Emissions Trading Scheme and Directed Technological Change: Evidence from China

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Emissions Trading Scheme (ETS)

- What is ETS?
- Emissions trading schemes (ETS) have begun to play a promising role in combating climate change.
  - **In force:** 28 EU Member States and Iceland, Liechtenstein and Norway Switzerland, Quebec in Canada, eight pilots in China, Saitama and Tokyo in Japan, Kazakhstan, North Korea, New Zealand, and California and Massachusetts in the USA.
  - **Implementation scheduled:** Mexico, Taiwan in China, Nova Scotia in Canada, Ukraine and Virginia in the USA.
- Objectives of environmental regulations: emission reduction (primary) and incentivizing development of technological changes and innovations (equally important).
- This enables firm to reduce marginal cost of emissions in the long-run.

This Paper

- contributes to the literature of CO2 mitigation regulation and directed technological change
- I do this in a specific context of pilot ETS that were rolled out in China.
- Does China pilot ETS affect regulated firms' innovation activity? And how?
- Number of patent applications per year is used as a proxy for firms' innovation ability.

Preliminary Results

- Overall, no statistically significant effect of pilot ETS on *green patenting* can be identified.
- However, the effects in two of the regions with highest carbon prices are significant.

Literature

- Little analysis of the impacts of emissions trading schemes beyond the EU setting
  - **Two most related articles** : Calel and Dechezlepretre 2016; Cui et al 2018.
  - More broad literature on the effect of ETS on firms' investment strategy and carbon leakage (aus dem Moore et al. 2017), productivity and competitiveness (Chan et al. 2013, Bushnell et al. 2013), and emission abatement (Anderson and Di Maria 2011, Petrick and Wagner 2014)
- The Chinese pilot ETS is of particular interest for three reasons
  - over 25% of global carbon emissions
  - national trading scheme launched in December 2017
    - covering 30% of national emissions
    - studying the pilot effect helps better anticipate the impacts of the national ETS
  - the emerging country context differs from the western context

In the pilot phase, there are 8 provinces and municipalities involved in the scheme. They differ in

1. Starting time
2. Allowances allocation
3. Coverage threshold (determines regulatory status)
4. Punishment of non-compliance
5. Measures and plans

carbon prices

Figure: Pilot ETS regions in China

A Model

- Purpose of this model:
  - provide a potential explanation for firms' decision on innovation.
  - when firms would innovate and to which extent?
- **Trade-off**: incurring R&D cost thus abate at lower cost and not innovating therefore abate at high cost.

A Model

- Assumptions:
  - a competitive industry with a mass of small firms;
  - homogeneous emissions
- Set-up:
  - whether or not to and how much to innovate;
    - Invest iff the compliance cost with the tech. $\leq$ the cost without tech.
    - Then choose the tech. level to minimize the abatement cost
  - the abatement level;

A Model

Each firm decides the **optimal abatement level** to minimize the abatement cost

$$\min_{a,k}\{C(a,k)+F(k)+t(e-a)\}. \tag{1}$$

This cost minimization problem gives

$$C_a(a,k)=t \tag{2}$$

- $C(a,k)$: Firms' abatement cost;
- $F(K)$: R&D cost;
- t: carbon price; k: the innovation level; e: the laissez-faire emissions.

function properties

A Model

A firm **invests in abatement R&D** iff. its total cost with positive innovation lies below cost in the absence of innovation:

$$F(k^I) \leq \left[C(a^O, k^O) - C(a^I, k^I)\right] + t\left(a^O - a^I\right). \tag{3}$$

Rewrite and solve for firms' value of innovating:

$$v = [C(a^O, k^O) - C(a^I, k^I)] - t(a^I - a^O) - F(k^I). \tag{4}$$

If $v = 0$, the firm is indifferent between innovating and not innovating, while for $v < 0$, the firm is better off not innovating. For positive v however, it will always be optimal for the firm to do innovation such that $k = k^I$.

A Model

Whether or not firms would innovate:

Proposition 1

There exists some level of carbon prices $t' > 0$ such that if $t < t'$, the firm does not innovate. If $t > t'$, the firm chooses a positive level of innovation.

How much firms would innovate:

Proposition 2

Conditional on a positive level of innovation, a higher emission price leads to a greater level of abatement innovation.

Data

1. Annual Survey of Manufacturing Enterprises (ASME)
    - Source: National Bureau of Statistics
    - 1999-2009, 2011-2013; approx. 300,000 firms
    - "Above-scale" firms: before 2011, yearly sales>5 millions Yuan; from 2011, 20 millions Yuan
    - Data: number of employees, sectors, balance sheet, income statement, cash flow statement, address
2. Regulatory Status
    - Source: Municipal/ Provincial DRC
    - All regulated regions except for Chongqing (not available) and Fujian (started late)
    - Keep: Profitable entities (schools, government officials, and hospitals dropped), 2621 firms left

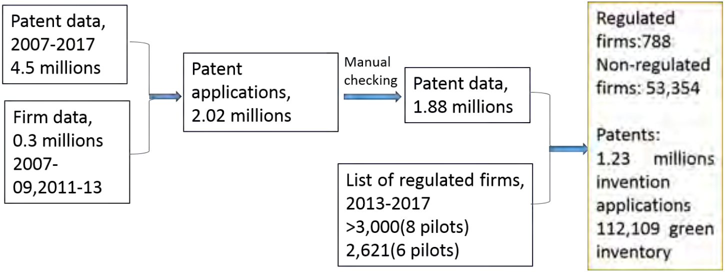
Number of regulated entities in these eight pilots across years:

pilot	year					Profitable	treatments
	2013	2014	2015	2016	2017	entities	(Size=2,621)
Beijing	NA	543	501	947	943	820	[illegible]
Shanghai	197	197	197	310	296	381	[illegible]
Shenzhen	639	636	635	574	508	588	[illegible]
Tianjin	114	112	109	109	109	117	112
Hubei	NA	138	167	236	244	364	[illegible]
Guangdong	194	194	186	244	246	283	[illegible]
Fujian	NA	NA	NA	277	271		
Chongqing	242	237	230	NA	195		

Data

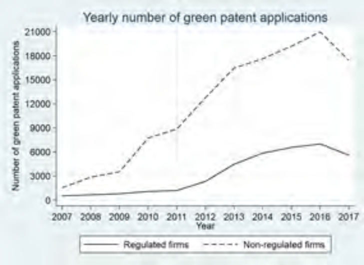
- Patent Data
  - Source: State Intellectual Property Office (SIPO), web-scraping of Patent Search and Analysis (PSA)
  - 2007-2017, around 4.2 millions invention applications;
  - Data: IPC classifications, application date, applicants, address, authorized or not, patent name
  - Number of **IPC Green Inventory** (UNFCCC) applications per year is used as an indicator to measure green innovation level
- The scope of environmentally sound technologies patents:
  1. Alternative energy production: renewable energy
  2. Transportation: vehicles
  3. Energy conservation
  4. Waste management
  5. Agriculture
  6. Administrative, regulatory or design aspects
  7. Nuclear power generation

Constructing Dataset



Data Preview

In that 112,109 green inventory, 10,346 from regulated firms; 101,763 from non-regulated firms.



Data Preview

Table: Summary Statistics on Number of Patent Applications

	RS+ASMI+SIPO		RS+SIPO	
	Non-regulated firms	Regulated firms	Non-regulated firms	Regulated firms
# Firms	53,354	788	370,267	1,495
# Green patents	101,763	10,346	520,380	69,300
# All patents	1,178,304	260,018	3804065	378066
Mean(all patents)	22	329	10.27	252
Green patent%	90.77%	9.23%	88.25%	11.75%

Data Preview

Regulated firms in average

1. have more employees, produce more, own more asset and have more liabilities
2. start up business 4 years earlier than non-regulated ones
3. are slightly more likely to be a state-owned company.

	treated	control	t-test
number of labor	2569.951	469.656	-23.3026
output	3138189	328952.9	-29.8403
current asset	1528074	153142.2	-33.9492
net receivable	315499.7	31227.48	-30.2989
fixed asset	1513761	147195.3	-18.0546
total asset	4110150	346457.5	-26.2309
current liability	1476911	148041.6	-31.6246
account payable	450725.2	38177.91	-32.3385
long liability	547686.3	46123.31	-15.7031
total liability	2080047	198264.6	-28.0835
equity	2029850	147598.1	-22.0490
capital	952960.4	73939.16	-18.6819
sales	3284581	328244.1	-29.4287
cost of goods sold	2744444	269000.8	-29.7432
other profit	10256.22	1435.071	-11.8268
sale expense	106991.4	9419.484	-25.6792
managing expense	144317.6	14766.12	-25.5174
financing expenses	29236.8	4254.777	-16.2129
operating revenue	232945.9	26436.48	-9.8876
investing profit	42734.87	1237.652	-16.4315
interest expense	30756.22	4165.4	-17.0945
non-operating income	12194.22	1461.638	-13.6997
net profit	240778	26195.36	-10.2500
income tax	36321.6	4097.861	-10.3933
value-added tax	112579.5	12439.89	-17.2168
accounting type	1	1.007085	0.8444
state ownership	3.112613	3.285895	2.9696
open year	1994.919	1998.709	9.3009
organization type	8.158779	8.111748	-0.3258
sector	33.48731	31.64717	-6.0618

Empirical Strategy

- First, match the pre-treatment data
  - solution to observable endogeneity
  - choose a comparable control group
  - the data limitation
- Coarsened exact matching (CEM) (Iacus et al. 2011)
  - Large number of control units hence few unmatched treated units
  - reduces model dependence
  - improvement on balance for one covariate in isolation
  - computationally efficient
  - lower imbalance and larger sample size

Empirical Strategy

- Second, the baseline difference-in-differences

$$greenpatent_{it} = \alpha + \beta_1 regulated_{it} + \alpha_i + \alpha_t + \epsilon_{it}. \quad (5)$$

$$\begin{aligned} greenpatent_{it} = \alpha + \beta_2 price_{lt} \times regulated_{it} + \\ \beta_3 length_{it} \times regulated_{it} + \alpha_i + \alpha_t + \epsilon_{it}. \end{aligned} \quad (6)$$

- $greenpatent_{it}$: number of green patent applications for firm i in year t;
- $regulated_{it} = 1$ if firm i is regulated in year t;
- $price_{lt}$: yearly average carbon prices in region l and year t;
- $length_{it}$: the number of years the firm i has been regulated in year t;
- α_i: firm FE; α_t: year FE.

Empirical Strategy

- The policy heterogeneity effects: diff. regulation in different pilot regions

$$greenpatent_{itl} = \alpha + \beta_1 regulated_{it} \times pilot_l + \alpha_i + \alpha_t + \epsilon_{itl}. \qquad (7)$$

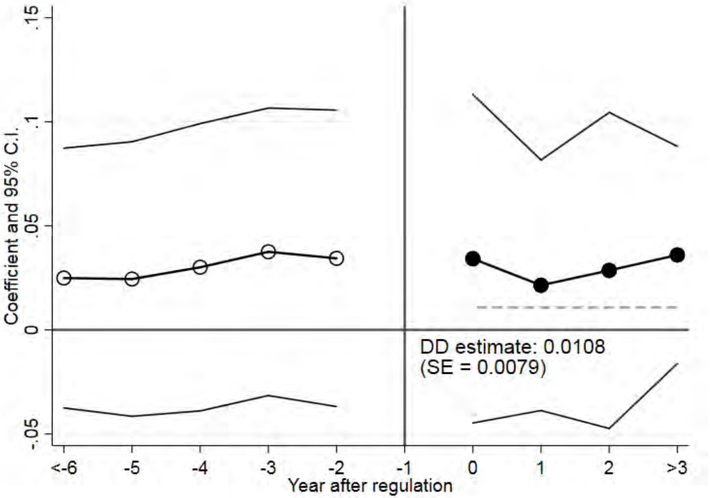
- $pilot_l$: categorical variable to stand for different regions with regulation in place.

Balance Check

CEM

- Covariates: firms in the same pilot region, match on the total number of patent applications, green patent applications, average of assets, operating revenue between 2007-2012 covariates cut-offs
- The multivariate imbalance L_1: $(1 - L_1)\%$ of the density of the two histograms for treated and control groups overlap. (Iacus et al. 2011)

Event Study



Coefficient and 95% C.I.
.15
.1
.05
0
-.05
DD estimate: 0.0108
(SE = 0.0079)
<-6
-5
-4
-3
-2
-1
0
1
2
>3
Year after regulation

Baseline Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
regulated	1.1923*	1.0055*	-0.0104		0.5382	0.0108				
	(0.3827)	(0.3904)	(0.0119)		(0.2128)	(0.0079)				
years of regulation				-0.0003			0.0048			0.0024
				(0.0051)			(0.0027)			(0.0019)
carbon price								0.0004*		0.0003*
								(0.0001)		(0.0001)
regulated in Beijing									0.0127***	
									(0.0014)	
regulated in Tianjin									-0.0038	
									(0.0016)	
regulated in Shanghai									0.0028	
									(0.0014)	
reguleted in Hubei									-0.0016	
									(0.0006)	
regulated in Guangdong									-0.0041*	
									(0.0014)	
regulated in Shenzhen									0.0245***	
									(0.0014)	
Observations	96908	96908	96908	96908	34543	34543	34543	34543	34543	34543
Mean dependent var.	0.2373	0.2373	0.2373	0.2373	0.4190	0.4190	0.4190	0.4190	0.4190	0.4190
Sd. of dependent var.	2.8377	2.8377	2.8377	2.8377	2.1553	2.1553	2.1553	2.1553	2.1553	2.1553
R-squared	0.0053	0.0163	0.9478	0.9478	0.0060	0.9971	0.9971	0.9971	0.9971	0.9971
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Region fixed effects	No	Yes	No	No	No	No	No	No	No	No
Sector fixed effects	No	Yes	No	No	No	No	No	No	No	No

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Robustness Check

Use different matching specifications

- Using the data in 2012 with the same percentiles: 2012 has the most comprehensive information about firms
- Using mean values 2007-2011 with the same percentiles
- Using mean values 2007-2009 with the same percentiles

Conclusions

- Overall, there is no sign that pilot ETS increases the innovation level.
- Carbon prices may impact the innovation positively.
  - The average carbon prices in Beijing and Shenzhen are the two highest among all the pilots
  - 51.8 (7.96 USD) and 44 Chinese Yuan (6.77 USD)

Appendix: Function Properties

Function properties:

- Firms' abatement cost is $C(a, k)$: increasing and convex in abatement level a and is decreasing in technology level k with diminishing returns to technology: $C_a > 0$, $C_{aa} > 0$, $C_k < 0$, $C_{kk} > 0$, $C_{ak} < 0$, $C_a(0, k) = 0$ (Fischer et al. 2003).
- Innovation fixed cost $F_0 > 0$. The variable component, $f(k)$ is increasing and convex in k: $f_k(k) \geq 0$ with equality if $k = 0$, and $f_{kk}(k) > 0$.

$$F(k) = \begin{cases} 0 & \text{if } k = 0 \\ F_0 + f(k) & \text{if } k > 0 \end{cases} \tag{8}$$

- Reducing emissions to zero, i.e. abating at level e induces an infinite marginal abatement cost, i.e. $\lim_{a \to e} C_a = \infty$.

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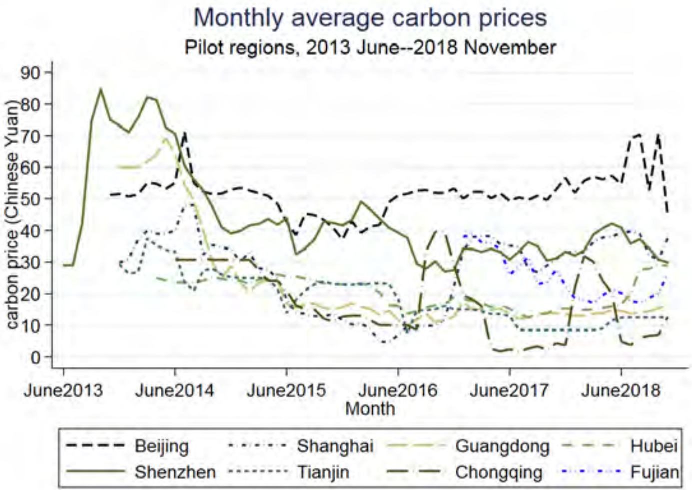
Appendix: carbon price



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Appendix: Covariates for CEM

Use the following percentiles for cut-off points of bins

- Number of green patent applications (75, 85, 90, 95, 99)
- Number of all the patent applications (0, 25, 50, 75, 90, 95, 99)
- Total assets (0, 0, 1, 10, 20, 35, 45, 60, 70, 90, 95)
- Operating revenue (0, 0, 1, 10, 20, 30, 45, 55, 80, 90, 95)

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Appendix: Covariates for CEM

Table: Cut-offs for number of green patent applications

percentile (%)	75	85	90	95	99
Beijing	0	1	2	6	39
Tianjin	0	1	1	2	10
Shanghai	0	1	1	3	14
Hubei	0	1	1	2	9
Guangdong	0	1	1	2	9
Shenzhen	0	1	2	4	25

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Appendix: Covariates for CEM

Table: Cut-offs for number of all the patent applications

percentile (%)	25	50	75	90	95	99
Beijing	1	2	6	20	40	195
Tianjin	0	1	5	16	34	113
Shanghai	1	2	6	14	28	98
Hubei	0	1	3	8	13	52
Guangdong	1	2	4	10	18	69
Shenzhen	1	2	6	16	32	303

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Appendix: Covariates for CEM

Table: Cut-offs for total assets (thousand yuan)

percentile (%)	1	10	20	35	45	60	70	90	95
Beijing	4210.5	14859	27344	52413	78348	137340	221971	849703	1810363
Tianjin	0	7231	13460	25187	39476	80362	142787	695407	1452217
Shanghai	4033	13808	24550	48550	71176	118753	172621	599792	1196864
Hubei	3999	12020	21212	37573	54541	98172	156942	677349	1673226
Guangdong	3582	13680	24068	44338	64957	120041	186316	686440	1345651
Shenzhen	4510	16106	27201	50379	73081	131375	202183	716791	1328742

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Appendix: Covariates for CEM

Table: Cut-offs for operating revenue (thousand yuan)

percentile	1	10	20	30	45	55	80	90	95
Beijing	5720	12357	22662	34837	57468	80197	255692	588271	1109967
Tianjin	0	8118	18617	25792	43293	62075	239640	531930	1265138
Shanghai	5854	13669	25777	39319	66256	93029	273385	577724	1169813
Hubei	5410	19082	27126	41020	70011	100813	302995	628157	1429375
Guangdong	6702	22127	35296	51086	85384	119760	369084	728750	1458668
Shenzhen	6582	18995	310234	44504	75063	104799	311611	652440	1282040

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