

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

Brita Bye<sup>§</sup>

Marit E. Klemetsen<sup>¶</sup>

September 1, 2016

## Abstract

Using a rich Norwegian panel data set that includes information about environmental regulations such as environmental taxes, non-tradable emission quotas and technology standards, all kinds of polluting emissions, and a large number of control variables, we analyze the effects of direct and indirect environmental regulations on environmental performance. We identify positive and significant effects of both direct and indirect policy instruments. Moreover, we test whether the two types of regulations lead to positive and persistent effects on environmental performance. We find evidence that direct regulations promote such effects. Indirect regulations, on the other hand, will only have potential persistent effects if environmental taxes are increasing over time.

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

**JEL classification:** C01, C23, D04, D22, H23, L51, Q51, Q58

---

\*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 of 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, the University of Oslo, and user partners.

<sup>§</sup>Statistics Norway, corresponding author, [Brita.Bye@ssb.no](mailto:Brita.Bye@ssb.no)

<sup>¶</sup>University of Oslo/Statistics Norway, [MaritElisabeth.Klemetsen@skatteetaten.no](mailto:MaritElisabeth.Klemetsen@skatteetaten.no)

# 1 Introduction

During the recent decades, environmental concerns have attracted increasing attention. Different kinds of environmental regulations have been introduced in order to curb polluting emissions to air, soil, and water. The regulations have been multifaceted ranging from direct pollution regulations (“command-and-control”), such as technology standards and non-tradable emission quotas, to indirect (“incentive-based”) regulations, such as environmental taxes and tradable emission quotas.<sup>1</sup>

Conventional economic theory predicts two main advantages of indirect regulations over direct regulations. Firstly, indirect policy instruments will result in more cost-efficient emission reductions<sup>2</sup> (Maloney and Yandle, 1984; Tietenberg, 1990; Keohane *et al.*, 1998; Stavins, 2001; Newell and Stavins, 2003; Perman *et al.*, 2011). 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 will provide “continuous dynamic incentives” by providing permanent incentives, through constant or increasing emissions prices, for reducing emissions through technological improvement, in contrast to direct regulation (Jaffe and Stavins, 1995; OECD, 2001; Perman *et al.*, 2011). On the other hand, direct regulations may be characterized by a binary switch as the required target is reached, and the literature suggests that there are no incentives for further technological improvements.

Other studies illustrate how the dualistic categorization of instruments as either incentive-based or command-and-control is misleading (see e.g., Bohm and Russel, 1985). The differences between these types of instruments are typically over-emphasized (Cole and Grossman, 1999), as several incentives arise from direct forms of regulations that are not fundamentally different from those that arise from taxes and tradable quotas. This is also evident from empirical analyses, see e.g., Cole *et al.* (2005) and Fères and Reynaud (2012). Studies

---

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

<sup>2</sup>For a flow pollutant or a uniform-mixed stock pollutant, Perman *et al.* (2011).

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 on all the dimensions of policy comparison (Palmer, 1980; Wiener, 1999; Goulder and Parry, 2008; Perman *et al.*, 2011). A natural but quite unexplored criterion is environmental performance.

In this paper we examine the impacts of direct and indirect policy instruments on environmental performance, measured as emission intensity. Moreover, we compare the long-term effects of direct and indirect regulations on environmental performance. We do this by testing the notion from the literature that indirect regulations provide “continuous dynamic incentives” that lead to persistent effects on emissions through technological improvement, in contrast to direct regulations, through an asymmetry test with regard to firms’ responses to stricter versus more lax regulations.

We contribute to the existing literature in three ways. Firstly, we measure environmental regulations and environmental performance at the firm level. Both regulations and emissions vary greatly across firms and a study of the effects of regulations should be carried out at the firm level. In addition to information on environmental taxes and tradable quotas that the firms face, our data include measures of direct regulations as technology standards and non-tradable emission quotas that enable us to identify the firms’ regulatory costs of the regulations. Inspection violation status – the regulator’s assessment of the severity of a violation – captures the risk that a firm may be sanctioned for violating its emission permit. Secondly, our data allow us to test whether the regulations provide persistent effects on environmental performance. Thirdly, we include the total range of Norwegian firms’ land-based pollutant emissions, that includes a whole range of industries, in our measure of environmental performance. We use the detailed emissions data in combination with weighted damage cost estimates (Rosendahl, 2000; Håndbok V712, 2006; de Bruin *et al.*, 2010) to calculate monetary estimates of the emission damages. These monetary estimates allow us to include and compare the whole range of emissions that cause very different types

of damages, ranging from cancer risks or loss of fertility to global warming. Including all types of emissions is particularly important in a study of direct regulations, since emissions other than green house gases are still often regulated through technology standards and non-tradable emission quotas. Studies of the effects of different types of regulations on environmental performance have until recently been quite scarce, with Cole *et al.* (2005) and Féres and Reynaud (2012) as earlier examples of direct regulations. Wagner *et al.* (2014), Klemetsen *et al.* (2016a), among others<sup>3</sup>, analyze the effects of the European Union emission trading system. Féres and Reynaud (2012) analyzes the impact of formal (direct) regulations and informal regulations (community pressure, etc.) on the environmental and economic performance of a regional group of Brazilian manufacturing firms. However, their formal regulations are partially measured as the number of inspections and do not include indirect regulations. We are not aware of any study using micro-data that includes indirect regulations in the form of environmental taxes as well as direct regulations.

In line with Cole *et al.* (2005) and Féres and Reynaud (2012) among others, we identify positive and significant effects of non-tradable emission quotas and technology standards on environmental performance. Moreover, we find positive and significant effects of environmental taxes. We also find evidence that direct regulations provide persistent effects. Indirect regulations, on the other hand, will only induce potential persistent effects if environmental taxes are increasing over time.<sup>4</sup> The results indicate that the dualistic categorization of the instruments as either “incentive-based” or “command-and-control” is overly simplistic.

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.

---

<sup>3</sup>See Martin *et al.* (2016) for a review of the empirical evidence for the EU ETS so far.

<sup>4</sup>Martin *et al.* (2014) finds a negative effect of the UK carbon tax on firms’ energy intensity. They do not, however, measure the effect on emission intensity or test for persistent effects.

## 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 the input of materials for the production processes and the use of dirty energy. We therefore 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, such as coke 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:

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

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 for input factor  $k$ ,  $P_{kit}$ , means solving the problem

$$\begin{aligned} \min_{Z_{kit}} \quad & P_{1it} Z_{1it} + P_{2it} Z_{2it} \text{ s.t.} \\ & \left[ Z_{1it}^\delta + (b_{2it} Z_{2it})^\delta \right]^{\frac{1}{\delta}} = y, \end{aligned} \quad (2)$$

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

$$Z_{kit} = y b_{kit}^\rho \left( \frac{P_{kit}}{P} \right)^{-\rho}, \quad k = 1, 2 \quad (3)$$

where  $P$  is the price index of the intermediate aggregate:

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

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

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

We assume that the total damage costs of emissions  $D_{it}$  from the use of dirty input are given by

$$D_{it} = \sum_n a_{nt} \lambda_{nit} Z_{2it} \equiv \kappa_{it} Z_{2it}, \quad (6)$$

where  $a_{nt}$  is the unit price (in euros) of damage from emissions of component  $n$  and  $\lambda_{nit}$  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  $\kappa_{it}$  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,  $Z_1$ :

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

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

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 then a measure of emission intensity: the damage costs from dirty input relative to the use of clean input.

We choose this measure of emission intensity as our measure of environmental performance. An emission intensity is usually measured as emissions in physical units divided by the use of the corresponding dirty input, while environmental performance is often measured as emissions divided by income or production level, as in the literature of Environmental Kuznets Curves<sup>5</sup>. Unfortunately, the physical emission intensity is only 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 are often volatile. By defining environmental performance as in equation (7), we are able to capture any substitution effects (and technology effects) resulting from relative energy prices. 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,  $\rho$ , and firm-specific effects,  $g_{it}$ , which will be specified in Sections 3 and 4. It may not be random to the firm what kind of regulations 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  $\ln(D_{it}/Z_{1it})$  and  $\ln(P_{2it}/P_{1it})$  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):

$$\Delta \ln \frac{D_{it}}{Z_{1it}} = \Delta g_{it} - \rho \Delta \ln \frac{P_{2it}}{P_{1it}} \quad (8)$$

Equation (8) states that environmental performance, measured as an emission intensity depends on the relative price between dirty and clean intermediary input, in addition to

---

<sup>5</sup>As 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 and political concern about regulating polluting emissions has contributed to this inverse u-shape. The contributions to this u-shaped curve can be decomposed into substitution-, technology-, and scale effects (Bruvoll and Medin, 2003; Bruvoll *et al.*, 2003; Bruvoll and Larsen, 2004).

several firm specific effects. The emission intensity measure will pick up substitution between electricity and other pollutants, although technology effects are also likely to be captured. More details on the econometric specification is given in Section 4.

### **3 Data sources and description of variables**

Our firm-level panel data draws on several data sources. All data sets are merged using organization number as the firm identifier. The data set spans 20 years, from 1993 to 2012. A key data set is the data from the Norwegian Environment Agency (NEA) on annual emissions of more than 260 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. The NEA data 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 (which include 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: energy and emissions, environmental regulations, and other determinants of environmental performance (control variables).

#### **3.1 Energy and Emissions**

Our dataset from the 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 damage, ranging from cancer risks or loss of fertility to global warming. To study the empirical effects of different environmental policies on our measure



of environmental performance – the damage costs of dirty factor input relative to clean input (Section 2, equation (7)) – we need to transform the emissions data into a common measurement scale. We use shadow prices of damages for each kind of emission to calculate the total damage in terms of monetary costs. Shadow prices are constructed prices for goods or production factors that are not traded in markets. Measuring shadow prices of polluting emissions is challenging in several ways. Firstly, it requires sophisticated methodology and in-depth knowledge about chemical compounds, as well as about the recipients in the environment. Secondly, it requires simplifying assumptions, that must be transparent and thoroughly discussed. Moreover, there are several examples of studies that do not rely on expert comparisons of damages from various chemical compounds, but instead involve measures based on 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 damage.

There is no comprehensive study of the 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 from many of the emissions. In addition, we use damage costs estimates evaluated at shadow prices that reflect the marginal damage of the firm’s annual emissions constructed in de Bruin *et al.* (2010)<sup>6</sup>. These damage estimates are averages for the Netherlands in 2008, and as local conditions may vary, we prefer to use Norwegian damage estimates whenever they are available. Especially damages from emissions to air can differ significantly between the Netherlands and Norway due to the considerably smaller population density in Norway. de Bruin *et al.* (2010) provides

---

<sup>6</sup>The Shadow Prices handbook (de Bruin *et al.*, 2010) is developed by CE Delft, an independent research and consultancy organization. The Handbook is available on the website of CE Delft. We use the damage estimates for a large proportion 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 to this report. The damage costs for emissions to air are obtained using NEEDS damage costs. The NEEDS project is an ExternE-related European study on the external costs of energy use. The damage costs for emissions to water are obtained using direct valuation of ReCiPe endpoint characterization factors. Since this method is less reliable than using NEEDS damage costs, damage estimates for emissions to water are only approximate.

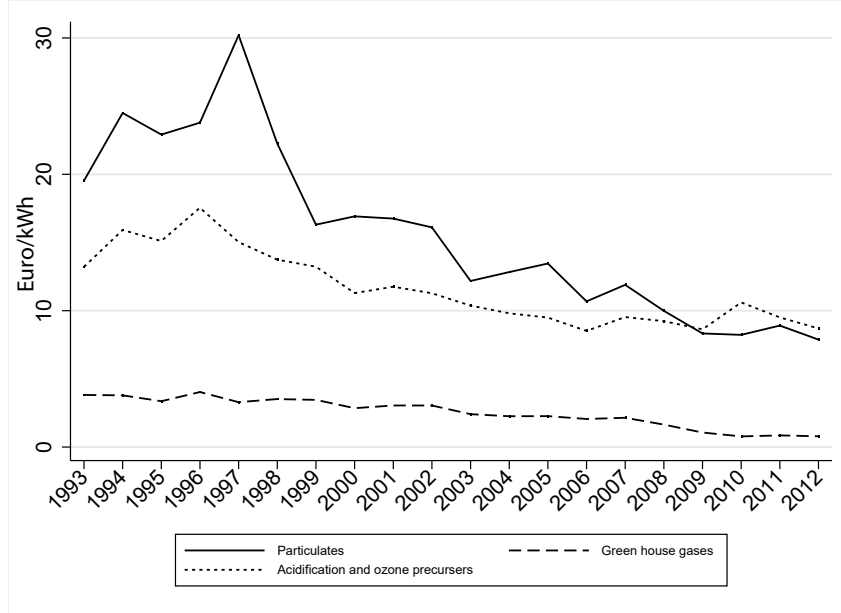


Figure 1: Emission intensities. Monetary values (fixed 2008 euros) of total estimated damage of emissions relative to total electricity use (kWh). Norwegian land-based firms with emission permits.

an extensive methodology for estimating shadow prices and deriving weighting factors for individual types of environmental impact. The assumptions are explicitly detailed and the methodology employed thoroughly described. We thus have a scientific background for the damage estimates used in this study. This enables us to obtain a linear approximation of aggregated damage estimates. Linear aggregate damage costs may overestimate 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.

Our measure of environmental performance is given by the emission intensity ( $D/Z_1$ ) (Section 2, equation (7)). We estimate the damage costs of a firm's total annual emissions  $D$  by multiplying the annual emission levels in  $kg$  by the damage estimates in fixed 2008 euros/kg, for each firm-year. We measure clean intermediary input,  $Z_1$  as the firm's use of electricity measured in kWh. Electricity amounts to 85 percent of firms' total energy use

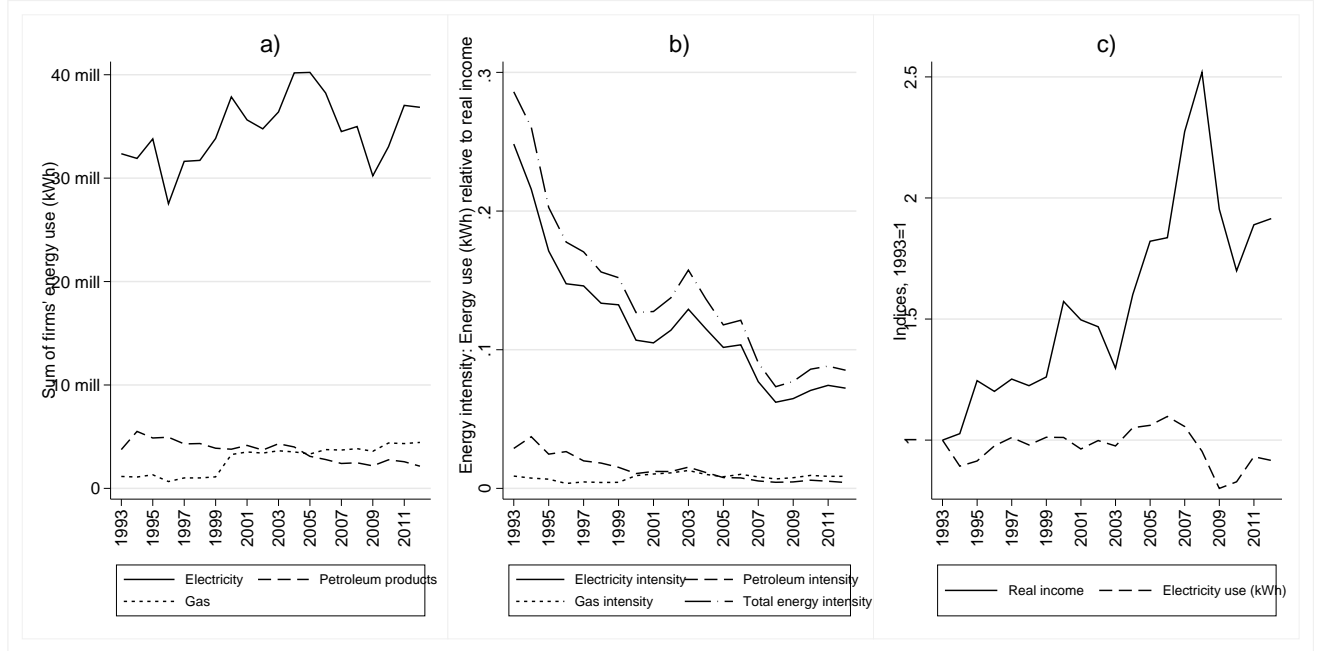


Figure 2: a): Total energy use (kWh). b): Energy use (kWh) relative to mean real operating income (deflated by PPI). c): Indices, mean real operating income (deflated by PPI) and electricity use (kWh). Norwegian land-based firms with emission permits.

in Norway, and hydro-power has been the main source of electricity during the estimation period.<sup>7</sup> Therefore, the use of electricity is an appropriate measure of clean factor input. We have data on firm-level electricity use from the Energy Statistics. Figure 1 illustrates the trend in the estimated emission intensity 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 intensity. Particulates and green-house gases have the largest reductions in emission intensities of 62 and 83 percent respectively, whereas the reduction for acidification and ozone precursors is 25 percent.

Our emission intensity measure can be positively affected by either reducing the damage costs (numerator) or by increasing the input of clean energy (denominator). Figure 2 provides calculated trends for energy use by Norwegian on-shore firms with emission permits.

<sup>7</sup> Norway is part of the European power market, but the exchange of power has been but minor in the estimation period.

Chart a) illustrates that electricity use has remained relatively constant over time, with a dip in 2009 of nearly 20 percent, following the financial crisis (NVE, 2013). The use of petroleum products (except gas) has followed a downward trend since 1997, while the use of gas has more than doubled over the period. Chart b) shows the development in different energy intensity measures. Measured relative to real operating income (deflated by the producer price index (PPI)), total energy intensity fell sharply until 2000-2001, and afterwards increased until 2003, then fell again, reaching a new low in 2007-2008, before increasing and then flattening out. 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 Chart a). The petroleum intensity follows a downward-sloping path, whereas the gas intensity is largely stable from the year 2000 onwards. The use of electricity fluctuates around  $\pm 10$  percent in the time period, so the fall in electricity intensity is caused by the increase in real operating income over the period, Chart c). Hence, the main driving force behind the improvements in our measure of environmental performance over the period (see Figure 1) is related to emission reductions and not to increased electricity use.

As mentioned in Section 2, another relevant measure of emission intensity would be the total environmental damage costs divided by deflated operating income. From Figure 2, Chart c), we see that mean operating income fluctuates significantly more than electricity use, especially from 2003 until 2010. Therefore, our measure of emission intensity is more robust towards volatile price- and income effects. Electricity use is a particularly good measure of the activity level in energy-intensive industries like manufacturing.

## 3.2 Environmental regulations

### 3.2.1 Direct regulations: non-tradable emission quotas and technology standards

In Norway, any emission that harms or may harm the environment is, as a general rule, prohibited.<sup>8</sup> Non-tradable emission quotas combined with technology restrictions are administered by the NEA and have existed since 1974. If a firm wishes to emit polluting substances it has to apply for a permit from the NEA. The NEA should in principle have an overview of most of the polluting activities that take place. It regulates and monitors the environmental performance of polluting operations involving more than 260 pollutants to air and water. Our data set includes everything from climate gases, such as  $CO_2$ , to pollutants associated with high cancer risk, such as heavy metals. The regulations consist of both non-tradable emission quotas and technology standards. Technology standards can either be designed as prohibitions on polluting production technologies or as a requirement of a specific clean technology. Such regulations are frequently 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 (“command-and-control”). However, such regulations involve several regulatory costs that provide firms with incentives for behavioral change. These incentives are not fundamentally different from those arising from indirect instruments.

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 Jaffe and Stavins (1995) and Klemetsen *et al.* (2016b) in assuming that the incentives for changes in environmental behavior are related to the possibility or threat of being sanctioned for violating a permit. The firm must weigh the need to produce and emit against the costs of possible sanctions of violations. A firm facing a binding emission permit can reduce the restrictions on production by substituting to less emission intensive factor

---

<sup>8</sup>Law prohibiting harmful pollution: <http://www.lovdata.no/all/nl-19810313-006.html>

inputs, reduce production or purchase or develop a more efficient technology. An important factor when the regulator considers using sanctions is the severity of the violation. Our data let us use the inspection violation status of the firm as a probability of being sanctioned (see below for a detailed description of this variable), in contrast to Jaffe and Stavins (1995) that use the excess level of emission pollutants as a proxy for the probability of being sanctioned. The reason for our choice is that regulators cannot observe emission levels, but must rely on self-reported levels.<sup>9</sup> Monitoring emissions is costly (and in practice difficult given current technologies), and hence, the regulators tend to focus on technology and institutional violations when meting out sanctions. A large majority of the firms whose emissions simply exceed the permits are neither sanctioned nor issued with warnings of sanctions. Compared to a measure using excess emissions, our measure more accurately reflects the risk that a firm will be sanctioned unless it takes action to comply.<sup>10</sup>

When a firm is granted an emission permit, the NEA assigns each firm to a risk class,  $R$ , 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., i.e. location specific) and the pollutant specific emission level. The risk classes vary from 1 (the highest) to 4 (the lowest), where risk class 1 comprises firms considered to be potentially highly environmentally harmful. A higher risk class (lower  $R$ ) is associated with higher regulatory costs for the firm in several ways, see Table 1. They are subject to more frequent and more costly inspections (columns 2-4), and warnings of higher fines (column 5).

Firms with emission permits 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 remain noncompliant.<sup>11</sup> The data on violations are

---

<sup>9</sup>However, firms may underreport emissions. A potential source of bias related to self-reported emissions is if after an inspection, firms found in violation report emissions more correctly (i.e. an increase in the reported emissions). If this is the case, the effect of direct regulations would be underestimated.

<sup>10</sup>Féres and Reynaud (2012) measure formal regulations as the number of inspections and average efficiency of warnings and fines from 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.

<sup>11</sup>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 number of qualitative requirements concerning institutional, technological as well as formal aspects of the plant. The data on the firms' violations probably

Table 1: NEA regulatory costs (in NOK<sup>1</sup>) by risk class

Risk class	Freq. inspection <sup>2</sup>	Price inspection	Freq. system revision	Fine warning <sup>3</sup>
$R = 1$	Each year	20,200	Every 3rd year	0-1,000,000
$R = 2$	Every 2nd year	15,200	Every 6th year	0-500,000
$R = 3$	Every 2nd/3rd year	11,700	-	0-250,000
$R = 4$	When needed	4,500	-	0-50,000

Source: *Lovdata; Forurensningsforskriften* (Law of pollution control)

<sup>1</sup>EUR 1  $\simeq$  NOK 9 (January 2015)

<sup>2</sup>Inspection frequency can deviate from the schedule when violations are detected.

<sup>3</sup>Inspection reports 2012. Fines are based on an evaluation by the NEA-officer. Fines rarely reach the maximum.

publicly available, which means that there is a possibility of bad publicity and stigmatization of the firm, either locally or nationally. The level of the sanctions is based on an assessment by the NEA. First, the noncompliant firms can be fined. Second, the firm can be prosecuted. Last, the firm's permit can be withdrawn, which will ultimately lead to a shutdown of production. Nyborg and Telle (2006) find that the majority of firms comply with the regulations after receiving a letter warning of sanctions. They conclude that the NEA regulations are generally considered to be binding.

The key variable measuring direct regulations in our analysis is inspection violation status,  $V$ .<sup>12</sup> This is a measure of the NEA's assessment of the severity of the inspection violations by the firm in a given year. The variable is ordinal and can take on three values:  $V = \text{None}$  (0) denotes a firm with no violations,  $V = \text{Minor}$  (1) denotes minor violations and  $V = \text{Serious}$  (2) denotes serious violations. This variable may vary over time for a given firm. Firms that are not regulated by the NEA can also be inspected, but this rarely

provide a good overview of the compliance with the environmental regulations. Data on self-reported violations are also available, although we only use the violation status from the NEA inspections.

<sup>12</sup>We have also considered alternative measures of direct regulations such as e.g. dummies on introduced technology standards, dummies on technology regime changes, and inspection frequency. Introducing dummies on technology standards would involve severe heterogeneity problems with regards to timing as the standards are typically implemented several years after they are announced, and as several firms are granted extensions. Dummies on regime changes, as used by Popp (2004), will likely pick up on several effects other than the change in regulation. Moreover, dummies will neither capture the timing of the firm specific regulatory costs, the differences in regulatory costs across firms facing direct regulations, nor the effects of the many different technology standards that are implemented. Finally, inspection frequency is likely to capture the regulator's conception of the risks associated with the firm's emissions, and not just the regulatory costs. The inspection frequency varies with risk class. We thus prefer controlling for risk class rather than including it in our measure of the regulation.

occurs. More serious violations involve a higher risk of being sanctioned. However, other factors than the severity of the violation can also be taken into account when the regulator considers possible sanctions.<sup>13</sup>

Our measure of regulatory costs, violation status, is likely to capture only a part of the incentive stemming from direct regulations. More specifically, violation status will capture the incentive for firms that are struggling to comply (specific deterrence). It is likely that many firms adapt to the technology requirements in time to avoid non-compliance entirely (general deterrence). Hence, the effect of violation status ( $V$ ) on environmental performance represents a lower bound on the total impact of direct regulation. It is this lower bound that we estimate in Section 4.

### 3.2.2 Indirect regulations

A number of indirect regulations have also been introduced in Norway. Carbon taxes and tradable carbon emission permits were introduced to follow up the Kyoto Protocol and commitments to the EU's 20-20-20 goal for reductions in greenhouse gas emissions. Norway is part of the European Union Emission Trading Scheme (EU ETS), which regulates carbon emissions in the EU and EFTA area.<sup>14</sup> The EU ETS covers approximately 50 percent of the carbon emissions in Norway. Emissions that are not covered by the EU ETS are mainly covered by the  $CO_2$ -tax. The  $CO_2$ -tax was introduced and levied on oil and gas from 1991, and it has varied greatly between fossil fuel types and end uses. There are also taxes on sulphur dioxide ( $SO_2$ ) and nitrogen oxide ( $NO_x$ ) emissions that are regulated by the Gothenburg Protocol, and taxes on emissions of hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) that are regulated by the Montreal Treaty.<sup>15</sup> There is also a tax

<sup>13</sup>Examples of possible factors are the likelihood that the firm will comply without sanctions being imposed, the ability of the firm to handle the requirement economically or practically, and finally, the risk class of the firm. The threats of sanctions tend to be more severe for the firm the higher is the risk class (the lower is  $R$ ) and therefore we control for the risk class, see Section 4. Firms with e.g. low economic performance may receive lower fines, offsetting a possible bias for weak economic firms to be more prone to comply after the warning in order to avoid the fine.

<sup>14</sup>The period 2005-2007 was a pilot first phase for EU ETS in EU and Norway. See the EU's quota directive (2003/87/EF) and European Environment Agency (2005). The oil and gas industry in Norway was not included in the first phase, but was included in the second from 2008. The processing industries, except for the aluminum industry, have been included since 2005; see also Ministry of the Environment (2011).

<sup>15</sup>Emissions of  $SO_2$  have been liable to environmental taxation since 1970, starting with a differentiated tax on



on electricity use for some industries/firms.<sup>16</sup>

Ideally, we would like to investigate the effect of environmental taxes, which are mostly levied on energy goods. However, in the data we cannot separate the energy pre-tax prices from the emission taxes. In any case, the firm likely adjusts to the total energy prices, including taxes and pre-tax prices. Energy prices as proxies for environmental taxes is thus common in the literature, see, e.g., Jaffe and Stavins (1995). Prices on dirty energy inputs at the firm level are calculated as the sum of the firm’s expenditures on petroleum products and gas divided by the use of petroleum and gas in kWh. We calculate electricity prices at the firm level by dividing total expenditures on electricity by electricity use in kWh.<sup>17</sup>

Figure 3 (Chart a)) shows the development in the firms’ mean real input prices (deflated by the PPI) of electricity, petroleum products, gas and materials.<sup>18</sup> We see that petroleum, gas, and materials have experienced a real price increase over the whole period, in spite of some wobbly periods in between. Especially real gas prices were considerably higher around 2000. The real electricity price has increased only slightly over the period, and it dropped in 2011.

According to equation (7) (Section 2) the relative price responsiveness between “dirty” and “clean” intermediary inputs influence the environmental performance of firms. We proxy the indirect regulations as the relative factor input price<sup>19</sup> 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. This variable is illustrated in Chart b) in Figure 3, and shows

---

mineral oils and extended to include a  $SO_2$ -tax on coke and coal in 1999. In 2002, this tax on coke and coal was replaced by a memorandum of understanding between the Ministry of the Environment and the Association for Processing industries. Taxes on HFC and PFC were introduced in 2003. The  $NOx$ -tax was introduced in 2007 on all  $NOx$ -emissions except those from the processing industry, combined with a  $NOx$ -fund for several industries (Hagem *et al.*, 2012). A tax on the chemicals trichloroethene and tetrachloroethene was introduced in 2000.

<sup>16</sup>Ministry of Finance (2007) gives a detailed description of energy and environmental taxation in Norway in recent decades and of the international environmental agreements that Norway has signed.

<sup>17</sup>Electricity prices are firm-specific in the energy-intensive part of the manufacturing industries, because prices are regulated by long-term contracts (<http://www.ssb.no/energi-og-industri/statistikker/elkraftpris>). Firms outside the manufacturing industries purchase electricity at market prices.

<sup>18</sup>The input price of materials are proxied by Production Input Prices (Statistics Norway). This variable is at a detailed industry level. Firm variation is achieved through the dirty and clean energy prices.

<sup>19</sup>Using factor input prices, e.g. energy prices as proxies for environmental taxes is common in the literature, see, e.g., Jaffe and Stavins (1995). Fluctuations in relative energy prices caused by e.g. world market oil price changes contribute to sharper estimated coefficients of relative price changes – our measure of indirect regulations such as taxes.

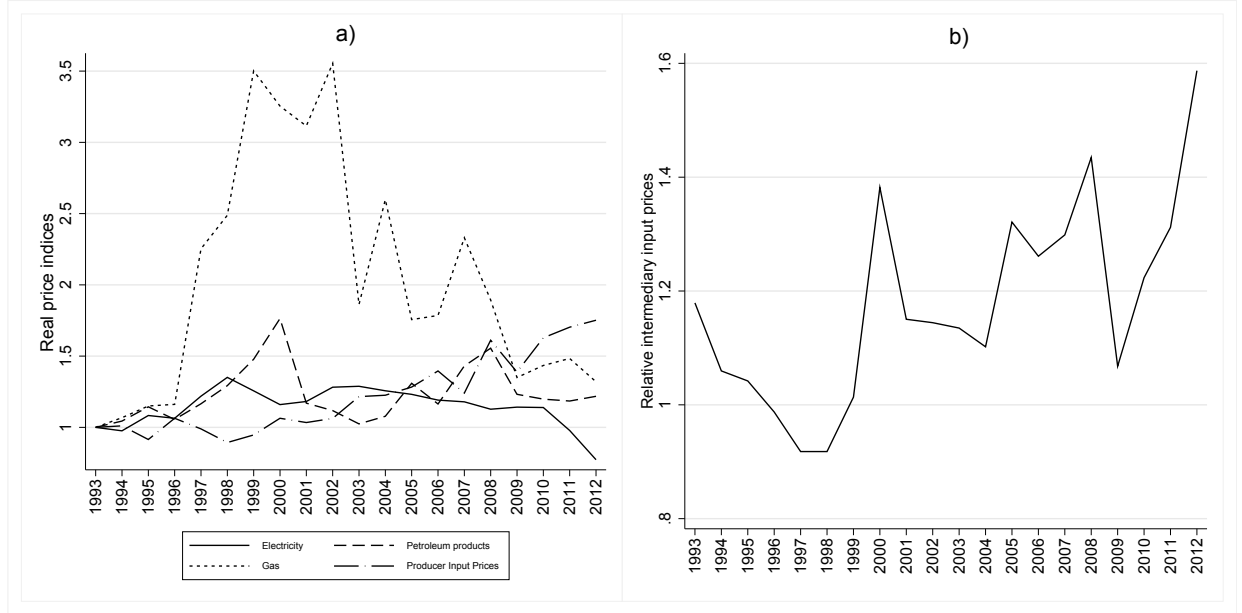


Figure 3: Chart a): Mean price indices. Chart b): Relative mean input prices between “dirty” and “clean” input factors. Norwegian land-based firms with emission permits.

an increasing trend. Variations in the relative factor input price includes both changes in pre-tax prices and changes in environmental taxes. Since environmental taxes are mostly directed towards energy related emissions, we perform a separate robustness analysis of the effect of relative dirty/clean input prices on a subsample of the emissions that are related to energy use only (see Section 4).<sup>20</sup> Figure 4 shows that both energy-related and non-energy-related emission intensities, after increasing in the mid-1990’s, follow a decreasing trend over time. The reduction is most pronounced for emissions from non-energy related inputs. The differences in the paths of the two emission intensities illustrates the importance of including all types of emissions in the measure of emission intensity when analyzing the effects of different kinds of regulations.

The pre-tax prices on petroleum and gas have fluctuated substantially over the data pe-

<sup>20</sup>The following pollutants are related to energy use:  $CH_4$ ,  $CO$ ,  $CO_2$ ,  $N_2O$ ,  $NMVOC$ ,  $VOC$ ,  $NO_x$ ,  $S$ ,  $SO_x$ . Moreover, the following pollutants are energy use related when they are emitted to air:  $AS$ ,  $C_2F_6$ ,  $CD$ ,  $CF_4$ ,  $CR-3$ ,  $CR-6$ ,  $CR-TOT$ ,  $CU$ ,  $HG$ ,  $PB$ ,  $SF_6$ ,  $ZN$ . See Table A.1 in the Appendix for a list of definitions of these pollutants. For an overview of the rest of the emission components included in the data we refer to Håndbok V712, 2006, and Tables 50 and 52 (in the Annexes) in de Bruin et al. (2010), available at the homepage of CE Delft.

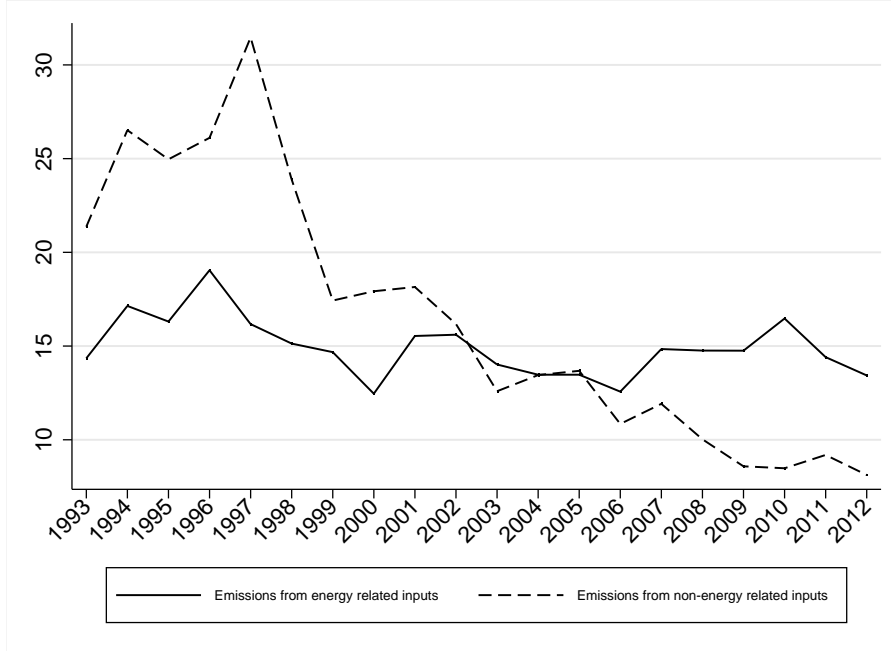


Figure 4: Mean firm-year emission intensity 1993-2012. Norwegian land-based firms with emission permits.

riod, such that identifying separate effects of taxes and quota-prices is difficult. Fluctuations in relative energy prices caused by e.g. world market oil price changes contribute to sharpen the estimated coefficient of relative price changes – our measure of indirect regulations such as taxes. As we come back to in Section 4.2, we can interpret the estimated coefficient related to relative energy prices as an elasticity. We include a dummy which is equal to 1 if the firm is part of the EU ETS in the given year. Our measure of indirect regulations – the relative price of “dirty” and “clean” energy inputs – may include potential effects on pre-tax energy prices from the tradable emission quota system. However, since the EU ETS quota prices have been very low, this effect should be minor so that the relative price between dirty and clean inputs capture the effects of environmental taxes.

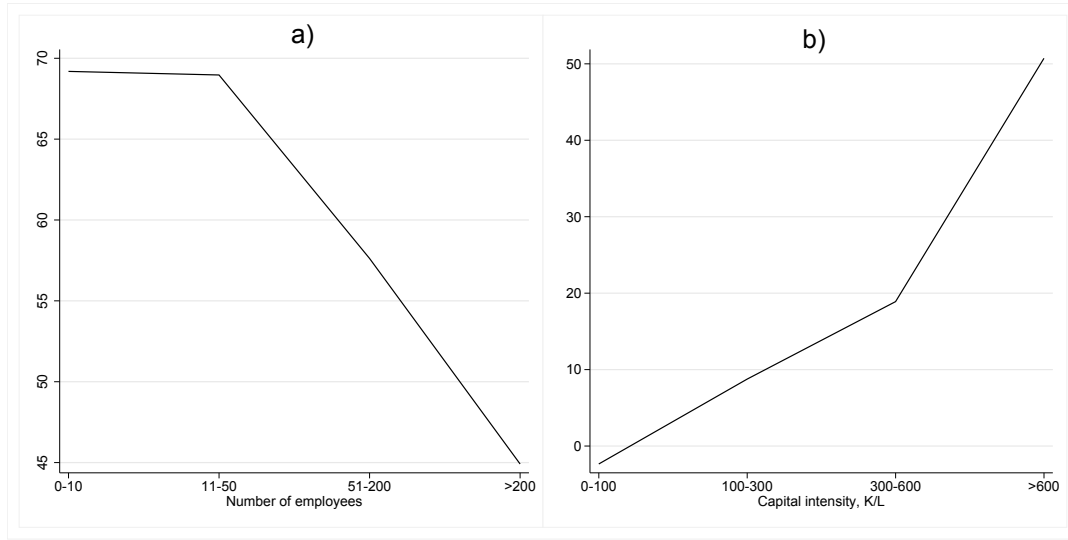


Figure 5: Firm characteristics (horizontal axes) and polluting firms' mean emission intensity (vertical axes). Norwegian land-based firms with emission permits.

### 3.3 Other determinants of environmental performance

Other firm-specific characteristics may also be important drivers of environmental performance. Figure 5 shows that both the number of employees and capital intensity are highly correlated with emission intensity and should be included as control variables when analyzing environmental performance. Chart a) illustrates how emission intensity decreases with firm size measured as the number of employees. This relationship 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 Chart b). More capital-intensive firms may have more polluting production processes and use more dirty energy and material inputs.

Figure 6 shows that emission intensity differs systematically across industries. In addition to the aforementioned control variables, we include risk class dummies (see Section 3.2.1 for details) of the firms, as well as year- and industry dummies as control variables to account

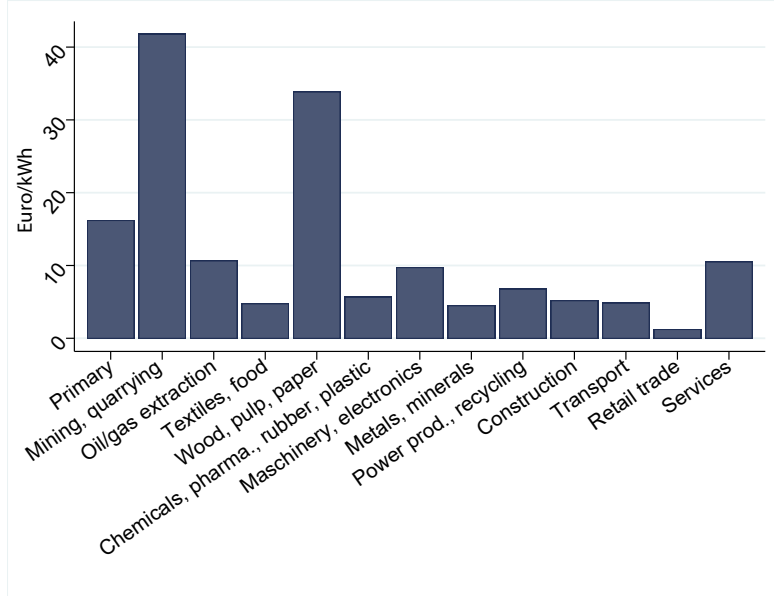


Figure 6: Mean firm-year emission intensity per industry. Norwegian land-based firms with emission permits.

for common trends (see Figure 4) and industry-specific effects.

### 3.4 Sample summary statistics

Our initial sample of 741 incorporated Norwegian land-based firms with emission permits includes 741 firms and 7209 firm-year observations for the years 1993 to 2012. Table 2 presents descriptive statistics for the main variables. After dropping observations with missing values, the final unbalanced panel data set consists of 3,187 (firm-year) observations and 421 firms. All variables contain firm-level variation. The industry aggregation of the sample in the given time period is illustrated in Table 3. A majority of the polluting firms are in the manufacturing industries.<sup>21</sup>

<sup>21</sup>Since we only include firms with emission permits we only study firms that are dirty. There are few dirty firms in less pollution intensive industries as services, retail trade, construction and transport.

Table 2: Summary statistics: Norwegian land-based firms with emission permits, 1993-2012

Variable	Obs	Mean	25th Perc	Median	75th Perc	Min	Max
Environmental performance <sup>1</sup> ( $D/z_1$ )	5002	88.1	.07	2.4	14.7	0	40415
Relative input prices <sup>2</sup> ( $P_2/P_1$ )	4053	3.2	.81	1	1.2	.1	4
Violation status <sup>3</sup> ( $V$ )	7209	.45	0	0	1	0	2
Number of employees	5872	267	22	78	225	0	20114
Capital intensity	5595	2017	176	434	1065	0	235161
EU ETS dummy <sup>4</sup>	7209	.05	0	0	0	0	1
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	.21	0	0	0	0	1

<sup>1</sup>Real monetary value of annual firm damage costs (in fixed 2008-euros) of emissions relative to electricity use (kWh).

The variable can take the value 0 if e.g. the firm is temporarily inactive. This is the case for very few observations.

<sup>2</sup>Measure of indirect regulation: dirty intermediary input (weighted average of energy and material) prices relative to clean energy (electricity) price.

<sup>3</sup>Measure of direct regulation, capturing the risk that a firm may be sanctioned for an inspection violation.

<sup>4</sup>Measure of EU ETS regulation, equal to 1 if the firm is regulated by the EU ETS in a given year.

## 4 Empirical model and results

### 4.1 Empirical model

Our study investigates the impacts of different types of emission regulations on environmental performance. In Section 2, we presented the theoretical model for producer behavior and derived the expression for 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). As discussed in Section 3.2.2 environmental taxes affect the relative prices of the input factors. A change in the relative prices of input factors provides incentives to substitute inputs with 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 reducing their 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

Table 3: Distribution across industries, 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 of textiles and food	1392	19.3 %
Manufacturing of wood, pulp and paper	495	6.9 %
Manufacturing of chem., pharmac., rubber, and plastic	1034	14.3 %
Manufacturing of metals and minerals	1320	18.3 %
Manufacturing of machinery and 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%

to reduce emission intensity through implicit costs associated with an increased probability of being sanctioned, as discussed in Section 3.2.1. 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):

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

$D$  is total damage costs for firm  $i$ .  $P_2/P_1$  is the relative input factor price between dirty intermediary input,  $Z_2$ , and clean input,  $Z_1$ . Direct regulations are 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).  $V$  is thus a proxy for a binding constraint that provides incentives for emission reductions.<sup>22</sup> 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 how close the firm is to a vulnerable area, how much the firm

<sup>22</sup>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 since the firm will at some point return to a complying state.

pollutes, and, finally, the differing numbers of inspections of the firm. 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 other control variables that may influence environmental performance, represented by the vector  $\mathbf{X}$ : capital intensity, number of employees, and whether the firm is part of the EU ETS – represented by a dummy variable for the relevant years.<sup>23</sup> Finally,  $\Delta\varepsilon$  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.

The coefficient  $\rho$  reflects the average effect of indirect regulations represented by relative input factor prices,  $\pi$  reflects the average effect associated with the risk of being sanctioned for violating direct regulations, and  $\beta$  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 one year to deal with potential issues of reversed causality.

We estimate equation (9) as a mixed model, where the coefficients of  $\ln(P_2/P_1)_{i,t}$  and  $V_{i,t-1}$  are firm-specific.  $\rho$  and  $\pi$  in equation (9) are the average values of the firm-specific  $\rho_i$  and  $\pi_i$  parameters, respectively. Thus, we allow firms to have heterogeneous responses to environmental regulations. It is essential to allow for heterogeneous treatment effects since firms may have different price elasticities, and thus respond differently to relative price changes. Moreover, firms may respond differently to inspection violations. For example, one can envisage some firms that purchase the required technology when a violation is detected, and some firms that purchase the required technology when the regulator detects and classifies the violation as a serious one. We do not allow for random coefficients in the control variables in  $\mathbf{X}$ , because they are of secondary interest.

---

<sup>23</sup> By including the EU ETS dummy we separate the potential effect of the environmental taxes from the effects of the tradable EU ETS quotas, although they are probably very small, see also Section 3.2.2.



## 4.2 Results of the main specification

The results of the estimations of the main specification, equation (9), are shown in Table 4. We perform the analysis for the whole sample denoted alternative I, and an alternative sample, where we only include the energy-related emissions in the response variable,  $\Delta \ln(P/z_1)$ , denoted alternative II. This could potentially be of importance since indirect regulations are mainly directed towards energy related emissions. The sample in alternative II is thus more likely to identify the causal effects from indirect regulations.

If the response variable – the emission intensity – increases, the firm becomes *less* efficient. If environmental taxes through increased relative input price create incentives for emission intensity reductions, we expect the estimated coefficients on  $\ln(P_2/P_1)$  to be negative. This is the case for the estimated coefficient  $\rho$  which is equal to -0.10 and significant well below the 10 percent level (alternative I). This estimated coefficient can be interpreted as an elasticity: A 1 percent increase in the relative price leads to a 0.1 percent improvement in the emission intensity.

If the measure of direct regulation,  $V$ , increases, the firm is assumed to experience the regulation as stricter. Hence, if this creates an incentive for reducing the emission intensity, we expect a negative sign on the estimated coefficient of this variable. This is the case, as  $\pi$  is -0.08 and significant at the 5 percent level. Direct regulations also improve firms' environmental performance, in line with Cole *et al.* (2005) and Fères and Reynaud (2012) – among others. This coefficient is smaller than the estimated coefficient of the relative input price. However, 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 not capture the entire effect from this policy, since many firms are likely to adapt when they are required to, thus avoiding non-compliance.  $\pi$  should thus be interpreted as a lower bound for the effect of direct regulations.

Regarding the control variables, 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). As expected, the estimated coefficients for risk class 2 are higher than for risk class 3 with both alternatives since a change to a stricter risk class (2 is stricter than 3) 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 estimate related to capital intensity is positive (0.09) and significant at the 10 percent level. Hence, more capital intensive firms seem in general to be more dependent on dirty factor inputs and/or more pollution intensive processes. The number of employees has a negative estimated coefficient, significant at the 10 percent level. This indicates that there are 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, as a study of the causal effect of the EU ETS requires a different methodological approach (see Klemetsen *et al.* (2016a) for the effects of the EU ETS on Norwegian plants. 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.

Alternative II reports the results from the estimation using only the subsample of energy-related emissions. Compared to alternative I, the sample size is reduced from 3187 to 2100. Some drop in significance levels is therefore expected. The positive results with respect to the effects of indirect regulations on environmental performance are strengthened as  $\rho$  is -0.14, significant at the 5 percent level. This is expected, since we now only include energy-related emissions, the types of emission that are typically regulated by taxes. On the other hand, direct regulations are generally directed towards other types of emissions than energy-related ones. Therefore the drop in  $\pi$  to -0.05, as well as the loss of significance is expected, since few of the emissions in this sample are subjected to direct regulations. This is also the explanation for the loss in significance of the risk class dummies. This sample is preferred for estimating the effects of indirect regulations, while alternative I provides the preferred

Table 4: Results of the main specification

Explanatory variables:	Coef.	I		II <sup>1</sup>	
		Est.	S.E.	Est.	S.E.
$\Delta \text{Log of relative input prices}$	$\rho$	-.10*	.06	-.14**	.06
Violation status	$\pi$	-.08**	.04	-.05	.04
Control variables	$\beta$				
Risk class dummies <sup>2</sup>					
$\Delta D$ (Risk class = 1)	omitted				
$\Delta D$ (Risk class = 2)		3.91***	1.40	1.32	1.94
$\Delta D$ (Risk class = 3)		2.76***	.89	.69	1.36
$\Delta \text{Log of capital intensity}$		.09*	.05	-.11*	.06
$\Delta \text{Log of number of employees}$		-.09*	.06	.01	.04
EU ETS dummy		-.13	.15	-.17	.15
Constant	$\alpha$	.10	.14	-.03	.13
AR(1) coefficient ( $\Delta \varepsilon_{it}$ )	$\phi$	-.33***	.03	-.16***	.03
Equation		(9)		(9)	
Number of firm-year observations		3187		2100	
Number of firms		421		273	

NOTE: Full set of industry and year dummies included but not reported.

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1. Standard errors in parentheses.

<sup>1</sup>The response variable,  $\Delta \ln^D/z_1$ , only includes a sub-group of energy-related emissions

See Sections 3.2.2 and 4.1 for details.

<sup>2</sup>The reference category consists of firms in risk class 4. Risk class 1 is the strictest.

sample selection for investigating the effects of direct regulation.

The estimated coefficient of the control variable capital intensity changes sign, -0.11, thus firms in this subsample become less polluting when the capital intensity increases. These firms may have machinery or production processes that use less dirty input than the average firm in the total sample. We can no longer detect any scale effects, as the significance level on the estimate related to the number of employees has dropped. A plausible explanation is that the firms in this subsample are larger. The estimated AR-coefficient is halved in absolute value when the sample only consists of energy-related emissions.

### 4.3 Allowing Violation status to have non-linear effects

In the main specification (equation (9)), we have assumed linear effects from our measure of direct regulations, Violation status. This assumption might not hold. In this robustness analysis, we investigate whether Violation status have non-linear effects by including it through dummy variables. Instead of using the variable  $V \in [0, 1, 2]$  we include dummies for  $V = 1$  (denoted by  $V_1$ ) and  $V = 2$  (denoted by  $V_2$ ). The reference category is no violations ( $V = 0$ ). The new specification of the model is

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

Table 5 shows the results of the estimations of equation (10). The estimated coefficient of the dummy variable for a minor violation is -0.10, significant at the 10 percent level, and the estimated coefficient of the dummy variable for a serious violation is -0.18, which is significant at the 5 percent level. The coefficients are monotonically increasing as expected with the highest incentive for environmental improvements 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 4 are thus confirmed. The rest of the results in Table 5 are almost identical to alternative I in Table 4.

### 4.4 Persistent (long-term) effects

Finally, we test whether the two types of regulations provide persistent effects on environmental performance. We test whether such persistent effects exist by performing a test of asymmetric responses to stricter and more lax regulations, respectively. If the improvement is not offset when the regulation is relaxed, there are persistent effects of the regulation.

Firms can respond differently to stricter regulations. They can purchase or develop new technology (which is likely to lead to persistent effects since technology shifts are irreversible

Table 5: Results when  $V$  is represented through dummy variables

Explanatory variables:	Coef.	Est.	St.E.
$\Delta \text{Log of relative input prices}$	$\rho$	-.10*	.06
Violation status dummies			
Violation status = 1	$\pi_1$	-.10*	.06
Violation status = 2	$\pi_2$	-.18**	.09
Control variables	$\beta$		
Risk class dummies <sup>1</sup>			
$\Delta D$ (Risk class = 1)	omitted		
$\Delta D$ (Risk class = 2)		3.91***	1.40
$\Delta D$ (Risk class = 3)		2.76***	.89
$\Delta \text{Log of capital intensity}$		.09*	.05
$\Delta \text{Log of number of employees}$		-.06*	.04
EU ETS dummy		-.13	.15
Constant	$\alpha$	.10	.15
AR(1) coefficient ( $\Delta \varepsilon_{it}$ )	$\phi$	-.35***	.04
Equation		(10)	
Number of firm-year observations		3187	
Number of firms		421	

NOTE: Full set of industry and year dummies included but not reported

\*\*\* p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1. Standard errors in parentheses.

<sup>1</sup>The reference category consists of firms in risk class 4. Risk class 1 is the strictest.

– at least in the short run), or they can adjust their production activity and substitute clean for dirty input factors (temporary adaptations). Persistent effects are proven to exist if stricter regulations make the firm adapt e.g., by 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 its production activity through factor substitution, it is likely that the effect of a stricter regulation will cease if the regulation is reversed. Formally, this 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 input price and violation status) is zero over time. Symmet-

ric responses to stricter and more lax regulations imply that an increase in environmental performance over time can only be achieved by continuously enforcing stricter direct regulations or by increasing the relative factor input price. We return to this when discussing the results. Our first step is to estimate the equation:

$$\begin{aligned} \Delta \ln \left( \frac{D}{Z_1} \right)_{it}^* &= \alpha_t + \rho^+ \cdot D \left( \Delta \ln \left( \frac{P_2}{P_1} \right)_{it} > 0 \right) \cdot \Delta \ln \left( \frac{P_2}{P_1} \right)_{it} + \rho^- \cdot D \left( \Delta \ln \left( \frac{P_2}{P_1} \right)_{it} < 0 \right) \cdot \Delta \ln \left( \frac{P_2}{P_1} \right)_{it} \\ &+ \pi^+ \cdot D (\Delta V_{i,t-1} > 0) \cdot V_{i,t-1} + \pi^- \cdot D (\Delta V_{i,t-1} < 0) \cdot V_{i,t-1} + \beta \cdot \Delta X_{i,t-1} + \Delta \varepsilon_t \quad (11) \end{aligned}$$

We want to test the long-term effects of a temporary change in  $V$  and  $\ln(P_2/P_1)$ . A temporary change in the regulatory measure in year  $t$  is characterised by  $V_{t-1} = 0$ ,  $V_t = 1$ ,  $V_{t+1} = 0$ ; or  $\ln(P_2/P_1)_{t+1} = \ln(P_2/P_1)_{t-1}$ . The long-term effect on  $\ln(D/Z_1)_t$  is zero if  $\Delta \ln(D/Z_1)_t + \Delta \ln(D/Z_1)_{t+1} = 0$ , which is equivalent to symmetric effects from stricter and more lax regulations: *i*)  $\rho^+ - \rho^- = 0$  and *ii*)  $\pi^+ - \pi^- = 0$ .

The results are reported in Table 6, where alternative I entails the whole sample of emissions and alternative II entails energy-related emissions. Again, alternative I is appropriate for analyzing the effects of direct regulations whereas alternative II is appropriate for analyzing the effects of indirect regulations. The results of alternative I imply that there might be persistent effects of direct regulations. The estimated effect of an increase in the probability of being sanctioned ( $\Delta V = 1$ ) has a negative and significant effect on the emission intensity, whereas, when this regulatory enforcement vanishes ( $\Delta V = -1$ ), the estimated effect is not reversed (as the estimated coefficient is even positive but not significant). The results of alternative II implies that the estimated effect of indirect regulations are symmetric, however. An increase in the relative factor input price has only a slightly greater effect on emission intensity than the 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 regulations and

the effect of more lax regulations is equal to zero, i.e., we test the hypotheses *i)* and *ii)* above.

From Table 7, we see that hypothesis *ii)*  $\pi^+ - \pi^- = 0$  can be rejected well within the 10 percent significance level (p-value 0.064). Direct regulations thus provide persistent effects on the emission intensity. This result challenges the notion from the literature (Jaffe and Stavins, 1995; OECD, 2001; Perman *et al.*, 2011) that direct regulations do not provide continuous dynamic incentives. Firms that are exposed to direct regulations are still continuously incentivized to minimize the costs of achieving a given level of pollution even if the quota is fixed. Direct regulations may imply a high implicit (or shadow) cost of emissions, providing incentives for technological change and emissions reductions as confirmed by our data. Moreover, technology standards typically require firms to either use a specific Best Available Technology (BAT), or prohibit a specific dirty type of technology. If the standard is designed as a prohibition, firms may see it as profitable to develop the technology that later is defined as the BAT, as this may have a large market value (Perman *et al.*, 2011; Klemetsen *et al.*, 2016b). Prohibiting dirty technologies can thus spur a positive demand for clean technology alternatives. Finally, firms can be motivated by considerations of pre-emptiveness (Maxwell *et al.*, 2000), anticipating that the regulation is likely to become more stringent over time.

Moreover, continuous dynamic effects is only one of several factors that can generate persistent effects. There is considerable uncertainty about future prices and the development of clean technologies. Firms facing indirect regulations may want to postpone technology shifts due to this uncertainty. A benefit of direct regulations is that they send transparent signals to the firms. Insofar as technology shifts are irreversible in the short run, persistent effects of direct regulations are thus expected.

Table 6: Results of the dynamic specification (persistent effects)

Explanatory variables:	Coef.	I		II	
		Est.	St.E.	Est.	St.E.
<b>ΔLog of relative input prices</b>					
ΔLog of relative input prices: Δ > 0	ρ <sup>+</sup>	-.12*	.07	-.12**	.05
ΔLog of relative input prices: Δ < 0	ρ <sup>-</sup>	-.11*	.07	-.10	.08
<b>Violation status</b>					
ΔViolation status:Δ > 0	π <sup>+</sup>	-.15**	.07	-.06	.06
ΔViolation status:Δ < 0	π <sup>-</sup>	.03	.04	.03	.11
Control variables	β				
Risk class dummies <sup>1</sup>					
Δ D (Risk class = 1)	omitted			omitted	
Δ D (Risk class = 2)		3.88***	1.33	1.41	1.82
Δ D (Risk class = 3)		2.70***	.89	0.76	1.25
ΔLog of capital intensity		.11	.07	-.14	.11
ΔLog of number of employees		-.06	.13	.03	.10
EU ETS dummy		-.13	.26	-.20	.18
Constant	α	.07	.16	.10	.20
AR(1) coefficient (Δε <sub>it</sub> )	φ	-.34***	.02	-.19***	.03
Equation		(11)		(11)	
Number of firm-year observations		2734		1792	
Number of firms		384		241	

NOTE: Full set of industry and year dummies included but not reported.

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1. Standard errors in parentheses.

<sup>1</sup>The reference category consists of firms in risk class 4. Risk class 1 is the strictest.

Table 7: Tests of significance of long-term coefficients

Long-term coefficient	$H_0$	I		II	
		Est.	p-value	Est.	p-value
$\rho^+ - \rho^-$	$\rho^+ - \rho^- = 0$	-.01	.9230	-.02	0.8333
$\pi^+ - \pi^-$	$\pi^+ - \pi^- = 0$	-.18	.0664	-.12	0.5490



Next, we see that the hypothesis *i*)  $\rho^+ - \rho^- = 0$  cannot be rejected (p-value 0.8333 with alternative II). This result implies that a temporary stricter regulation (tax increase) will not have a persistent effect since the firms will simply substitute back to the initial factor input combinations when the relative input price decreases. However, Figure 3, Chart b) illustrates a positive trend in the relative input price in Norway in the estimation period. Hence we cannot exclude persistent effects of indirect regulations. The policy implication is that indirect regulations only have potential persistent effects on the emission intensity if environmental taxes (or purchaser prices on dirty energy) are increasing over time. Constant and/or increasing environmental taxes are necessary for tax instruments to create persistent and positive effects on environmental performance. 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 6), they are not very different from the main model (alternative I) in Table 4. However, we see that the significance levels of the log of capital intensity, log of number of employees and the EU ETS dummy have dropped.

We have also 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 take two years to reach full effect. The sum of the effects of indirect regulations over two years is found to be 0.22 (the sum of the estimated coefficients is significantly different from zero at the 5 percent level). The estimated full effect of direct regulations is 0.20 (significantly different from zero at the 10 percent level). Omitting lags of the explanatory variables means that our estimated main model specifications can be interpreted as long-run (steady-state) relationships between dependent and independent variables.

## 5 Conclusions

In this paper, we have analysed the effects on environmental performance measured as an emission intensity of both direct and indirect environmental regulations. Moreover, we test whether direct and indirect regulations generate persistent effects on emission intensities through technological improvements. Our firm-level data set allows us to analyze the effects of different types of regulations such as environmental taxes, non-tradable emission quotas, and technology standards.

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. 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 factor input price. Hence, constant and/or increasing environmental taxes are necessary if tax instruments are to have persistent effects on environmental performance. Finally, we find evidence that direct regulations lead to persistent effects on environmental performance. Even if the quota is fixed, non-tradable quotas may create an incentive for a 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. The likely increased demand and the lucrative possibility of patenting a BAT technology may generate large future income for the firm. There is considerable uncertainty about the development of future clean technologies and 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 send transparent signals to firms. Finally, firms can be motivated by other strategic concerns.

Insofar as environmental performance improvements are an aim for environmental regu-

lations, or if cost-efficiency may be difficult to obtain, there are no reasons to prefer one type of regulation over another. Hence, we may still use direct regulations when the conditions for these regulations are better.

## References

- Andreoni, J., Levinsohn, A. (2001): The simple analytics of the Environmental Kuznets Curve, *Journal of Public Economics* 80, 269-286.
- Bohm, P., Russel, C. (1985): Comparative Analysis of Alternative Policy Instrument, in Kneese, A.V. and Sweeney, J.L., (eds.). *Handbook of Natural Resource and Energy Economics* 1 (10). Elseviers Science Publishers, Amsterdam.
- de Bruin, S., Korteland, M., Markowska, A., Davidson, M., de Jong, F., Bles, M., Sevenster, M. (2010): *The Shadow Price Handbook - Valuation and weighting of emissions and environmental impacts*. CE Delft, Delft. Available at the homepage of CE Delft
- Bruvoll, A., Fæhn, T., Strøm, B. (2003): Quantifying central hypotheses on environmental Kuznets curves for a rich economy: A computable general equilibrium study, *Scottish Journal of Political Economy* 50, 149-173.
- Bruvoll, A., Medin, H. (2003): Factors behind the Environmental Kuznet's Curve, evidence from Norway, *Environmental and Resource Economics* 24, 27-48.
- Bruvoll, A., Larsen, B.M. (2004): Greenhouse gas emissions in Norway: Do carbon taxes work?, *Energy Policy* 32(4), 493-505.
- Cole, D., Grossman, P. (1999): When Is Command-and-Control Efficient? Institutions, Technology, and the Comparative Efficiency of Alternative Regulatory Regimes for Environmental Protection. *Wisconsin Law Review* 5, 887-938.
- Cole, M.A., Elliott, R.J.R., Shimamoto, K. (2005): Industrial characteristics, environmental regulations and air pollution: an analysis of the UK manufacturing sector, *Journal of Environmental Economics and Management* 50, 121-143.
- Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003, establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC, OJ L 275, 25/10/2003, 32-46.

- Féres, J., Reynaud, A. (2012): Assessing the Impact of Formal and Informal Regulations on Environmental and Economic Performance of Brazilian Manufacturing Firms, *Environmental and Resource Economics* 52, 65-85.
- Goulder, L., Mathai, K. (2000): Optimal CO<sub>2</sub>-abatement in the presence of induced technological change, *Journal of Environmental Economics and Management* 39, 1-28.
- Goulder, L., Parry, W. (2008): Instrument Choice in Environmental Policy. *Review of Environmental Economics and Policy*, 2(2), 152-174.
- Heine, D., Norregaard, J., Parry, W.H. (2012): Environmental Tax Reform: Principles from Theory and Practice to Date, IMF Working Paper, WP/12/180.
- Håndbok V712 - Konsekvensanalyser (2006): The Norwegian Public Roads Administration (NPRA)/Vegdirektoratet, Norway. Available at the website of NPRA
- Jaffe, A., Stavins, R. (1995): Dynamic incentives of environmental Regulations: The effects of alternative policy instruments on technology diffusion. *Journal of Environmental Economics and Management* 29, 43-63.
- Johnstone N., Hascis, I., Popp, D. (2010): Renewable energy policies and technological innovation: Evidence based on patent counts, *Environmental and Resource Economics* 45, 133-155.
- Keohane, N., Revesz, R., Stavins, R. (1998): The choice of regulatory instruments in environmental policy. *Harvard Environmental Law Review* 22(2), 313-367.
- Klemetsen, M., Rosendahl, K. E., Jacobsen, A. L. (2016a): ,The impacts of the EU ETS on Norwegian Plants' environmental and economic performance, Discussion Papers 833, Statistics Norway.
- Klemetsen, M., Bye, B., Raknerud, A. (2016b): Can non-market regulations spur innovations in environmental technologies? A study on firm level patenting, forthcoming in *The Scandinavian Journal of Economics*.

- Lucas, R.E.B., Wheeler, D., Hettige, H. (1992): Economic Development, Environmental Regulation, and the International Migration of Toxic Industrial Pollution: 1960-88. Policy Research Working Papers No. 1062, the World Bank.
- Maloney, M., Yandle, B. (1984): Estimation of the Cost of Air Pollution Control Regulation, *Journal of Environmental Economics and Management* 11, 244-263.
- Martin, R., de Preux, L., Wagner, U.J. (2014): The impact of carbon tax on manufacturing: Evidence from microdata, *Journal of Public Economics* 117 (Sept.), 1-14.
- Martin, R., Muûls, M., Wagner, U. J. (2016). The impact of the European Union Emissions Trading Scheme on regulated firms: What is the evidence after ten years? *Review of Environmental Economics and Policy* 10 (1), 129-148.
- Maxwell, J., Lyon, T., Hackett, S. (2000): Self Regulation and Social Welfare: The Political Economy of Corporate Environmentalism. *Journal of Law and Economics* 43(2), 583-618.
- Ministry of Finance (2007): En vurdering av særavgiftene, NOU 2007:8.
- Ministry of Finance (2013): Nasjonalbudsjettet 2013, St. meld. Nr 1 (2013–2014).
- Newell, R., Stavins, R. (2003): Cost Heterogeneity and the Potential Savings from Market-Based Policies. *Journal of Regulatory Economics* 23(1), 43-59.
- NVE (2013): Energiintensiv industri: En beskrivelse og økonomisk analyse, *Rapport* 69/2013, Norges vassdrag- og energidirektorat.
- Nyborg, K., Telle, K. (2006): Firms' Compliance to Environmental Regulation: Is There Really a Paradox? *Environmental and Resource Economics* 35, 1-18.
- OECD (2001): Tax and the Economy. A Comparative Assessment of OECD Countries. Tax Policy Studies No. 6, Organisation for economic co-operation and development, Paris.
- Palmer, A.R., Mooz, W.E., Quinn, T.H., Wolf, K.A. (1980): Economic Implications of Regulating Chlorofluorocarbon emissions from nonaerosol applications, Document Number: R-2524-EPA, U.S Environmental Protection Agency.

- Perman, R., Ma, Y., Common, M., Maddison, D., McGilvray, J. (2011). *Natural Resource and Environmental Economics*, 218-221, 4th ed. London: Longman.
- Reinelt, P. S., Keith, D. W. (2007): Carbon Capture Retrofits and the Cost of Regulatory Uncertainty, *Energy Journal* 28(4), 101-128.
- Rosendahl, K. E. (2000): Luftforurensninger – effekter og verdier (LEVE): Helseeffekter og samfunnsøkonomiske kostnader av luftforurensning., *Report*, (TA-1718/2000), Statens forurensningstilsyn.
- Stavins, R. (2001): “Experience with Market-Based Environmental Policy Instruments”. *Handbook of Environmental Economics* 1(9), 355-435.
- Telle, K. (2004): Effects of inspections on plants’ regulatory and environmental performance - Evidence from Norwegian manufacturing industries. Discussion Papers 381, Statistics Norway.
- Tietenberg, T. (1990): Economic Instruments for Environmental Regulation. *Oxford Review of Economic Policy* 6(1), 17-33.
- Wagner, U. J., Muûls, M., Martin, R., Colmer, J. (2014). The causal effects of the European Union Emissions Trading Scheme: Evidence from French manufacturing plants. Unpublished.
- Wiener, J. (1999). Global environmental regulation: Instrument choice in legal context. *The Yale Law Journal* 108(4), 677-800.

## Appendix

Table A.1: Energy use related emissions

Compound	Formula
Carbon dioxide	$CO_2$
Carbon monoxide	$CO$
Methane	$CH_4$
Sulfur	$S$
Sulfur oxides	$SO_x$
Nitrous oxide (laughing gas)	$N_2O$
Nitrogen oxides	$NO_x$
Non-methane volatile organic compounds	$NMVOC$
Volatile organic compounds	$VOC$
Arsenic	$AS$
Hexafluoroethane	$C_2F_6$
Cadmium	$CD$
Perfluoromethane	$CF_4$
Chromium(III)	$CR - 3$
Chromium(VI)	$CR - 6$
Chromium total	$CR - TOT$
Copper	$CU$
Mercury	$HG$
Lead	$PB$
Sulfur hexafluoride	$SF_6$
Zinc	$ZN$

NOTE: The 9 first pollutants are related to energy use. The remaining 12 are energy use related when emitted to air.