UNIVERSITY of SALZBURG

Environmental Regulation and Investment: Evidence from European Country-Industry Data

Andrea M. Leiter, Arno Parolini and Hannes Winner

Working Paper No. 2010-01

WORKING PAPERS IN ECONOMICS AND FINANCE

Environmental Regulation and Investment: Evidence from European Country-Industry Data

Andrea M. Leiter*, Arno Parolini†, and Hannes Winner‡

January 2010

Abstract

This paper contributes to the empirical literature on the relationship between environmental regulation and firm behavior. In particular, we ask whether and how strongly an industry's investment responds to stringency in environmental regulation. Environmental stringency is measured as (i) an industry's total current expenditure on environmental protection, and (ii) a country's revenue from environmental taxes. Focusing on European industry level data between 1995 and 2005, we estimate the differential impact of environmental stringency on four types of investment: gross investment in tangible goods, in new buildings, in machinery, and in 'productive' investment (investment in tangible goods minus investment in abatement technologies). Both environmental variables enter positively, and their quadratic terms exhibit significantly negative parameter estimates. This, in turn, indicates a positive but diminishing impact of environmental regulation on investment.

Keywords: Investment, environmental regulation, pollution abatement costs, Europe.

JEL classification: D92, H23, Q52

*Corresponding author: University of Innsbruck, Department of Economics and Statistics, Universitaetsstrasse 15, A-6020 Innsbruck, Austria; phone: +43-512-507-7404, fax: +43-512-507-2980, email: andrea.leiter@uibk.ac.at.

†University of Innsbruck, Department of Economics and Statistics, Universitaetsstrasse 15, A-6020 Innsbruck, Austria; email: arno.parolini@uibk.ac.at.

‡University of Salzburg and Oxford University Centre for Business Taxation; Kapitelgasse 5-7, 5010 Salzburg, Austria; email: hannes.winner@sbg.ac.at.

1 Introduction

Environmental economists typically arrive at very different conclusions about the impact of environmental regulation on firm behavior. For instance, one argument that has recently attracted increasing attention is that firms intend to locate their business activities in countries or regions where environmental standards are relatively low. By way of contrast, others emphasize the availability of (clean) natural resources as factor inputs. In this case, one would expect a positive rather than a negative impact of environmental regulation on firm activities.

This paper analyzes the role of environmental regulation on industry-specific investment in European countries. Unlike the previous literature mainly focusing on the effects of environmental stringency on international investment (i.e., locational choices of multinational firms), we ask whether tighter environmental standards are associated with higher or lower investment at *a given plant location*.[1] Specifically, we are interested in the differential impact of environmental regulation on four types of country-industry-specific investment: (i) gross investment in tangible goods, (ii) gross investment in construction and alteration of buildings (henceforth investment in new buildings), (iii) gross investment in machinery, and (iv) 'productive' investment, defined as the difference between gross investment in tangible goods minus investment in abatement technologies. Environmental regulation is measured as (i) an industry's total current expenditures on environmental protection, and (ii) a country's revenue from environmental taxes. Empirically, we rely on a dataset of 23 European countries and three industries (i.e., mining and quarrying, manufacturing and electricity, gas and water supply) between 1995 and 2005. This represents the lowest level of aggregation for environmental stringency available for a broader cross section of European countries.

Our empirical findings suggest that environmental regulation as measured by environmental expenditures and revenues from environmental taxation is positively related to (all types of) investment. Further, we observe a significantly negative quadratic term for both measures of en-

[1] There are only few papers on the impact of environmental regulation on local investment (see Garofalo & Malhotra 1995, Greenstone 2002, for U.S. evidence). We discuss these contributions below.

vironmental regulation. These findings are robust over a wide variety of sensitivity checks (e.g., when using emission-based indicators of environmental regulation such as total greenhouse gas emissions). Taking these results together, environmental regulation obviously reveals a positive but diminishing impact on investment in our sample of European countries and industries.

The paper is organized as follows. In Section 2, we briefly review the related empirical literature. Section 3 derives the empirical investment equation, where a special focus is given to the inclusion of environmental regulation. Section 4 summarizes the data and discusses the variables used in the empirical specification. In Section 5, we present the empirical findings and a sensitivity analysis. Section 6 concludes.

2 Previous empirical research: An overview

According to the survey of Jaffe, Peterson, Portney & Stavins (1995: 146) "*[t]wo sources of evidence can be used to investigate the sensitivity of firms' investment patterns to environmental regulations: changes in direct foreign investment and siting decisions for domestic plants*."[2] Thereby, studies on local investment at a given plant location are relatively scarce compared to the large body of research focusing on the role of environmental regulation on investment decisions of multinational firms (FDI).[3] Two notable exceptions are Garofalo & Malhotra (1995) and Greenstone (2002).

Garofalo & Malhotra (1995) rely on the manufacturing sector in 34 U.S. states between 1983 and 1989. They find a modest negative impact of pollution abatement expenditures on state-industry-specific net capital formation. Greenstone (2002) utilizes data from U.S. manufacturing firms and county-specific information on pollutant-specific attainment status between 1967 and 1987 (subsumed under four time periods). The empirical findings suggest that stringent regulations retard investment.

[2] One obvious reason to keep attention on both types of investment is that (the change in) foreign direct investment is, by definition, also included in local investment.

[3] See List & Co (2000), Brunnermeier & Levinson (2004) and Copeland & Taylor (2004), for excellent overviews over this literature.

By way of contrast, studies on environmental regulation and FDI are less clear with regard to the relationship between those variables.[4]

The focus of this paper is on the impact of environmental regulation on local, country-industry-specific investment. In this context, two important conclusions can be drawn from the above mentioned research. From a theoretical point of view, we can firstly derive three potential effects regarding the influence of environmental regulation on investment decisions of firms. The *'pollution haven hypothesis'* states that firms (especially from dirty industries) tend to locate their production activities in countries or regions with low environmental standards to avoid higher environmental compliance costs. In this case, we would expect a negative relationship between environmental regulation and investment. The *'factor endowment hypothesis'*, in contrast, emphasizes that abundance in (natural) resources improves the production possibilities of firms. Accordingly, industries may accept tighter regulations in order to benefit from abundant input factors, so that more stringent regulations do not necessarily reduce firm activities (see Copeland & Taylor 2004). Porter & van der Linde (1995) point out that properly designed environmental policies might increase the application of new, innovative technologies. This results from a company's incentive to invest in cleaner production technology to mitigate higher abatement costs (at a given production level). Such investments may either originate from local firms or from companies abroad (inward FDI) and may lead to higher productivity and, therefore, to an advantage over industries in other countries/regions without such regulations (in the following, we refer to this view as *'Porter hypothesis'*). Then, we would expect a positive impact of environmental regulation on investment activities of firms.

The second lesson that can be drawn from the previous research is that the estimation results are sensitive to the measurement of environmental regulation and to the empirical specification (see Jeppesen, List

[4]A negative association has been found, for example, by Xing & Kolstad (2002), List, Millimet, Fredriksson & McHone (2003), Brunnermeier & Levinson (2004), Jug & Mirza (2005), Spatareanu (2007), Dam & Scholtens (2008), Levinson & Taylor (2008). Positive effects of environmental regulation on FDI are observed in Levinson (1996), Cole & Elliot (2003), Dean, Lovely & Wang (2005) and Costantini & Crespi (2008). Mulatu, Florax & Withagen (2004), Javorcik & Wei (2004) and Cave & Blomquist (2008) provide mixed evidence on this issue.

& Folmer 2002 for a survey). Generally, environmental stringency relates to restrictions imposed on polluters to increase their cost of production. Such regulations include social and product norms, legal standards or emission charges. To proxy these dimensions of environmental policies, previous studies used pollution abatement costs (see Garofalo & Malhotra 1995, Gray & Shadbegian 1998, Keller & Levinson 2002, Levinson & Taylor 2008, Shadbegian & Gray 2005, Jug & Mirza 2005), environmental taxes (see see Levinson 1999, Dean, Lovely & Wang 2005), attainment status of counties regarding particular environmental regulations (see Greenstone 2002), pollutant emissions in tons (see Xing & Kolstad (2002), the difference between shadow and market price of the polluting input (see Van Soest, List & Jeppesen 2006), or composite measures in form of various indices (see List & Co 2000, Cagatay & Mihci 2006). We follow this lead using expenditures on environmental protection (i.e., abatement costs) as the first indicator of environmental regulation. Second, we refer to environmental taxation arguing that a high burden of such taxes is associated with tighter regulation (see Levinson 1999, Dean, Lovely & Wang 2005). Environmental tax burden is measured by the revenue from environmental taxes. Finally, we provide a sensitivity analysis, where both measures are replaced by emission-based indicators, i.e., waste water generated and greenhouse gas emissions.

With regard to the empirical specification, some authors point to the fact that the observed causal influence of environmental regulation on economic activities might be prone to endogeneity. Most importantly, environmental policy not only influences the behavior of firms, but probably is itself affected by firm activity (see Eliste & Fredriksson 2002, Cole, Elliott & Fredriksson 2006, on reversed causality between environmental regulation and trade and FDI). One obvious way to circumvent this problem is to use instrumental variable estimation. However, it turns out that it is nearly impossible to find convincing instruments varying over countries and industries.[5] Therefore, we use an alternative approach by treating the covariates as predetermined.[6]

3 Empirical specification

To estimate the impact of environmental regulation on investment we use a static (long run) framework as proposed by Garofalo & Malhotra (1995), Keller & Levinson (2002), Xing & Kolstad (2002) and Spatareanu (2007), among others.[7] Our basic specification reads as

$$\begin{aligned} I^k_{ic,t} =& \beta_1 E^{TCE}_{ic,t-1} + \beta_2 \left(E^{TCE}_{ic,t-1}\right)^2 + \beta_3 E^{REV}_{c,t-1} + \beta_4 \left(E^{REV}_{c,t-1}\right)^2 \\ &+ \beta_5 Q_{ic,t-1} + \beta_6 C_{ic,t-1} + \lambda_i + \mu_{ct} + \varepsilon_{ic,t}, \end{aligned} \tag{1}$$

where i, c and t are industry, country and time indices. Eq. (1) is estimated for four types of investment, denoted by the superscript k: gross investment in tangible goods (I^T), gross investment in new buildings (I^C), gross investment in machinery (I^M), and productive investments (I^P), defined as the difference between total investments in tangible goods and investments in abatement technologies. E^{TCE} indicates country-industry-specific expenditures on environmental protection, and E^{REV} represents a country's revenue from environmental taxes. The inclusion of our control variables, country-industry-specific output, Q, and the corresponding cash flow (difference between value added and labor cost), C, is mainly motivated by the empirical investment literature (see, e.g., Blundell, Bond & Meghir 1996). λ_i denotes industry-specific effects not varying over time. μ_{ct} indicates country-time-specific effects

[5] The instruments usually proposed by the literature (e.g., public infrastructure, availability of technological resources, labor force) are typically correlated with environmental regulation but also with economic activities (e.g., trade and FDI, but also investment), serving at best as weak instruments from an empirical point of view. Apart from this, these variables are typically not available annually at the country-industry level.

[6] Of course, this does not guarantee that endogeneity vanishes in our application. However, in section 4 we present evidence from an analysis of variance that such a (reversed) causality is rather unlikely in our sample of European industries (see Table 2 below).

[7] With the exception of Garofalo & Malhotra (1995) all other studies represent FDI-regressions. Our specification comes very close to the ones in these papers, with the difference that we leave out "trade"-specific variables such as bilateral distance, differences in factor input costs or relative market thickness.

including country and time effects as well as interactions thereof (e.g., the business cycle effects). ε is the remainder error.

Following the literature on dynamic investment functions, the dependent variable and each of the independent variables (except the dummy variables and the error term) are weighted by the country-industry-specific capital stock $K_{ic,t}$. Since this capital stock is not observable in our dataset, we use the perpetual inventory method to derive

$$K_{ic,t} = (1-\delta)K_{ic,t-1} + I^T_{ic,t}, \tag{2}$$

where δ denotes the economic depreciation rate.[8] The initial capital stock $K_{ic,0}$ is calculated as

$$K_{ic,0} = \frac{0.5(I^T_{ic,0} + I^T_{ic,1})}{\overline{\Delta I^T_{ic}}}, \tag{3}$$

with $\overline{\Delta I^T_{ic}}$ representing the country-industry-specific average growth rate of I^T.

Our dependent variable is a ratio, $\frac{I^k}{K}$, strictly bounded between zero and one. Using a logg-odds transformation, i.e., $\ln\left(\frac{I^k/K}{1-I^k/K}\right)$, as proposed by Wooldridge (2002: 662) results in a dependent variable which ranges over all real values. Consequently, parameters can be consistently estimated by OLS.

Investments in tangible goods, I^T, represent the main type of investment in our study. Investments in intangible goods like concessions, patents, licenses or software are excluded. We further refer to two subgroups of I^T, investments in new buildings, I^C, and in machinery, I^M.[9] The fourth type of investment that we rely on is productive investment,

[8] δ is calculated as a weighted average over the economic depreciation rates for machinery (12.25 percent) and for new buildings (3.61 percent). These rates are based on the empirical study of Hulten & Wykoff (1981). According to OECD (1991), the weights are 50 percent for machinery and 28 percent for new buildings (the remaining 22 percent are inventories, not included in our study). These weights are the usual ones taken in the literature.

[9] Investment in new buildings is relatively sticky in the sense that it is not as easy to reverse as investment in machinery. Consequently, firms relying predominantly on this type of investment are not as flexible to react to changes in environmental regulation as firms investing mainly in machinery (which might adjust investment easier on a short-term basis). From this, we would expect that investment in machinery is more sensitive to environmental stringency than investment in new buildings.

I^P, which is calculated as the difference between total investments in tangible goods and investments in abatement technologies.[10] Focusing on this type of investment we follow the previous research recommending to distinguish between capital available for production and abatement capital (see, e.g., Conrad & Wastl 1995, Garofalo & Malhotra 1995, Gray & Shadbegian 1998, Gray & Shadbegian 2003, or Shadbegian & Gray 2005). This allows for testing whether changes in investment are mainly driven by investments in abatement technology or not.

We use two measures of environmental stringency simultaneously. An industry's current expenditure on environmental protection, E^{TCE}, is a common proxy for environmental policies. The underlying idea is that pollution abatement costs are higher if a country imposes tighter environmental regulations. Similarly, it can be argued that environmental tax rates and, therefore, a country's revenue from environmental taxation, E^{REV}, is associated with stronger environmental stringency. In addition to the simple linear measures of environmental regulation, we include quadratic terms of both stringency variables to allow for the possibility that the effects of environmental regulation might change at tighter stringency levels (see, e.g., Jaffe, Peterson, Portney & Stavins 1995, Ederington, Levinson & Minier 2005).[11]

Finally, we treat the explanatory variables in eq. (1) as predetermined to avoid a possible endogeneity bias (see, e.g., Eliste & Fredriksson 2002, Copeland & Taylor 2004, Cole, Elliott & Fredriksson 2006, and Levinson & Taylor 2008). It should be noted that our specification in eq. (1) is very close to a standard investment function as proposed by the dynamic investment literature (see Blundell, Bond & Meghir 1996). The main difference to these studies is the omission of the lagged dependent

[10] Eurostat provides data on investments in equipments for pollution control that are part of gross investment in tangible goods. Such investments are "...resulting from actions and activities which have as their prime objective the prevention, reduction and elimination of pollution and any other degradation of the environment." (see Commission Regulation (EC) No 2700/98 of 17 December 1998, page L344/6). Subtracting environmentally induced investment from gross investment in tangible goods yields the volume of investment that is spent on productive technologies.

[11] A log-odds transformed model as ours automatically assumes a non-linear relationship between environmental regulation and investment. However, likelihood ratio tests provide evidence that quadratic terms of our stringency measures should be included in the empirical model.

variable. However, our indicators of environmental stringency are not varying much over time (at least for one variable; see the discussion in section 4). Therefore, it is nearly impossible to measure the impact of environmental stringency on investment precisely in a dynamic setting. In the robustness section we provide evidence that we arrive at qualitatively similar results to eq. (1) when including the lagged dependent variable in the empirical model.

4 The Data

Data description: The data are taken from the Eurostat databases. The variables used in the empirical analysis and a detailed description thereof are listed in Table A1 in the Appendix. Total current expenditures on environmental protection and revenues from environmental taxation are covered by the Environmental Accounts Database. Information on the country-industry-specific variables investment, output, value added and labor costs are available from the Annual Enterprise Statistics. Overall, our dataset includes 23 countries over a time period from 1995 to 2005.[12] It covers information from three industries according to the NACE 1-digit classification code: mining and quarrying, manufacturing and electricity, gas and water supply.[13]

Total current expenditures on environmental protection are country-industry-specific and represent the private costs for pollution abatement. They comprise all payments related to an industry's operating activities, such as payments of rents, use of energy, or the purchase of services. Transfers (e.g., payments of environmental taxes or fees) and depreciation allowances for environmental equipment are excluded, since these outlays are not directly related to services purchased to monitor, control or reduce negative consequences imposed on environment caused by

[12] Originally, the Eurostat database includes information from 27 EU member countries and five non-EU member countries (Croatia, Iceland, Norway, Switzerland and Turkey). Due to missing data, especially for the environmental variables, we exclude Croatia, Denmark, France, Greece, Iceland, Luxembourg, Malta, Switzerland, Turkey, leaving a sample of 23 European economies.

[13] Generally, these data are also available at the NACE 2-digit level. However, focusing on that lower level of aggregation would induce a serious loss of observations, so that we decided to rely on the NACE 1-digit level.

business activities (Eurostat 2005: 31). Revenue from environmental taxation is available at the country level,[14] and it includes revenues from energy, transport, pollution and resource (except oil and gas) taxation (see Eurostat 2001).

Descriptive statistics: Overall, our sample includes 690 observations. However, due to missing observations in the explanatory variables we only use around 420 observations. Tables A2 and A3 report the descriptive statistics of our main variables, Table A4 reports the corresponding correlation matrix. The average investment ratio (investment to capital stock) of tangible goods amounts to 9.2 percent, with a minimum of 0.4 and a maximum of around 42.8 percent. The mean of productive investment is about 9.0 percent, indicating that only a small fraction of overall investment in tangible goods is captured by environmental investments. Investments in new buildings (machinery) are around 2.2 (6.5) percent, on average. With regard to our measures of environmental stringency we can see that firms, on average, spend 0.7 percent of the capital stock per annum to meet environmental standards. Finally, revenue from country-specific environmental taxation amounts to about three quarters of the industry-specific capital stock, on average.

Figure 1 depicts the averages of the four investment ratios between 1995 and 2005. All of them increased steadily over the course of the years. For instance, the share of investment in tangible goods to capital stock increased from about 6 percent in 1995 to about 10.5 percent in 2005. The corresponding share of productive investments changed in a similar way, but is slightly below tangible goods, indicating again, that investment in environmental protection itself seems less of importance in our sample of European economies. Further, Figure 1 clearly demonstrates that the lion's share of investments in tangible goods is due to investments in machinery. The absolute share of investments in new buildings to capital stock stood relatively constant at a value of two percent (or about 20 percent of total tangible goods).

[14] Notice that the environmental tax revenue is divided by the country-industry-specific capital stock, so that this variable is also available at the country-industry level.

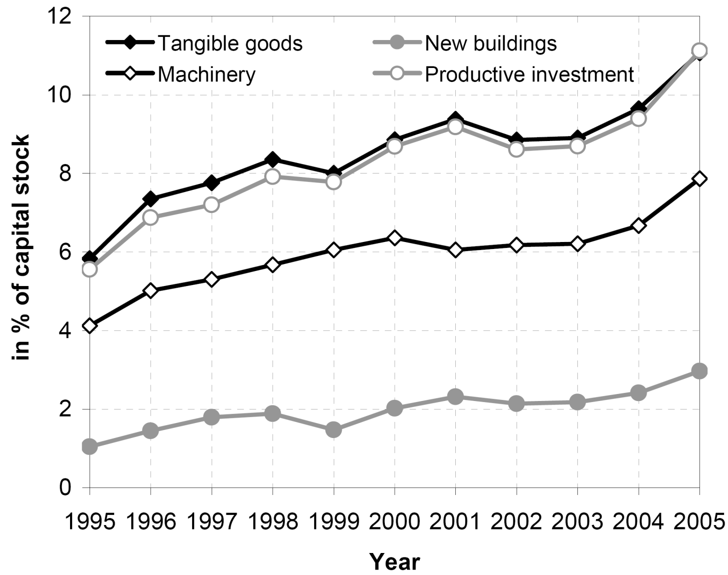


Figure 1: Types of investment, 1995-2005

Figure 2 provides information on our measures of environmental stringency, i.e., current expenditures on environmental protection (left-hand scale) and revenue from environmental taxation (right-hand scale), both related to industry-country-specific capital stocks. Expenditures on environmental protection are scattered around 0.6 percent until 2003. Since then, this share increased sharply up to 1.1 percent. Revenues from environmental taxation dropped from 55 percent to 37 percent between 1995 to 1996, and increased from 40 percent to 87 percent between 1996 and 2000. Afterwards, we observe values around 80 percent.

Generally, our measures of environmental regulation, and especially revenues from environmental taxation, are not varying much over time. This can be shown by means of an analysis of variance (ANOVA), where the total variance of both indicators are dissected into their major components: a set of dummy variables (the 'model') and a remaining error (the 'residual'). In our case, the model variance includes three main effects (country, industry and time) and three interactions (country$\times$industry, country$\times$time and industry$\times$time).[15] The ANOVA-results are presented

[15]Since we are only interested in the decomposition of the variance of the environmental stringency measures, we do not include any explanatory variables. Therefore,

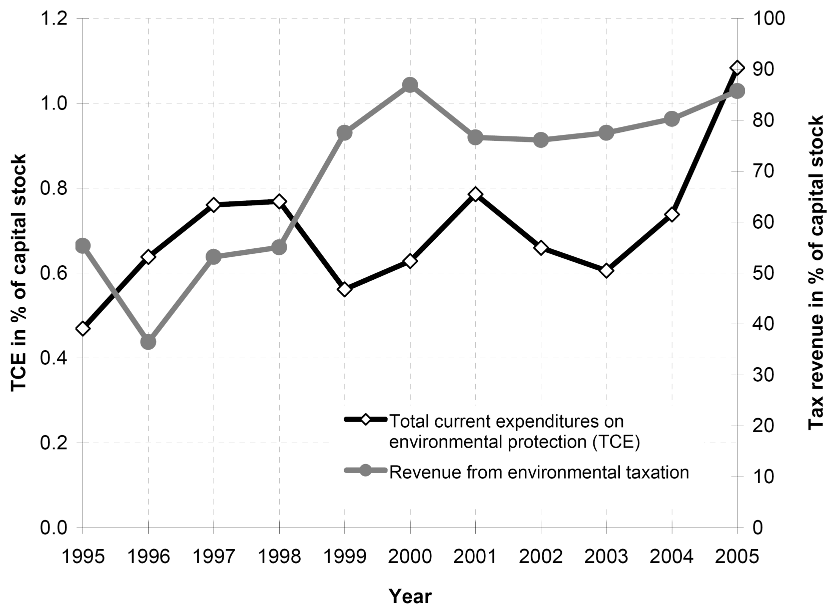


Figure 2: Environmental regulation, 1995-2005

in Table 1. Columns 1 and 2 (expenditures on environmental protection) and 6 and 7 (revenues from environmental taxation) inform about the absolute and relative share of each of the variance component on the total variance of the stringency measures. Accordingly, more than half of the variance in expenditures on environmental protection is due to time-invariant, country-industry-specific effects ($24.2 + 0.1 + 24.2 + 8.6 = 57.1$ percent), the remaining part is due to the time-variant dimension of this variable ($3.9 + 20.8 + 1.9 + 16.3 = 42.9$ percent). For revenue from environmental taxation, we observe a considerably lower share of time-varying components ($0.4 + 1.2 + 0.8 + 2.0 = 4.4$ percent). Therefore, it should be not surprising that this variable turns out insignificant in a dynamic panel data model. Our specification in eq. (1) includes industry, country and time fixed effects and interaction terms between country and time effects (along with the constant), wiping out 57.6 percent ($24.2 + 0.1 + 3.9 + 20.8 + 8.6$) of the total variation in E^{TCE} and 68.8 percent ($20.0 + 13.8 + 28.5 + 33.4$) in the variation of E^{REV}. There-

the model variance and the residual variance add up to the total variance. It is important to note that the main effects are nested in the interactions, putting a restriction on the parameters of the main and the interaction effects (i.e., the main effects add up to zero, and also the sum of the interactions is zero).

fore, the fixed effects in our empirical model leave out 42.4 (31.2) percent in the total variation of expenditures in environmental protection (revenue from environmental taxation). This should be enough variation to identify effects of environmental regulation on investment.

Next, let us focus on the relationship between our variables of interest, i.e., environmental stringency and investment. In Table 2, we decompose the variance in the change of investment ratios into several components: our measures of environmental stringency, E^{TCE} and E^{REV}, fixed country, industry and time effects as well as interactions between country and time effects (the choice of this set of dummy variables is suggested by Table 1). With regard to environmental stringency, we define two indicator variables taking a value of one if a change between the years $t-1$ to t is observed for each variable (in Table 2, this change is indicated as 'contemporaneous' change in E^{TCE} and E^{REV}). Table 2 contains three parts, differing with regard to the timing of the left-hand-side variable. The top panel refers to once-lagged changes of investment ratios (i.e., the change between the years $t-2$ and $t-1$). The panel in the middle relies on the contemporaneous change in investment ratios (i.e., a change between $t-1$ and t), and the bottom panel employs the lead of investment ratios (i.e., the change between t and $t+1$). Such an analysis might be useful to obtain information about the timing of investment decisions and about possible adjustment effects.

As can be seen from the bottom panel in the Table, both measures of environmental regulation are significant in explaining variation in post investment changes (the exception is investment in new buildings). With regard to contemporaneous changes in investment, environmental tax revenue enters significantly, but not current expenditures on environmental protection. Finally, we observe insignificant effects of environmental regulation on past investment growth (the exception here is investment in machinery, where we find weak significance for environmental tax revenue). Taking these findings together, environmental regulation today obviously affects investment tomorrow, but not today's and yesterday's investment decisions. Therefore, it seems that causation runs mainly from stringency to investment (for a discussion, see Cameron & Trivedi 2005: 749). This, in turn, strongly advocates a specification as in eq. (1),

Table 1: Analysis of variance for environmental stringency

	Environmental protection expenditures to capital stock					**Revenue from environmental taxation to capital stock**				
Source	Absolute	in %	d.f.	F-statistic	P-value	Absolute	in %	d.f.	F-statistic	P-value
Country effects	0.00607	24.2	21	13.9	0.000	134.11	20.0	21	94.1	0.000
Industry effects	0.00003	0.1	2	0.7	0.487	92.25	13.8	2	679.3	0.000
Time effects	0.00098	3.9	9	5.2	0.000	2.35	0.4	9	3.8	0.000
Country×industry effects	0.00607	24.2	41	7.1	0.000	191.00	28.5	41	68.6	0.000
Country×time effects	0.00520	20.8	131	1.9	0.000	7.99	1.2	131	0.9	0.746
Industry×time effects	0.00047	1.9	18	1.3	0.222	5.05	0.8	18	4.1	0.000
Constant (overall mean)	0.00216	8.6	1			223.92	33.4	1		
Model	0.02099	83.7	222	4.6	0.000	656.67	98.0	222	43.6	0.000
Residual	0.00409	16.3	197			13.38	2.0	197		
Total	0.02508	100.0	419			670.04	100.0	419		

Notes: 420 observations in both models. Adjusted R^2 is 0.837 for environmental expenditures and 0.958 for environmental tax revenue. d.f. . . . degrees of freedom.

Table 2: Analysis of variance of a change in investment ratios

Category (indicator variable)	*Type of investment*			
	I^T	I^C	I^M	I^P
Past change in investment: $I^k_{t-1} - I^k_{t-2}$				
Contemp. change in E^{TCE} (Partial *SS*)	0.0020	0.0000	0.0010	0.0020
	(0.240)	(0.906)	(0.402)	(0.264)
Contemp. change in E^{REV} (Partial *SS*)	0.0026	0.0002	0.0055	0.0026
	(0.182)	(0.311)	(0.053)	(0.201)
Model *SS*	0.4138	0.0805	0.3036	0.3758
Total *SS*	0.8353	0.1308	0.6891	0.8089
R^2	0.495	0.615	0.441	0.465
Observations	338	298	315	320
Contemporaneous change in investment: $I^k_t - I^k_{t-1}$				
Contemp. change in E^{TCE} (Partial *SS*)	0.0000	0.0004	0.0002	0.0000
	(0.940)	(0.164)	(0.696)	(0.994)
Contemp. change in E^{REV} (Partial *SS*)	0.0053	0.0000	0.0064	0.0056
	(0.055)	(0.959)	(0.034)	(0.059)
Model *SS*	0.5386	0.1147	0.3314	0.4905
Total *SS*	1.0633	0.1787	0.7785	1.0179
R^2	0.507	0.642	0.426	0.482
Observations	420	368	371	389
Post change in investment: $I^k_{t+1} - I^k_t$				
Contemp. change in E^{TCE} (Partial *SS*)	0.0112	0.0000	0.0092	0.0114
	(0.007)	(0.660)	(0.015)	(0.009)
Contemp. change in E^{REV} (Partial *SS*)	0.0080	0.0000	0.0077	0.0077
	(0.023)	(0.924)	(0.025)	(0.031)
Model *SS*	0.5015	0.1085	0.3259	0.4576
Total *SS*	0.9388	0.1587	0.7146	0.8975
R^2	0.534	0.684	0.4561	0.510
Observations	338	308	303	318

Notes: Country, industry and time effects as well as interaction terms between country and time effects are included in the 'model' but are not reported for the sake of brevity. *SS* ... Sum of squares. *p*-values in parentheses.

i.e., one where investment today is explained by once-lagged stringency measures.

Figures A1 to A4 in the Appendix provide further insights into the relationship between environmental stringency and investment. Specifically, we plot each of the four types of investment on each of the measures of environmental regulation, separately. The entries in the figures indicate country averages over time and industries, the dashed lines represent the average values from Table A2. Two important conclusions can be drawn from these graphs: First, there is large country level variation not only in investment ratios, but also with regard to the environmental variables. For instance, the share of investment in tangible goods to capital stock is lying between 2.6 percent (Cyprus) and 16.6 percent (Spain). Similarly, there are countries with an environmental tax revenue up to 10 percent (e.g., Cyprus, Romania); other ones obtain a revenue of nearly twice the capital stock (e.g., Spain or Latvia; see Table A3 in the Appendix). Second, and more importantly, there is obviously a positive relationship between all measures of environmental regulation and each type of investment (see the solid regression lines in the figures).

5 Empirical Results

5.1 Baseline results

Table 3 summarizes our empirical findings. The dependent variables, represented in columns 1 to 4, are gross investment in tangible goods, I^T, gross investment in new buildings, I^C, gross investment in machinery, I^M, and productive investment, I^P. Each of these variables is log-odds-transformed as described above. All variables reported in the table are weighted by the country-industry-specific capital stock, $K_{ic,t}$. In all models discussed below, we exclude observations with a remainder error in the upper and lower end percentile range (about 10 observations of the sample).

The model fit seems generally well. The R^2 measures are around 0.6, the fixed effects are highly significant throughout, and the control variables are broadly as expected. Output, Q, exhibits a significantly positive sign. The cash flow variable is only significant for investment in new buildings, but enters negatively, which is in line with the dynamic investment literature (see, e.g., Bond & Meghir 1994).

With regard to our variables of interest, let us briefly discuss our expectations before we present the corresponding empirical result. As suggested in Section 2, there are opposite hypothesis underlying the relationship between environmental regulation and investment. The pollution haven hypothesis motivates a negative association between both variables, while both the factor endowment as well as the Porter hypothesis would support a positive sign. Overall, we are not able to provide an unambiguous theoretical expectation on the relationship of interest. Depending on which view is dominant in the data, we would obtain a negative or a positive coefficient for our variables of environmental regulation.

Table 3: Estimation results

	Type of investment			
Independent variable	I^T	I^C	I^M	I^P
$(E^{TCE}/K)_{t-1}$	10.461***	11.454	23.470***	15.084***
	(3.855)	(10.734)	(6.587)	(5.004)
$(E^{TCE}/K)^2_{t-1}$	−29.311**	−31.700	−73.059***	−45.598***
	(12.984)	(37.658)	(22.696)	(16.692)
$(E^{REV}/K)_{t-1}$	0.372***	1.024***	0.604***	0.484***
	(0.113)	(0.246)	(0.131)	(0.139)
$(E^{REV}/K)^2_{t-1}$	−0.052***	−0.157***	−0.074***	−0.070***
	(0.019)	(0.040)	(0.022)	(0.023)
$(Q/K)_{t-1}$	0.161**	0.157	0.265***	0.177**
	(0.063)	(0.151)	(0.079)	(0.079)
$(C/K)_{t-1}$	0.137	−1.278***	−0.051	−0.097
	(0.300)	(0.427)	(0.363)	(0.381)
Observations	420	366	368	389
Adj. R^2	0.601	0.646	0.627	0.579
F-tests				
Industry effects	4.9***	15.8***	12.9***	5.3***
Country effects	$6.8\cdot10^8$***	279.9***	2,456.8***	235.7***
Time effects	6.2***	5.4***	5.7***	3.4***
Country×time effects	72.2***	122.3***	10.2***	35.8***

Notes: Constant and fixed effects not reported. Robust standard errors in parenthesis. *, ** and *** indicate 10%, 5% and 1% levels of significance.

From Table 3 we can draw the following conclusions. First, the parameter estimates for E^{TCE} and E^{REV} are significantly positive, indicating a positive impact of environmental regulation on investment. Second, the quadratic terms of both variables are significantly negative, suggesting that the positive effect of environmental regulation diminishes with tighter regulations. The exception is investment in new buildings (second column), where we only observe significant parameter estimates for environmental taxation but not so for expenditures on environmental protection (E^{TCE} and its square). Finally, we observe a positive but diminishing impact of both measures of environmental regulation on productive investment. The estimated parameters for this investment type are similar to the ones of investment in tangible goods indicating that investment in abatement technologies are not a driving force behind the observed relationship between environmental regulation and investment (see Table A4 in the Appendix).

Overall, our estimation results do not provide a clear picture regarding the predominance of either the pollution haven hypothesis or the Porter and the factor endowment hypothesis. While the positive parameter estimates lend support to the latter hypotheses, the negative quadratic coefficients tend to confirm the pollution haven hypothesis.

Table 4: Marginal effects and elasticities

	Type of investment			
	I^T	I^C	I^M	I^P
Total current expenditure on environmental protection: E^{TCE}				
Marginal effect	0.801	0.221	1.239	1.117
Elasticity	0.103	0.196	0.199	0.141
Revenue from environmental taxation: E^{REV}				
Marginal effect	0.024	0.016	0.027	0.030
Elasticity	0.054	0.254	0.077	0.069

Notes: Marginal effects and elasticities are evaluated at the mean values of environmental stringency variables and investment.

Our empirical findings from Table 3 clearly suggest that country-industry-specific investment is systematically affected by environmental regulation. But how important is this effect in quantitative terms? To answer this question we calculate marginal effects of environmental regulation and the corresponding elasticities, evaluated at the mean of investment and our measures of environmental stringency.[16] The results

[16]Our empirical model might be generalized as $\ln\left(\frac{I/K}{1-I/K}\right) = g(z)$, where $g(z)$ is given by the right-hand-side of eq. (1). Rewriting this expression as $\frac{I}{K} = \frac{e^{g(z)}}{1+e^{g(z)}}$,

are presented in Table 4. The marginal effect of a one percentage point change in environmental expenditure is around 0.8 for investments in tangible goods, which translates into an elasticity of around 0.1. Accordingly, a 10 percent increase (in the absolute level) in expenditures on environmental protection is associated with an increase in investment in tangible goods by about 1 percent. The corresponding elasticities for investment in new buildings and in machinery are much higher (around 0.2). For environmental tax revenues we obtain elasticities between 0.05 and 0.08, with the exception of investment in new buildings (about 0.25). Finally, we observe nearly identical (much higher) elasticities for I^C and (than) I^M with respect to E^{TCE} (E^{REV}), implying that investment in machinery does not respond more sensitively to environmental regulation than investment in buildings.

5.2 Robustness

We undertake several robustness checks, always based on our specification in eq. (1). First, we address the measurement of environmental stringency. Previous research has emphasized that pollution abatement costs might capture environmental stringency inappropriately (see, e.g., Jeppesen, List & Folmer 2002, Levinson & Taylor 2008). Therefore, we replace E^{TCE} and E^{REV} by emission-based measures of environmental stringency, i.e., information on waste water generated, E^{WW}, and total green house gas emissions, E^{GHG}. These variables are available from Eurostat's Water Database and Air Pollution/Climate Change Database,[17] where E^{WW} is available at the country-industry level and E^{GHG} is country-specific. We control for industry size by weighting emis-

and differentiating with respect to each variable of environmental regulation E^r/K $\forall r \in \{TCE, REV\}$ yields the marginal effect $\frac{\partial(I/K)}{\partial(E^r/K)} = \frac{[\partial g(z)/\partial E^r/K]e^{g(z)}}{[1+e^{g(z)}]^2}$, which can be evaluated at the mean values of (E^{TCE}/K) and (E^{REV}/K) holding the remaining right-hand-side variables of eq. (1) at their mean values.

[17] Waste water generated is defined as the quantity of water polluted during use by adding waste or heat (in cubic meters). The origin can be industrial or domestic use (used water from bathing, toilets, cooking etc.). Greenhouse gas emissions are based on the aggregated emissions of the six greenhouse gases of the 'Kyoto basket' (in 1000 tonnes CO_2-equivalents): carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

sion volumes with the number of enterprises within a country-industry pair. If high pollution intensities are a result of weak environmental regulation, we would expect a negative impact of E^{WW} and E^{GHG} on investment, which would be in line with the results from Table 3.[18] To account for possible non-linearities we include quadratic terms of both variables again.

The results of this robustness exercise are reported in Table A5. Obviously, the inclusion of E^{WW} and E^{GHG} reduces the sample size drastically. For total green house gas emissions, we observe significant parameter estimates for both the linear and the quadratic terms in all investment specifications. The negative coefficients on E^{GHG} and the positive signs of the quadratic terms seem to confirm our results from Table 3. Regarding E^{WW}, we find a significantly negative (positive) parameter estimate for investment in machinery (in new buildings). The corresponding quadratic terms are positive in the case of machinery and negative for new buildings. For investment in tangible goods and productive investment we obtain insignificant coefficients. Overall, our findings for E^{GHG} are in line with the parameter estimates from Table 3, which is not the case for E^{WW}, where we obtain ambiguous results.

In the second set of sensitivity analysis we include public subsidies intended to provoke environmental protection activities of firms as additional control variable.[19] Subsidies reduce a company's compliance costs and are, therefore, expected to stimulate industrial activities. On the other hand, if abatement costs are initially high it would be worthwhile for a firm to invest in environmental friendly technologies. Receiving a subsidy in this situation might reduce the abatement costs providing benefits for a firm to ignore environmental standards. In this case, sub-

[18] Most of the literature assumes that causality runs from environmental stringency to pollution intensity. Accordingly, weak environmental regulation causes a high pollution intensity. However, this causality might be reversed, so that higher pollution intensities increase the pressure to implement tighter regulations. In this case, we would find positive coefficients for E^{WW} and E^{GHG} and negative ones for their squares, contradicting our results from Table 3.

[19] Subsidies subsume all types of transfers financing environmental protection activities, and also transfers to or from other countries. If a country pays out more transfers than it receives from subsidies, a negative entry is recorded in the database (see Eurostat 2005: 83). The data are taken from the Eurostat's Environmental Accounts Database.

sidies are negatively associated with investment. In addition, Eliste & Fredriksson (2002), relying on the relationship between environmental regulation and trade, demonstrate that the estimation results might be seriously biased when leaving out subsidies from the empirical model. The estimation results in Table A6 indicate that this seems not the case in our sample of European industries. Again, we obtain significantly positive parameter estimates for both indicators of environmental regulation, and their squared terms exhibit significantly negative signs. For environmental subsidies itself we observe negative estimates (with the exception of investments in machinery), and positive coefficients for their squared variables.

Next, it might be argued that our estimation results are sensitive to the way that all variables are standardized in the empirical model. One particular caveat might be that we do not obtain the capital stock from the data, but calculate the corresponding series using the perpetual inventory method. To account for this argument, we use an alternative weighting scheme by dividing each variable of eq. (1) with country-industry-specific labor costs, $L_{ic,t}$, rather than the corresponding capital stock. Table A7 in the Appendix reveals that we loose about 50 to 100 observations now, depending on the type of investment. However, compared to the estimation results in Table 3 we arrive at similar conclusions about the impact of environmental regulation on investment when using this standardization. The only exception is that E^{TCE} and its squared term are now insignificant for investments in tangible goods, but we also observe significant parameter estimates for investment in new buildings, which were insignificant before.

Finally, we estimate a dynamic panel model rather than a static one. Such a specification has been proposed by Blundell, Bond & Meghir (1996) and Bond & Meghir (1994), among others. Specifically, we include a lagged dependent variable and its square on the right-hand-side of eq. (1), and estimate this model by applying a system GMM approach as developed by Blundell & Bond (1998). The estimation results are summarized in Table A8. The dynamic model seems to confirm our previous findings with regard to expenditures on environmental protection, but not so for revenues on environmental taxation, where we only obtain insignificant parameter estimates throughout.

Overall, our sensitivity analysis summarized in Tables A6 to A8 in the Appendix suggests that our results regarding the impact of environmental regulation on investment are qualitatively not contradicted when using alternative measures of environmental stringency, additional control variables or different empirical specifications.

6 Conclusions

There is no consensus among environmental economists whether environmental regulation causes a positive or a negative impact on firm behavior. Some authors argue that firms are low cost seekers and, therefore, reduce activities when they are confronted with tight environmental standards (pollution haven hypothesis). Others, in contrast, emphasize the role of (clean) natural resources and innovative technologies in the production process (factor endowment hypothesis and Porter hypothesis). Under this view, environmental regulation should foster firm activities.

In this paper we focus on investment decisions and assess how country-industry-specific investment is influenced by environmental regulation. We analyze four types of investment: Gross investment in tangible goods, gross investment in new buildings, gross investment in machinery and productive investments (investment in tangible goods minus investment in abatement technologies). Environmental stringency is measured as (i) total current expenditures on environmental protection, and (ii) revenue from environmental taxation. Our data set covers country-industry-specific information from 23 European countries and three industries (mining and quarrying, manufacturing, and electricity, gas and water supply) between 1995 and 2005.

Our empirical findings allow to derive a consistent picture about the effects of environmental regulation on investment. Both, total current expenditures and revenues from environmental taxation exert a positive impact on all types of country-industry-specific investment. However, the quadratic terms of both variables enter significantly negative, suggesting that the positive effects of environmental stringency are diminishing with tighter regulations. On average, we find elasticities of about 0.15 for expenditures on environmental protection, and around 0.06 for revenues from environmental taxation. In other words, a 10 percent increase in expenditures on environmental protection (revenue from environmental taxation) is associated with an increase in (country-industry-specific) investment of about 1.5 (0.6) percent. At first glance, our evidence from European countries and industries seems to contradict the findings of previous U.S. studies. However, the negative quadratic terms on environmental regulations suggest that the impact of stringency on investment turns out to be negative at tighter regulation regimes, so that the difference to previous research is not sharp.

The remaining question is how these findings fit into the above mentioned hypotheses regarding the impact of environmental stringency on firm behavior. As far as our country-industry-specific evidence can be inferred to firm-level behavior, the positive parameter estimates on both measures of environmental regulation lend support to the Porter and the factor endowment hypotheses. However, the negative coefficients of their quadratic terms indicate that the pollution haven hypothesis seems to hold if environmental regulation is relatively tight. After all, the evidence presented in this paper does not entirely confirm one of the above mentioned hypotheses on the impact of environmental regulation on investment decisions of firms.

Acknowledgments

We are grateful to Klaus Moeltner, Marc Nerlove, Harald Oberhofer, Michael Pfaffermayr, Matthias Stöckl and participants at seminars at the Universities of Innsbruck, Maryland (College Park), Munich and Nevada (Reno), and at the annual meetings of the European Association of Environmental and Resource Economists in Amsterdam (Netherlands) 2009 and the International Institute of Public Finance (IIPF) in Cape Town (South Africa) 2009, for valuable discussions and comments.

References

Blundell, R. & Bond, S. 1998, 'Initial conditions and moment restrictions in dynamic panel data models', *Journal of Econometrics* **87**, 115–143.

Blundell, R., Bond, S. & Meghir, C. 1996, Econometric models of company investment, *in* L. Matyas & P. Sevestre, eds, 'The econometrics of panel data: A handbook of the theory with applications', second edn, Vol. 33 of *Advanced Studies in Theoretical and Applied Econometrics*, Kluwer Academic, Boston and London, pp. 685–710.

Bond, S. & Meghir, C. 1994, 'Dynamic investment models and the firm's financial policy', *Review of Economic Studies* **61**, 177–222.

Brunnermeier, S. B. & Levinson, A. 2004, 'Examining the evidence on environmental regulations and industry location', *The Journal of Environment and Development* **13**, 6–41.

Cagatay, S. & Mihci, H. 2006, 'Degree of environmental stringency and the impact on trade patterns', *Journal of Economic Studies* **33**, 30–51.

Cameron, A. C. & Trivedi, P. K. 2005, *Microeconometrics: Methods and applications*, Cambridge University Press, Cambridge et al.

Cave, L. A. & Blomquist, G. C. 2008, 'Environmental policy in the European Union: Fostering the development of pollution havens?', *Ecological Economics* **65**, 253–261.

Cole, M. A. & Elliot, R. J. R. 2003, 'Do environmental regulations influence trade patterns? Testing old and new trade theories', *The World Economy* **26**, 1163–1186.

Cole, M. A., Elliott, R. J. R. & Fredriksson, P. S. 2006, 'Endogenous pollution havens: Does FDI influence environmental regulations?', *Scandinavian Journal of Economics* **108**, 157–178.

Conrad, K. & Wastl, D. 1995, 'The impact of environmental regulation on productivity in German industries', *Empirical Economics* **20**, 615–633.

Copeland, B. R. & Taylor, M. S. 2004, 'Trade, growth, and the environment', *Journal of Economic Literature* **42**, 7–71.

Costantini, V. & Crespi, F. 2008, 'Environmental regulation and the export dynamics of energy technologies', *Ecological Economics* **66**, 447–460.

Dam, L. & Scholtens, B. 2008, ‘Environmental regulation and MNEs location: Does CSR matter?’, *Ecological Economics* **67**, 55–65.

Dean, J. M., Lovely, M. E. & Wang, H. 2005, ‘Are foreign investors attracted to weak environmental regulations? Evaluating the evidence from China’, World Bank Policy Research Working Paper 3505.

Ederington, J., Levinson, A. & Minier, J. 2005, ‘Footloose and pollution-free’, *The Review of Economics and Statistics* **87**, 92–99.

Eliste, P. & Fredriksson, P. G. 2002, ‘Environmental regulations, transfers, and trade: Theory and evidence’, *Journal of Environmental Economics and Management* **43**, 234–250.

Eurostat 2001, *Environmental taxes — A statistical guide*, Luxembourg. http://epp.eurostat.ec.europa.eu/pls/portal/docs/PAGE/PGP_DS_ENVACC/PGE_DS_ENVACC/TAB63667842/2.PDF.

Eurostat 2005, *Environmental expenditure statistics: Industry data collection handbook*, Luxembourg. http://epp.eurostat.ec.europa.eu/pls/portal/docs/PAGE/PGP_DS_ENVACC/PGE_DS_ENVACC/TAB63667842/4.PDF.

Garofalo, G. A. & Malhotra, D. M. 1995, ‘Effect of environmental regulations on state-level manufacturing capital formation’, *Journal of Regional Science* **35**, 201–216.

Gray, W. B. & Shadbegian, R. J. 1998, ‘Environmental regulation, investment timing, and technology choice’, *The Journal of Industrial Economics* **46**, 235–256.

Gray, W. B. & Shadbegian, R. J. 2003, ‘Plant vintage, technology, and environmental regulation’, *Journal of Environmental Economics and Management* **46**, 384–402.

Greenstone, M. 2002, ‘The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures’, *Journal of Political Economy* **110**(6), 1175–1219.

Hulten, C. R. & Wykoff, F. C. 1981, The measurement of economic depreciation, *in* C. R. Hulten, ed., ‘Depreciation, inflation, and the taxation of income from capital’, Washington D.C., pp. 81–125.

Jaffe, A. B., Peterson, S. R., Portney, P. R. & Stavins, R. N. 1995, ‘Environmental regulation and the competitiveness of U.S. manufacturing: What does the evidence tell us?’, *Journal of Economic Literature* **33**, 132–163.

Javorcik, B. S. & Wei, S. 2004, 'Pollution havens and foreign direct investment: Dirty secret or popular myth?', *Contributions to Economic Analysis & Policy* **3**, 1–32. http://www.bepress.com/bejeap/contributions/vol3/iss2/art8.

Jeppesen, T., List, J. A. & Folmer, H. 2002, 'Environmental regulations and new plant location decisions: Evidence from a meta-analysis', *Journal of Regional Science* **42**, 19–49.

Jug, J. & Mirza, D. 2005, 'Environmental regulations in gravity equations: Evidence from Europe', *World Economy* **28**, 1591–1615.

Keller, W. & Levinson, A. 2002, 'Pollution abatement costs and foreign direct investment inflows to U.S. states', *The Review of Economics and Statistics* **84**, 691–703.

Levinson, A. 1996, 'Environmental regulations and manufacturer's location choices: Evidence from the Census of Manufacturers', *Journal of Public Economics* **62**, 5–29.

Levinson, A. 1999, 'State taxes and interstate hazardous waste shipments', *American Economic Review* **89**, 666–677.

Levinson, A. & Taylor, M. S. 2008, 'Unmasking the pollution haven effect', *International Economic Review* **49**, 223–254.

List, J. A. & Co, C. Y. 2000, 'The effects of environmental regulations on foreign direct investment', *Journal of Environmental Economics and Management* **40**, 1–20.

List, J., Millimet, D. L., Fredriksson, P. G. & McHone, W. W. 2003, 'Effects of environmental regulations on manufacturing plant births: Evidence from a propensity score matching', *The Review of Economics and Statistics* **85**, 944–952.

Mulatu, A., Florax, R. J. G. M. & Withagen, C. 2004, 'Environmental regulation and international trade: Empirical results for Germany, the Netherlands and the US, 1977-1992', *Contributions to Economic Analysis and Policy* **3**, 1–28.

OECD 1991, 'Taxing Profits in a Global Economy: Domestic and International Issues', Paris.

Porter, M. E. & van der Linde, C. 1995, 'Toward a new conception of the environment-competitiveness relationship', *Journal of Economic Perspectives* **9**, 97–118.

Shadbegian, R. J. & Gray, W. B. 2005, 'Pollution abatement expenditures and plant-level productivity: A production function approach', *Ecological Economics* **54**, 196–208.

Spatareanu, M. 2007, 'Searching for pollution havens: The impact of environmental regulations on foreign direct investment', *Journal of Environment and Development* **16**, 161–182.

Van Soest, D. P., List, J. A. & Jeppesen, T. 2006, 'Shadow prices, environmental stringency, and international competitiveness', *European Economic Review* **50**, 1151–1167.

Wooldridge, J. M. 2002, *Econometric analysis of cross section and panel data*, MIT-Press, Cambridge and London.

Xing, Y. & Kolstad, C. D. 2002, 'Do lax environmental regulations attract foreign investment?', *Environmental and Resource Economics* **21**, 1–22.

Table A1: List of variables and variable definitions

Variable abbreviation	Description
Gross investment (dependent variable)	
(I^T/K)	Gross investment in tangible goods (in % of capital stock)
(I^C/K)	Gross investment in construction and alteration of buildings (in % of capital stock)
(I^M/K)	Gross investments in machinery and equipment (in % of capital stock)
(I^P/K)	Productive investment (in % of capital stock): Gross investment in tangible goods minus investment in abatement technolgies
Independent variables	
(E^{TCE}/K)	Total current expenditures on environmental protection (in % of capital stock)
(E^{REV}/K)	Revenue from total environmental taxation (in % of capital stock)
(Q/K)	Output (in % of capital stock)
(C/K)	Cashflow (value added minus labor costs; in % of capital stock).
Variables used in sensitivity analysis	
(E^{SUB}/K)	Public subsidies for financing environmental protection activities (in % of capital stock)
(E^{WW}/N)	Waste water generated (in million m^3 per enterprise)
(E^{GHG}/N)	Emission of greenhouse gases (CO2 equivalent; in million tons per enterprise)
Variables used for calculation	
K	Capital stock (in million euros), inferred from gross investments in tangible goods via perpetual inventory method
N	Number of enterprises registered in the business register
I^E	Total investment in environmental protection; sum of investment in pollution treatment and investment in pollution prevention (in million euros)
L	Labor costs (in million euros)
V	Value added at factor costs (in million euros)

Table A2: Descriptive Statistics

Variable	Obs.	Mean	Std.Dev.	Min.	Max.
Dependent variable: Gross investment to capital stock (in % of capital stock)					
Tangible goods	420	9.19	5.04	0.35	42.83
New buildings	368	2.19	2.21	0.0007	14.67
Machinery	371	6.46	4.59	0.27	40.91
Productive investment	389	8.96	5.12	0.32	42.65
Independent variables (in % of capital stock)					
Total current expenditures on environmental protection	420	0.73	0.78	0.00	7.09
Revenue from environmental taxation	420	74.31	126.46	1.96	598.64
Output	416	107.34	76.26	1.30	503.16
Cash flow	412	17.48	17.42	−8.51	202.49
Additional variables used in the sensitivity analysis					
Public subsidies to capital stock (in %)	210	3.61	15.54	−120.47	116.90
Waste water generated per enterprise (in thousand m^3)	221	832.04	2,501.52	0.00	17,549.43
Total greenhouse gas emissions per enterprise (in thousand tons)	398	202.61	317.68	0.84	2,427.06
Variables used for calculation					
Capital stock (in billion euros)	420	62.47	128.32	0.04	849.98
Number of enterprises (in tsd.)	416	37.51	96.40	0.01	56.85
Gross investment in tangible goods (in billion euros)	420	4.69	9.07	0.05	58.59
Gross investment in constructions (in billion euros)	368	0.71	1.26	0.0002	7.19
Gross investment in machinery (in billion euros)	371	3.99	8.14	0.003	51.21
Investment in abatement technology (in million euros)	389	180.36	355.51	0.00	2,207.34
Total current expenditures on environmental protection (in million euros)	420	603.71	1,570.56	0.00	10,702.30
Environmental tax revenue (in billion euros)	420	10.81	15.61	0.07	57.35
Value added (in billion euros)	413	27.52	65.61	0.02	42.95
Labor costs (in billion euros)	412	16.59	46.56	0.07	385.01
Public subsidies (in billion euros)	210	362.33	416.91	−248.32	1,718.99
Greenhouse gas emissions (in million tons CO_2 equivalent)	402	218.30	263.69	8.37	1,036.33
Waste water generated (in million m^3)	223	431.44	773.01	0.00	4,235.00

Table A3: Descriptive Statistics at the country and industry-level

Observational Unit	(I^T/K)	(I^C/K)	(I^M/K)	(I^P/K)	(E^{TCE}/K)	(E^{Rev}/K)
Countries						
Austria	6.33	1.05	4.65	6.09	0.57	17.61
Belgium	5.75	0.57	5.01	5.47	0.78	89.36
Bulgaria	13.72	3.84	9.55	12.88	1.10	40.55
Cyprus	2.58	0.89	1.65	2.47	0.13	10.64
Czech Republic	7.17	1.77	3.55	6.84	0.72	15.18
Estonia	13.00	4.25	8.14	12.46	0.98	44.51
Finland	7.93	1.18	5.71	7.44	0.66	157.55
Germany	6.12	0.41	5.38	–	1.45	95.22
Hungary	8.35	2.67	5.44	8.07	0.49	125.75
Italy	8.21	0.73	7.12	7.26	1.56	86.76
Latvia	14.66	5.18	8.82	14.57	0.17	172.62
Lithuania	11.05	5.37	4.06	11.05	0.46	64.57
Netherlands	6.17	1.70	4.14	5.95	0.66	34.47
Norway	7.71	2.26	5.54	8.44	0.64	12.90
Poland	7.95	3.51	7.62	7.23	1.78	27.18
Portugal	8.56	0.09	7.51	8.57	0.18	42.01
Romania	6.35	2.94	3.49	6.11	0.27	6.37
Slovakia	7.87	2.29	4.46	7.52	0.72	40.80
Slovenia	14.02	4.80	8.65	12.93	1.22	139.57
Spain	16.58	1.65	14.13	15.78	0.50	189.04
Sweden	8.07	1.12	6.47	7.65	0.43	67.18
United Kingdom	7.10	1.23	5.55	6.69	0.51	28.24
Industries						
Mining & Quarrying	9.21	1.97	6.59	9.12	0.72	207.13
Manufacturing	9.22	1.91	6.81	9.01	0.79	8.42
Electricity, Gas, Water	9.15	2.69	5.90	8.79	0.67	32.57

Notes: All entries represent the mean values of the corresponding variables, expressed in % of the capital stock.

Table A4: Correlation matrix

	Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1)	Investment in tangible goods	1.00	0.55	0.82	0.99	0.08	0.23	0.20	0.57	-0.17	-0.02	-0.11
(2)	Investment in new buildings	0.62	1.00	0.37	0.55	0.11	0.05	0.07	0.20	-0.28	0.16	0.05
(3)	Investment in machinery	0.81	0.12	1.00	0.82	0.12	0.25	0.11	0.40	-0.08	-0.08	-0.09
(4)	Productive investment	0.99	0.61	0.80	1.00	0.05	0.23	0.19	0.56	-0.17	-0.01	-0.11
(5)	Total current expenditures on environmental protection	0.00	0.02	0.04	-0.01	1.00	0.14	0.36	0.16	-0.01	0.26	0.17
(6)	Revenue from environmental taxation	0.30	-0.10	0.44	0.30	-0.08	1.00	0.29	0.30	0.06	0.00	-0.04
(7)	Output	0.17	-0.07	0.32	0.15	0.45	-0.29	1.00	0.58	-0.01	0.06	-0.07
(8)	Cash flow	0.35	-0.07	0.42	0.36	0.23	-0.08	0.47	1.00	0.01	0.06	-0.06
(9)	Public subsidies to capital stock	-0.26	-0.11	-0.23	-0.28	0.10	0.15	-0.17	-0.33	1.00	0.01	0.18
(10)	Waste water generated per enterprise	-0.08	-0.06	-0.04	-0.07	0.12	-0.07	0.04	0.01	-0.02	1.00	0.58
(11)	Total greenhouse gas emissions per enterprise	-0.15	-0.11	-0.12	-0.14	-0.04	0.14	-0.23	-0.14	0.03	0.75	1.00

Notes: Entries for demeaned variables $(x_i - \bar{x})$ above the diagonal. All variables except waste water generated and total greenhouse gas emissions are weighted by the country-industry-specific capital stock.

Table A5: Alternative measures of environmental stringency (sensitivity)

	Type of investment			
Independent variable	I^T	I^C	I^M	I^P
$(E^{WW}/N)_{t-1}$	0.001	0.121*	−0.150***	0.019
	(0.027)	(0.069)	(0.036)	(0.032)
$(E^{WW}/N)^2_{t-1}$	−0.000	−0.012*	0.007***	−0.001
	(0.001)	(0.006)	(0.002)	(0.002)
$(E^{GHG}/N)_{t-1}$	−1.455***	−3.094***	−1.394***	−1.817***
	(0.269)	(1.106)	(0.441)	(0.388)
$(E^{GHG}/N)^2_{t-1}$	0.728***	3.315***	0.493*	0.966***
	(0.166)	(1.241)	(0.279)	(0.336)
$(Q/K)_{t-1}$	0.362***	0.555***	0.246*	0.466***
	(0.081)	(0.176)	(0.128)	(0.091)
$(C/K)_{t-1}$	0.671	−2.444**	2.007**	0.484
	(0.442)	(1.192)	(0.856)	(0.450)
Observations	264	204	219	212
Adj. R^2	0.760	0.834	0.754	0.713
F-tests				
Industry effects	20.8***	8.6***	19.7***	21.7***
Country effects	293.9***	155.6***	$1.8{\cdot}10^{5***}$	9.9***
Time effects	356.3***	250.7***	$7.6{\cdot}10^{5***}$	106.9***
Country×time effects	$3.3{\cdot}10^{4***}$	$1.1{\cdot}10^{4***}$	$9.3{\cdot}10^{4***}$	$69.5{*}{*}{*}$

Notes: Constant and fixed effects not reported. Robust standard errors in parenthesis. *, ** and *** indicate the 10%, 5% and 1% level of significance.

Table A6: Inclusion of subsidies (sensitivity)

	Type of investment			
Independent variable	I^T	I^C	I^M	I^P
$(E^{TCE}/K)_{t-1}$	21.696***	13.129	23.364**	22.308***
	(5.642)	(22.325)	(9.692)	(5.829)
$(E^{TCE}/K)^2_{t-1}$	−68.234***	−23.871	−77.464**	−68.737***
	(18.258)	(76.118)	(32.343)	(19.053)
$(E^{REV}/K)_{t-1}$	0.447***	1.336***	0.569***	0.445***
	(0.133)	(0.301)	(0.181)	(0.150)
$(E^{REV}/K)^2_{t-1}$	−0.051**	−0.175***	−0.052*	−0.049**
	(0.021)	(0.048)	(0.028)	(0.023)
$(E^{SUB}/K)_{t-1}$	−0.257**	−0.765**	−0.007	−0.252*
	(0.128)	(0.332)	(0.175)	(0.139)
$(E^{SUB}/K)^2_{t-1}$	0.015*	0.025	0.028	0.014
	(0.009)	(0.233)	(0.121)	(0.009)
$(Q/K)_{t-1}$	0.034	0.170	−0.134	0.035
	(0.087)	(0.244)	(0.113)	(0.108)
$(C/K)_{t-1}$	3.364***	−1.869	4.629***	3.278***
	(0.812)	(1.629)	(1.043)	(0.964)
Observations	199	172	169	188
Adj. R^2	0.627	0.695	0.653	0.631
F-tests				
Industry effects	10.9***	36.7***	6.5***	6.3***
Country effects	9.5***	74.7***	1,199.5***	319.4***
Time effects	369.7***	15.3***	9.1***	94.6***
Country×time effects	6.6***	8.1***	7.8***	38.3***

Notes: Constant and fixed effects not reported. Robust standard errors in parenthesis. *, ** and *** indicate the 10%, 5% and 1% level of significance.

Table A7: Weighting by labor costs (sensitivity)

	Type of investment			
Independent variable	I^T	I^C	I^M	I^P
$(E^{TCE}/L)_{t-1}$	1.819	3.725**	4.685***	5.518**
	(1.911)	(1.788)	(1.408)	(2.538)
$(E^{TCE}/L)^2_{t-1}$	−1.613	−5.151*	−5.238***	−4.448
	(2.276)	(2.671)	(1.609)	(2.903)
$(E^{REV}/L)_{t-1}$	0.135***	0.082***	0.113***	0.119***
	(0.027)	(0.031)	(0.025)	(0.031)
$(E^{REV}/L)^2_{t-1}$	−0.002***	−0.001**	−0.002***	−0.001*
	(0.001)	(0.001)	(0.001)	(0.001)
$(Q/L)_{t-1}$	0.063***	−0.011	0.058***	0.076**
	(0.019)	(0.022)	(0.021)	(0.034)
$(C/L)_{t-1}$	0.080	0.148	−0.030	−0.176
	(0.209)	(0.107)	(0.137)	(0.274)
Observations	293	348	319	280
Adj. R^2	0.753	0.643	0.634	0.655
F-tests				
Industry effects	26.7***	26.9***	8.7***	19.0***
Country effects	$7.0 \cdot 10^9$***	215.8***	271.6***	$1.7 \cdot 10^4$***
Time effects	120.9***	41.6***	6.2***	80.4***
Country×time effects	404.0***	3.9***	$2.6 \cdot 10^4$***	$4.6 \cdot 10^7$***

Notes: Constant and fixed effects not reported. Robust standard errors in parenthesis. *, ** and *** indicate the 10%, 5% and 1% level of significance.

Table A8: Dynamic model (sensitivity)

Independent variable	*Type of investment* I^T	I^C	I^M	I^P
Lagged investment ratio	0.804***	0.854***	0.487***	0.813***
	(0.078)	(0.056)	(0.117)	(0.075)
(Lagged investment ratio)^2	−4.929***	18.031	2.957	−6.174***
	(1.545)	(27.660)	(2.463)	(1.847)
$(E^{TCE}/K)_{t-1}$	0.292**	0.139	0.524**	0.349**
	(0.142)	(0.245)	(0.236)	(0.147)
$(E^{TCE}/K)^2_{t-1}$	−11.229**	−5.413	−15.108*	−13.799***
	(5.143)	(9.418)	(8.994)	(5.327)
$(E^{REV}/K)_{t-1}$	0.006	−0.009	0.028	0.011
	(0.062)	(0.128)	(0.086)	(0.065)
$(E^{REV}/K)^2_{t-1}$	0.008	0.005	0.020	0.006
	(0.015)	(0.029)	(0.020)	(0.016)
$(Q/K)_{t-1}$	−0.024	−0.041	0.216**	−0.054
	(0.053)	(0.068)	(0.097)	(0.061)
$(C/K)_{t-1}$	1.055***	0.078	0.258	1.271***
	(0.174)	(0.248)	(0.185)	(0.212)
Observations	330	273	284	316
Time effects (χ^2)	14.1	25.6***	5.9	18.6**
Hansen (χ^2)	47.1	39.0	42.7	41.5
	[1.000]	[1.000]	[1.000]	[1.000]
AR(1)	−4.0	−2.5	−2.5	−3.6
	[0.000]	[0.011]	[0.012]	[0.000]
AR(2)	−0.8	0.9	0.7	−1.1
	[0.426]	[0.350]	[0.497]	[0.266]

Notes: Constant and time effects not reported. Robust standard errors in parenthesis. P-values in brackets. *, ** and *** indicate the 10%, 5% and 1% level of significance.

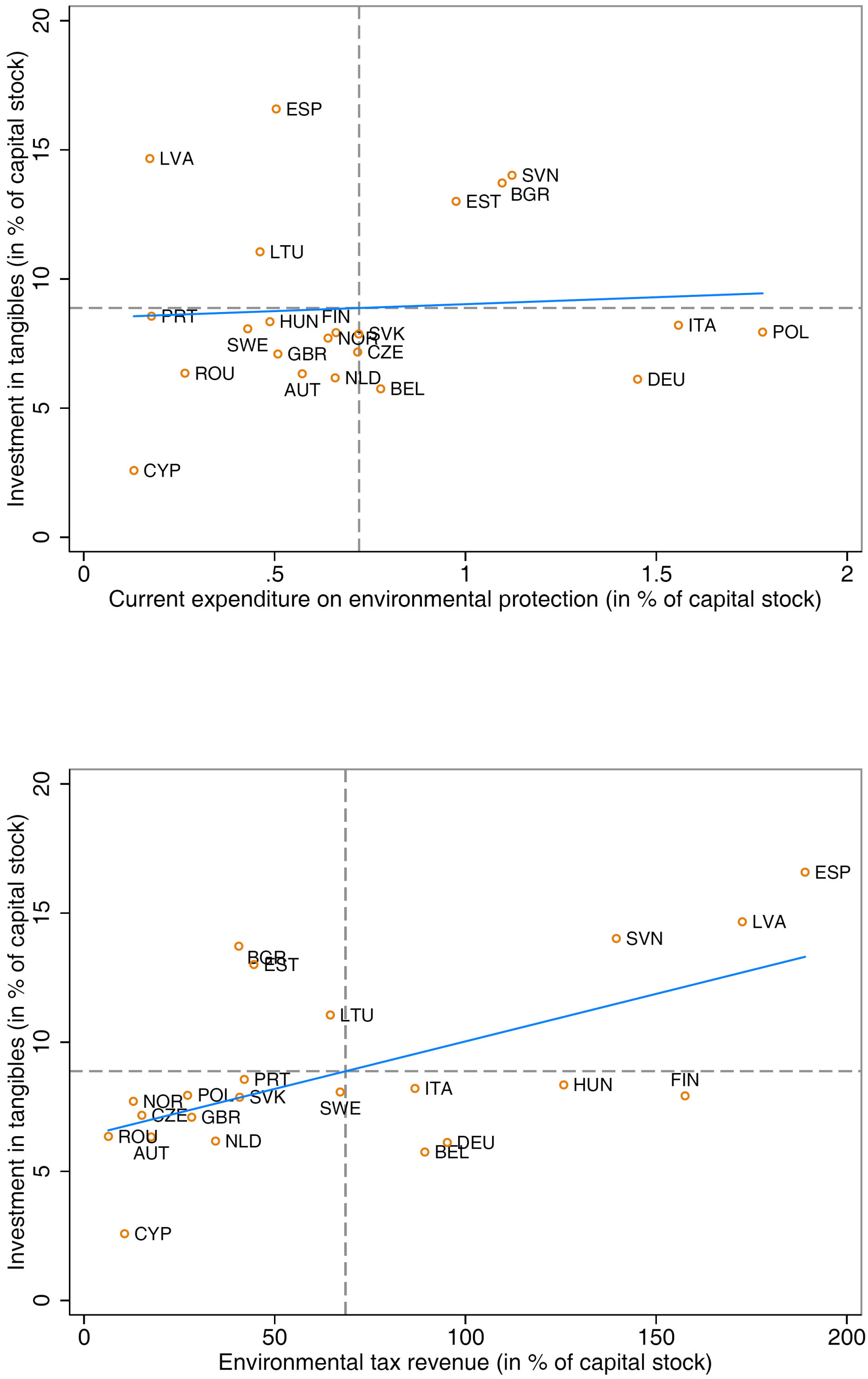
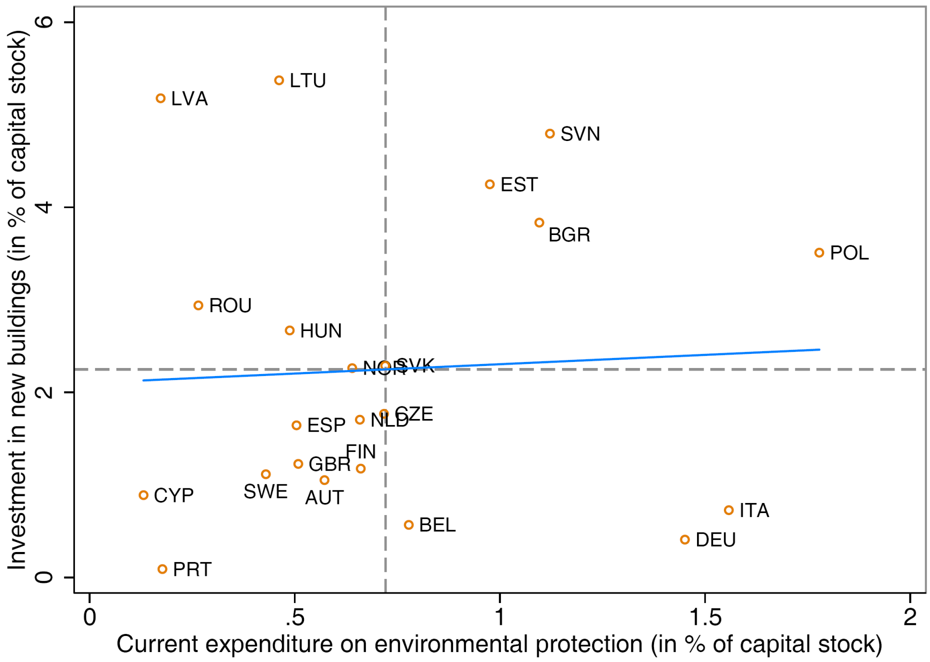


Figure A1: Investment in tangible goods and environmental stringency



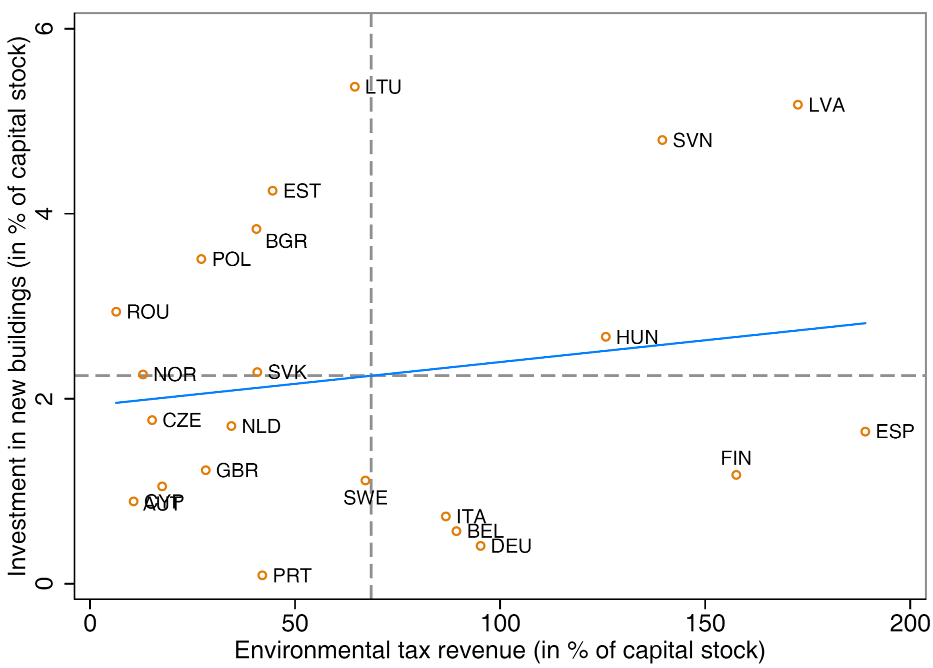
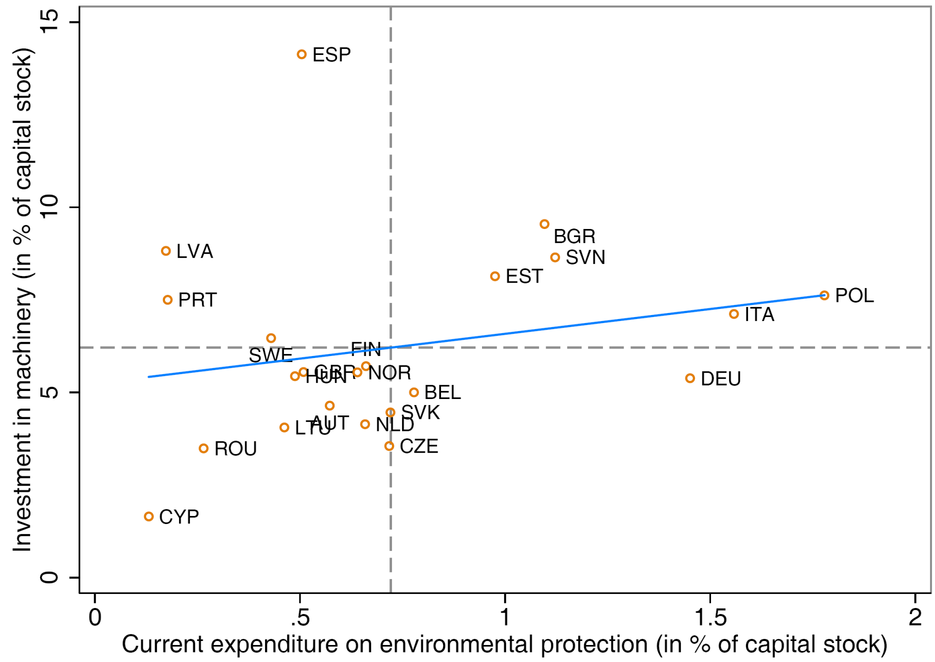


Figure A2: Investment in new buildings and environmental stringency



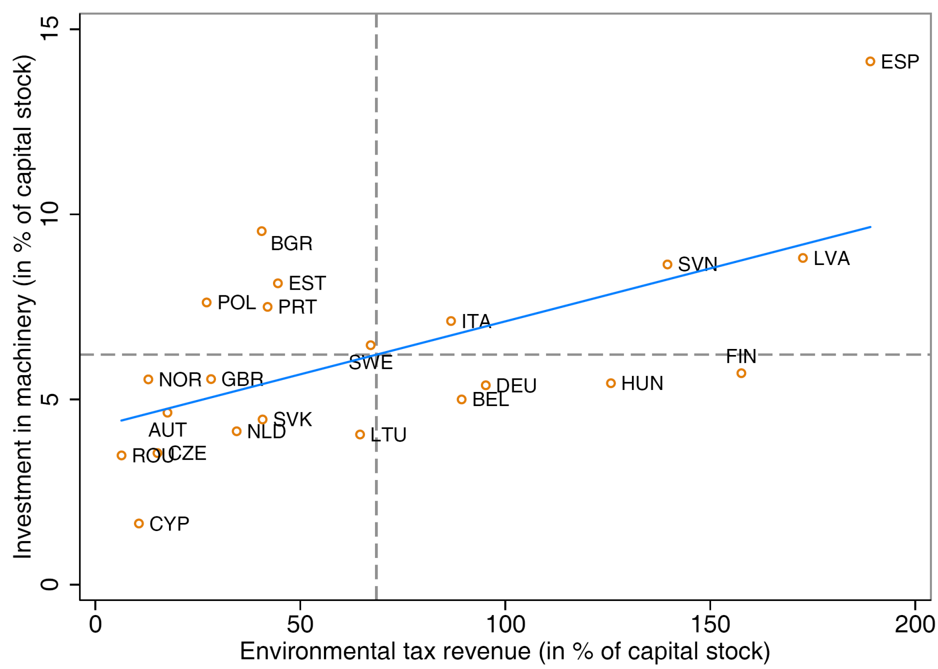
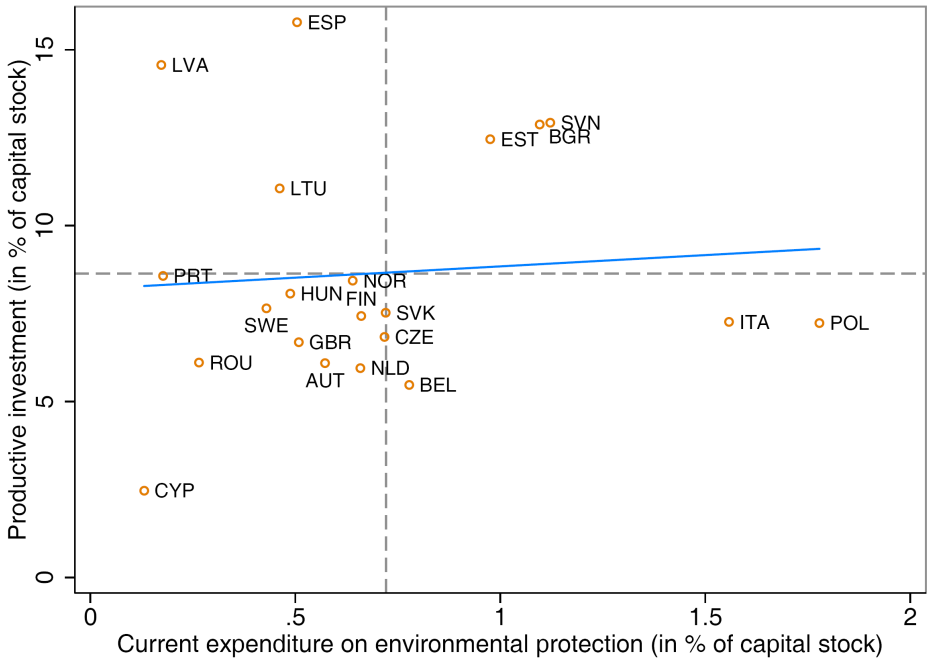


Figure A3: Investment in machinery and environmental stringency



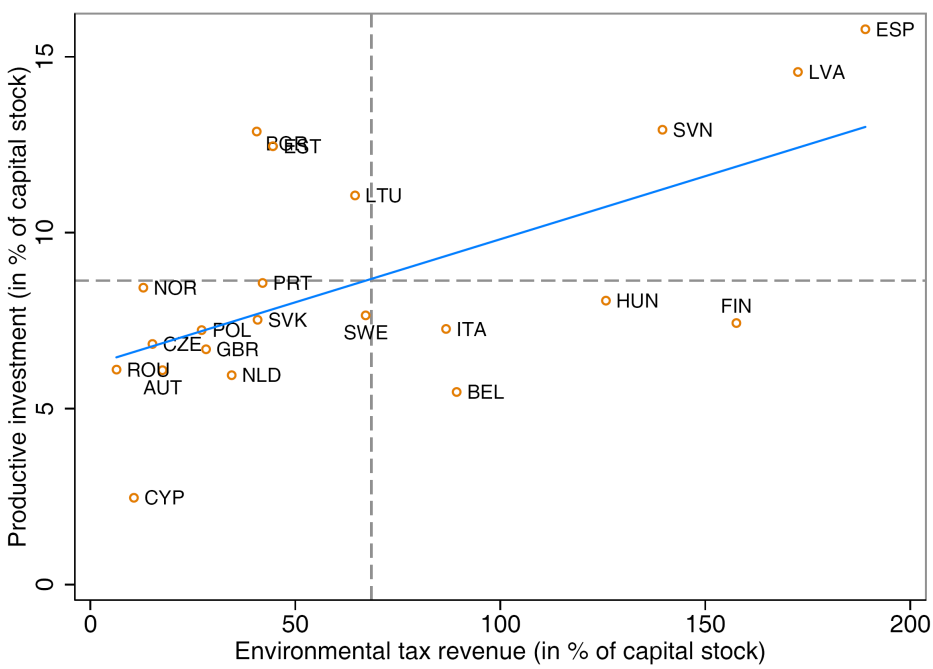


Figure A4: Productive investment and environmental stringency