission standard states that no emission is allowed, i.e., $s_t = 0$. The term is bounded from below by zero, which occurs when the emission standard is greater than or equal to the firm's unconstrained emission rate, implying that the emission standard does not affect the firm, i.e., $s_t \geq e_t^*$. The second term measures the degree of compliance and reflects the degree to which a firm's actual emission reduction corresponds to what is required. This term rests on the assumption that actual emission rates are reasonable indicators of the emission rates actually permitted. Emission enforcement is defined as a two-year moving average of the ratio of the actual reduction to the imposed reduction by the emission standard. The term has an upper bound of one, which occurs when the actual emission rate is less than the emission standard, i.e., $e_t < s_t$. It is bounded from below by zero when the actual emission equals the unconstrained emission, i.e., $e_t = e_t^*$.

In order to restrict the regulatory intensity measure between zero and one, the two terms are measured and bounded individually before being multiplied.

$$R_t = (\frac{e_t^* - s_t}{e_t^*})\left(\frac{e_t^* - e_t}{e_t^* - s_t}\right), \tag{2}$$

Regulatory stringency measures are constructed for the air pollutants nitrogen oxide (NOx), sulphur dioxide (SOx), and carbon dioxide (CO_2) from the pulp and paper industry. The pulp and paper industry is also a big emitter of effluents which may be included in an optimal construction of

R, but unfortunately this has not been possible due to a lack of reliable data. An argument against the inclusion of water pollutants in the construction of the regulatory stringency measure is that it is not fully clear whether the reduction of such emissions has also been driven by market-related considerations [62]. Evidence in favor of the hypothesis of regulation-induced technological change with respect to mitigation of water pollutants is given in [63]. However, the result regards regulation practices in Sweden specifically and could not easily be extended to other countries. In fact, it could not be ruled out that market-driven reductions of emissions have also been a factor regarding air pollutants. This especially regards emissions of SOx, which, for example, can depend on natural gas prices. A counterargument regarding the accuracy of R based on air pollutants could be that the technological capacity to use such low-sulphur fuels indeed might be a function of (earlier) environmental regulation, and that it therefore mirrors their stringency correctly but with a lag.

2.5. Econometric Issues

For the estimation of the regression, an error corrected least square dummy variables model (LSDV) for small dynamic panels is used [64]. It has later been extended to unbalanced panels by Bruno [65], which is the type of data used in this study.

Similar to GMM methods, the LSDV model is originally a microeconometric model designed for dynamic panels with N greater than T, a prerequisite which is not fulfilled by the dataset [65]. This problem of not allowing for heterogeneous slope coefficients amongst the cross-sectional units is a limitation that one should be aware of when drawing conclusions. Nevertheless, even if not being optimal for the dataset, the error corrected LSDV model appears to be the best possible alternative at hand. Another general criticism of the model choice could be the use of microeconometric methods for analysis of data with inherent macroeconomic properties. The pulp and paper industry could, for example, be subject to national macroeconomic shocks which are not common for the whole sample and which would constitute an omitted variable bias in the regressions. Further, some of the explanatory variables could be argued as being predetermined or simultaneously determined with the dependent variable. An alternative way of investigating the relationship between the variables in the model which deals with these problems could be to use a vector autoregressive model (VAR), but in that instance, the search for a true causal effect of independent variables such as environmental regulations must be abandoned.

To control for unit roots, both an Im-Pesaran-Shin [66] and a Choi Fisher-type [67] panel unit root test are conducted. The test results indicate that the presence of a unit root is rejected for all variables.

Something which can also distort the results of panel data regressions is a cross-sectional correlation between the individual countries in the panel. The assumption of independency of the observations will be violated if there is a correlation between the groups and will make the estimator inefficient or, in the worst case, even biased. The consequences may be more severe in dynamic panels. Theoretically, it is likely that the pulp and paper industry in one country to some extent depends on the development in the pulp and paper industry in other countries. In order to control for cross-sectional dependence, a Breusch-Pagan LM test is conducted [68]. The test rejects the null hypothesis of no correlation between the residuals. Further, the technique suggested by Koedijk [69] for computing the pairwise correlation between each group for the differenced series of the variables has also been performed on the dependent and independent variables. The correlation is higher than 0.5 between groups in the majority of variables, which gives a further indication that there is a non-negligible correlation amongst the countries. The presence of a cross-sectional correlation is an argument in favor of the model including the year dummy since this mitigates the adverse effects on the reliability of the regression [70].

2.6. Data

The sample consists of the pulp and paper industry in eight European countries (Austria, Belgium, Finland, France, Spain, Sweden, and the UK) and constitutes an unbalanced panel composed for the period 1993–2009. Descriptive statistics are presented in Table 1.

Table 1. Descriptive statistics.

Variable	Obs	Mean	Std. dev	Min	Max	Unit
TFP	136	95.5	8.96	73.3	117	Index number, year 2005 = 100
RegNOx	136	0.26	0.18	0.00	0.80	Index, between 0 and 1
RegSOx	136	0.50	0.29	0.00	0.99	Index, between 0 and 1
$RegCO_2$	136	0.19	0.13	0.00	0.60	Index, between 0 and 1
Price Paper	129	1066	298	725	2256	Export price in $2010 per tonne
Price Pulp	129	659	155	407	1241	Export price in $2010 per tonne
Capacity usage	130	0.87	0.07	0.58	0.98	Synthetic measure, ranges between 0 and 1
R&D expenditures	136	17,083	15,079	2437	61,139	Millions in $2010 prices
Total production	136	10,200,000	7,812,489	1,457,000	27,300,000	Tonnes

Data on total factor productivity are collected from the EU-KLEMS database and is constructed using growth accounting measuring the efficiency of the inputs capital, labor, energy, and material. TFP is quantified by a Törnquist index, assuming that the underlying (unknown) production function of the pulp and paper industry can be properly quantified by the translog functional form [55,71]. TFP in the EU-KLEMS database has been calculated using the value-added method, which does not distinguish between productivity changes caused by changes in the amount of inputs or changes in input prices. If not explicitly taken into account, a price fall in one variable (e.g., energy) will bias the measurement of productivity upwards, making it appear higher than it would otherwise be if it was measured correctly. This property is often a source of bias in productivity studies only taking input changes in capital and labor into account. However, by deflating expenses with price indexes, changes in prices of intermediate inputs and services are implicitly taken into account in the EU-KLEMS data, something which gives it an advantage when conducting productivity studies compared to data from other statistical databases not containing this information.

The data on yearly emissions of NOx, Sox, and CO_2 originate from the European Environment Agency [72], except for Finland and the Netherlands, for which the data have been collected from the Finnish Forest Industries Federation [73] and from the Koninklijke vereniging van Nederlandse papier en kartonfabrieken [74]. The emission standards are constructed for each county using a comprehensive database on climate and environmental policies outlining how emissions are regulated to achieve national and EU standards.

Data on R&D expenses, exchange rates, and price indexes used to deflate variables expressed in current prices are gathered from the OECD statistics database [75]. R&D expenses are defined as the total gross domestic spending on R&D and are illustrated in Figure 1. In general, the counties exhibit the same pattern: a slow increasing trend over the entire time period with a small trough around the year 2000 and a drop in R&D expenses for the last years. In addition, France and UK are the big spenders in relation to the other countries, which are clustered around similar levels.

Data used in the construction of the capacity usage measure, output prices, and total output production have been collected from FAO—the Food and Agricultural Organization of the United Nations [76]. Output prices are defined as the export prices of pulp and paper converted into real USD prices to enable a comparison between the countries. Total output production is defined as total production including the sum of both pulp and paper. Capacity utilization has either been obtained directly from the FAO or calculated using data on total capacity and total production from the same source. Finally, the interaction variables are constructed by combining the regulation stringency measure for all three pollutants and three dummy variables indicating the imposition of the integrated pollution prevention and control directive [9], the IED [10] and the EU ETS [77].

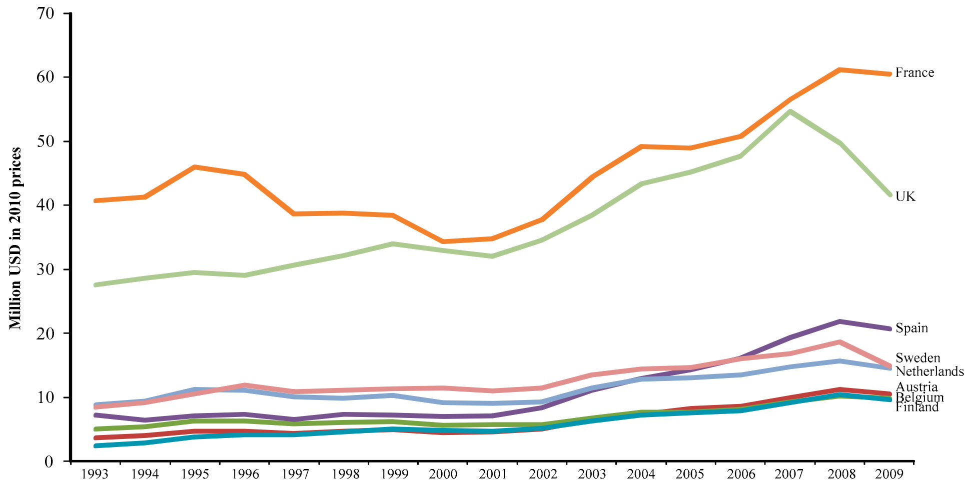

Figure 1. R&D expenses by county and year in million USD (2010 value).

3. Results and Discussion

An inspection of the data on TFP in the pulp and paper industry indicates an increasing general trend in productivity, except for Spain. Equally, the regulation stringency measure on general indicates an increasing pattern. Thus, at first, it appears as if abatement should be associated with improvements in productivity. However, this does not answer the question as to whether the productivity increases have been higher than what would have been the case in the absence of environmental regulation, nor does it indicate whether the higher productivity is caused by technological change.

The regression results suggest that the interaction effect between general regulation stringency and important regulative events is not statistically significant (with a few exceptions). Also, the correlation between all the interaction variables and the year dummies is problematically high. The model specification including interaction variables is therefore not further investigated. The specification including lagged variables on regulation stringency, R&D expenses, and pulp and paper prices is analyzed using up to three time periods. The specifications including more than one set of each of the lagged independent variables exhibit substantial multicollinearity. However, if only one set is included, no problematic correlation is found, and both lagged regulation stringency measures with respect to NOx and lagged R&D expenditures are statistically significant with a positive sign. When comparing different specifications using contemporaneous values of the independent variables, as well as combinations of lagged variables, a model using one-year lags of the regulation stringency measure and two-year lags of R&D expenditures performs best in terms of significance. In the specification only using contemporaneous values of the regulation stringency variables, similar results are found. However, the regression is not robust to the same extent since the statistical significance of the NOx stringency variable is conditioned on the number of lags of R&D expenditures.

The fact that the productivity response is most pronounced with a one-year lag indicates that factors such as learning and the calibration of new technology, which could both be assumed to possess some sort of dynamic properties, are dominating the result. Regression results for each of the three specifications (the base specification including the time dummy, the specification using a linear time trend, and the base specification with no time dummies) are presented in Tables 2–4. Before the regressions, a linear transformation of the *R* vector has been done so that the coefficients can be interpreted as percentage change.

Table 2. Estimated coefficients of the dynamic regression model using fixed effects and time dummies (n = 113).

Variable	Coefficient		Std.	z	$p > \lvert z \rvert$	Coefficient Lower Bound	Coefficient Upper Bound
Lag TFP	0.81	***	0.08	10.9	0.00	0.67	0.96
lagRegNOx	0.17	***	0.07	2.52	0.01	0.04	0.30
lagRegSOx	−0.05		0.05	−0.93	0.35	−0.15	0.05
lagRegCO$_2$	−0.03		0.06	−0.52	0.60	−0.16	0.09
PricePaper	0.00		0.00	−0.29	0.77	−0.01	0.01
PricePulp	−0.01	**	0.00	−1.98	0.05	−0.02	0.00
2-year lagged R&D exp.	0.00	***	0.00	2.69	0.01	0.00	0.00
Capacity usage	0.20		13.7	0.01	0.99	−26.6	27.0
Total production	0.00	***	0.00	4.39	0.00	0.00	0.00
Country fixed effects	8 DV						
Time dummy	17 DV						

*** 1-percent significance, ** 5-percent significance.

Table 3. Estimated coefficients of the dynamic regression model using fixed effects and a linear time trend (n = 113).

Variable	Coefficient		Std.	z	$p > \lvert z \rvert$	Coefficient Lower Bound	Coefficient Upper Bound
Lag TFP	0.81	***	0.06	14.4	0.00	0.70	0.92
lagRegNOx	0.18	***	0.07	2.56	0.01	0.04	0.32
lagRegSOx	−0.07		0.05	−1.39	0.17	−0.17	0.03
lagRegCO$_2$	−0.06		0.07	−0.96	0.34	−0.20	0.07
PricePaper	0.00		0.00	0.39	0.70	−0.01	0.01
PricePulp	0.00		0.00	−1.52	0.13	−0.01	0.00
2-year lagged R&D exp.	0.00	**	0.00	2.27	0.02	0.00	0.00
Capacity usage	9.73		9.55	1.02	0.31	−8.98	28.4
Total production	0.00	***	0.00	5.58	0.00	0.00	0.00
Year	−0.15		0.30	−0.51	0.61	−0.73	0.43
Country fixed effects	8 DV						

*** 1-percent significance, ** 5-percent significance.

Table 4. Estimated coefficients of the dynamic regression model without time controls (n = 113).

Variable	Coefficient		Std.	z	$p > \lvert z \rvert$	Coefficient Lower Bound	Coefficient Upper Bound
Lag TFP	0.80	***	0.05	16.2	0.00	0.70	0.90
lagRegNOx	0.18	***	0.07	2.51	0.01	0.04	0.32
lagRegSOx	−0.09	**	0.04	−2.34	0.02	−0.16	−0.01
lagRegCO$_2$	−0.07		0.07	−0.93	0.35	−0.20	0.07
PricePaper	0.00		0.00	0.34	0.74	−0.01	0.01
PricePulp	−0.01		0.00	−1.52	0.13	−0.01	0.00
2-year lagged R&D exp.	0.00	**	0.00	2.41	0.02	0.00	0.00
Capacity usage	11.5		9.22	1.25	0.21	−6.55	29.6
Total production	0.00	***	0.00	5.53	0.00	0.00	0.00
Country fixed effects	8 DV						

*** 1-percent significance, ** 5-percent significance.

In Table 2, the coefficient of lagRegNOx indicates that a 1% increase in abatement is associated with a 0.17% increase in TFP on average, holding the output constant. Reductions of emissions of SOx and CO_2 are not statistically significant. Pulp prices have a small impact on productivity with an expected negative sign; an increase of one dollar per tonne pulp lowers productivity by 0.01%. Lagged R&D expenditures and total production are both positive, but have a small economic effect. Total production of pulp and paper is very likely to be determined simultaneously with TFP and therefore the coefficient must be interpreted with care. The relatively modest effect of R&D expenditures could be a consequence that R&D is measured as gross domestic spending. This implies that the variation in the variable might be due to changes in expenditures directed to other areas than those directly relevant for the pulp and paper industry. Capacity usage is not statistically significant, most likely since it captures the same effect as total production. Lastly, the lagged dependent variable is statistically significant, suggesting that a 1% increase in TFP in a given time period predicts a future increase of 0.81%.

Table 3 presents the results using the specification with a linear time trend. Similar results are obtained with the exception of the pulp price, which is no longer statistically significant. Equally, the linear time trend is not statistically significant. The latter is in contradiction with the theoretical assumptions regarding the impact of time and could be a result of a bad fit between the assumed linearity and the true development path of productivity.

In Table 4, the results from the dynamic specification without time effects are presented. Basically the same results are obtained as previous specifications. The noticeable difference is that the lagged regulation stringency variable for SOx is statistically significant with a negative sign. However, it could be suspected that this regression specification suffers from both omitted variable bias with respect to time, as well as cross-sectional dependence. The latter is also present to a larger extent in the regression using the linear time trend. The relatively similar results of the two alternative regression specifications suggest that the result of the base specification is fairly robust.

The residuals from the base specification do not exhibit any conspicuous patterns or curvatures, neither in the overall regression nor in the independent variables. A check of influential outliers suggests that an observation for Finland has a strong impact on the result. This is caused by a huge drop in TFP, which is left unexplained even if factors such as capacity usage are controlled for. By omitting the outlier, the same result in terms of significance is obtained, but the magnitude of the coefficient for lagRegNOx is reduced to 0.08.

The overall results of the regressions show that the abatement of NOx has affected TFP positively with a one-year lag. However, since the R measure is not explicitly based on regulation stringency, but on the possible outcome of such a policy, caution is warranted in the interpretation that environmental regulations have had a positive causal effect on productivity and technological change. The improved productivity is likely to depend on investments in new capital and learning, which coincide with lower emissions. It cannot be excluded that these productivity improvements would have happened anyway regardless of the presence of environmental regulation. This also bears on the question regarding the stationarity of the data. Even if the unit root tests suggest that the data is stationary, the test results cannot be relied on uncritically since they were originally constructed for much longer time periods. For the same reason, the positive coefficient on the lagged dependent variable should be interpreted as a predictor of the value of the subsequent observation when moving along the trend, not as a causal relationship in which a high level of TFP improves the possibility for further increases.

In the context of the pulp and paper industry, the results could be argued to be plausible. The pulp and paper industry is energy intensive suggesting that the underlying production process determines the level of NOx, SOx, and CO_2 emissions. As such, the emission levels among individual pulp and paper mills vary considerably due to different production processes and manufactured paper assortments. That is, the emissions are released in the context of generating heat and electricity, as well as in the processing of pulping chemicals. There are a number of ways in which a pulp and paper mill can control SOx and NOx emissions. For example, NOx emission control practices include the modification of combustion techniques, such as low-NOx burners (LNBs) and over-fire air (OFA), and post-combustion techniques, known as flue gas treatment (FGT), of which Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) are the most developed. In addition, SOx emissions, from auxiliary and recovery boilers, can be controlled by installing a scrubber. As the results suggest, NOx is the only statistically significant regulatory intensity measure. Although the extensive and increasing use of biofuels by the pulp and paper industry should have a positive impact on CO_2 emissions, it is also expected to lead to more NOx emissions, increasing the need for NOx compliance. The latter is the case since biofuels usually contain more nitrogen compared to gas or oil and, in many cases, biofuel is also of a lower fuel quality, which can complicate combustion conditions for optimal NOx control [78].

Finally, the question remains as to whether regulation facing the industry has been binding or not. There is evidence that technological change in the pulp and paper industry, even in the presence of environmental regulation, has been labour-saving and energy-using [47]. In summation, the result of the study can be said to indicate that measures which have implied lower emissions of NOx have increased TFP, albeit being uncertain whether these gains could have been even greater in the absence of environmental regulation.

4. Conclusions

In this study, the impact of environmental regulations on technological change is empirically analyzed for the pulp and paper industry. The effect on technological change is disentangled with an econometric approach using industry total factor productivity (TFP) as the dependent variable. The environmental regulation stringencies are calculated using actual emissions of the air pollutants nitrogen oxides, sulphur dioxide, and carbon dioxide. In addition, a number of control variables, such as capacity utilization, output prices, total output production, and R&D expenditure, are included.

The results indicate that the regulation of nitrogen oxides is associated with productivity improvements with a one-year lag, whereas regulations regarding sulphur dioxide and carbon dioxide have not had any statistically significant impact. In line with the a priori expectations, the price of pulp is connected to a negative effect, while lagged R&D expenditures and total production have had corresponding positive impacts, even if very small. Both the price of pulp and, in particular, total production, could be hypothesized to be determined simultaneously with TFP, and consequently, the coefficients of these variables should be interpreted with care. Capacity usage is not found to have any statistically significant effect.

An important policy implication is that the abatement of emissions in the pulp and paper industry, aside the objective of correcting external effects, could also have a positive effect on industry productivity and technological change. However, since the chosen proxy for regulation not only mirrors environmental regulation stringency, but probably also investments in new capital and learning which coincide with lower emissions, the result does not automatically imply that the maximum productivity growth has been reached. The results could therefore not be viewed as a proof of the strong Porter hypothesis postulating that stringent well-designed environmental regulations increase productivity growth compared to a no-policy scenario. Also, if productivity growth in the pulp and paper industry is connected to regulation-induced research activities which come at the expense of R&D in other sectors of the economy, this constitutes an overall opportunity cost of environmental regulation which is not caught by this investigation of the effects on the industry level.

Acknowledgments: Financial support from the Bio4Energy research environment and the Swedish Research Council Formas (dnr. 213-2014-184) is gratefully acknowledged.

Author Contributions: Johan Brolund and Robert Lundmark. conceived and developed the research approach; Johan Brolund performed the econometrics estimations; Johan Brolund and Robert Lundmark analyzed the data and results; Johan Brolund and Robert Lundmark wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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