Working Paper 14/2014

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The CREE Centre acknowledges financial support from The Research Council of Norway, University of Oslo and user partners.
ISBN: 978-82-7988-184-1
ISSN: 1892-9680
http://www.cree.uio.no

The impacts of alternative policy instruments on environmental performance: A firm level study of temporary and persistent effects

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Keywords: emission intensity, environmental performance, environmental regulation, command-and-control, environmental taxes, long-term effects

Abstract

We study the effects of various environmental regulations on environmental performance measured as emission intensity. Moreover, we aim to test whether any such effects are persistent or only temporary. Conventional theory predicts that indirect regulations as opposed to direct regulations provide continuous dynamic incentives for emission reductions. Our unique Norwegian firm level panel data set allow us to identify effects from different types of regulations such as environmental taxes, non-tradable emission quotas and technology standards. The data includes information of different environmental regulations, all kinds of polluting emissions, and a large number of control variables for all polluting incorporated firms. Empirically we identify positive and significant effects from both direct and indirect policy instruments. We also investigate whether the regulations provide continuous dynamic incentives that lead to persistent effects. In contrast to what the literature suggests, we find evidence that direct regulations promote persistent effects. Indirect regulations will, on the other hand, only have potential persistent effects if environmental taxes are increasing over time.

We are grateful to Arvid Raknerud for many valuable suggestions and comments. Thanks also to Terje Skjerpen, Diana Iancu, Cathrine Hagem, Reyer Gerlagh, and participants at the 5th WCERE Congress in Istanbul and the 4th CREE workshop at Lysebu. Øyvind Hetland at the Norwegian Environment Agency has given us access to data and provided helpful information. While carrying out this research, the authors have been associated with CREE - Oslo Centre for Research on Environmentally friendly Energy. The CREE Centre acknowledges financial support from The Research Council of Norway, University of Oslo and user partners.

1 Introduction

Environmental regulations are used to internalize external costs stemming from various forms of pollution. To be effective, such regulations must alter the costs of production (Lucas *et al.*, 1992). Regulatory costs can create an incentive to reduce the production activity level, make the production process less polluting by purchasing or developing more efficient technology, or substituting dirty input factors with cleaner alternatives.

During the last decades, environmental concerns have gained increased attention in both developing and developed economies. Different kinds of environmental regulations have been introduced in order to curb pollution emissions to air, soil and water. The regulations have been many-sided ranging from strict direct pollution regulations (command-and-control) as technology standards and non-tradable emission quotas, to indirect (incentive-based) regulations such as environmental taxes and tradable emission quotas.[1]

Conventional economic theory predicts two main advantages of indirect regulations over direct regulations. First of all, indirect policy instruments provide the more cost-efficient emission reductions[2] (Stavins, 2001; Tietenberg, 1990; Newell and Stavins, 2003; Perman *et al.*, 2011; Keohane *et al.*, 1998, Maloney and Yandle, 1984). Numerical simulation experiments confirm that the costs of direct regulations may be considerable (Perman *et al.*, 2011) although this is not confirmed by empirical studies (Cole and Grossman, 1999). Secondly, the literature predicts that indirect regulations promote "continuous dynamic incentives" by providing permanent incentives for reducing emissions through technological improvement, in contrast to direct regulation (Jaffe and Stavins, 1995; OECD, 2001; Perman *et al.*, 2011). A firm facing indirect regulations such as tradable quotas or an emission tax will generate dynamic gains through responses over time to its incentives if the taxes remain constant or increase over time. The incentive structure will stimulate continuous environmental technological improvements. On the other hand, direct regulations may be characterized by a binary switch, as the required target is reached, but the literature suggests that there are no incentives for further technological improvements.

Other studies illustrate how the dualistic categorization of instruments as incentive-based or command-and-control is misleading (see e.g., Bohm and Russel, 1985). Although we find no studies that empirically investigate the persistent effects of regula-

[1] Heine *et al.* (2012) is a recent contribution that summarizes principles and practices of environmental tax reforms that also includes administrative and direct regulations.

[2] For a flow pollutant or a uniform-mixed stock pollutant, Perman *et al.* (2011).

tions on environmental performance, some studies state that the differences between these types of instruments are typically over-emphasized (Cole and Grossman, 1999) as there are several incentives arising from direct forms of regulations that are not fundamentally different from those arising from taxes and tradable quotas. This is also evident from empirical analyzes, see e.g., Cole *et al.* (2005) and Féres and Reynaud (2012). Studies typically focus on the evaluation criteria *economic efficiency* (a policy's aggregate net benefits) and *cost-effectiveness* (Goulder and Parry, 2008). No single policy instrument ranks first along all the dimensions of policy comparison (Palmer, 1980; Goulder and Parry, 2008; Perman *et al.*, 2011; Wiener, 1999). A natural but quite unexplored criterion is environmental performance, measured as an emission intensity.

In this paper we analyze the effects of alternative policy instruments on environmental performance, measured as an emission intensity, and especially investigate whether we can empirically identify significant differences between the effects of direct and indirect regulations on environmental performance, using a firm level data set. In particular, we test the notion from literature that indirect regulations promote "continuous dynamic incentives" that lead to persistent effects on emissions through technological improvement, in contrast to direct regulations. Our unique firm-level data set allows us to analyze the effects from different types of regulations such as environmental taxes, non-tradable emission quotas and technology standards. We investigate whether any of these regulations promote continuous dynamic incentives (leading to persistent effects) through an asymmetry test with regard to the firms' responses to stricter versus more lax regulations.

Our extensive Norwegian firm level panel data set over the years 1993-2012 includes information about different types of environmental regulations, the total range of Norwegian firms' land based pollutant emissions (more than 260 different pollutants), and a large number of control variables including key economic variables for all polluting Norwegian incorporated firms. We use the detailed emissions data in combination with weighted damage cost estimates of the emissions from the Shadow Prices Handbook (de Bruin *et al.*, 2010)[3] and Norwegian damage estimates whenever these exist (Håndbok

[3] The Shadow Prices handbook (de Bruin *et al.*, 2010) is developed by CE Delft, an independent research and consultancy organization. The Handbook is available at the homepage of CE Delft. We use the damage estimates for a large share of the several hundred substances listed in Tables 50 (Damage costs for emissions to air) and 52 (Damage costs for emissions to water) in the Annexes of this report. The damage costs for emissions to air are obtained using NEEDS damage costs. The NEEDS project is an ExternErelated European study on the external costs of energy use, completed in 2008. The damage costs for emissions to water are obtained using direct valuation of ReCiPe endpoint characterization factors. Since this method is a less reliable method than using NEEDS damage costs, damage estimates to water are only approximate.

V712, 2006; Rosendahl, 2000), to calculate monetary estimates of the emission damages. These monetary estimates allow us to include and compare the whole range of emissions such as heavy metals, particulates, acidification and ozone precursors, and green house gases. The pollutants cause different types of damages, ranging from cancer risks or loss of fertility to global warming. We use these monetary estimates of costs of emissions to measure environmental performance. We are thus able to conduct a study of the effects of various environmental regulations on a measure of environmental performance that includes all types of emissions. Including all types of emissions is particularly vital in a study of direct regulations, as emissions other than green house gases are still often regulated through technology standards and non-tradable emission quotas. Our firm-level panel data set also contains information about different types of environmental regulations as tradable and non-tradable emission quotas, technology restrictions and environmental taxes.

We contribute to the existing literature in three ways. Firstly, the large scale of different types of emissions in our data enables us to perform a comprehensive study of the effects of the various environmental policy instruments that has been used. Secondly, our data allow us to test an important assumption from literature (untested at the firm level), namely that only indirect regulations provide continuous dynamic incentives for emission reductions leading to persistent effects. Thirdly, we include a large set of control variables that are likely to influence the environmental performance. We control for economic effects as scale effects (size measured by the number of employees), technology effects (capital intensity measured as capital stock divided with the number of employees), and for whether the firm is included in the European Union Emission Trading System (EU ETS). The only study we find that analyzes effects of regulations on environmental performance, Féres and Reynaud (2012), analyze the impact of formal regulations (direct) and informal (community pressure, etc.) regulations on environmental and economic performance of a regional group of Brazilian manufacturing firms, but their formal regulations do not include what we denote as indirect regulations.

In line with Cole *et al.* (2005) and Féres and Reynaud (2012) – among others, we identify a positive and significant effect of non-tradable emission quotas and technology standards on environmental performance. Moreover, we find positive and significant effects of environmental taxes proxied as the relative price between dirty intermediary inputs and clean energy inputs. We also find evidence that direct regulations promote continuous dynamic incentives that lead to persistent effects, in contrast to what is suggested by the literature (Jaffe and Stavins, 1995; OECD, 2001; Perman *et al.*, 2011). Our results indicate that the dualistic categorization of the instruments as either "incentive-based" or "command-and-control" is overly simplistic, and that the notion from literature that only indirect regulations promote continuous dynamic incentives does not hold, as we identify persistent effects from direct regulations. Indirect regulations will, on the other hand, only have potential persistent effects if environmental taxes are increasing over time.

The rest of the paper is organized as follows. A theoretical motivation for our econometric model is presented in Section 2. Section 3 contains a description of the data, while the econometric model and results are presented in Section 4. Finally, Section 5 concludes and suggests some policy implications.

2 A production function with clean and dirty inputs

In order to identify effects of the different regulations on environmental performance, we need a flexible production function. Polluting emissions are (mostly) related to input of materials for the production processes and use of dirty energy. Therefore, we specify a production function that includes clean and dirty inputs. Whereas labor L, capital K and renewable energy are examples of clean inputs, oil products and dirty materials, as choke and coal are examples of dirty inputs. Assume that we have two types of *intermediary* inputs; clean inputs, Z_1, and dirty inputs, Z_2, which are imperfect substitutes, and that the production function is separable in (Z_1,Z_2) and (L,K) as follows:

$$Q_{it} = f\left(K_{it}, L_{it}, \left[Z_{1it}^{\delta} + (b_{2it}Z_{2it})^{\delta}\right]^{\frac{1}{\delta}}\right), \tag{1}$$

where Q_{it} is output, and total intermediary input is a Constant Elasticity of Substitution (CES) aggregate of Z_1 and Z_2, where Z_1 is the numeraire input (with $b_{1it} = 1$) and the parameter b_{2it} determines the efficiency of input factor 2 (dirty intermediary inputs) relative to factor 1 (clean intermediary inputs). The elasticity of substitution between Z_1 and Z_2 is $\rho = {}^{1}/_{(1-\delta)}$. Cost-minimization, with respect to Z_1 and Z_2 given firm-specific prices on input factor k, P_{kit}, means solving the problem

$$\begin{gathered}\min\nolimits_{Z_{kit}} P_{1it}Z_{1it} + P_{2it}Z_{2it} \text{ s.t.} \\ \left[Z_{1it}^{\delta} + (b_{2it}Z_{2it})^{\delta}\right]^{\frac{1}{\delta}} = y,\end{gathered} \tag{2}$$

where y denotes the intermediate aggregate. This has the well-known solution

$$Z_{kit} = yb_{kit}^{\rho}\left(\frac{P_{kit}}{P}\right)^{-\rho}, \; k = 1, 2 \tag{3}$$

where P is the price index of the intermediate aggregate:

$$P = \left[\sum_{k=1}^{2}\left(\frac{P_{kit}}{b_{kit}}\right)^{\gamma}\right]^{\frac{1}{\gamma}} \text{ with } \gamma = \frac{\delta}{\delta - 1}. \tag{4}$$

The relative demand between input of dirty and clean intermediates is given by

$$\ln Z_{2it} - \ln Z_{1it} = \rho \ln b_{2it} - \rho \ln \frac{P_{2it}}{P_{1it}}. \tag{5}$$

We assume that total damage costs of emissions from the use of dirty input is given by

$$D_{it} = \sum_{n} a_{nt}\lambda_{nit}Z_{2it} \equiv \kappa_{it}Z_{2it}, \tag{6}$$

where a_{nt} is the unit price (in Euros) of damage from emissions of component n and λ_{nit} is the emissions (in physical units) of component n from the use of one unit of dirty input Z_2 in firm i at time t. This implies that there is a linear relationship between emissions from dirty inputs and the total damage costs. We can interpret κ_{it} as the emission coefficient from the use of dirty input Z_2, at time t measured as damage costs. Inserting equation (6) into equation (5) and taking logarithms gives the following equation for the damage costs of emissions from firm i at time t relative to the use of clean input, Z_1:

$$\ln D_{it} - \ln Z_{1it} = \ln \kappa_{it} + \ln Z_{2it} - \ln Z_{1it} \Leftrightarrow$$

$$\ln \frac{D_{it}}{Z_{1it}} = g_{it} - \rho \ln \frac{P_{2it}}{P_{1it}}, \tag{7}$$

where $g_{it} = \ln \kappa_{it} + \rho \ln (b_{2it})$ which will be represented in terms of observed and unobserved variables to be specified in Sections 3 and 4. The left hand side of equation (7) is the damage costs from dirty input relative to the use of clean input (clean energy input).

We choose this measure of emission intensity as our measure of environmental performance. Usually an emission intensity is measured as emissions in physical units divided by the use of the corresponding dirty input, while environmental performance often is measured as emissions divided by income or production level, as in the literature of Environmental Kuznets Curves[4]. Unfortunately, the physical emission intensity is applicable to the very few factors where we can observe both physical input and emissions, while emissions divided by deflated operating income will include substitution-, scale- and technology effects, as well as revenue components that often are volatile. By defining environmental performance as in equation (7) we are able to control for all these effects. Our measure of clean intermediary input (the numeraire) is electricity, which until recently mostly has been supplied by hydroelectricity in Norway, for more details see Section 3. From equation (7) we see that environmental performance is a function of the relative price between dirty intermediary input and clean intermediary input, P_{2it}/P_{1it}, the elasticity of substitution, ρ, and firm specific effects, g_{it}, that will be specified in Sections 3 and 4. It may not be random to the firm what kind of regulations that are implemented by the authorities. This may cause an endogeneity problem. In order to identify causal effects we differentiate equation (7) to remove firm fixed effects and unit roots. We later show that both $\ln\left(D_{it}/Z_{1it}\right)$ and $\ln\left(P_{2it}/P_{1it}\right)$ are highly non-stationary time series (at the aggregate level). Hence, differentiation is necessary to remove stochastic (unit root) and linear trends in both the dependent and explanatory variables. Our econometric model in Section 4 is based on the differentiated version of equation (7):

$$\triangle \ln \frac{D_{it}}{Z_{1it}} = \triangle g_{it} - \rho \triangle \ln \frac{P_{2it}}{P_{1it}} \tag{8}$$

3 Data sources and description of variables

We have obtained our firm-level panel data from several data sources. All data sets are merged using organizational number as the firm identifier. The data span 20 years, from 1993 to 2012. A key data set comprises the data from the Norwegian Environment Agency (in the following referred to as NEA) on annual emissions of more than 260

[4] As the economies have become richer support has been found for the existence of an Environmental Kuznets Curve (EKC) which implies an inverse u-shaped relationship between emissions (even for green house gas emissions, Cole et.al., 2005) and country income (GDP), Andreoni and Levinson (2001). There are different hypotheses for the existence of an EKC, but it is reasonable to believe that the growing environmental political concerns toward regulating polluting emissions have contributed to this inverse u-shape. The contributions to this u-shaped curve can be decomposed into substitution effects, technology effects, scale effects etc (Bruvoll and Medin, 2003; Bruvoll et al., 2003; Bruvoll and Larsen, 2004).

different pollutants emitted to air and water, emission permits, assigned risk classes, inspections and violations from inspections of all land-based Norwegian firms that have emission permits from the NEA. We use this data set as the basis for our sample selection, as emissions are only reported for these firms. All together, this leaves us with 741 firms and 7209 firm-year observations.

The data above are supplemented with annual data from three different registers at Statistics Norway: The Accounts statistics, the Environmental Accounts and the National Accounts. Hence, our data set also includes firm level economic variables, prices of electricity and fossil fuels (that includes energy- and environmental taxes), electricity and fossil fuel use measured in kWh, and tradable carbon emission quotas. A detailed description of the key variables is provided below, where they are grouped into three main categories: i) Energy and emissions, ii) environmental regulations and iii) control variables. These data allow us to include several control variables at the firm level.

3.1 Energy and Emissions

Our dataset from NEA includes emissions of various pollutants ranging from heavy metals to green house gases. The emissions are measured in a wide range of physical units and cause different types of damages ranging from cancer risks or loss of fertility to global warming. To study the empirical effects of different environmental policies on environmental performance, we need to transform the emissions data to a common measurement scale. We use shadow prices of damages for each kind of emission to calculate total damages in terms of monetary damage costs (Håndbok V712, 2006; Rosendahl, 2000; de Bruin *et al.*, 2010). Shadow prices are constructed prices for goods or production factors that are not traded in markets. Measuring shadow prices of polluting emission is challenging in several ways. Firstly, it requires sophisticated methodology and in-depth knowledge about chemical compounds, as well as the recipients of the environment. Secondly, it requires simplifying assumptions, that must be transparent and discussed thoroughly. Moreover, there are several examples of studies who do not rely on expert comparisons of damages of various chemical compounds, but rather involve measures with the naive assumption that one unit of any compound causes the same damage (!) (Lucas *et al.*, 1992). Obviously, chemical compounds are different: An emission of a kilo of hazardous mercury and a kilo of CO_2 cause very different types and degrees of damages.

There is no comprehensive study of damage costs of Norwegian emissions, but by collecting damage estimates from different sources (Håndbok V712, 2006; Rosendahl, 2000), we are able to establish data for Norwegian damage costs of many of the emissions. In addition, we use damage costs estimates evaluated at shadow prices reflecting marginal damage of the firm's annual emissions constructed in de Bruin *et al.* (2010). These damage estimates are averages for the Netherlands, and as local conditions may vary, we prefer using the Norwegian damage estimates whenever these are available. Especially damages from emissions to air may differ significantly between the Netherlands and Norway due to the considerably smaller population intensity in Norway. de Bruin *et al.* (2010) provides an extensive methodology for estimating shadow prices and deriving weighting factors for individual types of environmental impact. We thus have a scientific background for the damage estimates used in this study, and the assumptions are explicitly detailed and the methodology employed is thoroughly described. This enables us to obtain a linear approximation for aggregated damage estimates for all firm-years by multiplying the annual emission levels in *kg* with the damage estimates in fixed 2008 euros/kg. Linear aggregate damage costs may over- or underestimate the true damage costs, depending on whether the observed emissions in our data are lower or higher than the emission levels the marginal damage costs were estimated for. Marginal damage costs will often increase with the level of emissions.

Economic growth has a tendency to increase emissions, while technological progress typically will reduce emissions per unit produced.[5] We measure environmental performance (the emission intensity) as the estimated damage costs of a firm's total annual emissions D, for each firm-year in fixed 2008 Euros, relative to the input of clean energy, Z_1, which is the firm's use of electricity measured in kWh, see Section 2 . This gives our emission intensity measure, $({}^{D}/_{Z_1})$. Electricity amounts to 85 % of firms' total energy use in Norway, and hydro power has been the main source of electricity in Norway during the estimation period. Therefore, we use input of electricity as the clean energy input (numeraire). We have data on firm level electricity use from the Energy Statistics. Figure 1 illustrates the trend in the emission intensity (aggregate damage estimates relative to the use of electricity in kWh) of three examples of pollutants: particulates, green house gases and acidification and ozone precursors. All three groups of pollutants exhibit a downward trend in emission intensities. Particulates and green house gases have the largest reductions in emission intensities of 62 and 83 per

[5] The literature on Environmental Kuznets Curves (EKC) typically finds that emissions are positively correlated with a country's income growth to a certain level, but as the country gets even richer it will start abating emissions such that the EKC is falling as the country gets even richer.

cent respectively, whereas the reduction for acidification and ozone precursors is 25 per cent.

Figure 2 provides calculated trends for energy use Norwegian on-shore firms with emission permits. The left panel (Chart a) illustrates that electricity use has remained relatively constant over time, with a dip in 2009 of nearly 20 per cent, following the financial crisis (NVE, 2013). The use of petroleum products (except gas) follows a downward trend since 1997, while the use of gas has more than doubled over the period. Chart b) displays different energy intensity measures. Measured relative to real income, total energy intensity fell sharply until 2000-2001, and afterwords increased until 2003, for so falling and reaching a new dip in 2007-2008, before increasing and then flattening out again. Decomposing the energy intensity into electricity intensity and gas- and petroleum intensities, we see that the wobbly path is caused by changes in electricity use, as indicated by the left panel (Chart a)). The petroleum intensity follows a downward sloping path, whereas the gas intensity is mostly stable from the year 2000 and onwards. The use of electricity fluctuates around +/- 10 percent in the time period, so the fall in the electricity intensity is caused by the increase in real operating income. Hence, the main driving force behind the improvements in environmental performance over the period as (see Figures 1 and 6) is related to emission reductions and not increased electricity use. Our emission intensity measure can be affected positively by either reducing the numerator (the damage estimates of the emissions for a given level of clean energy input) or by increasing the denominator (the input of clean energy). Another relevant measure of emission intensity would be total environmental damage costs divided by deflated operating income (as a measure of production volume). However, our measure of emission intensity is more robust towards volatile price- and income effects at the firm level since it is measured relative to the volume of electricity measured in kWh. Electricity use is a particularly good measure of activity level in energy intensive industries like manufacturing. Chart c) of Figure 2 illustrates the trends in mean operating income and electricity use. Operating income fluctuates significantly more than electricity use, especially from 2003 until 2010.

3.2 Environmental regulations

A number of environmental regulations have been introduced in Norway over the last four decades. Non-tradable emission quotas combined with technology restrictions are administered by the NEA and has existed since 1974. Such regulations are frequently

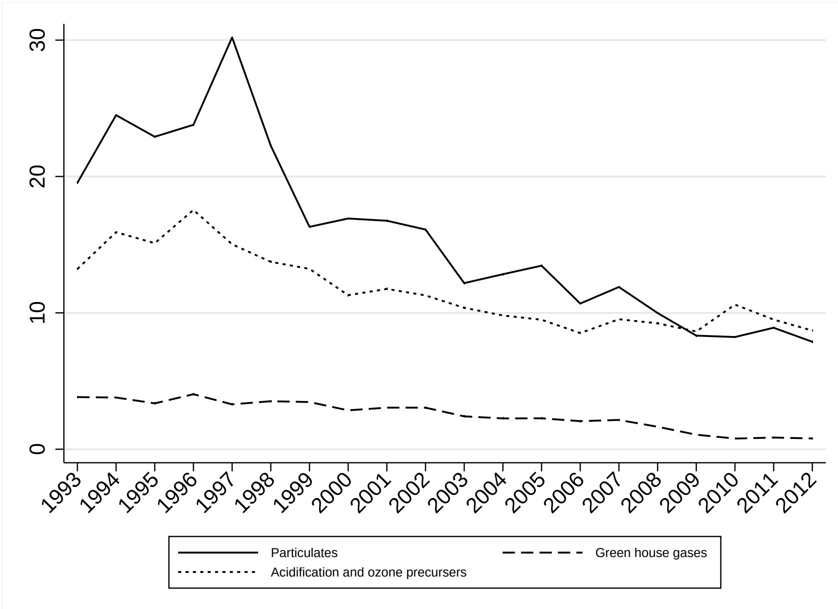

Fig. 1: Monetary values (in fixed 2008 euros) of total estimated damages of Norwegian emissions relative to total electricity use (in kWh). All Norwegian onshore firms with emission permits.

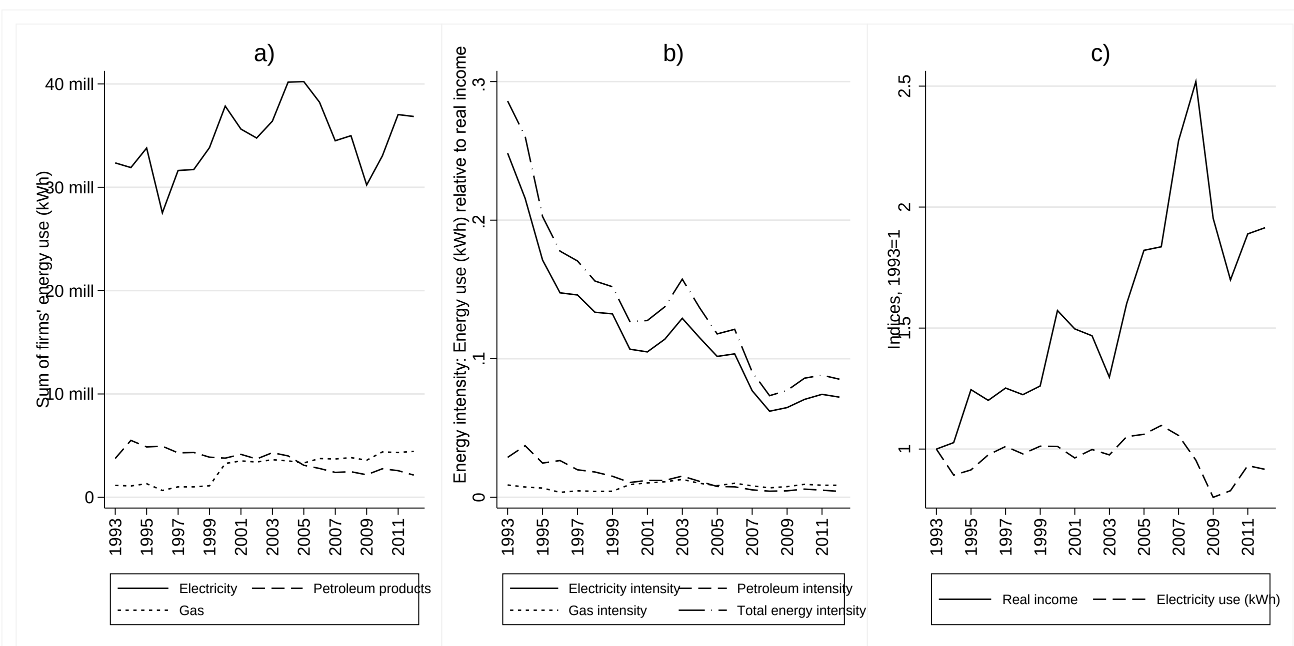

Fig. 2: Norwegian on-shore firms with emission permits. Chart a): Firms' total energy use (kWh). Chart b): Energy use (kWh) relative to real operating income (using a producer price index as deflator) Chart c): Trend in mean real operating income and electricity use (kWh).

used when a regulator faces complexities such as multiple emission types and targets, heterogeneous recipients and uncertainty with regard to marginal damage. This regulation is typically categorized as a direct policy instrument (also referred to as "command-and-control"). Moreover, Norway is part of the European Union Emission Trading Scheme (EU ETS), which regulates green house gas emissions in the EU and EFTA area (Ministry of Finance, 2013). Finally, there are several environmental taxes on polluting emissions. These two latter types of regulation can be categorized as indirect policy instruments (also referred to as "market-based" or "incentive-based" regulations). In the following we will discuss how the different types of regulations can induce changes in production and pollution. The main notion is that regulatory costs can come in the form of prices, which is the case for indirect regulations, or in the form of threats of sanctions, which is typically the case for direct regulations. Such regulatory costs, whether in the form of prices or threats of sanctions, will provide incentives for behavioral change. The difference between direct and indirect instruments is thus smaller than what is often perceived. The largest difference in practice, is perhaps that direct regulations tend to be a bit more extensive, in the sense that the more detailed permits allow the regulator to regulate more dimensions of the production. Indirect regulations tend to be more flexible. In theory, a tax or a tradable emission allocation can also take into account many dimensions, such as the timing or the location of the emission, but in practice it rarely does.

3.2.1 Direct regulations: Non-tradable emission quotas and technology standards

The dualistic categorization of instruments as either "incentive-based" or "command-and-control" creates the notion that the latter type of regulation does not lead firms to face pollution prices or incentives for emission reductions. However, such regulations involve several regulatory costs providing firms with incentives for behavioral change. These incentives are not fundamentally different from those arising from indirect instruments. Firstly, the NEA can fine non-complying firms. Secondly, the NEA has the authority to prosecute the firm. Thirdly, firms may face costs in terms of local stigmatization and bad publicity since data on violations are publicly available. Lastly, the firm's permit can be withdrawn, which will ultimately lead to close-down of production. These regulation costs impose a limit on the firms' production activity.

To measure the incentive or the regulatory costs of this form of direct regulation, we need to identify when the regulation is binding, and how strict the regulation is (if binding). We follow Klemetsen *et al.* (2013) and Jaffe and Stavins (1995) in assuming that the incentives for changes in environmental behavior are related to the possibility (or threat) of being sanctioned for violating a permit. Rather than using the (excess) level of emission pollutants as a proxy for the probability of being sanctioned, as in Jaffe and Stavins (1995), we use the inspection violation status of the firm (this variable is described below). The reason for our choice is that regulators cannot observe emission levels, but must rely on self-reported levels. Hence, they tend to focus on technology and institutional violations when meting out sanctions. A large majority of the firms that exceed the permit are never sanctioned. In fact, the correlation between excess emissions and the Violation status of a firm is only 0.13. Our measure more accurately reflects the risk that a firm will be sanctioned unless it takes action to comply.[6]Another possible measure of direct regulations is to simply use the year a specific technology standard is implemented. However, such a measure will be more vulnerable to heterogeneity issues with respect to timing. Firms are informed about a forthcoming standard several years in advance. Some firms adapt to the standard early, some firms adapt late, and some firms make contracts with the NEA, that allow the firm to use the old technology for a period of time after the initial deadline. Determining the appropriate lag structure of the effect of a technology standard is thus challenging. Our measure is much less vulnerable to such issues, as an inspection violation more correctly captures the timing of the regulatory costs. An important part of the regulatory costs of direct regulation is thus captured by the Violation status of the firm (denoted V). This reflects the risk that a firm will be sanctioned unless it takes action to reduce its production level or change technology to reduce emission levels or intensity.

The firms are subject to regular inspections. If a violation is detected during an inspection, the firm receives a letter from the NEA with a warning of sanctions that will be imposed on the firm should it stay out of compliance.[7] The level of the sanctions is based on an assessment by the NEA officer in charge. An important factor when

[6] Féres and Reynaud (2012) measure formal regulations as the number of inspections and average efficiency of warnings and fines of the local environmental agencies. The only firm level variable connected to direct regulations is a dummy variable that describes the license status of the firm.

[7] When inspecting plants, the NEA focuses on violations of procedures and general maintenance of equipment rather than on actual emissions (Telle, 2004). The complete permits also contain a variety of qualitative requirements concerning institutional, technological as well as formal aspects of the plant. The data on the firms' violations probably provide a good overview of the compliance with the environmental regulations. Data are also available for violations of emission quotas based on self-reported emission levels are also available, although we only use the violation status from the NEA inspections.

the regulator considers using sanctions is the severity of the violation. We have data on inspection violations and the regulator's assessment of the severity of the inspection violation. The variable is ordinal and have three values: $V = 0$ denotes a firm with no violations, $V = 1$ denotes minor violations and $V = 2$ denotes serious violations. More serious violations involve a higher risk of being sanctioned. Nyborg and Telle (2006) find that the majority of firms comply with the regulations after receiving a letter of warning of sanctions. They conclude that the NEA regulations are generally considered to be binding. Each firm with an emission permit is assigned with a risk class[8]. Since the inspection frequency varies across risk classes, it is important to control for risk class.

Our measure of direct regulations, violation status, is likely to capture only part of the incentive stemming from direct regulations. More specifically, the measure will capture most of the incentive for firms that are struggling to comply. However, it is likely that many firms adapt to the technology requirements in time, and thus avoid non-compliance (violations). An improvement in the environmental performance for these firms that did not follow directly after a violation may also be an effect of the technology requirement. Hence, our measure of direct regulations is likely to capture only a part of the full incentive.

3.2.2 Indirect regulations

Environmental taxes

Carbon taxes were introduced to follow up the Norwegian authorities policies to curb climate gas emissions following the Brundtland commission (UN, 1987). Later Norway has signed the Kyoto-protocol and made commitments to the EU's 20-20-20 goal for reductions in greenhouse gas emissions (see e.g. Climate Cure 2020, 2010). For Norway, CO_2 emissions that are not covered by the EU ETS are mainly covered by the CO_2 tax. The CO_2 tax was levied on oil and gas from 1991, and it varies greatly between fossil fuel types and end uses. There are also taxes on sulphur dioxide (SO_2) and

[8] Risk classes are assigned by the regulator to each firm with an emission permit. The assignment of a risk class is based on the strength of the recipient of the emission (e.g. the vulnerability of a river, its wind and stream conditions, popularity of a recreation area, etc.) and the emission level. The risk classes vary from 1 to 4, where risk class 1 comprises firms considered to be potentially highly environmentally harmful. Firms considered the least dangerous are placed in risk class 4. A higher risk class (where 1 is the "highest") is associated with higher regulatory costs for the firm in several ways. They are subject to more frequent and more costly inspections, and warnings of higher fines (see Klemetsen *et al.*, 2013).

nitrogen oxide (NO_x) emissions that are regulated by the Gothenburg protocol, and taxes on emissions of hydro fluorocarbons (HFC) and per fluorocarbons (PFC) that are regulated by the Montreal treaty. A tax on the chemicals trichloroethene and tetrachloroethene was introduced in 2000. This implies that there are several taxes on the consumption of fossil fuel products, but the tax rates may differ between the industries/firms and over the data period. There is also a tax on electricity consumption for some industries/firms.[9]

Ideally, we would like to investigate the effect of environmental taxes and these taxes are mostly levied on energy goods. However, in the data we cannot separate the energy base price from the emission taxes. In any case, the firm adjusts to the total energy price including taxes, and our proxy for the emission taxes should capture this appropriate incentive for the firm. Hence, for each firm we calculate energy goods prices. Electricity prices are estimated on firm level as expenditures on the use of electricity in (fixed 2008) euros divided by electricity use in kWh. Dirty energy prices are estimated on firm level as the the sum of the firm's expenditures (in fixed 2008 euros) on the use of petroleum products and gas relative to the use of petroleum and gas (in kWh).

Figure 3 (Chart a)) shows the development over time in the firms' mean real prices of intermediary inputs, i.e., electricity, petroleum products, gas and material prices (using a producer price index as deflator). Material input factors are proxied by Production Input Prices (Statistics Norway). Both petroleum, gas and materials have experienced a real price increase in the period, in spite of some wobbly periods. Especially real gas prices was considerable higher around 2000. The real electricity price has increased only slightly over the period, and drops in 2011.

We study the effects of indirect regulations in the form of relative price responsiveness between "dirty" and "clean" intermediary inputs on the entire population of Norwegian firms' on-shore emissions. We proxy the indirect regulations as the relative factor input price[10] between the firm's dirty factor input price (cost-share weighted average of petroleum, gas and material prices) divided by the firm's electricity price.[11] This variable is illustrated in Chart b) of Figure 3, and shows an increasing trend in the relative input price (dirty input prices have increased more than clean energy (electric-

[9] Ministry of Finance (2007) contains a detailed description of energy and environmental taxation in Norway in recent decades and of the international environmental agreements that Norway has signed.

[10] Using factor input prices as e.g. energy prices as proxies for environmental taxes is common in the literature, see e.g. Jaffe and Stavins (1995).

[11] We estimate firm level electricity, petroleum and gas prices through dividing the annual use in NOK with the annual use in kWh. Material input factors are proxied by Production Input Prices from Statistics Norway. Production Input Prices is the only variable that is not at the firm level, but rather at a detailed industry level. Firm variation is achieved through the dirty and clean energy prices.

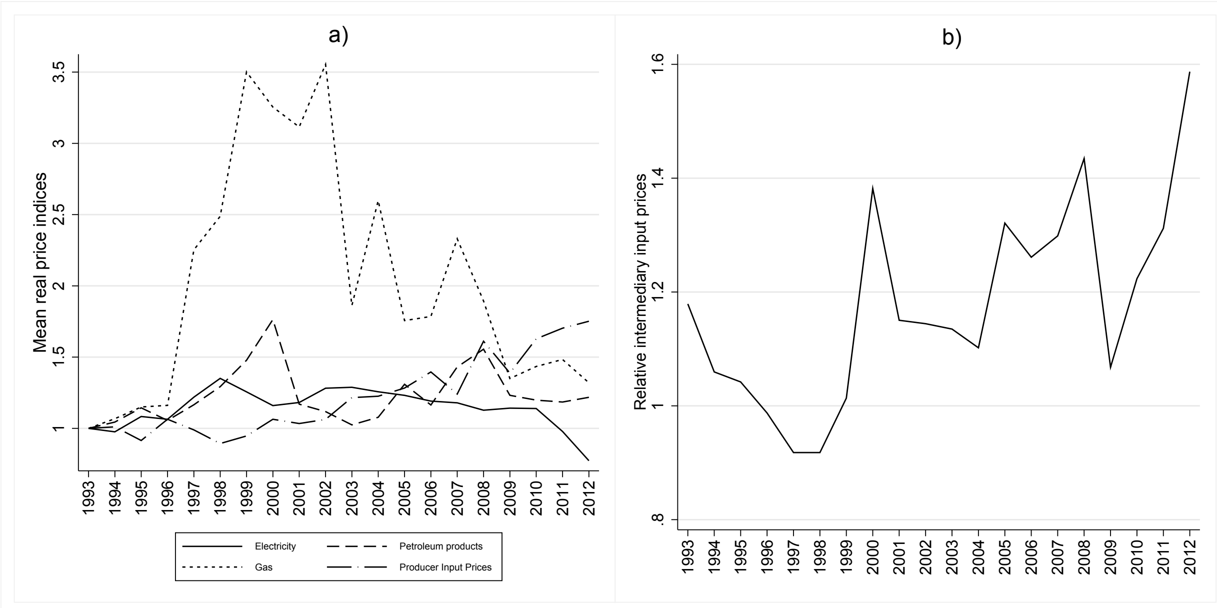

Fig. 3: Chart a): Mean prices (1993-2012) of electricity, petroleum, gas and material (Production Input Prices). Chart b): Relative prices between dirty intermediary input factors (petroleum, gas and material prices weighted by their average cost share) and electricity

ity) prices over the time period). Variations in the relative factor input price includes both changes in the input factor market prices and changes in environmental taxes. Indirect regulations is mostly directed towards fossil fuels related emissions (SO_2, NO_x, volatile organic compounds, particulates, and most green house gases). Since relative energy prices (dirty/clean) are directed towards energy related emissions, we perform a separate robustness analysis on the effect of relative input prices on a sub-sample of the emissions that are related to energy use (more on this in Section 4).[12]

EU ETS

Norway is part of the European Union Emission Trading Scheme (EU ETS), which regulates carbon emissions in the EU and EFTA area.[13] The onshore firms that are

[12] The following pollutants are related to energy use: CH_4, CO, CO_2, N_2O, $NMVOC$, VOC, NO_2, NO_x, S, SO_2, SO_x. Moreover, the following pollutants are energy use related when they are emitted into air: AS, C_2F_6, CD, CF_4, $CR-3$, $CR-6$, $CR-TOT$, CU, HG, PB, SF_6, ZN.

[13] The period 2005-2007 was a pilot first phase for EU ETS in EU and Norway, see the EU's quota directive (Directive 2003/87/EC). The oil and gas industry in Norway was not included in the first phase, but in the second from 2008. The processing industries, except for the aluminum industry, have been included since 2005.

part of the EU ETS receives tradable free quotas. In the pilot period (2005-2007) 10% of Norwegian firms' CO_2-emissions were included, while in Phase II (2008-2013) nearly all manufacturing firms' CO_2-emissions were included. For the period 2008 to 2012 the allocation rules were not harmonized within the EU ETS and Norway were issuing fewer free quotas (as per cent of total quotas) than the other countries. The quota price in the EU ETS has fallen substantially from 2008-2012 (from 30 Euro to less than 10 Euro). This is probably a combination of over-allocation of free quotas in the EU and the recession in the aftermath of the financial crisis in 2008, and to a lesser extent due to polluting firms reducing their emission intensity.

We include as a control variable a dummy variable which is equal to 1 if the firm is part of the EU ETS in the given year. Our measure of indirect regulations (relative price of dirty inputs and clean energy) can in theory include the potential effects from tradable emission quota prices, through energy prices that may be influenced by the the quota price. However, as the EU ETS quota prices are very low the effects on the energy prices should be minor, so the relative prices between dirty and clean inputs capture the effects of environmental taxes (which are in fact included in our observed relative input prices). By including the EU ETS dummy as a control variable we separate the (potential) effect of the environmental taxes from the effects of the tradable EU ETS quotas – although they are probably very small.

3.3 Other explanatory variables

Figure 4 shows that some firm specific characteristics are highly correlated with emission intensity and should be included as control variables when analyzing environmental performance. In contrast to studies at the industry level, we are able to take into account both observed and unobserved firm heterogeneity, and thereby reduce the problem of omitted variable bias in our analysis. Panel a) illustrates how emission intensity decreases with firm size measured as the number of employees. This relation could be due to scale advantages as larger firms may have more efficient production. In absolute numbers, emission levels are likely to increase with firm size, but larger firms tend to be more emission efficient. Moreover, capital intensity – measured as the capital stock relative to the number of employees – and emission intensity are positively related as illustrated in Panel b). More capital intensive firms may depend more on polluting energy and material inputs. In addition to the aforementioned control variables we

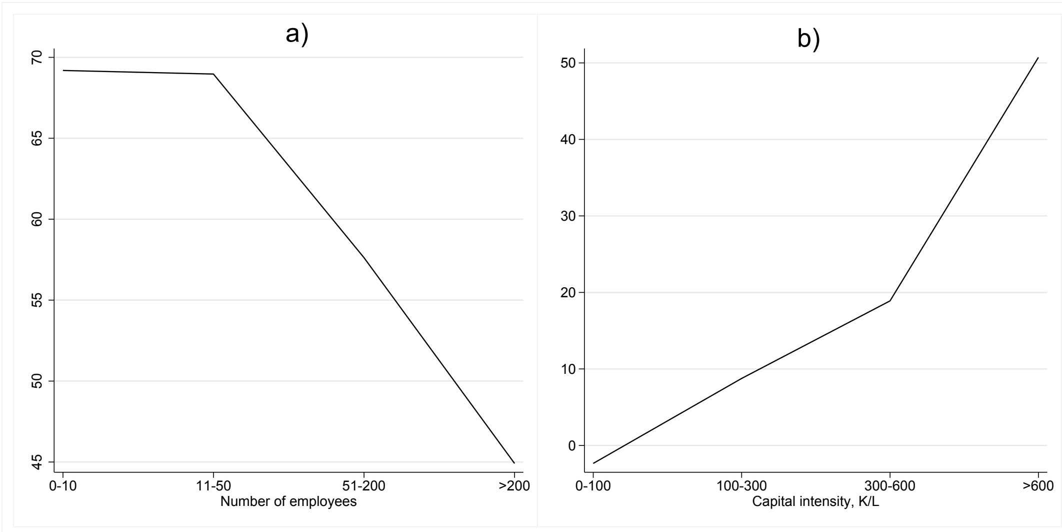

Fig. 4: Polluting firms' mean emission intensity along the vertical axis in both panels. Firm characteristics along the horizontal axes (grouped in categories).

include risk class dummies (see Section 3.2.1 for details) of the firm, as well as year- and industry dummies as control variables to account for common trends and industry specific effects.

To control for trends in emissions at the industry level is vital, since common trends and industry specific effects are likely to be present. The importance of this is illustrated in Figure 5 which shows that emission intensity differs systematically across industries, and in Figure 6 which shows that both energy related and non-energy related emission intensities, after increasing in the mid-1990s, follow a decreasing trend over time. The reduction is most pronounced for emissions from non-energy related inputs. The differences in the paths for the two emission intensities illustrates the importance of including all types of emissions in the measure of emission intensity when analyzing effects of different kinds of regulations, cf. also the Introduction. Industry and year effects are included in all estimations. The industry aggregation is illustrated in Table 2.

3.4 Summary statistics

Our initial sample of 741 incorporated Norwegian onshore firms with emission permits contains 7209 firm-year observations over the years 1993 to 2012. Table 1 contains

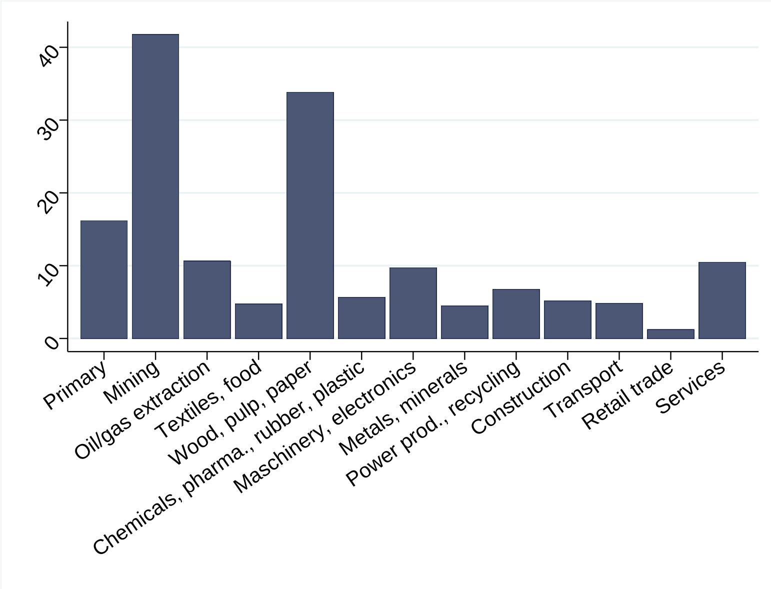

Fig. 5: Mean firm-year emission intensity per industry. Emission intensity is defined as the estimated damage costs (in fixed 2008 euros) of the firm's emissions per electricity use (in kWh)

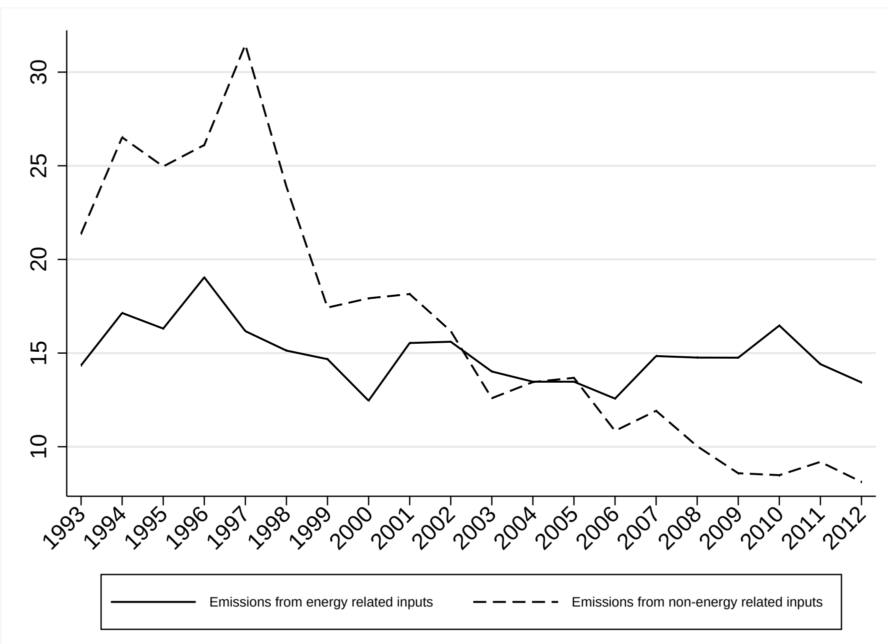

Fig. 6: Mean firm-year emission intensity over time. Emission intensity is defined as the estimated damage costs (in fixed 2008 euros) of the firm's emissions divided by electricity use (in kWh).

summary statistics for our initial sample of Norwegian on-shore firms with emission permits in the given time period. All variables contain firm level variation.

Table 1: **Summary statistics: Norwegian onshore firms with emission permits in 1993-2012**

Variable	Obs	Mean	25% Perc	Median	75% Perc	Min	Max
Response variable							
Environmental performance[1] (D/Z_1)	5002	88.1	.07	2.4	14.7	0	40415
Explanatory variables							
Relative input prices[2] (P_2/P_1)	4053	3.2	.81	1	1.2	.1	4
Violation status[3] (V)	7209	.45	0	0	1	0	2
Control variables							
EU ETS dummy[4]	7209	.05	0	0	0	0	1
Number of employees	5872	267	22	78	225	0	20114
Capital intensity	5595	2017	176	434	1065	0	235161
Dummy for							
$R_t = 1$	7209	.12	0	0	0	0	1
$R_t = 2$	7209	.23	0	0	0	0	1
$R_t = 3$	7209	.44	0	0	1	0	1
$R_t = 4$	7209	.16	0	0	0	0	1

[1]Real monetary value of firm damage costs (in fixed 2008-euros) of emissions relative to electricity use (kWh)

[2]Measure of indirect regulation, dirty intermediary input (weighted average of energy and material) prices relative to clean energy price

[3]Measure of technology standards and non-tradable emission quotas (see Section 3.2.1)

[4]Measure of EU ETS regulation, equal to 1 if regulated by EU ETS

Table 2 provides the industry distribution of the sample in the given time period. A majority of the polluting firms are in the manufacturing industries.

Table 2: **Distribution across industries of firm-years 1993-2012**

Industry	Obs. (firm-years)	Share of obs.
Primary	419	5.8 %
Mining and extraction (excl. oil and gas)	605	8.4 %
Oil and gas extraction	108	1.5 %
Manufacturing (textiles, food)	1392	19.3 %
Manufacturing (wood, pulp, paper)	495	6.9 %
Manufacturing (chem., pharmac., rubber, plastic)	1034	14.3 %
Manufacturing (metals, minerals)	1320	18.3 %
Manufacturing (machinery, electronics)	713	9.9 %
Power production and recycling	572	7.9 %
Transport	56	0.8 %
Construction	50	0.7 %
Retail trade	239	3.3 %
Services	460	6.4 %
Sum	7209	100%

4 Econometric model, estimation and results

4.1 Econometric model

Our study investigates the impacts on environmental performance of different types of emission regulations. In Section 2 we presented the theoretical model for producer behavior and derived an expression of environmental performance as an emission intensity measured as the total damage costs of the emissions from all intermediary inputs relative to the use of clean energy input (equation (7)), and in differentiated form in equation (8). Environmental taxes (indirect regulations) affect the relative prices of the input factors (see Section 3.2.2). A change in the relative prices of input factors provides incentives to substitute inputs towards the relatively less expensive input factor. Hence, if the dirty intermediary inputs become more expensive relative to clean energy, our economic model predicts that firms will respond by lowering the use of the dirty input factor. A reduction in the use of dirty input factors will then reduce the emission intensity. Similarly, direct regulations can provide firms with incentives to reduce emission intensity through implicit costs associated with an increased probability of being sanctioned. Hence, there are potential incentives for emission intensity reductions stemming from both direct and indirect regulations. We set up the main econometric model based on equation (8) in Section 2:

$$\triangle \ln \left(\frac{D}{Z_1}\right)^*_{it} = \alpha_t + \rho \cdot \triangle \ln \left(\frac{P_2}{P_1}\right)_{i,t} + \pi \cdot V_{i,t-1} + \beta \cdot \triangle X_{i,t-1} + \triangle \varepsilon_t \tag{9}$$

D is total damage costs for firm i. The calculations of the damage costs are presented in Section 3.1. P_2/P_1 is the relative input factor price between dirty intermediary input, Z_2 (polluting energy and materials), and clean input, Z_1 (clean energy which is electricity). This relative input price includes environmental taxes. Section 3.2.2 provides more details on the calculations of this relative price index, which is our measure of indirect regulations. Direct regulations (technology restrictions and non-tradable emission quotas) is measured through the ordinal variable Violation status (V) representing the implicit costs of violating a binding permit (included in the term g_{it} in the theoretical model in Section 2). This measure of direct regulations is in line with Klemetsen *et al.* (2013). V is thus a proxy for a binding constraint that gives incentives for emission reductions.[14] In order to make sure that we are not simply capturing the dirtier and hence more heavily inspected firms, we control for the risk class of the firm through risk class dummies (see Section 3.2.1). These dummies are likely to capture the differing numbers of inspections of the firm, how close the firm is to a vulnerable area, and finally, how much the firms pollute. Hence, this control variable is likely to capture some of the incentives for emission reductions, and thus lead to underestimation of the true effect of direct regulations on environmental performance.

We also include control variables, represented by the vector X (see the data description in Section 3.3) that may influence environmental performance: capital intensity, number of employees, and whether the firm is part of the EU ETS - represented by a dummy variable for the relevant years (see Section 3.2.2 on why this is included as a control variable, even if the EU ETS is an example of an indirect regulation). Finally, $\triangle\varepsilon$ is the differentiated error term, which we allow to have an auto regressive structure of order 1. This is realistic since potential omitted variables captured in the error term are likely to be correlated within a given firm.

In equation (9), ρ reflects the average effect from indirect regulations represented by relative input factor prices, π reflects the average effect from direct regulations, and β represents a vector of coefficients for the control variables. We consider relative factor input prices to be exogenous to the firms. The other explanatory variables are lagged

[14] Even if all other variables are differentiated, $V_{i,t-1}$ is a level variable measured relative to 0. A violation is in itself a change from steady state as the firm will at some point return to a complying state. We include V as a level variable because we want to test the hypothesis that the firms' response to violations may have a persistent long term effect on environmental performance. That is, even if the violation ceases, the effect on environmental performance is not reversed. If V was included only through $\triangle V$ we would assume that the regulation did not have a persistent effect (i.e., that the effect of the regulation was zero/offset over time). However, this is rather what we want to test. We do so in Section 4.4 by testing if a positive $\triangle V$ leads to the same effect as a negative $\triangle V$ (a test of symmetry). The results from this test support that our specification of V at level form in equation (9) is valid.

one year to deal with potential issues of reversed causality and to allow the firms to adapt to the regulation.

We estimate equation (9) as a mixed model where the coefficients of $\ln\left({}^{P_2}/{}_{P_1}\right)_{i,t}$ and $V_{i,t-1}$ are firm-specific. The ρ and π in equation (9) are the average value of firm-specific ρ_i and π_i parameters, respectively. Thus we allow firms to have heterogeneous responses to environmental regulations. It is essential to allow for heterogeneous treatment effects as firms may have different price elasticities, and thus respond differently to relative price changes. Moreover, firms may respond differently to inspection violations. E.g., one can imagine some ("well-behaved") firms that purchase the required technology in time, other firms that do so when a violation is detected, and some ("bad-behaved") firms who purchase the required technology when the regulator detects and classifies the violation as a serious one. The mixed model specification estimates the average coefficient estimates ("treatment effects"). We do not allow for random coefficients in the control variables in X, because these are of secondary interest.

The results of the estimation of the main specification (equation (9)) are given in Table 3, alternative (I). We also perform this analysis on an alternative sample, where we only include the energy related emissions in the response variable, $\triangle \ln\left({}^{D}/{}_{Z_1}\right)$, denoted alternative (II) in Table 3. This could potentially be of importance for estimating the effect of indirect regulations, as these turn out to be directed mainly towards energy related emissions. With the sample in alternative (II) it is thus more likely to identify the causal effects from indirect regulations. In Section 4.2 we have restricted the measure of direct regulations – Violation status – to be linear. This assumption is strong. In Section 4.3 we test this assumption by allowing the effect to be non-linear (Table 4). In Section 4.4 we present the tests and results (Tables 5 and 6) from the analysis of persistent effects of the regulations.

4.2 Results of main specification

The results of the estimations are given in Table 3. If the response variable, emission intensity, increases, the firm becomes *less* efficient according to our performance measure. If environmental taxes through increased relative input price create incentives for emission intensity reductions, we expect the estimated coefficients on $\ln\left({}^{P_D}/{}_{P_1}\right)$ to be negative. Alternative (I) shows that this is indeed the case for the estimated coefficient with an estimate of ρ equal to -0.10. The estimated coefficient is significant well below the 10 % level. This effect can be interpreted as an elasticity: A 1% increase in the relative price leads to a 0.1% improvement in the emission intensity.

If the measure of direct regulation, V, increases, the firm is assumed to experience the regulation as stricter (see Section 3.2.1). Hence, if this creates an incentive for reducing the emission intensity, we expect a negative sign on the estimated coefficient of this variable. The results show that this is the case, as the estimated coefficient is -0.08 and the result is significant at the 5 % level. The interpretation is that direct regulations also improve firms' environmental performance. The estimated coefficient of Violation status (direct regulation) is smaller than the estimated coefficient of the relative energy prices (indirect regulation). It would, however, be wrong to interpret this result as if indirect regulations have a larger influence on environmental performance than direct regulations. We cannot compare the estimated coefficients directly, as the measure of direct regulations is an ordinal variable. In addition, as mentioned in Section 3.2.1, our measure of direct regulations – Violation status – will likely not capture the entire effect from this policy, as many firms are likely to adapt not only after a violation is detected, but adapt when they are required to, thus avoiding non-compliance.

The dummy variable for risk class 1 is omitted because there is no within-firm variation (the NEA seldom makes changes in the risk class categorization of firms). The estimated coefficients for risk class 2 is higher than for risk class 3 as expected as a change to a higher risk class means that the firm is now considered by the NEA to be more pollutive (or close to an area that is now considered more vulnerable). The estimated effect of capital intensity is positive (0.09) and significant at the 10 % level. Hence, more capital intensive firms seem in general to be more dependent on dirty factor inputs. The number of employees has a negative estimated coefficient, which is significant at the 10 % level. This indicates that there are some positive scale effects, so that larger firms may have more efficient technology. The estimated coefficient of the EU ETS dummy is negative but not significant. This variable is only used as a control variable, even if it is an example of an indirect regulation. The main reason is that the sample is too small to estimate a causal effect from EU ETS. The estimated coefficient of the auto-regressive part of the differentiated error term is negative and highly significant as is typically the case with error terms in differences.

Table 3: **Results of main specification**

		I		II[1]	
Explanatory variables:	Coef.	Est.	St.E.	Est.	St.E.
$\triangle$Log of relative input prices[2]	ρ	-.10*	.06	-.14**	.06
Violation status[3]	π	-.08**	.04	-.05	.04
Control variables	β				
Risk class dummies[4]					
$\triangle D$ (Risk class = 1)	omitted				
$\triangle D$ (Risk class = 2)		3.91***	1.40	-1.32	1.94
$\triangle D$ (Risk class = 3)		2.76***	.89	.69	1.36
$\triangle$Log of capital intensity		.09*	.05	-.11*	.06
$\triangle$Log of number of employees		-.09*	.06	.01	.04
EU ETS dummy		-.13	.15	-.17	.15
Constant	α	.10	.14	-.03	.13
AR(1) coefficient ($\triangle\varepsilon_{it}$)	ϕ	-.33***	.03	-.16***	.03
Equation		(9)		(9)	
Number of firm-year observations		3087		2100	
Number of firms		421		273	

NOTE: Full set of differentiated industry and year dummies included but not reported.
*** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses.
[1]The response variable, $\triangle \ln D/Z_1$, only includes a sub-group of energy related emissions See Sections 3.2.2 and 4.1 for details.
[2]A measure of indirect regulation: Prices of dirty input factors (weighted average of energy and material prices) relative to clean energy price.
[3]A measure of the direct regulation of non-tradable quotas and technology standards.
[4]The reference category consists of firms in risk class 4. Risk class 1 is the strictest.

Direct regulations are typically directed towards a wide range of emissions. Indirect regulations, on the other hand, turn out to be mostly directed towards energy related emissions (stemming from the use of so-called dirty energy goods as e.g., fossil fuels). To check the robustness of the estimation results we thus estimate the model for the subgroup of energy related emissions (i.e., D now contains only damages from emissions that are related to energy use). This sub-sample may allow us to better identify the effects from indirect regulations.

Alternative (II) (in Table 3) reports the results from the estimation using only the sub-sample of energy related emissions. Compared to the main specification, the sample size is reduced from 3187 to 2100, thus some drop in significance levels is expected. This sample is, however, slightly preferred for estimating the effects of indirect regulations.

The positive results with respect to indirect regulations on environmental performance are strengthened. This is expected, since we now only include the types of emission that are typically taxed (energy related emissions). The estimated coefficient on relative input prices now becomes -0.14 which is significant at the 5 % level. On the other hand, direct regulations are generally directed towards other types of emissions than energy related ones. Therefore the drop in the estimated coefficient of Violation status to -0.05 as well as the loss of significance in alternative (II) is expected, since few of the included emissions are now subjected to direct regulations. Alternative (I) thus provides the preferred sample selection for investigating the effects of direct regulations.

The estimated coefficient of the control variable capital intensity changes sign (-0.11) in alternative (II). This sub-sample of firms may have machinery that uses less dirty input than the average firm in the total sample. Firms in this sub-sample thus become less polluting when the capital intensity increases. In alternative (II), we can no longer detect any scale effects, as the significance level has dropped. A plausible explanation is that the firms in this sub-sample are quite larger. When the entire sample of emissions are included, the estimated AR-coefficient of the error term is estimated to -0.33, whereas it is halved in absolute value when the sample consists only of energy related emissions.

4.3 Robustness check: Allowing Violation status to have non-linear effects

In our main specification (equation (9)) we have assumed linear effects from the measure of direct regulation, Violation status. This assumption might not hold. In this robustness analysis we investigate the effects of the regulations on environmental performance when Violation status is included through dummy variables. That is, instead of the variable $V \in [0,1,2]$ we now have included dummies for $V = 1$ (denoted by V_1) and $V = 2$ (denoted by V_2). The reference category is no violations ($V = 0$).

$$\triangle \ln\left(\frac{D}{Z_1}\right)^*_{it} = \alpha_t + \rho \cdot \triangle \ln\left(\frac{P_2}{P_1}\right)_{i,t} + \pi_1 \cdot V_{1,t-1} + \pi_2 \cdot V_{2,t-1} + \beta \cdot \triangle X_{i,t-1} + \triangle \varepsilon_t \quad (10)$$

Table 4 provides the results of the specification in equation (10) where the linear assumption of Violation status is dropped. The estimated coefficient of the dummy variable for a minor violation is now -0.10, significant at the 10 % level, and the estimated coefficient of the dummy variable reflecting a serious violation is -0.18, which is significant at the 5 % level. The coefficients are monotonically increasing as expected (with the highest incentive for environmental improvements occurring when the firm is detected with a serious violation, i.e. having the highest probability of being sanctioned). The results for the main model in Table 3 are thus confirmed. The remaining estimates in Table 4 are almost identical to those of alternative (I) in Table 3.

Table 4: **Results when V is represented through dummy variables**

Explanatory variables:	Coef.	Est.	St.E.
$\triangle$Log of relative input prices[1]	ρ	-.10*	.06
Violation status dummies[2]			
Violation status = 1	π_1	-.10*	.06
Violation status = 2	π_2	-.18**	.09
Control variables	β		
Risk class dummies[3]			
$\triangle D$ (Risk class = 1)	omitted		
$\triangle D$ (Risk class = 2)		3.91***	1.40
$\triangle D$ (Risk class = 3)		2.76***	.89
$\triangle$Log of capital intensity		.09*	.05
$\triangle$Log of number of employees		-.06*	.04
EU ETS dummy		-.13	.15
Constant	α	.10	.15
AR(1) coefficient ($\triangle\varepsilon_{it}$)	ϕ	-.35***	.04
Equation		(10)	
Number of firm-year observations		3087	
Number of firms		421	

NOTE: Full set of differentiated industry and year dummies included but not reported
*** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses.
[1]A measure of indirect regulation: Prices of dirty input factors (weighted average of energy and material prices) relative to clean energy price.
[2]A measure of the direct regulation of non-tradable quotas and technology standards.
[3]The reference category consists of firms in risk class 4. Risk class 1 is the strictest.

4.4 Persistent (long term) effects

Finally, we test the notion from literature that indirect regulations promote continuous dynamic incentives (leading to persistent effects) for emission reductions, in contrast to direct regulations (OECD, 2001; Jaffe and Stavins, 1995; Perman *et al.*, 2011). If the regulations is relaxed the improvement in environmental performance of the regulation may be offset over time. If the improvement is not offset when the regulation is relaxed, there are persistent effects of the regulation. We test whether there are such persistent effects by performing a test of asymmetric responses of stricter and more lax regulations, respectively.[15]

Firms can respond differently to stricter regulations. They can purchase or develop new technology (which is likely to lead to persistent effects as technology shifts are irreversible – at least in the short run), or they can adjust their production activity and substitute clean for dirty input factors (temporary adaptations). We look for persistent effects by testing whether stricter regulations and more lax regulations have asymmetric effects on environmental performance. Persistent effects are proven to exist if stricter regulations makes the firm adapt (by e.g. purchasing new and cleaner technology) and that this adaptation is not reversed if the regulation becomes more lax. On the other hand, if the regulation only makes the firm adapt by e.g. adjusting the production activity through factor substitution, it is likely that the effect of a stricter regulation ceases if the regulation is reversed. We can compare the effect of stricter indirect regulations (increased environmental taxes) or stricter direct regulations (increased probability of being sanctioned measured through Violation status) with the effect of more lax regulations. If stricter regulations lead the firm to improve their environmental performance, and a more lax regulation do not completely nullify this effect, it implies that there is a persistent effect of the regulation. Formally, this test is a test of the hypothesis that the sum of the coefficients corresponding, respectively, to positive and negative changes in the measures of regulatory stringency (relative prices and violation status) is zero over time. Symmetric responses to stricter and more lax regulations imply that a decrease in emissions from intermediary inputs over time (a decreasing trend) can only be achieved by continuously enforcing stricter direct regulations or increases in the relative factor price (indirect regulations). We will come back to this when discussing the results. Our first step is to estimate the equation:

$$\triangle \ln \left(\frac{D}{Z_1}\right)^*_{it} = \alpha_t \; + \; \rho^+ \cdot D\left(\triangle \ln \frac{P_2}{P_1} > 0\right) \cdot \triangle \ln \frac{P_2}{P_1} + \; \rho^- \cdot D\left(\triangle \ln \frac{P_2}{P_1} < 0\right) \cdot \triangle \ln \frac{P_2}{P_1}$$

[15] We have tested how long it takes until the regulation has full effect by including lagged versions of each regulation variable. By starting backwards and removing insignificant lags until rejection, we find that both types of regulation on average takes two years to reach full effect. The sum of the effects of indirect regulations over two years is found to be 0.22 (that the sum of the estimated coefficients is zero can be rejected at the 5% level). The estimated full effect of direct regulations is 0.20 (significantly different from zero at the 10 % level). Omitting lags of the explanatory variables means that our estimated (main) model specifications can be interpreted as long-run (steady-state) relations between dependent and independent variables.

$$+\ \pi^{+} \cdot D\left(\triangle V_{t-1}>0\right) \cdot V_{t-1}\ +\ \pi^{-} \cdot D\left(\triangle V_{t-1}<0\right) \cdot V_{t-1} +\ \beta \cdot \triangle X_{i,t-1} + \triangle \varepsilon_t \quad (11)$$

Table 5: **Results of dynamic specification (persistent effects)**

Explanatory variables:	Coef.	Est.	St.E.
$\triangle$Log of relative input prices[1]			
$\triangle$Log of relative input prices: $\triangle > 0$	ρ^{+}	-.12*	.07
$\triangle$Log of relative input prices: $\triangle < 0$	ρ^{-}	-.11*	.07
Violation status[2]			
$\triangle$Violation status:$\triangle > 0$	π^{+}	-.15**	.07
$\triangle$Violation status:$\triangle < 0$	π^{-}	.03	.04
Control variables	β		
Risk class dummies[3]			
$\triangle\, D$ (Risk class = 1)	omitted		
$\triangle\, D$ (Risk class = 2)		3.88***	1.33
$\triangle\, D$ (Risk class = 3)		2.70***	.89
$\triangle$Log of capital intensity		.11	.07
$\triangle$Log of number of employees		-.06	.13
EU ETS dummy		-.13	.26
Constant	α	.07	.16
AR(1) coefficient ($\triangle\varepsilon_{it}$)	ϕ	-.34***	.02
Equation		(11)	
Number of firm-year observations		2734	
Number of firms		384	

NOTE: Full set of differentiated industry and year dummies included but not reported.
*** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses.
[1]A measure of indirect regulation: Prices of dirty input factors (weighted average of energy and material prices) relative to clean energy price.
[2]A measure of the direct regulation of non-tradable quotas and technology standards.
[3]The reference category consists of firms in risk class 4. Risk class 1 is the strictest.

We want to test the long-term effects of a temporary change in V and $\ln\left({}^{P_2}/{}_{P_1}\right)$. That is, $\triangle V_t = -\triangle V_{t+1}$ and $\triangle \ln\left({}^{P_2}/{}_{P_1}\right)_t = -\triangle \ln\left({}^{P_2}/{}_{P_1}\right)_{t+1}$. If this is the case, an increase (decrease) in the regulatory measure in year t is reversed in year $t+1$ (e.g. $V_{t-1} = 0$,$V_t = 1$, $V_{t+1} = 0$; or $\ln\left({}^{P_2}/{}_{P_1}\right)_{t+1} = \ln\left({}^{P_2}/{}_{P_1}\right)_{t-1}$). The long-term effect on $\ln\left({}^{D}/{}_{Z_1}\right)_t$ is zero if $\triangle \ln\left({}^{D}/{}_{Z_1}\right)_t + \triangle \ln\left({}^{D}/{}_{Z_1}\right)_{t+1} = 0$, which is equivalent to symmetric effects from stricter and more lax regulations: *i)* $\rho^{+} - \rho^{-} = 0$ and *ii)* $\pi^{+} - \pi^{-} = 0$.

The results of Table 5 imply that there might be persistent effects from direct regulations. The estimated effect of an increase in the probability of being sanctioned ($\triangle V = 1$) has a negative and significant effect on the emission intensity, whereas when this regulatory enforcement vanishes ($\triangle V = -1$), the estimated effect is not reversed (as the estimated coefficient is even positive). The estimated effect of indirect regulations, however, seem to be symmetric. An increase in relative factor price provides only a slightly greater effect on emission intensity compared to the reversed effect from a decrease in relative factor price. We investigate this further by testing the null hypothesis if the sum of the effect of stricter and the effect from more lax regulations is equal to zero. This is equivalent to a test of the long-term effects of a temporary change in V and in $\ln(P_2/P_1)$. That is, we test the hypotheses i) and ii) above.

Table 6: **Tests of significance of long-term coefficients**

Long term coefficient	Estimate	H_0	p-value
$\rho^+ - \rho^-$	-.01	$\rho^+ - \rho^- = 0$	.9230
$\pi^+ - \pi^-$	-.18	$\pi^+ - \pi^- = 0$	.0664

From Table 6, we see that the null-hypothesis of no persistent effects in direct regulations (i.e., that the estimated effect of $\triangle V_t = 1$ and $\triangle V_t = -1$), can be rejected well within the 10 % significance level (p-value 0.064). Direct regulations thus promote continuous dynamic incentives that leads to persistent effects on the emission intensity. Firms respond to direct regulations by making technology changes that are irreversible. This result contradicts the notion from literature (OECD, 2001; Jaffe and Stavins, 2005; Perman *et al.*, 2011) that direct regulations do not promote continuous dynamic incentives. The result is not unexpected as firms who are exposed to direct regulations are still incentivized to minimize the costs of achieving a given level of pollution (i.e., even if the quota is fixed). Also, technology standards typically require firms to either use a specific Best Available Technology (BAT), or prohibit a specific dirty type of technology. For the firms such regulations may imply a high implicit (or shadow) cost of emissions giving incentives to technological change and emissions reductions as confirmed by our data. Technology standards are in theory considered to provide little incentives for innovation (see e.g. Johnstone *et al.*, 2010). However, firms may see it as profitable to develop the technology that is defined as the BAT as this may have a large market value (Perman *et al.*, 2011; Klemetsen *et al.*, 2013). Other strategic concerns may also enter.

Moreover, we see that the null-hypothesis of no persistent effects of indirect regulations (i.e., that the estimated effect of increased relative input price minus the estimated effect of an equally decreased relative input price) cannot be rejected. This result implies that a temporary stricter regulation will not have a persistent effect as the firms would simply substitute back to the initial factor input combinations when the relative input price decreased. However, Chart b) of Figure 3 illustrates a positive trend in relative intermediary input price, and hence we cannot exclude persistent (long-term) effects of indirect regulations. The policy implication is that indirect regulations (in Norway during the estimation period) only have potential persistent (long-term) effects on emission intensity if environmental taxes are increasing over time. If the positive trend in relative intermediary input price is reversed, there will be no persistent effect of indirect regulations. Therefore, constant and/or increasing environmental taxes are necessary for tax instruments to create continuous dynamic incentives. This result is in line with the literature on e.g. optimal carbon tax paths when induced technological change is present, see e.g. Goulder and Mathai (2000).

With regard to the estimated coefficients of the control variables (Table 5), they are not very different from alternative (I) in Table 3. However, we see that the significance levels of log of capital intensity, log of number of employees and the EU ETS dummy have dropped.

5 Conclusions

Conventional economic theory predicts two main advantages of indirect regulations over direct regulations. Firstly, indirect regulations minimize the aggregate cost of achieving a given level of environmental protection. Secondly, indirect regulations promote “continuous dynamic incentives” that lead to persistent effects on emissions through technological improvement, in contrast to direct regulations. Studies typically focus on the evaluation criteria *economic efficiency* and *cost-effectivene*ss. However, no single policy instrument ranks first among all the dimensions of policy comparison (Palmer, 1980; Goulder and Parry, 2008; Perman et.al., 2011; Wiener, 1999). Each instrument has its strength and weaknesses. In this paper we investigate the effects on environmental performance measured as an emission intensity of the two types of environmental regulations, and especially investigate whether there are any significant differences between the effects of direct and indirect regulations. In particular, we test whether indirect regulations promote “continuous dynamic incentives” leading to persistent effects on emissions through technological improvements, in contrast to direct regulations, as the literature suggests. Our firm-level data set allows us to analyze the effects from different types of regulations such as environmental taxes, non-tradable emission quotas and technology standards. The firm level panel data set spanning over the years 1993-2012 includes information about different types of environmental regulations, the entire population of Norwegian firms' land based pollutant emissions, and a large number of control variables for all polluting Norwegian incorporated firms. We are thus able to conduct a comprehensive study of the effect of various environmental regulations on our measure of environmental performance that includes all types of emissions.

Our results show that the dualistic categorization of the instruments as either "incentive-based" or "command-and-control" is overly simplistic. We identify a positive and significant effect of non-tradable emission quotas and technology restrictions on environmental performance as in line with Cole *et al.* (2005) and Féres and Reynaud (2012) – among others. Moreover, we find positive and significant effects of environmental taxes proxied by the relative price between dirty and clean input factors. However, we find that firms respond symmetrically to increases and decreases in the relative intermediary input price. Hence, constant and/or increasing environmental taxes are necessary if tax instruments are to create persistent effects on environmental performance. In Norway during the estimation period there has been a positive time trend in the relative factor input price between dirty intermediary input and clean energy input. Thus we cannot exclude the possibility of persistent effects of indirect regulations. Finally, we find evidence that direct regulations promote continuous dynamic incentives leading to persistent effects, in contrast to former beliefs (OECD, 2001; Jaffe and Stavins, 1995; Perman *et al.*, 2011). Non-tradable quotas may, even if the quota is fixed, create an incentive for the firm to reach this level at the lowest cost by reorganizing the production process, or investing in new technologies. Moreover, firms can realize the scope for commercializing a cheaper and more efficient technology given the likely increased demand and the lucrative possibility of patenting a BAT technology which is likely to generate large future income for the firm (Perman *et al.*, 2011; Klemetsen *et al.*, 2013). There are considerable uncertainties regarding the development of future clean technologies and the BAT, and firms facing indirect regulations may want to postpone technology shifts due to this uncertainty (see e.g. Reinelt and Keith, 2007). Direct regulations promote transparent signals to the firms, reducing the risk of new technology investments. Finally, firms can be motivated by considerations of pre-emptiveness[16] anticipating that the regulation is likely to become more stringent

[16] Pre-emptiveness involves firms voluntarily restraining their own conduct; they "self-regulate". They may act preemptively in order to lead the development of the technology standard; to preempt more stringent public policies from being introduced; to prevent the entry of new firms; to steer a technology

over time.

As far as environmental performance improvements are at aim for environmental regulations, or if cost efficiency is difficult to obtain, there is no reason to prefer one type of regulation over another. Hence, we may still use direct regulations when the conditions for these regulations are better.

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standard in a specific direction; to attract good publicity in order to increase consumer demand; etc. See e.g., Maxwell et.al. (2000) for further reading.

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