DISCUSSION PAPER

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Effects of Information-Based Regulation on Financial Outcomes: Evidence From the European Union's Public Emission Registry

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**Effects of Information-based Regulation on Financial Outcomes:
Evidence from the European Union's Public Emission Registry**

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Abstract: Information-based policies play an important role in environmental protection efforts around the world. These policies use information provision and/or disclosure to shape behavior in order to meet the policy objective; for example, mandatory information disclosure requires firms to measure and report their pollutant emissions. This study investigates the influence of a particular information-based policy – the European Union's mandatory and public emission registry of polluting facilities – on financial outcomes of German firms: revenues, costs, and profits. Using detailed firm-level data for the years 1998 to 2016, we exploit size- and pollution-specific reporting thresholds to isolate the effect of this policy. We compare firms that own facilities required to report in the first EPER wave with similar firms that do not own such facilities. For this comparison, we deploy both a difference-in-differences design and an event study. Our findings suggest that the introduction of EPER in 2001 increased both operating revenues and expenditures, yielding a neutral impact on the operating profits of affected firms. These results support neither of the two competing hypotheses regarding financial outcomes: costly regulation hypothesis and Porter Hypothesis.

JEL Codes: K32, L21, O31, Q52, Q58

Keywords: Information-based Regulation, Environmental Policy, Financial Performance, Porter Hypothesis

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1. Introduction

Government agencies around the world use a variety of policies to protect and restore environmental quality by constraining and reducing pollutant emissions and discharges. The first wave of environmental policies focused on technology-based performance and design standards. The second wave of environmental policies emphasized incentive-based approaches, such as emission charges and cap-and-trade permit markets. The third wave of environmental policies has focused on information-based policies, such as the U.S. Community Right to Know Act, which established the Toxics Release Inventory (TRI).[4] The last set of policies uses information provision and/or disclosure to shape behavior in order to meet a policy objective, such as meeting an aggregate emissions target. As one example, mandatory information disclosure (e.g., TRI) requires firms to measure and report their pollutant emissions. Compared to the many studies on traditional standards and market-based policies, few studies assess the impact of information-based policies on firms. The extant literature mainly focuses on the effectiveness of these policies at reducing pollution and the financial valuation of the public disclosed information as reflected in housing and stock markets (e.g., von Graevenitz et al., 2018; Massier and Römer, 2012).

Our study investigates the influence of a European information-based policy, namely, a mandatory and public emission registry of polluting facilities, on financial outcomes of German firms: revenues, costs, and profits. Using detailed firm-level data, we exploit size- and pollution-specific reporting thresholds to isolate the effect of this policy. As our primary specification, we compare firms that own facilities required to report emission information with similar firms that do not own such facilities.

Since 2001, the European Union (EU) has required certain polluting facilities to monitor and measure their air pollutant emissions, wastewater discharges, underground injections, and toxic and hazardous waste transfers and then report these measured releases and transfers under the European Pollutant Emission Register (EPER) and later under the European Pollutant Release and Transfer Registry (E-PRTR). Once member states receive the pollution reports, the member states enter the measurements into the EPER/E-PRTR database and then disclose this database to the public two to three years after reporting. The European Environmental Agency publishes the database on its website as well as national agencies' websites. While the publication of the EPER database did not receive much attention in the

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[4] To be clear, these waves overlap. Nearly all nations continued to use effluent limits and several nations continued to implement incentive-based policies even after introducing information-based policies.

general public, the publication of the E-PRTR database has garnered meaningful media coverage.

This information collection and disclosure may influence polluting facilities' environmental management, such as treatment equipment, and production management decisions, such as innovation activities, as well as facilities' financial outcomes. The collection and disclosure spawn internal forces within a facility and external forces outside a facility. The internal process of monitoring and measuring pollution may prompt a facility to re-assess its environmental management efforts, which serves as a type of self-audit. Insight from this audit should lower the marginal cost of environmental management and innovation activities, prompting facilities to improve their environmental management efforts and expand their innovation efforts. Moreover, processing the emissions information may raise awareness of environmental management issues among upper management personnel, also prompting more environmental management and innovation, as described in Section 4.

Once facilities collect and process this information, they report it to environmental agencies, who disclose it to the general public. Given this disclosure, the rule may spur efforts by multiple external stakeholders: customers, workers, investors, and members of the local communities in which polluting facilities operate. Armed with more complete information on facilities' ecological impacts, these stakeholders are more likely to reward facilities that tread lightly on the earth and punish facilities that tread heavily on the earth. Facilities should improve their environmental management and expand their innovation activities because the marginal benefits of these two efforts are greater when external stakeholders understand better facilities' environmental performance, as described in Section 4.

Of course, improved environmental management implies higher abatement costs and expanded innovative activities imply higher R&D costs. Thus, facilities face a trade-off. While greater abatement raises revenues as long as customers are willing to pay more for "greener" products and lowers input costs, along with local community pressure costs (e.g., zoning restrictions), greater abatement carries arguably substantial costs. Even though expanded innovation activities enhance these revenue increases and cost reductions, these activities carry their own costs.

Absent the external stakeholders' increased scrutiny, facilities should increase abatement and innovation only to the extent that these activities improve profits. If the monitoring, measuring, processing, and reporting costs are negligible, the increased abatement and innovation activities should improve profits. Once the information disclosure rule fans the scrutiny of external stakeholders, the impact of the E-PRTR policy on profits is

ambiguous, whether or not the required monitoring, measuring, processing, and reporting costs are trivial. In this case, the role of innovation is important. Under conventional, neoclassical economic wisdom, innovation helps to mitigate the negative impact of a regulation on facilities' profitability but cannot offset or overcome this negative impact. However, under the Porter hypothesis, innovation offers an opportunity for the information-based regulation to generate "innovative offsets" that lead to improved profitability.

A rich literature explores the impacts of environmental protection laws on facilities' abatement efforts, innovation activities, and financial outcomes, along with other related decisions and outcomes (e.g., employment, labor productivity). Much of this literature explores these impacts through the lens of conventional neoclassical theory (e.g., Gray, 1987; Jorgenson and Wilcoxon, 1990). However, a substantial portion of the literature examines these impacts through the lens of the Porter hypothesis or at least with an eye to testing these two competing paradigms (e.g., Rassier and Earnhart, 2015).

Another literature examines the impacts of information disclosure rules on facilities' abatement efforts and financial performance (e.g., Power et al., 2011). The latter set of studies focuses exclusively on market-based measures of financial performance, e.g., stock market returns (e.g., Hamilton, 1995; Konar and Cohen, 1997).[5] Evidence of the role of community pressure with regard to the TRI has recently emerged (Wang et al., 2021). Housing market impacts further confirm the role of emission information on public perceptions (e.g., Mastromonaco, 2015), though for Germany and the E-PRTR, studies find no significant impacts on local housing markets (von Graevenitz et al., 2018).

Our study contributes to both literatures by examining the impact of an information disclosure rule on facilities' profitability, which represents an accounting-based measure of financial performance, while testing the two competing hypotheses: (1) costly regulation hypothesis, as derived from the neoclassical paradigm, and (2) Porter hypothesis. Our study is the first to examine the link from an information disclosure rule to profitability. We enhance this contribution by decomposing profits into its two constituent components: revenues and costs. This decomposition helps to identify the underlying causal mechanisms because they differ between revenues and costs. For example, investor pressure affects only costs. Moreover, while the extant research mostly focuses on the U.S. TRI program, research on its European equivalent in terms of the EPER and E-PRTR remains scarce. Our study provides the first analysis of the effect of the EPER introduction on European firms.

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[5] A recent working paper by Yang et al. (2021) may represent the exceptional study examining accounting-based measures of financial performance, e.g., revenues, return on assets.

To generate these contributions, we construct a basic conceptual framework, from which we theoretically derive hypotheses, and empirically tests these hypotheses using data on German manufacturing and energy generating firms between 1998 and 2016. Our empirical analysis focuses on a comparison between firms owning facilities required to register emissions under the first EPER wave and other firms. For this comparison, we employ both a difference-in-differences design and an event study. Our results indicate that the introduction of EPER in 2001 increased both operating revenues and expenditures, yielding a neutral impact on operating profits. Evidence further suggests that financial expenditures rose for EPER-treated firms after emissions information was published. These results support neither the costly regulation hypothesis nor the Porter Hypothesis; instead, they reveal that information-based regulation leaves facilities unharmed.

The rest of this study expands upon these points. First, Section 2 reviews the literature. Section 3 describes the regulatory context. Section 4 constructs the conceptual framework. Section 5 builds the econometric framework. Section 6 describes the data. Section 7 explains the econometric methods. Section 8 interprets the empirical results. Section 9 concludes.

2. Literature Review

Our study contributes to two related strands of the literature. The more relevant literature strand examines the impacts of government information disclosure rules on facilities' abatement efforts and financial performance. The other literature strand explores the impacts of other environmental protection laws on facilities' management decisions (e.g., innovation activities) and financial outcomes, along with other related decisions and outcomes (e.g., productivity).

2.1. Impacts of Government Information Policies on Facilities' Decisions and Financial Outcomes

For the topic of information policies, Tietenberg (1998) offers an excellent survey on the earlier literature and overview of the role played by information disclosure policies. We divide our review on more recent studies into those with a theoretical contribution and those with a more empirical focus.

2.1.1. Theoretical Research

The theoretical literature is quite sparse. As the exceptional theoretical studies, Blackman et al. (2004) and Powers et al. (2011) explore the impact of an information disclosure rule on a facility's abatement decision, identifying a facility's benefits from implementing a required self-audit and the external pressure costs imposed by a facility's

stakeholders (e.g., customers), while Cohen and Santhkumar (2007) theoretically examine the impacts on emissions and social welfare.

2.1.2. Empirical Research

The empirical literature on information disclosure explores both mandatory disclosure and voluntary disclosure. We focus on studies that scrutinize mandatory disclosure (Tietenberg, 1998; Tietenberg and Wheeler, 2001), and do not discuss studies of voluntary disclosure (e.g., Sinclair-Desgagne and Gozlan, 2003; Blanco et al., 2009).

Within the category of mandatory disclosure, Powers et al. (2011) distinguish three types of disclosure: (1) ad hoc announcements of environmental accidents and regulatory violations, (2) pollutant release transfer registries, and (3) performance evaluation and ratings program. Some studies explore the first type by examining the impact of good or bad environmental news on firms' stock prices (Laplante and Lanoie, 1994; Dasgupta et al., 2001; Dasgupta et al., 2006). Other studies examine the impact of disclosure stemming from registries, such as the TRI, on stock prices (Konar and Cohen, 1997; Hamilton, 1995). And some studies examine performance and ratings programs (Powers et al., 2011).

We focus our review on the second type of disclosure since EPER and E-PRTR clearly represent pollutant registries. Several studies scrutinize the impact of environmental information disclosure on pollution control (Konar and Cohen, 1997; Bennear and Olmstead, 2008; Bui, 2005; Koehler and Spengler, 2007; Foulon et al., 2002; Delmas and Shimshack, 2007; Garcia et al., 2007, 2009; Dasgupta et al., 2007; Wang et al., 2004; Uchida, 2007; Brouhle et al., 2009; Kathuria, 2009; Blackman, 2010; Doshi et al., 2013; Yang et al., 2021). Other studies examine the impact of information disclosure on stock prices (Konar and Cohen, 1997; Hamilton, 1995; Bui, 2005; Canon-de-Francia et al., 2008; Hibiki and Managi, 2010; Massier and Römer, 2012), as well as on house prices (Bui and Meyer, 2003; Mastromonaco, 2015; von Graevenitz et al., 2018).[6,7]

2.2. Impacts of Other Environmental Policies on Facility Decisions and Financial Outcomes

A related rich literature explores the impacts of other environmental protection policies on facilities' management decisions, including innovation activities, and financial

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[6] A related literature explores the roles of stakeholders' efforts to prompt better environmental management from polluting entities especially regulated businesses. For example, studies examine the role of local community pressure on abatement efforts (e.g. Earnhart, 2004) and location decisions (e.g. De Silva et al., 2016; Wang et al., 2021).

[7] A related literature explores the effects of information disclosure from non-governmental organizations and firms' voluntary information disclosure efforts on corporate strategies and outcomes. For example, Lyon and Shimshack (2015) examine the effect of Newsweek's Green Companies Rankings.

outcomes, along with other related outcomes. This literature helps to understand how increased regulatory scrutiny can improve, at least eventually, corporate profitability.

2.2.1. Theoretical Research

Within this literature, several studies theoretically explore the impacts of environmental protection policies on facilities' management decisions and financial and operational outcomes. Some theoretical studies use a neoclassical lens (e.g., Palmer et al., 1995). Other theoretical studies use the Porter Hypothesis lens to assess environmental policy effects on innovation and financial outcomes. We distinguish these studies based on the channels underlying the Porter effect – increased environmental regulation spurs innovation and eventually improves profitability, which mostly divide between market failures and organization failures. Within the set of market failure studies, some studies examine market power (Simpson and Bradford, 1996; André et al., 2009). Other studies examine the market failure of asymmetric information between firms and consumers (Ambec and Barla, 2007; Rege, 2000). Other studies explore the market failure of R&D spillovers (Mohr, 2002; Jaffe et al., 2005; Xepapadeas and Zeeuw, 1999; Feichtinger et al., 2005). Another set of studies explore organizational failure, generally due to organizational inertia (Ambec and Barla, 2002; Campbell, 2003; DeCanio, 1994). Other studies examine the role of behavioral forces. (Kennedy, 1994; Ambec and Barla, 2006; Aghion et al., 1997; Ambec and Barla, 2007; Gabel and Sinclair-Desgagné, 1998, 2001). See Appendix A for additional details.[8]

2.2.2. Empirical Research

Empirical studies also explore the impacts of environmental protection laws on facilities' management decisions and financial and operational outcomes. For our review, we focus on studies examining the same dependent variables as our study: financial outcomes.[9] Several studies examine the effect of environmental regulatory policies on corporate profitability (Brännlund et al., 1995; Alpay et al., 2002; Rassier and Earnhart, 2015). Additional studies explore the impact of environmental regulation on production costs (Gray, 1987; Jorgenson and Wilcoxon, 1990).

Other studies examine the impacts of environmental regulation on firm decisions and outcomes *related to* the dependent variables examined in our present study, e.g., productivity. Various studies explore the effect of environmental regulation on productivity (Gollop and Roberts, 1983; Smith and Sims, 1985; Gray, 1987; Dufour et al., 1998; Alpay et al., 2002; Gray and Shadbegian, 2003; Greenstone et al., 2012; Berman and Bui, 2001). Greenstone

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[8] Four studies comprehensively survey the literature exploring the Porter Hypothesis (Wagner, 2003; Ambec and Barla, 2006; Brännlund and Lundgren, 2009; Ambec et al., 2013).

[9] Other studies analyze the effect of environmental policies on innovation (e.g., Jaffe and Palmer, 1997).

(2002) examines industrial activity by assessing the negative regulatory impacts on industrial production and employment.[10]

3. Regulatory Context

This section briefly describes the introduction of the mandatory information disclosure rule in Europe and the regulatory context in Germany. The Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control provides the basis for the first collection and publication of pollutant emissions within the European Union. The introduction of the European Pollutant Emission Register (EPER) is the direct result of Article 15(3) in the directive. Its main objective is to fulfill the public's right to know about the emissions occurring in their neighborhood. The EPER contains data on emissions to water and air of 50 pollutants from large and medium sized industrial point sources in the European Union. Pollutant emissions must be reported if the reporting threshold is exceeded. The thresholds are set in order to cover 90% of the total emissions of a pollutant substance from such point sources. Only certain economic sectors are required to report (e.g., most of the manufacturing and power sector) and in some cases only plants exceeding a certain capacity threshold.

The EU implemented the EPER program in late 2000 (Commission Decision 2000/479/EC), with 2001 as the first reporting year (published in 2004). The EPER initially covered 9,400 facilities in the EU15, Hungary and Norway. Annex I of the regulation provides details on the sectors mandated to report and relevant capacity and emission thresholds. The EU intended the EPER program to collect and report emissions every three years. The EU implemented the second wave in 2004, with reports published in 2006. This wave expanded the register to cover EU25 and Norway and contains information for 12,000 facilities.

The EU replaced the EPER with the European Pollutant Release and Transfer Registry (E-PRTR) in 2006 (Regulation (EC) No 166/2006). The E-PRTR reports information annually starting from 2007 (published in 2009). It expands the number of regulated sectors from 56 to 61 and the number of reported pollutants from 50 to 91 substances. In addition to emissions to air and water it also includes emissions into soil and waste disposal. In several cases, the reporting thresholds for individual substances were also adjusted with the introduction of the E-PRTR.

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[10] Dechezleprêtre and Sato (2017) review studies of regulatory impacts on country-level competitiveness; Cohen and Tubb (2018) provide meta-analysis on the regulatory impacts on competitiveness at both the firm-level and country-level.

The information from both the EPER and the E-PRTR is available from the European Environmental Agency and is published online. For the first publication of the E-PRTR in 2009 the German environmental agency created a website (www.thru.de) allowing interested persons to search for emissions near their homes and displaying the data on an interactive map.

We focus on the introduction of the EPER. At the time of the EPER introduction information on point source emissions was relatively scarce in Germany. Thus, most of the information reported in the EPER was new, at least to the public. However, other information sources became available later in the decade. From 2004 onwards, the EU Industrial Emissions Directive has required reporting of emissions of SO2, NOx, and particulate matter for combustion plants with thermal capacity exceeding 50 MW. Starting in 2005, the EU emissions trading scheme provided information on carbon emissions. In addition, the German 11th Federal Emissions Control Regulation began requiring the reporting of point source pollutants in 2008. Thus, the E-PRTR arrived at a time when other regulation also provided information on at least a subset of the E-PRTR reported pollutant substances.[11]

4. Conceptual Framework

This section constructs a simple conceptual framework for understanding the impacts of information-based regulation on innovation decisions and financial outcomes, drawing upon the framework of Blackman et al. (2004) and Powers et al. (2011).

4.1. Base Conceptual Model

In our base model, a single person manages a single firm that operates a single facility in Germany. Thus, we initially remove any opportunity for the firm manager to glean insight by comparing across multiple facilities and ignore any divergence between upper and lower managers regarding environmental management. Our extended model explores these two dimensions.

The firm employs capital equipment and labor to produce output. The firm sells its product at a fixed price. The firm hires workers at a fixed wage rate and obtains capital equipment at a fixed financing cost. In the absence of information-based regulation, customers, workers, investors, and other stakeholders perceive the firm as identical to other

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[11] For two German states, information was available prior to publication of the first EPER wave. The states of Baden-Wuerttemberg and North Rhine-Westphalia already had state level registries, but these were not publicly accessible. A comparison of the EPER data with those reported for these two states shows that the coverage rate of 90 % of emissions was mostly satisfied in North Rhine-Westphalia; in Baden-Wuerttemberg, coverage for some pollutants, e.g. particular matter of 10 microns (PM10), was much weaker. See "Erste Durchführung der Berichterstattung zum Europäischen Schadstoffemissionsregister (EPER) in Deutschland nach Art. 15 (3) IVU-Richtlinie", German Federal Environment Agency report on the implementation of the EPER by Sabine Grimm, Gabriel Striegel, Barbara Rathmer, and Christian Kühne, published in March 2004.

firms. With the information-based regulation in place, stakeholders can differentiate across firms based on environmental performance.[12]

We assume that the firm produces a fixed quantity of output and employs a fixed quantity of inputs. Rather than exploring regulatory impacts on input and output quantities, we explore the impacts of information-based regulation on the output and input prices.

In the process of producing its product, the firm generates pollutant emissions, which erode ambient environmental quality. The firm can reduce the level of pollution by expending abatement effort, which entails costs. Local community members derive welfare from local environmental quality. Pollution undermines this quality; thus, greater abatement improves this quality. In order to induce greater abatement effort from the firm, local community members impose costs on the firm for insufficient abatement.

The firm can also engage in innovation activities, which improve the productivity of abatement, labor, and capital equipment. To model these improvements, we allow innovation to reduce the cost of abatement, the effective price of labor, and the effective price of capital. We label these innovation activities as "process-based innovation". Innovation activities also improve the quality of the product ("product-based innovation"), which raises the price that customers are willing to pay for the product. Similar to abatement, labor, and capital costs, innovation may lower the costs imposed by local communities.

An information-based regulation requires the firm to monitor and measure its pollution and report these pollution measurements to the regulatory agency, who in turn disseminates this information to the public, including the firm's stakeholders, e.g., consumers. The firm bears costs of monitoring and measuring emissions and processing this information.[13]

The requirement to monitor and measure emissions and process this information improves the firm's understanding of its own emissions. As the firm's understanding grows, the costs of abatement fall as do environmental innovation costs. Disclosure of the firm's emissions impacts the firm's stakeholders. Consumers' desire to buy the firm's product depends positively on the firm's abatement level since abatement improves the quality of the product, assuming consumers care about the public good aspects of the firm's product (Kotchen, 2006). However, consumers do not possess complete information on the firm's abatement. Information disclosure on the firm's emissions expands the consumers' information set on abatement, thus, improving the consumers' confidence about their

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[12] Essentially, we assume that the firm is operating in imperfectly competitive markets.
[13] The lack of treatment informs stakeholders that the firm's emissions fall below any threshold relevant for the stakeholders.

understanding of the firms' abatement level. Armed with greater confidence, consumers increase the desire to buy the firm's product when abatement lies above some threshold but decrease their desire to buy the firm's product when abatement falls below this same threshold. As consumers' desire for the product rises, the product price increases. Thus, the information disclosure rule *indirectly* increases the product price for a firm that expends sufficient abatement effort but decreases the product price for a firm that expends insufficient abatement effort.

The required disclosure of emissions information similarly impacts workers. The firm's abatement improves the workers' non-pecuniary benefits of working for the firm so workers' desire depends positively on abatement. Similar to consumers, workers do not possess complete information on the firm's abatement. Information disclosure on the firm's emissions expands the workers' information set on abatement, thus, improving the workers' confidence about their understanding of the firms' abatement level. Armed with greater confidence, workers increase their desire to work for the firm when abatement lies above some threshold but decrease their desire to work for the firm when abatement falls below this same threshold. As workers' desire to work for the firm rises, the wage rate falls.

The required information disclosure similarly impacts investors, who provide capital equipment financing, and local community members. Collectively, the firm's output price, labor input price, capital input price, and local community pressure costs depend on both the firm's abatement level and the information disclosure requirement.

We assess the impact of the information disclosure requirement on the firm's two choice variables – level of abatement and extent of innovation activities – and financial outcomes. (See Appendix B for details.) The information rule lowers the marginal cost of abatement and improves the marginal benefits of abatement. On both counts, the information rule leads the firm to abate more.

Similarly, the information rule prompts the firm to innovate more. Internally, the required monitoring and measurement improves the firm's understanding of their environmental performance, which lowers the cost of innovation, prompting more innovation. Externally, the disclosure aspect of the information rule improves the marginal benefits of innovation.

The impacts of the information rule on all of the financial outcomes are ambiguous. The following hypotheses reflect these ambiguous impacts. (See Appendix B for details on the derivation of all hypotheses.)

> *Hypothesis H1*: The information rule increases the product price if abatement lies above the noted threshold or remains close enough to the threshold that the

impacts of increased abatement and innovation dominate (*Hypothesis H1a*); otherwise, the information rule decreases the product price, *P* (*Hypothesis H1b*).

Hypothesis H2: The information rule decreases total costs if abatement lies sufficiently above the noted threshold so that the rule's direct negative impacts on input costs and local community pressure costs dominate (*Hypothesis H2a*); otherwise, the information rule increases total costs because the increases in abatement costs, innovation costs, and monitoring/processing costs dominate (*Hypothesis H2b*).

Hypothesis H3: The information-based regulation increases profits if (a) revenues rise and total costs fall, (b) both revenues and total costs rise yet the increase in revenues <u>dominates</u> the increase in total costs, or (c) both revenues and total costs fall yet the decrease in revenues is <u>dominated by</u> the decrease in total costs (*Hypothesis H3a*); otherwise, the regulation lowers profits (*Hypothesis H3b*).

4.2. Simplified Models and Porter Effects

Our base model captures two forces unleashed by the information rule. Within the firm, the process of monitoring and measuring its emissions allows the firm to understand better its environmental management system, prompting the firm to innovate more and abate more. This internal force unambiguously lowers labor costs, capital costs, and local community pressure costs. However, this same force increases abatement costs, innovation costs, and emission monitoring and information processing costs. Thus, overall costs may fall or rise. In contrast, the identified internal force unambiguously increases revenues. Consequently, without any additional understanding, we cannot determine whether the internal force increases or reduces profits. This said, presumably the firm increases abatement and innovation in order to increase profits. If the monitoring and processing costs are negligible, then the increases in abatement and innovation must improve profitability. Of course, if the monitoring and processing costs are sufficiently substantial, increased abatement and innovation may not sufficiently raise profits in order to improve profitability overall. *Hypothesis H4* captures this relationship:

Hypothesis H4: In the absence of any increased scrutiny by external stakeholders, the information rule increases profits as long as the monitoring, measuring, and processing costs are negligible (*Hypothesis H4a*); if the emission information-related costs are sufficiently large, these costs outweigh the benefits of the

profit-improving abatement and innovation steps, leading to weaker profits (*Hypothesis H4b*).

Based on theoretical research on the Porter Hypothesis, which we review in sub-section 2.2.1, organizational failure may disrupt the firm's ability to identify all profit-maximizing actions prior to imposition of the information rule. In particular, the firm may not optimally exploit opportunities to conduct internal audits. In this case, the information rule may improve profits even when the monitoring, measuring, and processing costs are non-negligible. Consequently, we modify *Hypothesis H4a*:

> *Hypothesis H4a:* The information rule increases profits as long as the monitoring, measuring, and processing costs are negligible or organizational failure sufficiently disrupts the firm's ability to exploit opportunities to conduct voluntary internal audits prior to the information rule.

Similarly, we can focus on the external forces, ignoring the internal force. In general, the information rule ambiguously impacts revenues, total costs, and profits. However, based on theoretical research on the Porter Hypothesis, asymmetric information between firms and customers, as well as other stakeholders, may disrupt the firm's ability to identify all profit-maximizing actions prior to imposition of the information rule. In particular, the firm may not optimally exploit opportunities to raise revenues and lower input costs by expanding abatement effort. By design, the information rule mitigates any information asymmetry. This mitigation increases the likelihood of the information rule improving financial outcomes, as reflected in *Hypothesis H5*:

> *Hypothesis H5:* Relative to the case of symmetric information between the firm and stakeholders, under asymmetric information, the information rule prompts a firm: to enjoy a stronger increase in its revenues or bear a weaker decrease in its revenues; to enjoy a stronger reduction in its total costs or bear a weaker increase in its total costs; to enjoy a stronger increase in its profits or bear a weaker decrease in its profits.

5. Econometric Framework

For our empirical analysis, we implement both a difference-in-differences model and an event study. We utilize a quasi-experimental approach for both forms of analysis. We first estimate a differences-in-differences model to identify the effect of treatment by the EPER regulation on firm performance. We denote the outcome variable, e.g. financial performance, for firm i in year t as y_{it}. We denote the set of firm indicators and the set of year-specific indicators as μ_i and δ_t, respectively. We denote the treatment factor as T_{ik}, where k is one of four phases: 1st (2000-2004), 2nd (2005-2006), 3rd (2007-2010), and 4th (2011-2016). In our

base specification, this treatment factor indicator takes the value of one if and when the firm is treated by the information regulation and a value of zero otherwise. We construct the regression equation as follows:

$$y_{it} = \sum_{k=1}^{4} \beta_k T_{ik} + \mu_i + \delta_t + \epsilon_{it} , \tag{1}$$

where ϵ_{it} captures the error term, which we cluster at the firm level.

Our main focus is the introduction of the EPER. While the EU introduced the EPER on a European level in 2001, country reports indicate that Germany had already filed emission reports in 2000. Therefore, the first of our four phases starts in 2000 and we define treatment as entry into the first wave of the registry ($T_{ik} = 1$ for firms reporting in the EPER in 2000 for $k \geq 1$, and zero otherwise).[14]

We assess the impact of the first wave of the EPER on nine different outcome variables. We mainly focus on these measures: operating revenues (in logs), operating expenditures (in logs), and operating profits (in levels). To assess the robustness of our conclusions, we also examine measures of profitability, which scale profits by alternative measures of firm size: return on equity, return on (total) assets, and return on sales. To scrutinize the causality of our estimates, we also assess whether the EPER treatment effect on financial investment revenues, financial investment expenditures, and financial investment-related profits.

For our main outcome variables, we also examine the timing of responses using an event study, which estimates a coefficient for the interaction of EPER-reporting firms with each year, i.e., replacing subscript k with subscript t in equation (1). This approach allows us to assess whether outcomes depend on the collection of information in 2000 or the online publication of emissions information in 2004. Moreover, the event study allows us to test the assumption of parallel trends in the control period.

Identification in our research design is based on the conditional independence assumption: potential outcomes are independent of treatment conditional on observable factors, denoted as X_{it}: $y_{it} \perp T_{ik} \mid X_{it}$. To control for observable differences between treated and control firms, we use a genetic matching approach, as described in Section 7.

6. Data

We combine data from the EPER/E-PRTR on emissions and reporting status at the facility level with information about the parent company from the Orbis data set. Below we describe briefly the data sources and our final data set.

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[14] Though our main analysis concerns the introduction of the EPER, we also estimate a model allowing for "rolling enrollment", which includes firms that are required to report to the EPER in its second wave. The results are qualitatively similar, as reported in Appendix Table A1. Our main analysis focuses on the cleaner treatment definition to minimize selection bias.

6.1. Sources

The European Environmental Agency (EEA) makes the EPER and E-PRTR datasets available for download. Collectively, these data sets contain information on emissions for 2001, 2004, and annual data from 2007 to 2016. In total, across all years, 2,903 unique facilities report emissions in the German data. The data do not represent a balanced panel because facilities do not necessarily need to report every year due to reporting thresholds.

Information is provided at the facility level, where a facility is defined as "an industrial complex with one or more installations on the same site, where one operator carries out one or more Annex I activities" (Annex A4, of European regulation 2000/479/EC). In addition to information on pollutant emissions, the data set contains information on facility location, facility name, and name of a facility's parent company. The information does not contain company identifiers, only company names. We use name-based matching to assign company identifiers and identify the parent company in the Orbis database for Germany. We identify between 1,400 and 1,600 companies over all years depending on the definition (Bureau van Dijk ID, Trade register number, etc.). We limit the data set to companies operating in the manufacturing and energy sectors (NACE Rev. 2 sectors 10-35) within Germany.

The Orbis data are provided by Bureau van Dijk. The data vendor Creditreform collects the German data from annual reports. The database contains balance sheet information for more than 250,000 companies in Germany and covers the time period from 1998 to 2016. The data derive from corporate enterprises and cooperatives that are mandated to file annual reports according to German commercial law. The database identifies companies according to their trade register codes, Creditreform numbers, or Bureau van Dijk identifiers.

The data set includes information on the number of employees, the value of fixed assets, total costs, revenues, and profits, as well as specific expenditures on labor, materials, and R&D. We limit the sample to companies operating in the manufacturing and energy sectors.

6.2. Regression Sample

Based on the name of parent companies in the EPER and E-PRTR databases we matched facilities to companies. In total, we assign some 1,485 polluting facilities to approximately 1,108 companies. This assignment corresponds to matching 84 % of all E-PRTR facility-year observations.

Figure 1 shows the number of companies (firms) reporting for the first time in the EPER or E-PRTR (excluding those that reported earlier in the EPER). A substantial number

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of companies enter in 2001 or 2007. Entry into the registry follows from either a company acquiring or constructing a new facility or a company's existing facility exceeding at least one threshold for the first time.

6.3. Statistical Summary

Our analysis focuses on the effect of the first wave of the EPER. We consider companies required to report their 2001 emissions as treated. As few alternative sources of emissions information were available at the time of EPER introduction, this treatment definition is arguably likely to generate the largest effect. However, this definition requires us to rely heavily on data at the beginning of our sample period (1998-2001). In this early period the, Orbis data set is less dense than in later years, thus, reducing our sample size substantially. Once we account for missing values, our sample includes a total of 78 treated companies (out of 400 companies reporting in the first wave of the EPER) and 1,917 potential control companies.

Since reporting requirements in the EPER and E-PRTR depend on emissions exceeding certain thresholds, we expect that our sample over-represents large companies. Indeed, we confirm this expectation. Figure 2 reveals that the pre-treatment factors of companies reporting to the EPER and E-PRTR differ substantially from those companies that never report. This difference also holds for the companies reporting in the first wave of the EPER: they are larger than the potential control companies, in terms of revenues, expenditures, profits, and fixed assets. To address these differences, we use a matching approach for preprocessing the data in the spirit of Ho et al. (2007).

7. Empirical Methods

We examine the effect of the first EPER wave. We consider companies required to report their 2001 emissions as treated. We exclude companies reporting in later versions of the EPER/E-PRTR from the potential control group.[15] As the pre-treatment factors of the companies reporting in the EPER and the potential control companies vary substantially, we utilize a matching routine to control for observable differences. Consequently, we reduce the sample to comparable firms based on observables.

We implement genetic matching with replacement, using firm-level averages from 1998 and 1999. We match on four continuous variables: operating revenues, operating expenditures (logged), fixed assets (logged), and operating profits. We also match on the last

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[15] Companies reporting at a later stage under the E-PRTR program do not serve as a useful control group since reporting requirements apply only once when emission levels cross established thresholds, implying that the entry into treatment at a later stage is likely endogenous with respect to the outcome variables. In particular, output growth increases revenues and costs but also likely increases emissions, leading to the imposition of reporting requirements.

reporting year in Orbis as a proxy for the timing of exit from the market. Finally, we require exact matching on the 2-digit sector code (NACE Rev. 2). To improve balance within this matching routine, we implement a caliper of one standard deviation, i.e., the maximum standardized distance for each matching variable that is acceptable for matching treated and control firms.[16]

To assess the improvement in balance between the control and treatment groups, we examine Quantile-Quantile (QQ) plots of the matching covariates, as shown in Online Appendix Figure B1, which displays the full sample and matched sample. For all three continuous variables, the QQ plots indicate that the sample is better balanced after matching.[17]

Our matched sample consists of 1,505 company-year observations (subject to availability of the respective dependent variable), including 65 treated firms and 52 matched control firms, over the period from 1998 to 2016.

The validity of the difference-in-differences approach is generally based on the assumption that the treatment and control firms would have followed parallel trends absent treatment. Since this assumption is not testable, we explore the presence of parallel trends *prior* to treatment, which at least lends support to this assumption. With just two observations available prior to treatment, parallel pre-trends are difficult to test. However, we implement an event study to assess the timing of effects from the reporting requirements on the outcome variables. This event study also allows us to address the temporal ambiguity of treatment. The treatment start date might be the date of reporting <u>or</u> the date of the information's public release. In the latter case, an effect of EPER "treatment" should materialize only after 2004.

8. Empirical Results

We estimate the model specified in Section 5 for each of our three main outcome variables. Table 1 and Table 2 show the estimation results. The first, third, and fifth columns in each of the tables show the results from a regression using the full sample (i.e., without matching). The second, fourth, and sixth columns display the results from a regression using the matched sample. Table 1 displays the effects on operating revenues, expenditures, and profits, whereas Table 2 displays the effects on the profitability measures: return on equity,

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[16] In genetic matching, the caliper is applied to each matching covariate in contrast to propensity score matching, in which the caliper is only applied to the propensity score. Furthermore, we also implemented alternative matching routines using (1) propensity score matching, (2) no caliper, (3) other caliper settings [0.5, 1.5, and 2 standard deviations], and (4) one-to-two nearest neighbors matching. The matching configuration described in the main text yields the best balance based on inspection of QQ-plots.

[17] The QQ plots describe the distribution of the continuous variables in the treatment and control group by plotting the percentiles against each other. For a perfectly matched sample, the percentiles lie on the 45-degree line.

return on assets, and return on sales. The findings based on the matched sample suggest that the treatment of EPER reporting positively affects operating revenues and expenditures but not operating profits. Apparently, the increases in both revenues and expenditures statistically cancel each other out. As shown in Table 1, the phase-specific coefficient magnitudes and standard errors differ little between operating revenues and expenditures; thus, the coefficient p-values differ trivially despite the presence or absence of asterisks (*). Thus, the timing of impacts does not vary between operating revenues and expenditures.

We assess the robustness of our profit findings by examining three forms of profitability. The profitability results, shown in Table 2, affirm the lack of any significant link from treatment to profits, demonstrating that our conclusions are robust to the formulation of profits.

To assess the causality of our estimates, Table 3 reports the treatment effects on financial investment-related revenues, expenditures, and profits. These results suggest no impact on financial investment revenues and profits. However, EPER treatment surprisingly increases financial investment expenditures (in Phases 3 and 4). Perhaps the greater internal scrutiny of operations, prompted by the EPER reporting requirements, encourages companies to assess more strongly their financial investments too. Future research should explore this point further.

We further check the robustness of our results by using a rolling treatment definition: we identify firms as "treated" once they start reporting their emissions. Appendix Table A1 displays the estimates. As shown, the results prove qualitatively similar to those reported for the EPER introduction, our base treatment definition. (Online Appendix Figure B2 uses QQ plots of covariate balance to provide information on the matching quality for the rolling treatment definition.)

We further scrutinize the timing of treatment effects. In the reported regressions, we assess the effect of reporting 2001 emissions on the outcome variables over a period of 15 years from the time of reporting. The main specification considers four phases of treatment. The event study interacts the treatment indicator with year dummies, generating year-specific treatment effects. Figures 3, 4, and 5 display the event study results, which prove consistent with the main results, shown in Table 1. However, these year-specific treatment effects reveal that the positive impacts on revenues and expenditures emerge only starting in 2007.[18] As with the difference-in-differences results, the event study generates year-specific coefficient magnitudes and standard errors that differ little between operating revenues and expenditures;

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[18] Appendix Figures A1, A2, and A3 display the event study results for the rolling treatment definition. As shown, these results prove highly similar to the main specification event study results.

thus, the coefficient p-values again differ trivially despite the presence or absence of asterisks. Again, the timing of impacts does not vary between operating revenues and expenditures.

The displayed pattern seems to suggest that the publication of the emissions information plays an important role. As discussed in Section 4, the reporting of emissions information may mostly affect a firm via an internal channel, whereas publication of the emissions data most likely affects a firm via the external channel through stakeholder pressure. The EU published the first wave of EPER emissions information in 2004 and our estimates reveal a treatment impact starting in 2007. Based on this sequence, the external channel of stakeholder pressure proves more important than the internal channel of improved operational scrutiny.

This point notwithstanding, the delay in impact prompts further scrutiny. The EU publicly releases information in 2004 yet our estimates reveal no impact until 2007. Why would the effect of stakeholder pressure need three years to materialize? Perhaps stakeholders needed time to comprehend the implications of the released information, companies needed time to modify operations in response to stakeholder pressure, and stakeholders needed time to assess the environmental benefits of modified operations. Given these links, a delay of three years seems reasonable. Still, we acknowledge that the lack of a closer temporal link might suggest that other events confound our results. Further emissions reporting and publication by the treated firm occurred over the years since the initial EPER wave. Reporting by other companies (potential competitors) may have also entered into the registries at a later date, affecting the perception of the environmental performance of firms already in the registries.[19] The introduction of additional regulation in the form of the Industrial Emissions Directive (2004) or the EU emissions trading scheme (2005) may have affected the channels through which the reporting requirement affects firm performance.

Lastly, we assess the size of the estimated effects. The estimates seem unexpectedly large, with increases ranging from 20 % to almost 60 % for both operating revenues and expenditures. The size of the estimated impacts raises concern that our well-crafted identification strategy and properly implemented matching procedure may still prove inadequate for overcoming the limitations of our sample. In particular, our control period offers only two years of data (1998 and 1999). Perhaps this short control period does not

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[19] We test heterogeneous effects differentiating by emissions performance both in relative terms and over time (e.g., firms with above median emissions in the first reporting year, firms with increasing emissions over the years, firms with emissions increasing more than the median) but found no evidence to support heterogeneous effects along these channels. These results are available from the authors upon request.

allow our analysis to adjust for pre-treatment trends. Moreover, we acknowledge that large companies, which may have proven better managed, were more likely to be present in the early years of the Orbis dataset. In addition, the facilities owned by this subset of firms may have been more likely to face EPER reporting requirements. And the larger firms may have grown faster over our treatment period for reasons unrelated to the information regulation. We cannot rule out this confounding confluence of links.

9. Conclusions

Information-based policies play an important role in environmental policy around the world. This study investigates the influence of an information-based policy, namely, a mandatory and public emission registry of polluting facilities, on financial outcomes of German firms similar to the much studied Toxics Release Inventory (TRI) in the US. Using detailed firm-level data, we exploit size- and pollution-specific reporting thresholds to isolate the effect of this policy. In our analysis, we compare firms that own facilities required to report in the first wave of the EPER with similar firms that do not own such facilities. We find large positive effects on operating revenues and expenditures, but no impact on profitability of the firm. The timing of the effects and their size raises serious doubt about the extent to which they can be causally attributed to the introduction of the EPER.

The analysis of the EPER and E-PRTR is complicated by the fact that available data is thin in the years surrounding the introduction of the EPER. Moreover, the 2000s were also the years in which the EU Emissions Trading Scheme was implemented. The uncertainty surrounding the introduction of the EU ETS and the incentives provided by carbon pricing within the ETS may confound our estimates for later years after the introduction of the EPER. In addition, the EU introduced its Large Combustion Plant directive in 2004 which was implemented in Germany in 2007 and significantly tightened regulation of SO2, NOX and dust emissions from large combustion plants. Untangling the effects of the EPER and E-PRTR on firm performance in Germany and other European countries completely from effects of these other forms of environmental regulation is not possible given our limited data set. Much research remains needed to assess the impact of the introduction of the EPER and the E-PRTR registers on German companies.

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Figure 1

First Year of Entry into the EPER or E-PRTR Program
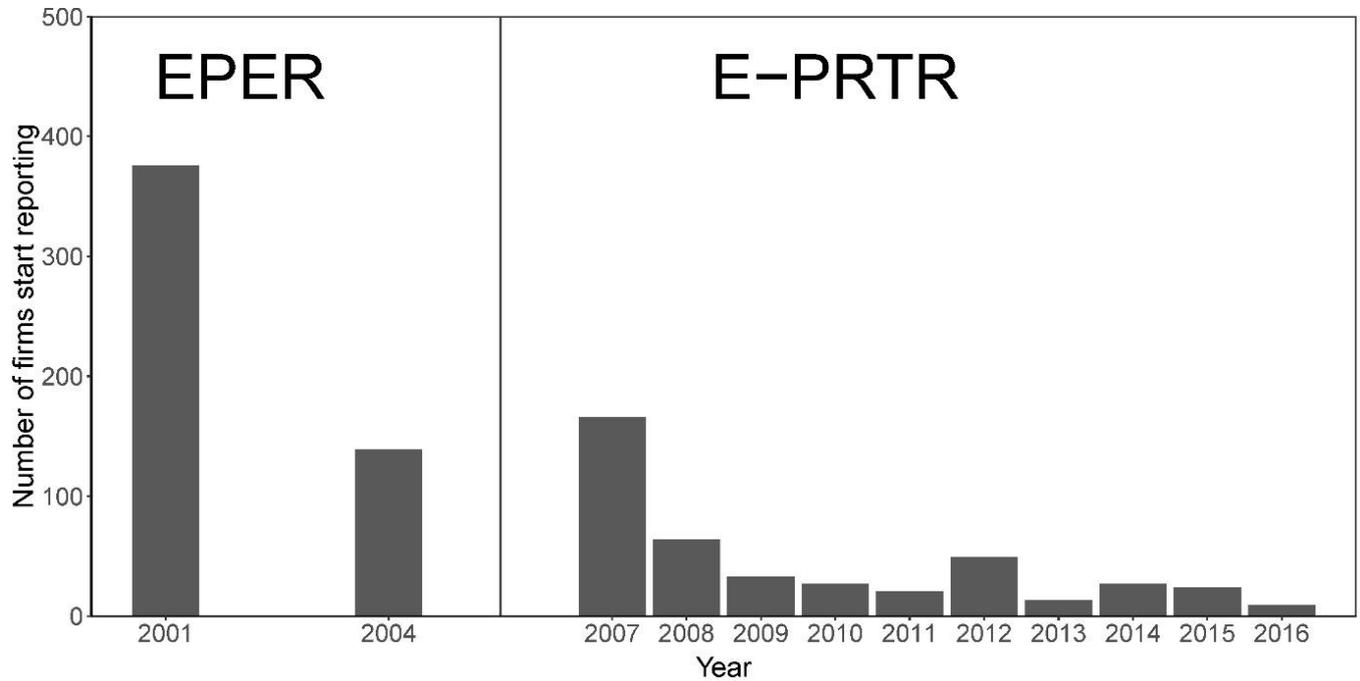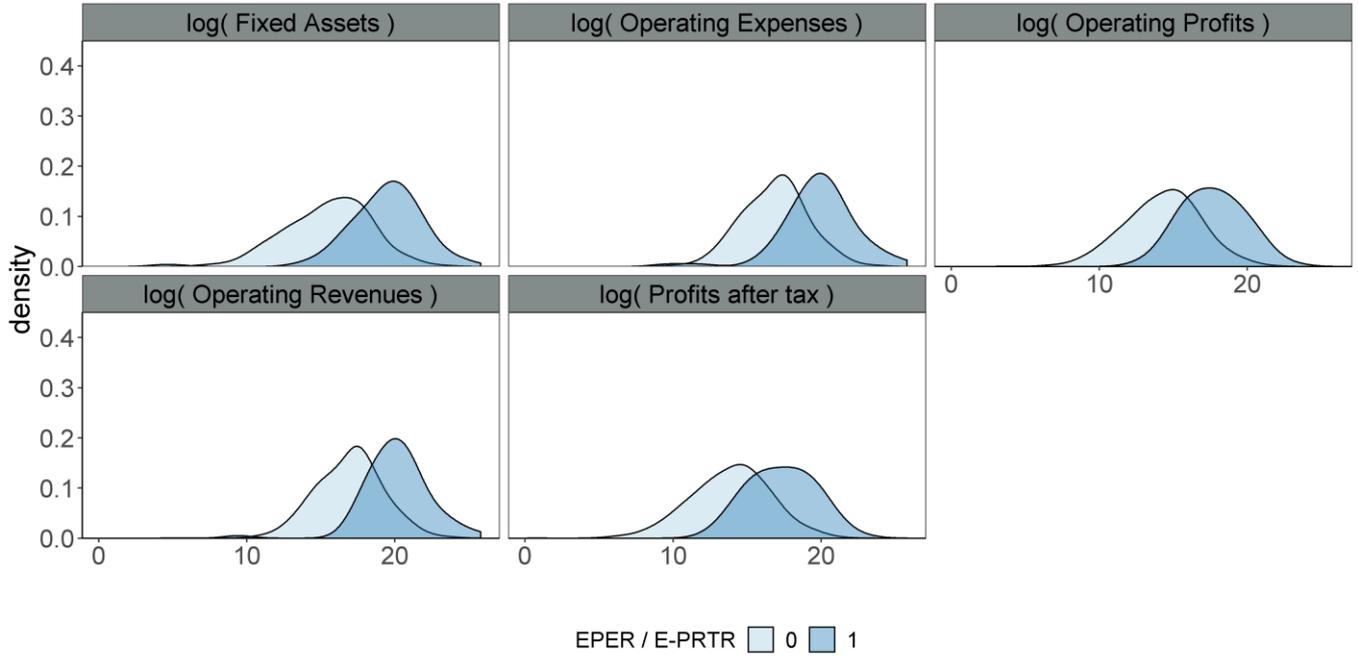

Notes:

This figure shows the number of firms reporting for the first time in the EPER (prior to 2007) or E-PRTR (from 2007 onwards).

This figure does not count firms reporting in the EPER again as reporting for the first time in the E-PRTR.

The spike in 2007 reflects the changes in thresholds for pollutants and the inclusion of emissions into the ground and waste transfers within the reporting requirements.

Figure 2

Density Plots of Company Financial Outcomes and Fixed Assets
for the Control Period of 1998 to 1999
by EPER/E-PRTR Reporting Status

Notes:
The light blue density shows the distribution of the financial outcomes and fixed assets for the companies not reporting to the EPER (potential controls), whereas the dark blue density shows the distribution for the EPER companies (treatment group).
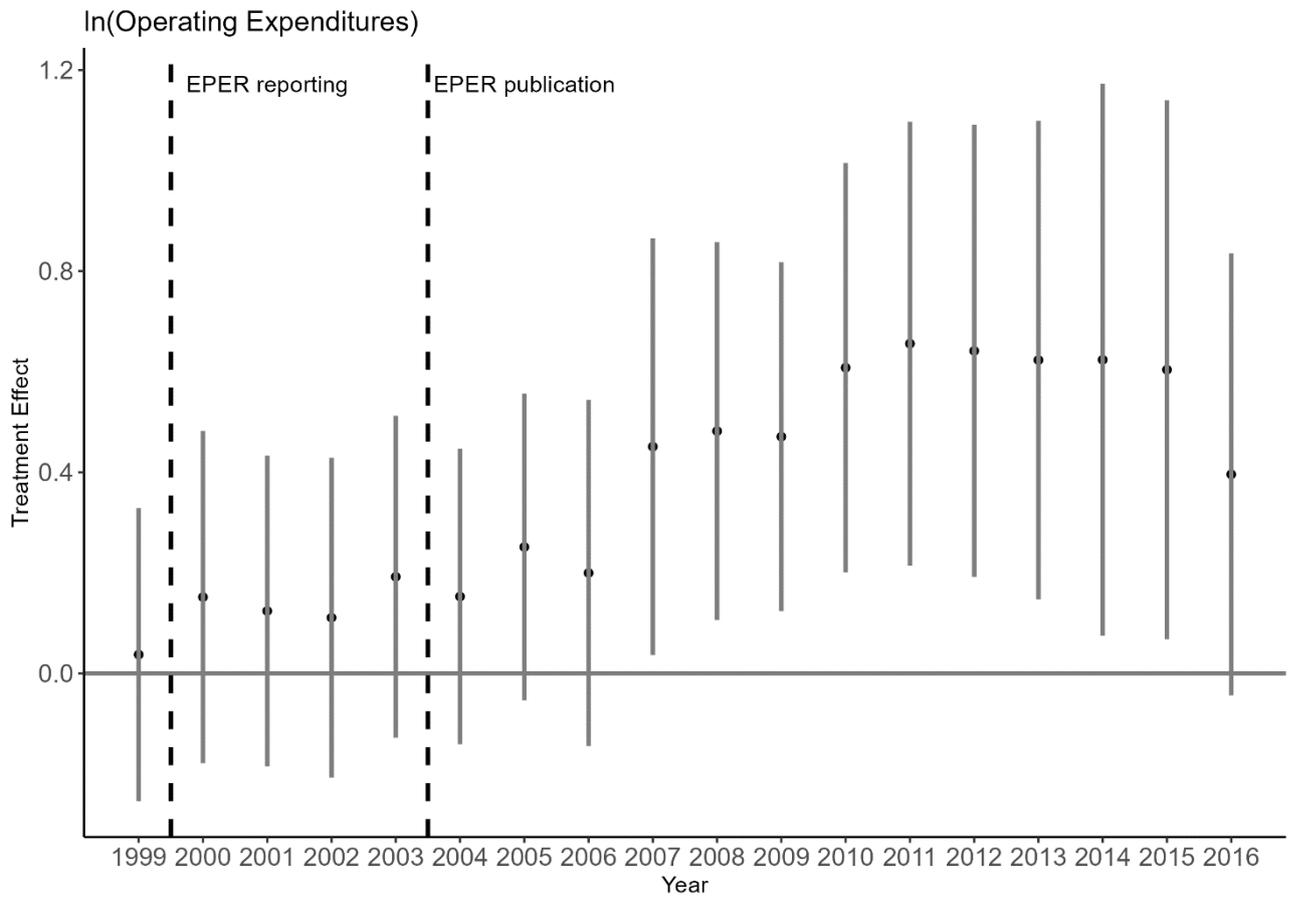
Figure 3

Event Study for Operating Revenues (logged)
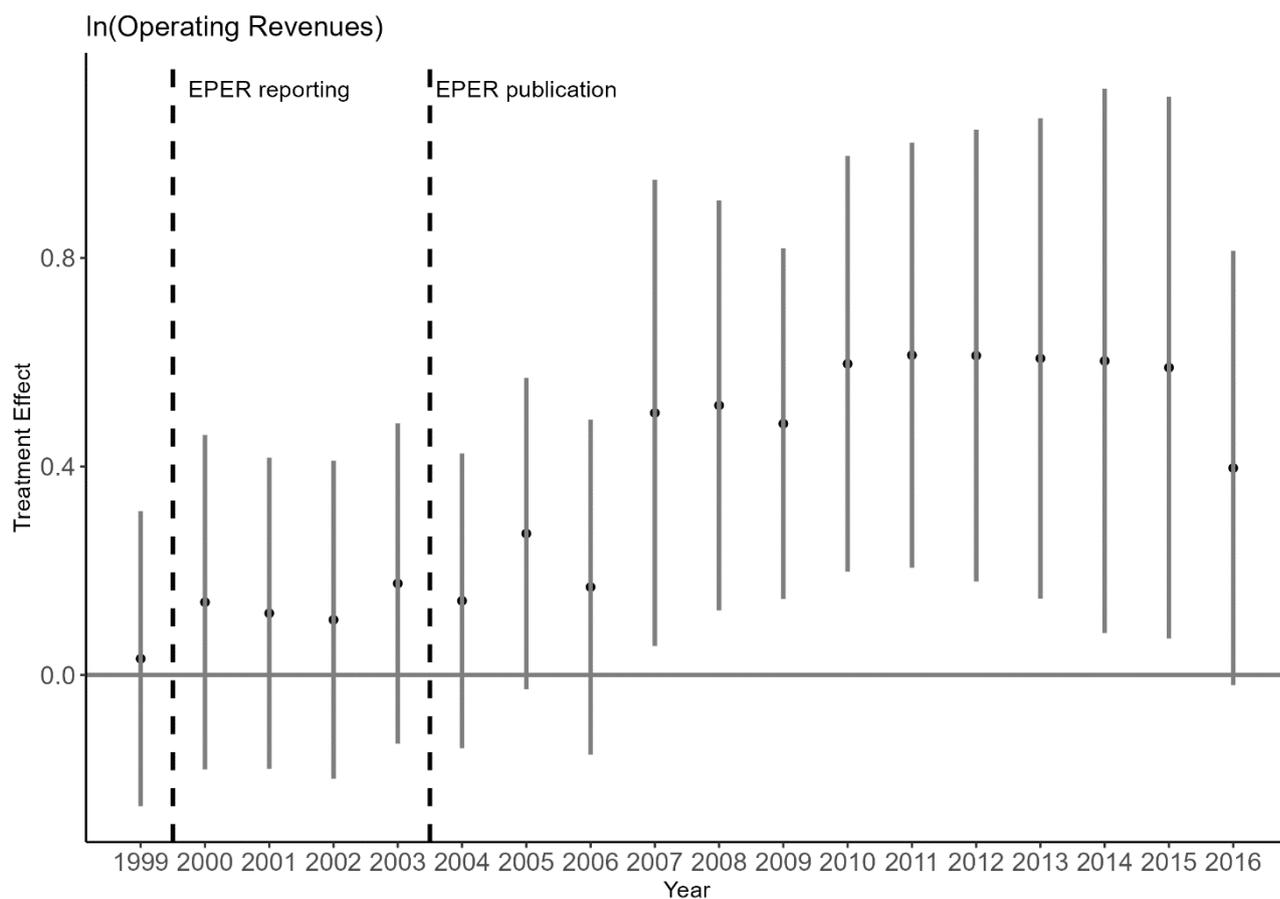
Notes:
The plots show year-specific treatment effects, i.e., point estimates and 95 % confidence
   intervals, based on interactions between the EPER treatment indicator and year
   dummies. The vertical dotted lines illustrate the start of the EPER treatment period,
   the first of the EPER reporting and the second the publication of the EPER database.
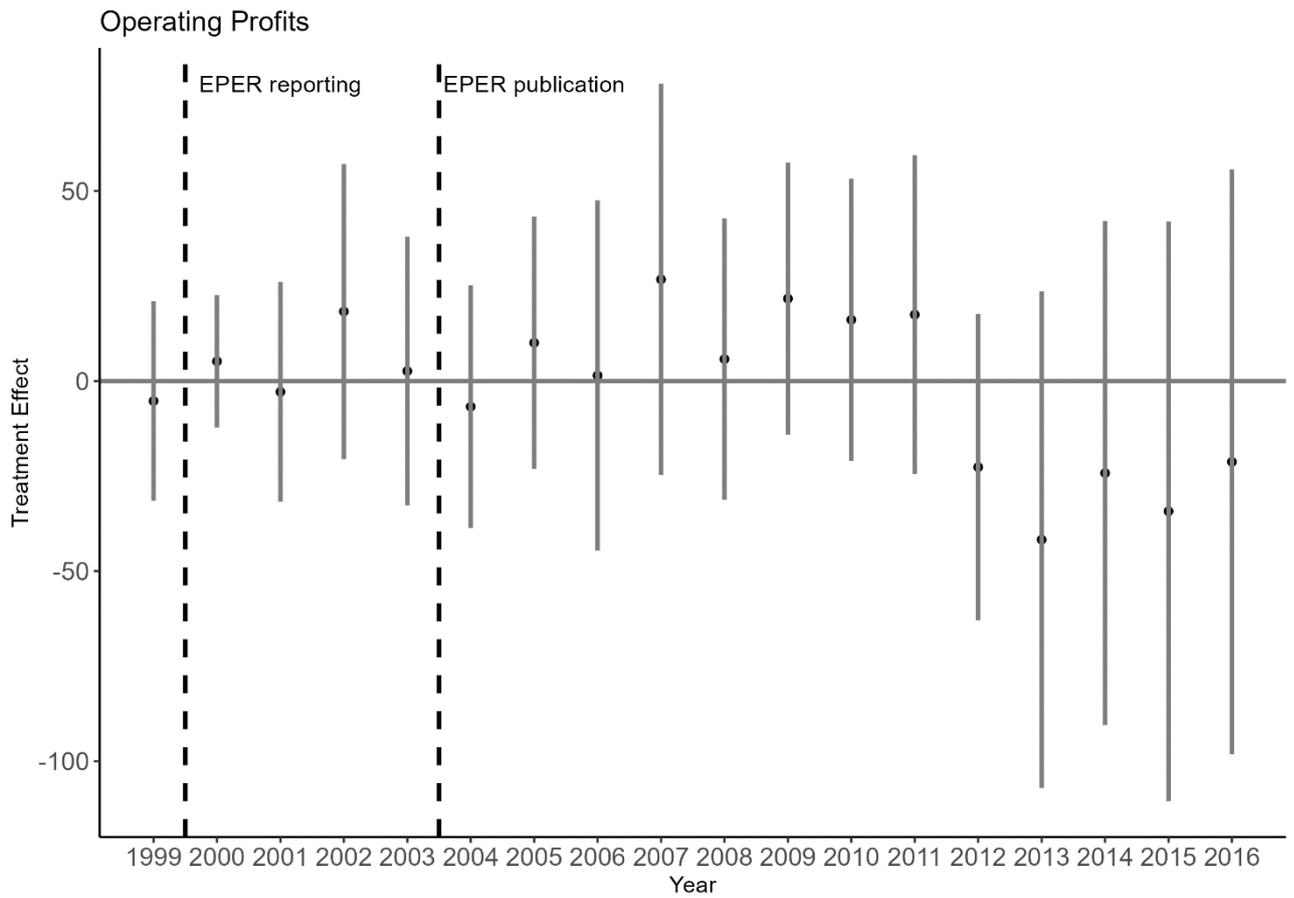
Figure 4

Event Study for Operating Expenditures (logged)

Figure 5

Event Study for Operating Profits

Notes:

The plots show year-specific treatment effects, i.e., point estimates and 95 % confidence intervals, based on interactions between the EPER treatment indicator and year dummies. The vertical dotted lines illustrate the start of the EPER treatment period, the first of the EPER reporting and the second the publication of the EPER database.

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Table 1

Estimation Results for the Main Specification:
Operating Revenues (logged), Operating Expenditures (logged), and Operating Profits

	Operating Revenues (logged)		Operating Expenditures (logged)		Operating Profits	
	All	Matched	All	Matched	All	Matched
Treatment Phase 1	0.041 (0.055)	0.119 (0.095)	0.086 (0.071)	0.126 (0.099)	-57.518 (105.598)	6.178 (9.454)
Treatment Phase 2	0.086 (0.067)	0.204* (0.121)	0.114 (0.083)	0.205 (0.126)	-0.944 (96.322)	8.646 (16.776)
Treatment Phase 3	0.047 (0.069)	0.508*** (0.173)	0.095 (0.084)	0.483*** (0.164)	22.520 (102.686)	20.520 (17.907)
Treatment Phase 4	-0.033 (0.076)	0.558*** (0.215)	0.004 (0.091)	0.576** (0.226)	93.157 (115.685)	-17.682 (29.010)
Observations	512,254	1,505	157,851	1,499	221,288	1,503
Adjusted R^2	0.97	0.92	0.97	0.91	0.71	0.78

Notes:
Significance levels: ***p<0.01, **p<0.05, *p<0.1.
Standard errors are clustered at the firm level.
All estimations include firm fixed effects and year fixed effects.
Data cover the period from 1998 to 2016.

Table 2

Estimation Results: Profitability

	Return on Equity		Return on Assets		Return on Sales	
	All	Matched	All	Matched	All	Matched
Treatment Phase 1	-6.834 (6.949)	21.133 (14.186)	-3.215* (1.642)	-0.840 (1.791)	-2.111 (1.996)	-1.465 (1.608)
Treatment Phase 2	0.1844 (7.048)	1.728 (9.999)	-2.014 (1.730)	0.386 (2.034)	-2.538 (2.110)	-0.007 (1.915)
Treatment Phase 3	-1.931 (7.237)	8.739 (12.149)	-2.602 (1.742)	2.275 (2.148)	-2.775 (2.097)	0.194 (1.990)
Treatment Phase 4	0.536 (7.051)	7.292 (9.500)	-3.926** (1.679)	-1.487 (1.971)	-4.248** (2.064)	-3.863 (2.429)
Observations	206,459	1,473	227,089	1,502	156,298	1,502
Adjusted R^2	0.47	0.35	0.53	0.49	0.55	0.49

Notes:
Significance levels: ***p<0.01, **p<0.05, *p<0.1.
Standard errors are clustered at the firm level.
All estimations include firm fixed effects and year fixed effects.
Data cover the period from 1998 to 2016.

Table 3

Estimation Results: Financial Investment Revenues (logged), Financial Investment Expenditures (logged), and Financial Investment Profits

	Financial Investment Revenues (logged)		Financial Investment Expenditures (logged)		Financial Investment Profits	
	All	Matched	All	Matched	All	Matched
Treatment Phase 1	0.209 (0.185)	0.418 (0.308)	0.038 (0.189)	0.103 (0.248)	-17.213 (25.122)	4.438 (3.004)
Treatment Phase 2	0.053 (0.229)	0.557 (0.511)	-0.007 (0.220)	0.489 (0.341)	16.671 (21.704)	24.050 (18.137)
Treatment Phase 3	-0.205 (0.226)	0.359 (0.417)	0.199 (0.224)	0.628* (0.372)	15.090 (30.766)	23.472 (14.456)
Treatment Phase 4	-0.254 (0.241)	0.382 (0.470)	0.548** (0.244)	0.961** (0.406)	35.553 (46.628)	32.907 (31.951)
Observations	207,090	1,438	218,202	1,428	228,582	1,501
Adjusted R^2	0.78	0.68	0.79	0.68	0.03	0.40

Notes:
Significance levels: ***$p<0.01$, **$p<0.05$, *$p<0.1$.
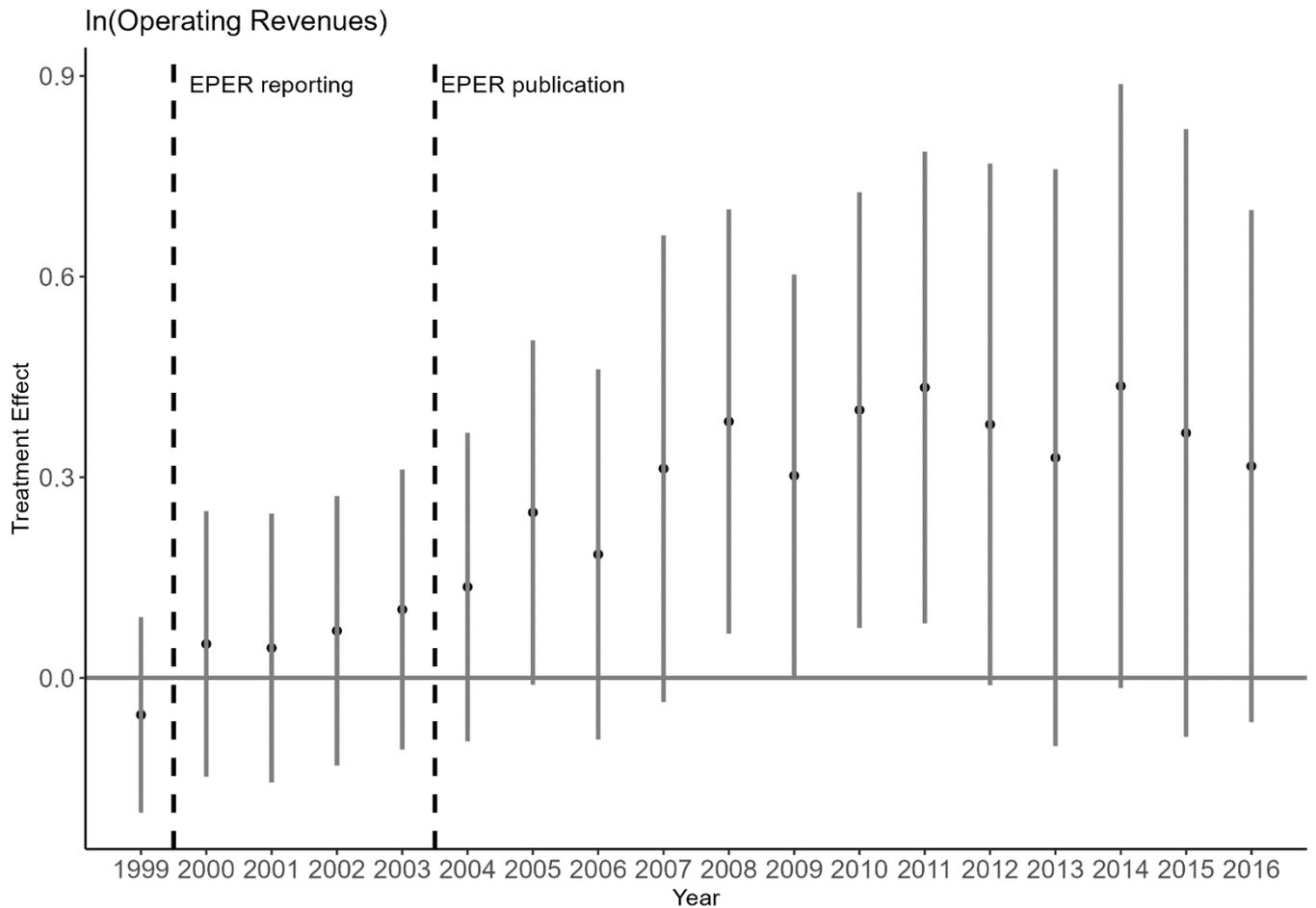Standard errors are clustered at the firm level.
All estimations include firm fixed effects and year fixed effects.
Data cover the period from 1998 to 2016.

APPENDIX FIGURES

Appendix Figure A1

Event Study for Operating Revenues (logged) for Rolling Treatment Definition
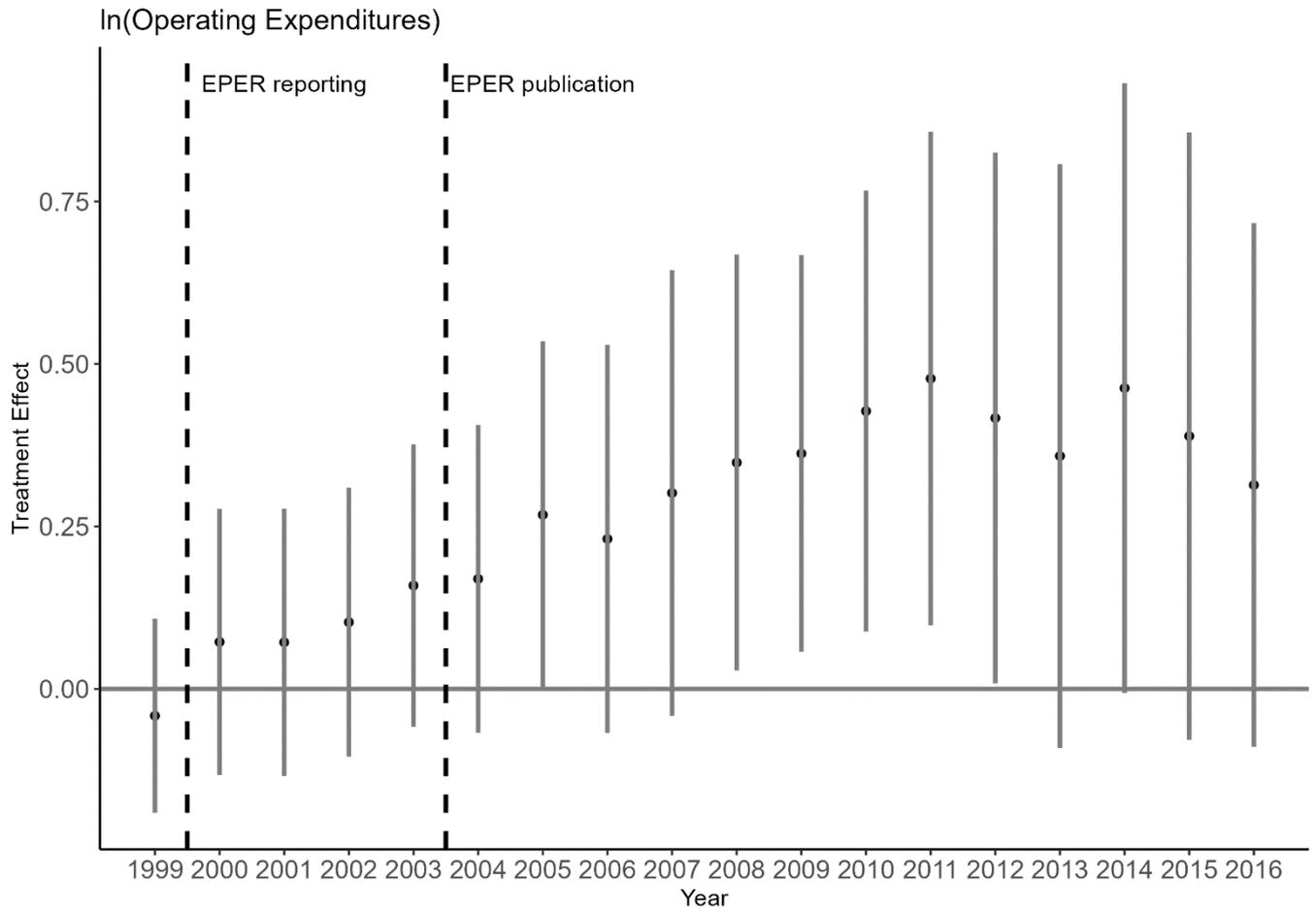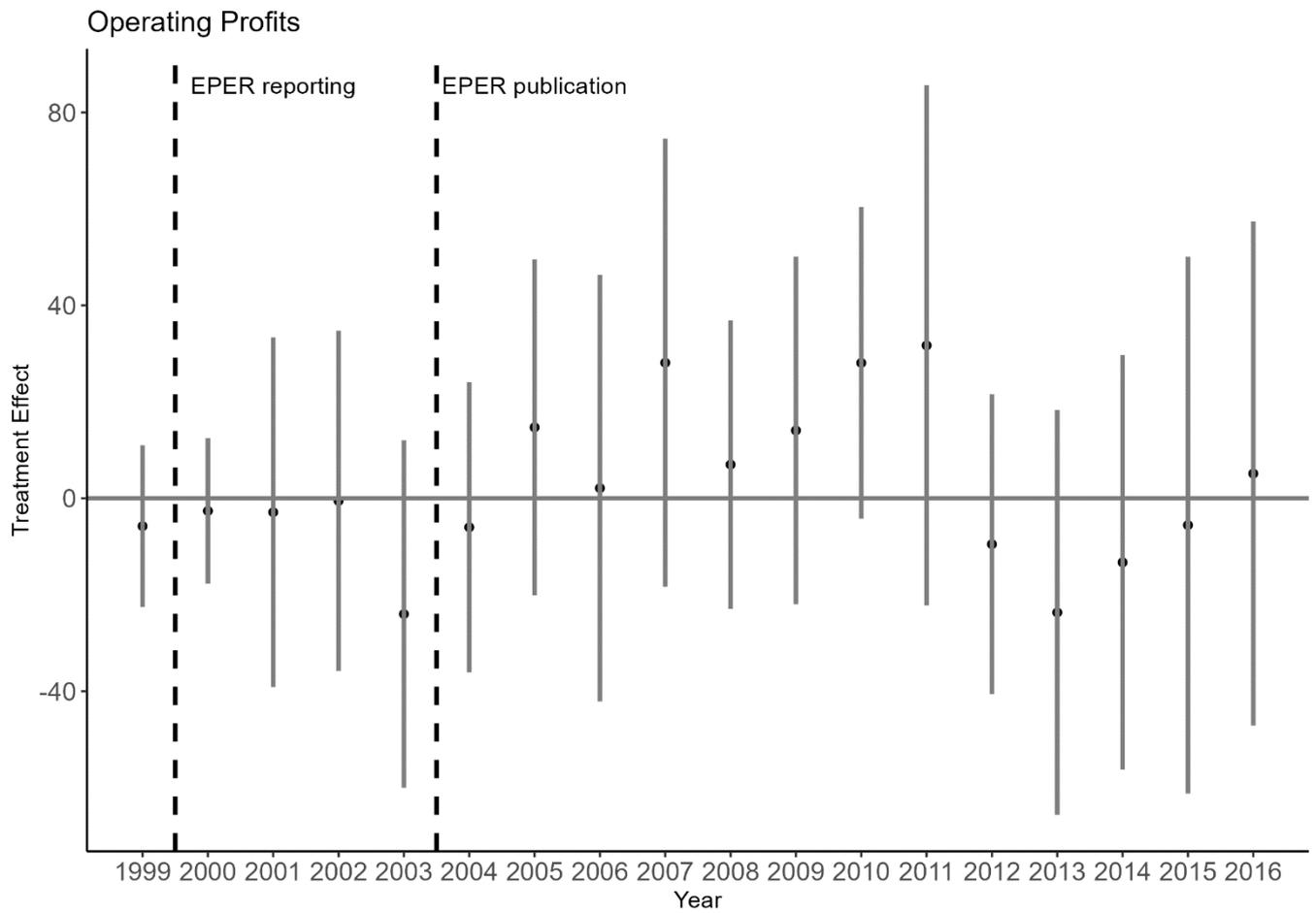

Notes:

The plots show year-specific treatment effects, i.e., point estimates and 95 % confidence intervals, based on interactions between the EPER treatment indicator and year dummies. The vertical dotted lines illustrate the start of the EPER treatment period, the first of the EPER reporting and the second the publication of the EPER database.

Appendix Figure A2

Event Study for Operating Expenditures (logged) for Rolling Treatment Definition

Notes:
The plots show year-specific treatment effects, i.e., point estimates and 95 % confidence intervals, based on interactions between the EPER treatment indicator and year dummies. The vertical dotted lines illustrate the start of the EPER treatment period, the first of the EPER reporting and the second the publication of the EPER database.

Appendix Figure A3

Event Study for Operating Profits for Rolling Treatment Definition

Notes:

The plots show year-specific treatment effects, i.e., point estimates and 95 % confidence intervals, based on interactions between the EPER treatment indicator and year dummies. The vertical dotted lines illustrate the start of the EPER treatment period, the first of the EPER reporting and the second the publication of the EPER database.

Appendix Table A1

**Estimation Results for Rolling Treatment Specification:
Operating Revenues (logged), Operating Expenditures (logged), and Operating Profits**

	Log (Operating Revenues)		Log (Operating Expenditures)		Operating Profits	
	All	Matched	All	Matched	All	Matched
Treatment Phase 1	0.076 (0.047)	0.108 (0.082)	0.104* (0.057)	0.133 (0.084)	28.446 (73.635)	-3.657 (11.364)
Treatment Phase 2	0.103* (0.056)	0.243** (0.122)	0.112* (0.067)	0.268** (0.130)	88.871 (77.758)	11.848 (17.821)
Treatment Phase 3	0.060 (0.059)	0.378** (0.147)	0.083 (0.069)	0.380** (0.149)	101.935 (85.972)	23.013 (14.413)
Treatment Phase 4	-0.013 (0.064)	0.407** (0.193)	-0.004 (0.075)	0.426** (0.202)	119.760 (86.286)	1.083 (20.689)
Observations	515,622	2,553	160,708	2,540	224,379	2,551
Adjusted R^2	0.97	0.92	0.97	0.92	0.68	0.77

Notes:
Significance levels: ***p<0.01, **p<0.05, *p<0.1.
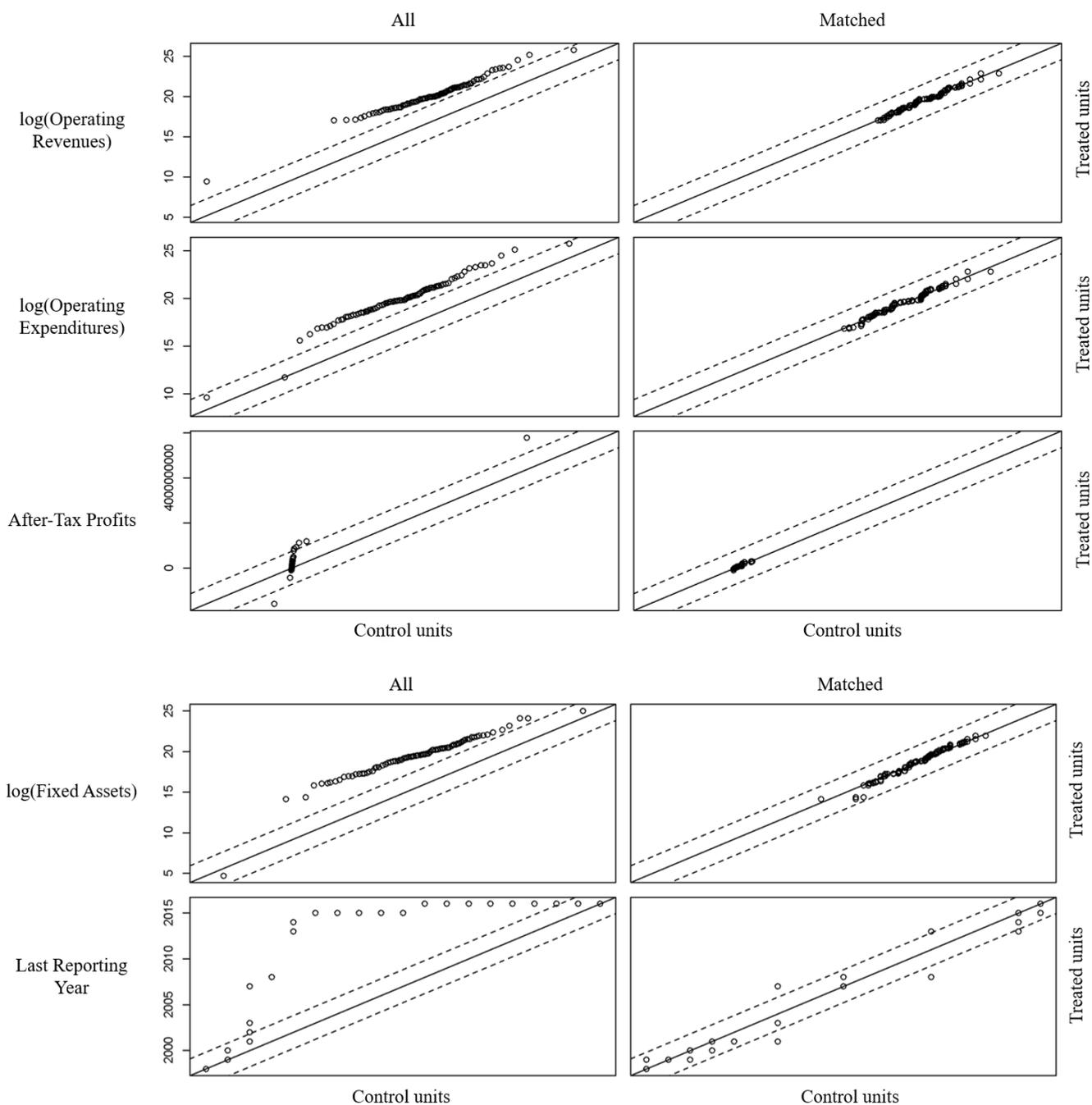Standard errors are clustered at the firm level.
All estimations include firm fixed effects and year fixed effects.
Data cover the period from 1998 to 2016.

Online Appendix Figure B1

QQ Plots for the Continuous Variables used in Matching:
Operating Revenues (logged), Operating Expenditures (logged), After-Tax Profits,
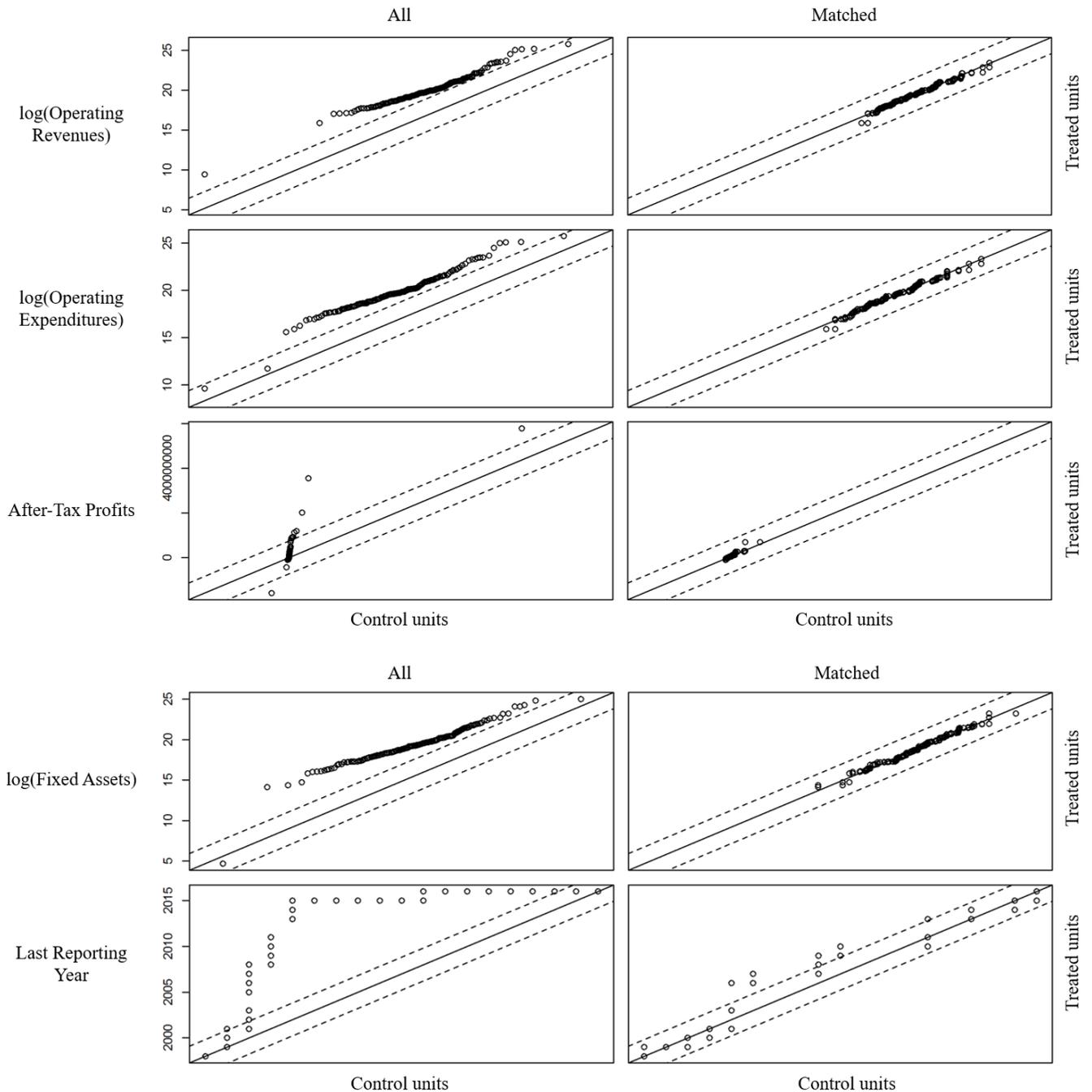**Fixed Assets, and Last Reporting Year**

Notes:

The QQ plots compare percentiles of the distribution of the variables in the treatment group
(Y-axis) and control group (X-axis).

The left panels show the full sample before matching (i.e., all companies) and the right panels
show the matched sample.

Online Appendix Figure B2

QQ Plots for the Continuous Variables used in Matching
for the Rolling Treatment Definition:
Operating Revenues (logged), Operating Expenditures (logged), After-Tax Profits,
Fixed Assets (logged) and Last Reporting Year

Notes:

The QQ plots compare percentiles of the distribution of the variables in the treatment group (Y-axis) and control group (X-axis).

The left panels show the full sample before matching (i.e., all companies) and the right panels show the matched sample.

APPENDICES

Appendix A: Theoretical Studies Using the Porter Hypothesis Lens

This appendix describes theoretical studies using the Porter Hypothesis lens to assess environmental policy effects on innovation and financial outcomes. The appendix distinguishes studies based on the reasons underlying the Porter effect – increased environmental regulation spurs innovation and eventually improves profitability, which mostly divide between market failures and organization failures.

Within the set of market failure studies, some studies examine market power. Simpson and Bradford (1996) explore the first mover advantage. André et al. (2009) examine imperfect competition and differentiated products; imposition of a minimum standard for environmental quality solves coordination problem across firms in a sector.

Other studies examine the market failure of asymmetric information between firms and consumers. Ambec and Barla (2007) explore vertically differentiated products based on environmental quality; regulation provides information to consumers. Rege (2000) examines the provision of trustworthy information on product quality.

Other studies explore the market failure of R&D spillovers. Mohr (2002) examines how each individual firm learns from other firms' experiences with new, more efficient, and cleaner technology. Each firm is reluctant to invest in R&D since experiences with new technology are publicly known by all firms. Regulation forces adoption of the new technology. Jaffe et al. (2005) examine knowledge spillovers from R&D. Xepapadeas and Zeeuw (1999) examine the positive impact of retirement of older vintage capital on productivity. Feichtinger et al. (2005) examine capital modernization and learning from others.

Another set of studies explore organizational failure, generally due to organizational inertia. Ambec and Barla (2002) examine the informational asymmetry between an owner and a manager, who possesses private information about the real costs of new technologies that enhance both productivity and environmental performance. Campbell (2003) examines asymmetric information between owner and manager and adoption of a rule of thumb for compensating the manager. DeCanio (1994) models firm inertia due to (1) asymmetrical consequences for failure and success and (2) asymmetrical information between upper management and lower management.

Other studies examine the role of behavioral forces. Behavioral studies demonstrate that mandatory information gathering and disclosure may help an owner overcome managerial inadequacies, such as risk-averse managers (Kennedy, 1994), present-biased managers (Ambec and Barla, 2006), and managers who are resistant to any costly change

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(Aghion et al., 1997; Ambec and Barla, 2007). Gabel and Sinclair-Desgagné (1998, 2001) use bounded rationality to explain inertia by emphasizing the importance of systems, procedures, and routines in the decision-making process.

Appendix B: Conceptual Framework

This appendix constructs fully a simple conceptual framework for understanding the impacts of information-based regulation on innovation decisions and financial outcomes, building on the framework of Blackman et al. (2004) and Powers et al. (2011).

B1. Base Conceptual Model

In our base model, a single person manages a single firm that operates a single facility in Germany. Thus, we initially remove any opportunity for the firm manager to glean insight by comparing across multiple facilities and ignore any divergence between upper and lower managers regarding environmental management. Our extended model explores these two dimensions.

B1.1. Set-Up

The firm employs capital equipment, K, and labor, L, to produce a quantity of output, Q. The firm sells its product at a price of P. The firm hires workers at a wage rate of W and obtains capital equipment at a financing cost of R. To simplify our analysis, we collapse the use of capital equipment and its acquisition through financing into a single dimension.[20] In the absence of information-based regulation, customers, workers, investors, and other stakeholders perceive the firm as identical to other firms. Once information-based regulation is introduced, stakeholders are able to differentiate across firms according to their environmental performance.

We assume that the firm produces a fixed quantity of output, Q, and employs a fixed quantity of inputs, K and L. Rather than exploring regulatory impacts on input and output quantities, we explore the impacts of information-based regulation on the output and input prices: P, W, and R.[21]

In the process of producing its product, the firm generates pollutant emissions, which erode ambient environmental quality. The firm can reduce the level of pollution by expending abatement effort, A. These abatement efforts entail costs, $C(A)$. Abatement costs rise in the extent of abatement at an increasing rate: $C'(A) > 0$ and $C''(A) > 0$.

Local community members derive welfare from local environmental quality. Pollution

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[20] We gain no meaningful additional insight by separating these two components.
[21] These modeling choices focus our framework on the firm's decisions about the extent of innovation and the level of pollution abatement. The former decision is consistent with our empirical analysis. We cannot empirically examine the latter decision since we lack abatement data for firms not required to report their pollutant releases and transfers under the E-PRTR policy.

undermines this quality; thus, greater abatement improves this quality. In order to induce greater abatement effort from the firm, local community members impose costs on the firm for insufficient abatement. For example, local community members can impose costs by issuing more restrictive zoning laws or road use policies. Put differently, local community members must issue to the firm a "social license to pollute" in order for the firm operate its facility within a local community (Gunningham et al., 2004). We denote the local community members willingness to issue this social license as M. Local community members are more willing to issue the firm's "social license to pollute" when abatement is higher: $M(A)$, where $M'(A) > 0$. As the local community's desire to issue the social license grows, local community pressure costs fall: $H(M)$, where $H'(M) < 0$.

The firm can also engage in innovation activities, I. These activities improve the productivity of abatement, labor, and capital equipment. To model these improvements, we allow innovation to reduce the cost of abatement, the effective price of labor, and the effective price of capital. To capture these relationships, we expand the abatement cost function, $C(A,I)$, and establish a wage rate function, $W(I)$, and a capital cost function, $R(I)$. As innovation rises, both total abatement costs and marginal abatement costs fall: $\partial C/\partial I > 0$ and $(\partial C/\partial A)/\partial I < 0$. As innovation rises, the effective wage rate falls, $\partial W/\partial I < 0$, and the effective capital cost falls, $\partial R/\partial I < 0$. We label these innovation activities as "process-based innovation".

Innovation activities also improve the quality of the product, which we label as "product-based innovation". This quality improvement raises the price that customers are willing to pay for the product. To capture this relationship, we establish a price function: $P(I)$, where $\partial P/\partial I > 0$.

Similar to abatement, labor, and capital costs, innovation may lower the costs imposed by local communities. Given this possible link, we expand the local community pressure function: $H(M,I)$. As innovation grows, local community costs falls: $\partial H/\partial I < 0$.[22,23]

We measure innovation activities in monetary terms, such as expenditures on R&D. Thus, the costs of innovation are simply I.

B1.2. Information-based Regulation

An information-based regulation requires the firm to monitor and measure its pollution and report these pollution measurements to the regulatory agency, who in turn disseminates this information to the public, including the firm's stakeholders: consumers,

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[22] We could alternatively model the community's willingness to issue the social license as a function of innovation: $M(A,I)$; this alternative approach generates hypotheses identical to those derived below.
[23] We doubt that innovation meaningfully influences the costs stemming from local community pressure; nevertheless, we retain this component for the sake of symmetry.

workers, investors, and members of the local community in which the firm operates its facility. We denote this information disclosure policy as D, where $D = 0$ indicates no regulation and $D = 1$ indicates imposition of the rule. We denote the firm's costs of monitoring and measuring emissions and processing this information as X. We assume reporting the information carries no additional costs.[24]

The requirement to monitor and measure emissions and process this information improves the firm's understanding of its own emissions, T. Thus, T depends positively on D: $T(D)$, where $\partial T/\partial D > 0$. As the firm's understanding grows, the costs of abatement fall. Thus, C depends negatively on T: $C(A,T)$, where $\partial C/\partial T < 0$. As important, *marginal* abatement costs depend negatively on T: $(\partial C/\partial A) / \partial T < 0$. By extension, improving the firm's understanding of their environmental performance lowers the cost of environmentally-related innovation.

Disclosure of the firm's emissions impacts the firm's stakeholders. Consumers' desire to buy the firm's product, G, depends on the firm's abatement level, A, and information disclosure, D: $G(A,D)$. The firm's abatement improves the quality of the product, assuming consumers care about the public good aspects of the firm's product (Kotchen, 2006), so consumers' desire depends positively on abatement: $\partial G/\partial A > 0$.[25] However, consumers do not possess complete information on the firm's abatement. Information disclosure on the firm's emissions expands the consumers' information set on abatement, thus, improving the consumers' confidence about their understanding of the firms' abatement level. Armed with greater confidence, consumers increase the desire to buy the firm's product when abatement lies above some threshold, $\hat{A}$, but decrease their desire to buy the firm's product when abatement falls below this same threshold, $\hat{A}$; i.e., disclosure prompts customers to reward firms that expend sufficient abatement but punish firms that expend insufficient abatement. Thus, $\partial G/\partial D > 0$ if $A \geq \hat{A}$ but $\partial G/\partial D < 0$ if $A < \hat{A}$.

As consumers' desire for the product, G, rises, the product price, P, increases: $P(I,G)$, where $\partial P/\partial G > 0$. Thus, the information disclosure rule *indirectly* increases the product price for a firm that expends sufficient abatement effort but decreases the product price for a firm that expends insufficient abatement effort.

The required disclosure of emissions information similarly impacts workers. Workers' desire to work for the firm, S, depends on the firm's abatement level, A, and information

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[24] The lack of treatment informs stakeholders that the firm's emissions fall below any threshold relevant for the stakeholders; this section identifies the relevant thresholds below.
[25] Technically, customers care about emissions; however, we model the firm's abatement choice; clearly, emissions and abatement represent two sides of the same coin given a fixed quantity of emissions under zero abatement, i.e., business-as-usual emissions.

disclosure, *D*: *S*(*A*,*D*). The firm's abatement improves the workers' non-pecuniary benefits of working for the firm so workers' desire depends positively on abatement: $\partial S/\partial A > 0$. Similar to consumers, workers do not possess complete information on the firm's abatement. Information disclosure on the firm's emissions expands the workers' information set on abatement, thus, improving the workers' confidence about their understanding of the firms' abatement level. Armed with greater confidence, workers increase their desire to work for the firm when abatement lies above the threshold of $\hat{A}$ but decrease their desire to work for the firm when abatement falls below this same threshold, $\hat{A}$. (To simplify our analysis, we assume that customers and workers consider the same abatement threshold; consideration of different threshold levels does not alter our hypotheses.) Thus, $\partial S/\partial D > 0$ if $A \geq \hat{A}$ but $\partial S/\partial D < 0$ if $A < \hat{A}$.

As workers' desire to work for the firm, *S*, rises, the wage rate, *W*, falls: *W*(*I*,*S*), where $\partial W/\partial S < 0$. Thus, the information disclosure rule *indirectly* decreases the marginal cost of labor for a firm that expends sufficient abatement effort but increases the marginal cost of labor for a firm that expends insufficient abatement effort.

The required information disclosure similarly impacts investors, who provide capital equipment financing. Investors' desire to finance the firm's capital equipment use, *V*, depends on the firm's abatement level, *A*, and information disclosure, *D*: *V*(*A*,*D*). The firm's abatement improves the (perceived) sustainability of the firm's operations, lowers the firm's exposure to environmentally related calamities, and/or offers non-pecuniary benefits to the investors (citations). Thus, investors' desire to finance the firm depends positively on abatement: $\partial V/\partial A > 0$. Similar to consumers and workers, investors do not possess complete information on the firm's abatement. Information disclosure on the firm's emissions improves the investors' confidence about their understanding of the firms' abatement level. Armed with greater confidence, investors increase their desire to finance the firm when abatement lies above the threshold $\hat{A}$ but decrease their desire to finance the firm when abatement falls below this same threshold of $\hat{A}$. Thus, $\partial V/\partial D > 0$ if $A \geq \hat{A}$ but $\partial V/\partial D < 0$ if $A < \hat{A}$.

As investors' desire to finance the firm, *V*, rises, the capital financing cost, *R*, falls: *R*(*I*,*V*), where $\partial R/\partial V < 0$. Thus, the information disclosure rule *indirectly* decreases the marginal cost of capital for a firm that expends sufficient abatement effort but increases the marginal cost of capital for a firm that expends insufficient abatement effort.

Lastly, the required information disclosure rule impacts local community members. Local members' desire to issue the social license to pollute, *M*, depends on information disclosure, *D*, as well as the firm's abatement level, *A*: *M*(*A*,*D*). Similar to consumers,

workers, and investors, local community members do not possess complete information on the firm's abatement. Information disclosure on the firm's emissions improves the community members' confidence about their understanding of the firms' abatement level. Armed with greater confidence, local members increase their desire to issue a license to the firm when abatement lies above threshold $\hat{A}$ but decrease their desire to issue this license when abatement falls below this same threshold. Thus, $\partial M/\partial D > 0$ if $A \geq \hat{A}$ but $\partial M/\partial D < 0$ if $A < \hat{A}$. As noted above, an increase in local community members' desire to issue the social license, M, prompts local pressure costs, H, to fall: $\partial H/\partial M < 0$. Thus, the information disclosure rule *indirectly* decreases local pressure costs for a firm that expends sufficient abatement effort but increases the local pressure costs for a firm that expends insufficient abatement effort.

Collectively, the firm's output price, P, labor input price, W, capital input price, R, and local community pressure costs, H, depend on both the firm's abatement level, A, and the information disclosure requirement, D.

B1.3. Firm's Choices over Abatement and Innovation

Next we assess the impact of the information disclosure requirement on the firm's two choice variables: level of abatement, A, and extent of innovation activities, I.

The information rule lowers the marginal cost of abatement, which clearly prompts more abatement. As important, the disclosure aspect of the information rule improves the marginal benefits of abatement. Specifically, these marginal benefits are greater when customers, workers, investors, and local members are more confident about their understanding of the firm's abatement efforts. Whether the firms' initial abatement level falls below or lies above the threshold level of $\hat{A}$, the firm increases its revenues and decreases its costs by expending greater abatement effort. (For example, imagine that customers' desire to buy the firm's product, G, depends linearly on A and D: $G = \theta A + \Phi D(A-\hat{A})$; the marginal effect of increased abatement on G is as follows: $\theta + \Phi D$.) On both counts, the information rule leads the firm to abate more. We identify the privately optimal level of abatement under the information disclosure rule as A^*.

Similarly, the information rule prompts the firm to innovate more. Internally, the required monitoring and measurement improves the firm's understanding of their environmental performance, which lowers the cost of innovation, prompting more innovation. Externally, the disclosure aspect of the information rule improves the marginal benefits of innovation, at least innovation that improves the productivity of abatement. The marginal benefits of innovation are greater when customers, workers, investors, and local

members are more confident about their understanding of the firm's abatement efforts.[26] We identify the privately optimal level of innovation under the information disclosure rule as I^*.

We note that the monitoring, measuring, and processing costs are fixed. Thus, they do not influence the firm's privately optimal levels of abatement and innovation. However, these costs clearly affect the financial outcomes, which we assess next.

B1.4. Firm's Financial Outcomes

Finally, we assess the impacts of the information-based regulation on financial outcomes, which depend directly on the information rule and indirectly via the firm's choices of abatement and innovation.

Revenues reflect the product of the firm's good output level, Q, and price, P. Assuming a fixed output quantity, revenues depend exclusively on the good price, P. The overall effect of the information rule on the price depends on countervailing forces. Increased abatement and expanded innovation unambiguously increase P. However, information disclosure ambiguously raises or lowers P depending on the chosen abatement level relative to the threshold $\hat{A}$. If A^* lies above $\hat{A}$, then information disclosure clearly increases the product price. If A^* falls below $\hat{A}$, then the information rule directly lowers the product price. However, if the price increase prompted by A^* and I^* *dominates* the price decrease prompted by an insufficient abatement effort (A^* falls below $\hat{A}$), the product price still rises. However, A* may lie below $\hat{A}$ so far that the information rule *overall* causes the product price to fall. *Hypothesis H1* captures this understanding:

> _Hypothesis H1_: The information rule increases the product price, P, if A^* lies above the threshold $\hat{A}$ or remains close enough to $\hat{A}$ that the impacts of increased abatement and innovation dominate (*Hypothesis H1a*); otherwise, the information rule decreases the product price, P (*Hypothesis H1b*).

Labor costs reflect the product of the labor level, L, and wage rate, W. Assuming a fixed labor quantity, labor costs depend exclusively on the wage, W. The overall effect of the information rule on the wage rate depends on countervailing forces. Increased abatement and expanded innovation unambiguously decrease W.[27] However, the direct effect of information disclosure ambiguously raises or lowers W depending on the chosen abatement level relative to the threshold $\hat{A}$. If A^* lies above $\hat{A}$, then information disclosure unambiguously decreases

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[26] Depending on the functional relationships linking innovation and stakeholders' desire to buy the firm's product, offer inputs, and issue a social license, the disclosure rule may also increase the marginal benefits of innovation that improves the productivity of labor and capital and lowers the cost of local community pressure. These additional benefits are not critical for deriving our hypotheses.

[27] We assume that innovation does not meaningfully raise the wage rate due to any increase in the marginal product of labor.

the wage rate. Even if $A*$ falls below $\hat{A}$, the information rule lowers the wage rate when the wage reduction prompted by greater abatement ($A*$) and innovation ($I*$) dominates the wage increase prompted by insufficient abatement effort ($A*$ falls below $\hat{A}$). However, $A*$ may fall below $\hat{A}$ so far that the information rule prompts the wage rate to rise.

Based on the same logic, we can demonstrate that capital costs, the product of the capital level, K (which is we assume is fixed), and the capital cost, R, may rise or fall in response to the information-based regulation.

A similar logic applies to local community pressure costs. If $A*$ lies above $\hat{A}$, then the information rule lowers local community pressure costs. However, once $A*$ falls below $\hat{A}$, the indirect effects of increased abatement and innovation must dominate; otherwise, the information rule leads to higher local community pressure costs.

The firm unambiguously increases its abatement effort, A. However, the information disclosure rule lowers abatement costs by increasing the firm's understanding of its emissions, T. And the rule prompts the firm to innovate more, which also lowers abatement costs. In general, overall abatement costs may increase or decrease. We assume that the increase in abatement efforts dominate so that total abatement costs, C, rise.[28]

The firm's total costs (TC) reflect the sum of labor costs, capital costs, abatement costs, local community pressure costs, innovation costs, and emission monitoring/processing costs:

$$TC = \{W[S(A*,D),I*]\times L\} + \{R[V(A*,D),I]\times K\} + C(A*,I*,T) + H[M(A,D)] + I* + X. \quad (A1)$$

Clearly, the information disclosure rule raises costs by (1) requiring the firm to monitor and measure emissions and process this information, (2) prompting greater innovation costs, and (3) leading to higher abatement costs. However, the information rule may raise or lower labor costs, capital costs, and local community pressure costs depending on the relative importance of the direct impacts and indirect impacts stemming from the increased abatement efforts and innovation activities and the greater abatement effort, $A*$, relative to the threshold abatement level of $\hat{A}$. *Hypothesis H2* captures this ambiguity:

> *Hypothesis H2*: The information rule decreases total costs, *TC*, if $A*$ lies sufficiently above the threshold $\hat{A}$ so that the rule's direct negative impacts on input costs and local community pressure costs dominate (*Hypothesis H2a*); otherwise, the information rule increases total costs because the increases in abatement costs, innovation costs, and monitoring/processing costs dominate (*Hypothesis H2b*).

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[28] This assumption is not critical; it merely helps us to focus on more meaningfully ambiguous effects.

Finally, we assess the impact of the information rule on profits, Π, which represent the difference between revenues, and costs:

$$\Pi = \{P[G(A,D),I] \times Q\} - TC. \tag{A2}$$

Clearly, the rule's impact on profits is ambiguous since the rule's impacts on revenues and total costs are ambiguous. *Hypothesis H3* captures this ambiguity:

> *Hypothesis H3*: The information-based regulation increases profits, Π, if (a) revenues rise and total costs fall, (b) both revenues and total costs rise yet the increase in revenues <u>dominates</u> the increase in total costs, or (c) both revenues and total costs fall yet the decrease in revenues is <u>dominated by</u> the decrease in total costs (*Hypothesis H3a*); otherwise, the regulation lowers profits (*Hypothesis H3b*).

B2. Simplified Models and Porter Effects

Our base model captures two forces unleashed by the information rule. Within the firm, the process of monitoring and measuring its emissions allows the firm to understand better its environmental management system, prompting the firm to innovate more and abate more. This internal force unambiguously lowers labor costs, capital costs, and local community pressure costs. However, this same force increases abatement costs, innovation costs, and emission monitoring and information processing costs. Thus, overall costs may fall or rise. In contrast, the identified internal force unambiguously increases revenues. Consequently, without any additional understanding, we cannot determine whether the internal force increases or reduces profits. This said, presumably the firm increases abatement and innovation in order to increase profits. If the monitoring and processing costs are negligible, then the increases in abatement and innovation must improve profitability. Of course, if the monitoring and processing costs are sufficiently substantial, increased abatement and innovation may not sufficiently raise profits in order to improve profitability overall. *Hypothesis H4* captures this relationship:

> *Hypothesis H4*: In the absence of any increased scrutiny by external stakeholders, the information rule increases profits as long as the monitoring, measuring, and processing costs are negligible (*Hypothesis H4a*); if the emission information-related costs are sufficiently substantial, these costs outweigh the benefits of the profit-improving abatement and innovation steps, leading to weaker profits (*Hypothesis H4b*).

Based on theoretical research on the Porter Hypothesis, which we review in sub-section 2.2.1, organizational failure may disrupt the firm's ability to identify all profit-maximizing actions prior to imposition of the information rule. In particular, the firm may not

optimally exploit opportunities to conduct internal audits. In this case, the information rule may improve profits even when the monitoring, measuring, and processing costs are non-negligible. Consequently, we modify *Hypothesis H4a*:

> _Hypothesis H4a_: The information rule increases profits as long as the monitoring, measuring, and processing costs are negligible or organizational failure sufficiently disrupts the firm's ability to exploit opportunities to conduct voluntary internal audits prior to the information rule.

Similarly, we can focus on the external forces, ignoring the internal force. In general, the information rule ambiguously impacts revenues, total costs, and profits. However, based on theoretical research on the Porter Hypothesis, asymmetric information between firms and customers, as well as other stakeholders, may disrupt the firm's ability to identify all profit-maximizing actions prior to imposition of the information rule. In particular, the firm may not optimally exploit opportunities to raise revenues and lower input costs by expanding abatement effort. By design, the information rule mitigates any information asymmetry. This mitigation increases the likelihood of the information rule improving financial outcomes, as reflected in *Hypothesis H5*:

> _Hypothesis H5:_ Relative to the case of symmetric information between the firm and stakeholders, under asymmetric information, the information rule prompts a firm:

(a) to enjoy a stronger increase in its revenues or bear a weaker decrease in its revenues;

(b) to enjoy a stronger reduction in its total costs or bear a weaker increase in its total costs;

(c) to enjoy a stronger increase in its profits or bear a weaker decrease in its profits.

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