

# Can non-market regulations spur innovations in environmental technologies?

A study of firm-level patenting

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# Market-based vs Non-market based regulations

**Market based regulation** –e.g., taxes, subsidies, tradable quotas

- Flexibility: encourage behavior through prices rather than explicit directives
- First-best. But in reality:
  - uncertainty about marginal damages
  - not strictly rational agents

**Non-Market based regulation** –e.g. technology standards, non-tradable emission quotas

- Most common today
- In practice necessary when regulator faces complex problems

# Literature review

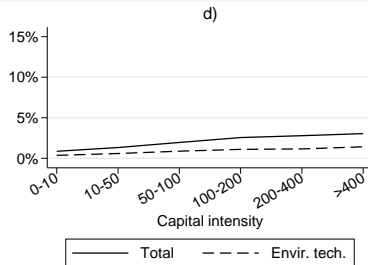
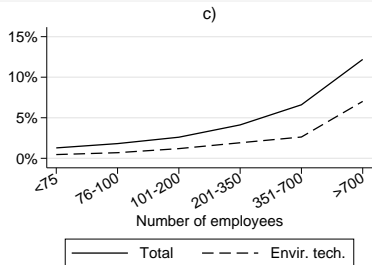
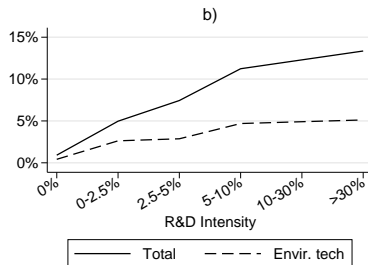
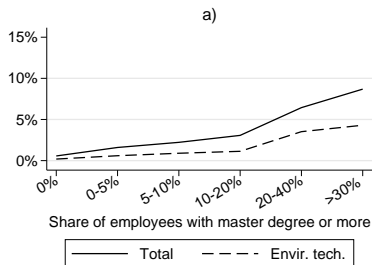
- Conventional theory: **Market-based policies create stronger incentives for innovation** (Downing & White, 1986; Milliman & Prince, 1989; Jung, Krutilla & Boyd, 1996; Wenders, 1975, Zerbe, 1970)
- Other examples of theory: **Depends on assumptions** (Fischer, Parry & Pizer, 2003; Malueg, 1987; Dietz & Michaelis, 2004)
- Empirical studies including non-market regulation: Brunnermeir & Cohen, 1999; Popp, 2003

# Research question and contribution

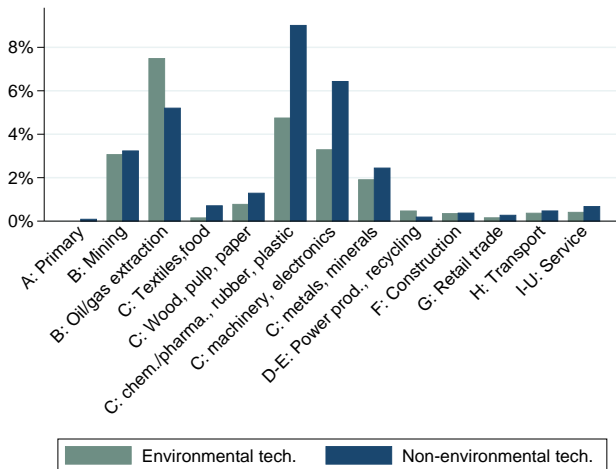
Can non-market regulations spur environmental patenting?

- Using firm level data
  - Non-tradable emission permits *are* firm/plant specific
  - Controlling for firm characteristics
- Better identify regulatory costs for the firm of non-market regulation
- Data on the entire population of Norwegian pollutants

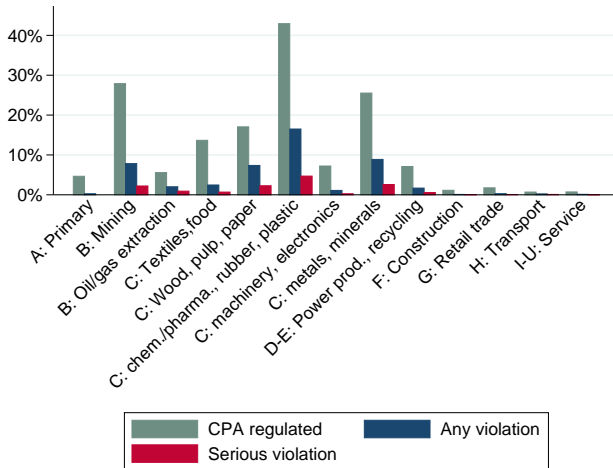
# Firm characteristics & patenting



# Patenting by industry



# Regulation by industry



# Industry distribution

Table 1: Distribution over industries 1993-2010

Industry	Obs. (firm years)	Perc. of obs.
Primary	2,365	1.8 %
Mining and extraction	696	0.5 %
Oil/gas extraction	1,135	0.9 %
Manufacturing (textiles, food)	8,895	7.0 %
Manufacturing (wood, pulp, paper)	2,435	1.9 %
Manufacturing (chem./pharmac., rubber, plastic)	1,892	1.5 %
Manufacturing (metals, minerals)	4,563	3.6 %
Manufacturing (machinery, electronics)	9,932	7.7 %
Power production/recycling	2,180	1.7 %
Construction	7,927	6.2 %
Retail trade	22,669	17.7 %
Transport	9,740	7.6 %
Services	51,088	39.9 %

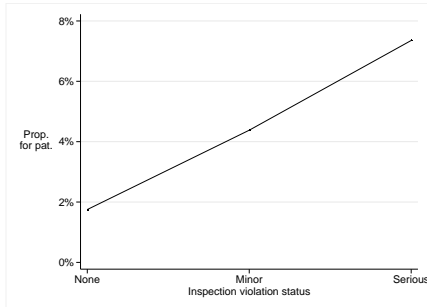


# Non-market regulation

- In Norway polluting is prohibited. Emitting firms need a permit from the Norwegian Environment Agency (EA)
- To measure regulatory costs, we must identify the **binding aspect of the regulation, and how strict the regulation is**
- Jaffe and Stavins (1995) model implicit costs of violating non-market regulations as the **probability that a sanction is imposed on the firm**

## Non-market regulation: Implicit violation costs, $V$

- Sanctions depend on the severity of violations:  
None/minor/serious,  $V_t \in \{0, 1, 2\}$
- In most cases, a warning letter is sufficient to make firms comply (Nyborg & Telle, 2004). Regulatory costs from sanction warnings are a **binding** aspect of the regulation



# Measures of non-market regulation

$V_t \in \{0, 1, 2\}$  measures **implicit regulatory costs of sanctions:**

- Threat of close-down and/or prosecution
- Fines
- Local stigma, bad publicity

# Risk Class

Table 2: EA regulatory costs by risk class

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

Risk class dummies ( $R_{t-1} \in \{1, 2, 3, 4\}$ ) capture risk class fixed effects, including **other regulatory costs**:

- inspection frequency, inspection and permit costs
- emission level

## Measure of Innovation (response variable)

- Environmental patent applications
- Environmental technologies identified using International Patent Classification codes

The response variable  $P$  is ordered:

Environmental Patent Application	Value	Obs. (firm years)
No envir. patent application	0	39,555
1 envir. patent application	1	466
> 1 envir. patent applications	2	291

## Econometric specification

$$P_{it}^* = \pi \cdot V_{it} + \sum_{k=1}^4 \gamma_k \cdot I(R_{i,t-1} = k) + \beta \cdot \mathbf{X}_{i,t-1} + v_i + \varepsilon_{it}$$

where  $\mathbf{X}_t$  represents exogenous variables (**firm** and **industry** specific),  $v_i$  firm specific random effect, and  $\varepsilon_{it}$  (i.i.d.) error term.

$$P_t = j \text{ iff } P_t^* \in [\lambda_j, \lambda_{j+1}], \quad j = 0, 1, 2$$

- Main parameters of interest are  $\pi$  and  $\gamma_1 - \gamma_4$ , representing effects from non-market based regulation
- $\pi$  reflects implicit costs of violations
- $\gamma_1 - \gamma_4$  reflect risk class fixed effects including other regulatory costs

# Descriptive statistics of main variables (1993–2010)

Table 3: Summary statistics 1993-2010

Variable	Obs.	Mean	Std. dev	Min	Max
$P_t$	40,312	.03	.20	0	2
$V_t$	40,312	.05	.25	0	2
Dummy for					
$R_t = 1$	40,312	.02	.13	0	1
$R_t = 2$	40,312	.03	.16	0	1
$R_t = 3$	40,312	.07	.25	0	1
$R_t = 4$	40,312	.02	.14	0	1
Control variables					
R&D intensity	37,790	.02	5.00	0	483
R&D tax credit	40,312	.35	.48	0	1
Profit margin	39,490	18.13	1794.05	-67,989	155,870
Capital intensity	36,367	.46	18.69	0	2,047
Share of high-skilled employees	37,438	.04	.10	0	1
Number of employees	37,659	139.62	484.50	0	27,710
Tradable quotas and environmental taxes	40,312	.01	1.09	0	175
Electricity price	39,981	25.10	11.39	0	41
162 (9×18) industry-year specific fixed effects					

Table 4: Ordered Probit Model with Random Effects

Response variable: Environmental Patent Applications Explanatory variables:	(1) Full sample <sup>1</sup>		(2) EA regul. sample <sup>2</sup>		
	Coef.	Est.	S.E.	Est.	S.E.
Implicit costs of violations	$\pi$	.48***	(.14)	.49***	(.13)
Risk class dummies <sup>3</sup>					
Risk class = 1	$\gamma_1$	.44*	(.24)	.46*	(.28)
Risk class = 2	$\gamma_2$	.30*	(.16)	.03	(.25)
Risk class = 3	$\gamma_3$	.13	(.18)		
Risk class = 4	$\gamma_4$	-.26	(.25)		
Control variables	$\beta$				
R&D intensity <sup>4</sup>		.05*	(.03)	1.07***	(.23)
Electricity price		-.04	(.04)	-.07	(.07)
Profit margin		-.05	(.14)	.02	(.05)
Size (employees)		.28***	(.04)	.04***	(.01)
Share of high-skilled employees		2.31***	(.23)	3.16***	(.66)
Capital intensity		.01	(.01)	.06	(.09)
Market-based regulation		-.14	(.88)	-.31	(.90)
Fraction of variance due to ind. effect ( $v$ )		.60***	(.03)	.62***	(.02)
Number of firm-year observations		34,838		10,409	
Number of firms		3,709		707	

NOTE: Full set of interactions between industry and year dummies ( $18 \times 9 = 162$  coefficients) included but not reported.

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

<sup>1</sup>Only polluting industries (see section 3.4). <sup>2</sup>Firms with EA emission permits.

<sup>3</sup>The reference category is firms without permits in the full sample, and  $R \in [3, 4]$  in the EA sample.

<sup>4</sup>In the EA sample, R&D intensity is replaced with a dummy for whether the firm obtained public R&D tax credit.



## Results cont'd

Table 5: Wald-tests of parameter restrictions

Test of:	(1) Full sample p-value (d.f.)	(2) EA regul. sample p-value (d.f.)
i) Tests of joint overall significance:		
All $\gamma$ -and $\pi$ -parameters are equal to 0	.0008 (5)	.0005 (3)
All $\gamma$ -parameters are equal to 0	.3530 (4)	.2149 (2)
ii) Tests of equality of coefficients:		
All $\gamma$ -parameters are equal	.2552 (3)	.1366 (1)

NOTE: In model (2) the coefficients  $\gamma_3$  and  $\gamma_4$  are not included (they belong to the comparison group)

We clearly reject that there is no connection between the propensity to patent and non-market based regulatory costs

Table 6: Linear Probability Model with Binary Response Variable

Response variable: Environmental Patent Applications Explanatory variables:	(1)		(2)		S.E.
	Coef.	Random effects Est.	Fixed effects Est.	S.E.	
Implicit costs of violations	$\pi$	.018***	(.008)	.018***	(.008)
Risk class dummies <sup>1</sup>					
Risk class = 1	$\gamma_1$	.035*	(.028)	.107***	(.021)
Risk class = 2	$\gamma_2$	.016*	(.009)	.004	(.018)
Risk class = 3	$\gamma_3$	.012**	(.006)	.027	(.021)
Risk class = 4	$\gamma_4$	-.010	(.006)	omitted	
Control variables	$\beta$				
R&D intensity		.011***	(.003)	.014***	(.004)
Electricity price		-.001	(.001)	-.001	(.002)
Profit margin		-.005	(.004)	-.006	(.005)
Size (employees)		.003***	(.000)	.001*	(.001)
Share of high-skilled employees		.130***	(.027)	.013	(.026)
Capital intensity		.003	(.015)	.002	(.002)
Market-based regulation		-.003**	(.006)	.006	(.004)
Fraction of variance due to ind. effect ( $\nu$ )		.27***	(.03)	.42***	(.02)
R-squared		.158		.012	
Number of firm-year observations		34,838		34,838	
Number of firms		3,709		3,709	

NOTE: Full set of interactions between industry and year dummies ( $18 \times 9 = 162$  coefficients) included but not reported.

\*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ . Standard errors in parentheses (adjusted for 3,709 clusters in firm).

<sup>1</sup>The reference category is firms without permits.

## Results Linear Model cont'd

Table 7: Wald-tests of parameter restrictions

Test of:	(1) Fixed effects p-value (d.f.)	(2) Random effects p-value (d.f.)
i) Tests of joint overall significance:		
All $\gamma$ - and $\pi$ -parameters are equal to 0	.0007 (5)	0 (5)
All $\gamma$ -parameters are equal to 0	.3135 (4)	0 (4)
ii) Tests of equality of coefficients:		
All $\gamma$ -parameters are equal	.3445 (3)	0 (3)

## Interpretation of results

- Non-market based regulation spur innovation in environmental technologies
  - Threat of sanctions impose a production activity limit (binding permit) for the firm that spurs development of new technologies
  - Prohibition of dirty technologies rather than requirements for specific clean technologies
- Today political reforms to shift towards market-based policies. A main reason for this is the belief that this will spur innovation. We can thus avoid some costly reforms.