Heterogeneous Responses to Carbon Pricing: Firm-level Evidence from Beijing Emissions Trading Scheme

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Motivation

- Carbon neutrality by 2060 in China
- China's national ETS launched in July 2021
- Effectiveness and design of the ETS?

This paper

- Effects of ETS, in the context of pilot ETS in Beijing Prices
    - By sector
    - By whether being heavy coal and oil users
    - Abatement mechanism
- Whether allowances allocation affects emissions?

Literature

- The effectiveness of the emissions trading scheme: Anderson and Di Maria (2011), Bayer and Aklin (2020), Petrick and Wagner (2014), Cao et al. (2021), Cui et al. (2021)
    - Our contribution: RDD gives better internal validity; more diverse sectors; more accurate data verified by third-party verifiers
- Whether the independence property holds in a cap-and-trade market: Hahn and Stavins (2011), Stavins (1995), Sandoff and Schaad (2009), Naegele (2018), Fowlie and Perloff (2013)
    - Our contribution: propose a more generalizable way of testing the independence property in cap-and-trade markets

Beijing ETS

Starts from 2013,

- Allowances allocation: mostly grandfathering on emissions
- Coverage threshold: 10,000 tons CO_2 in Phase I (2013-2015) and 5,000 tons CO_2 in Phase II (from 2016).

Data

- Firm-level energy consumption and emissions verified by third-party verifiers (by energy sources)
- Allowances received (2013-2015)
- A balanced panel (2009-2017), 971 firms, 8,739 obs
- Other variables: output value and ownership

Summary statistics-baseline sample

Table: Summary statistics, baseline sample

	(1) 2012 mean	(2) 2015 mean
Panel A, treat=0		
Total emissions (kton)	10.3	10.1
Coal consumption (ktce)	1.3	0.8
Oil consumption (ktce)	0.1	0
Natural gas consumption (ktce)	0.9	1.1
Electricity consumption (ktce)	3.8	4.1
Panel B, treat=1		
Total emissions (kton)	130.1	112.2
Coal consumption (ktce)	19.9	10.1
Oil consumption (ktce)	4.4	3.5
Natural gas consumption (ktce)	14.8	19.4
Electricity consumption (ktce)	22.3	23.7
Observations	741	741

Empirical strategy

Recall that...

- Phase one (2013-2015), threshold $10,000$ tons in 2012.
- Phase two (from 2016), threshold $5,000$ tons in 2015.

Treatment group: firms covered since 2013

Control group: firms included in the second stage of the Beijing ETS

Empirical strategy

Fuzzy regression discontinuity design

- **"regression discontinuity"**
  - Firms close to the cutoff should not be systematically different.
- **"fuzzy"** mainly because of the administrative errors:
  - For a firm that reached the cutoff, the prob. of being a pilot firm is smaller than 1.
  - The emissions data are not updated on time

Likelihood of being treated

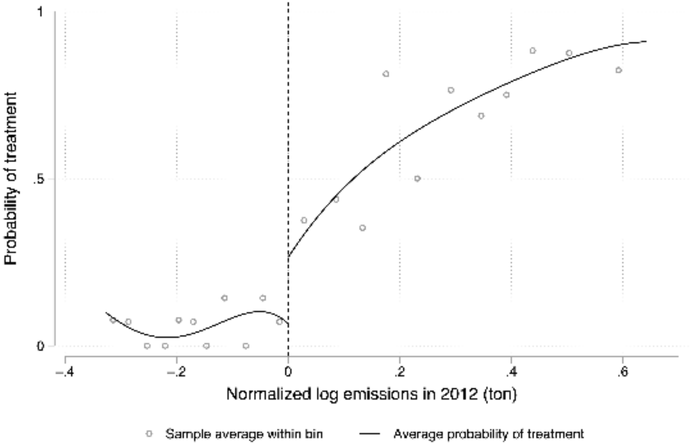


Figure: The probability of being treated

Likelihood of being treated: by subsample

Empirical strategy

- 2SLS:
  - First stage (linear, Gelman and Imbens (2019)):

$$treat_i = \alpha_0 + \alpha_1 T_i + f(Y_{2012,i}) + o_i + s_i + e_i + u_i \tag{1}$$

  - Second stage:

$$log(Y_{2015,i}) = \gamma_0 + \gamma_1 \hat{treat}_i + g(Y_{2012,i}) + o_i + s_i + e_i + w_i \tag{2}$$

- T_i defined as $\mathbf{1}[Y_{2012,i} > 10000] = 1$, **instrumental variable**;
- $f(Y_{2012,i}) = \alpha_2[log(Y_{2012,i}) - c] + \alpha_3[log(Y_{2012,i}) - c] \times T_i$
- $g(Y_{2012,i}) = \gamma_2[log(Y_{2012,i}) - c] + \gamma_3[log(Y_{2012,i}) - c] \times T_i$
- $log(Y_{2015,i})$: outcome variable; c: emission threshold; $log(Y_{2012,i})$: **running variable**, logarithm emissions in 2012
- $treat = 1$ if a firm was regulated from 2013 to 2015.
- o_i: ownership dummies; s_i: sector dummies; e_i: energy type in 2012.
- Different MSE-optimal **bandwidth** selectors, triangular **kernel** that puts higher weights on firms closer to c,

Empirical strategy

A key identifying consumption:

- firms around the cutoff could not systematically choose their treatment status.
  - details about the ETS design were not released to firms before its announcement
  - firms did not anticipate whether they would be regulated
  - the coverage threshold was announced at the end of 2013

McCrary density test

Results: overall

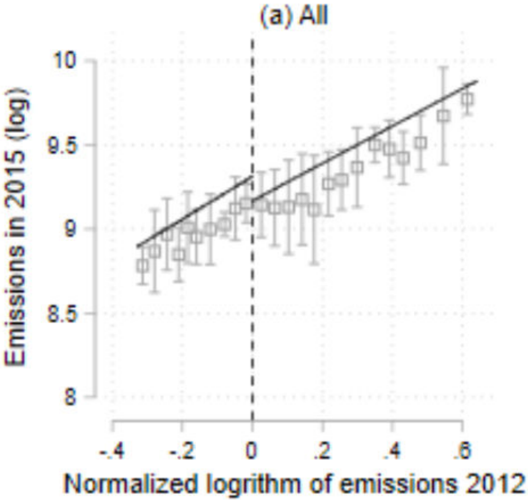
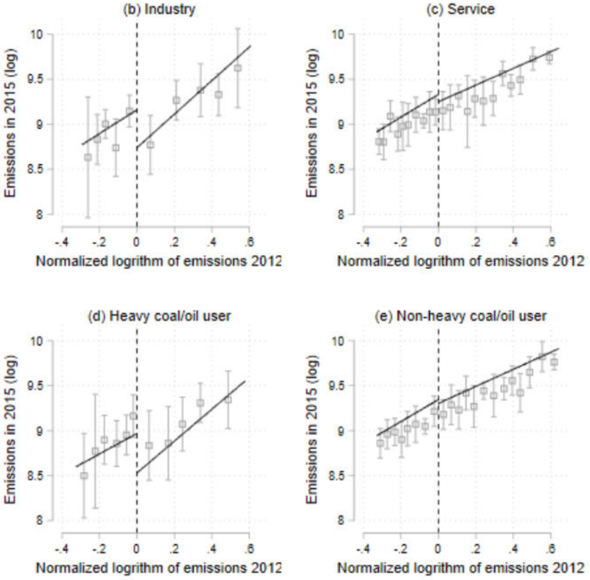


Figure: Local linear regression: emissions in 2015 conditional on the running variable-the distance to the cutoff

Results: sector heterogeneity



Results

Table: Effect of the ETS in Beijing on carbon emissions

	All	Sector		Heavy coal and oil users	
		Industry	Service	Yes	No
treat	-0.49*	-0.59**	-0.36	-0.75**	0.08
	(0.29)	(0.27)	(0.38)	(0.35)	(0.74)
Observations	328	76	252	103	225
1st stage F stat.	10.33	12.68	5.02	14.09	0.74

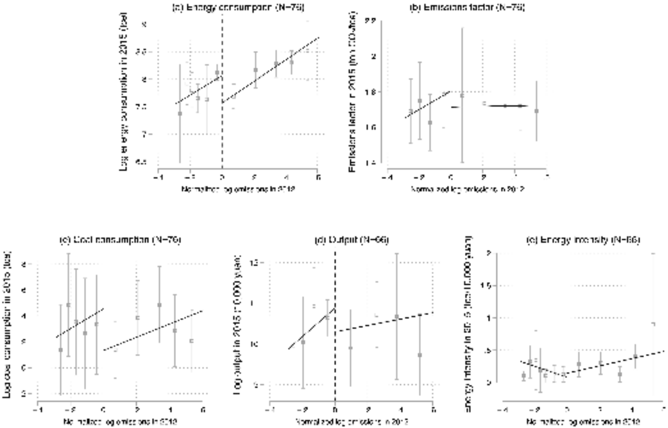
* $p < 0.1$, ** $p<0.05$, *** $p<0.01$

- Effects with firms involved since 2013, 2014 or 2015 included. 2013-2015

Abatement mechanism

- Output
- Energy consumption
- energy efficiency: energy consumption per unit of output
- Fuel-switching: carbon emissions per unit of energy consumption

Results



Results: Energy Consumption

Table: Distribution effects on coal consumption

	(1)	(2)	(3)	(4)
treat	-0.50*	-0.76**	-0.72**	-0.43*
	(0.30)	(0.37)	(0.34)	(0.24)
Observations	76	76	76	76
Mean	0.43	0.30	0.21	0.11
sd	0.50	0.46	0.41	0.32
1st stage F stat.	12.56	12.56	12.56	12.56
Coal consumption	> 0	> 1000	> 2000	> 3000

Note: 2SLS estimations of linear probability models for the probability of industrial firms having coal consumption (in tce) falling into each interval in 2015, with intervals specified in the last row. All columns include a full set of sector, ownership, and energy type dummies. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Robustness analysis

- Estimate the effects using different bandwidth Bandwidth
- Estimate the effects using uniform kernel Kernel
- Estimate the effects with matched-DID matched-DID
- Heavy fossil users defined with different cutoff on the share of coal and oil consumption
- Placebo tests: effects in 2009-2011 2009 2010 2011

Allowances and emissions

- In theory, allowances have no impacts on emissions. (Hahn and Stavins 2011, Coase 1960)
- Whether this is true in practice?

Allowance surplus and emissions reduction

Dynamic panel model 2SLS

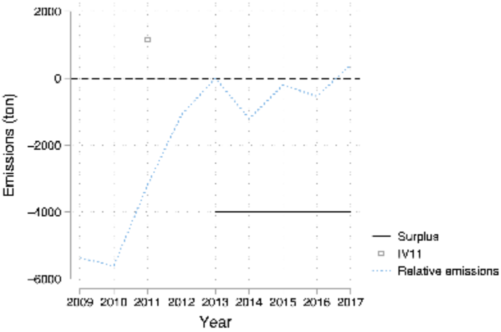
$$R_{i,t} = \alpha_0 + \alpha_1 E_i + u_{i,t}, \tag{3}$$

- $R_{i,t} = Y_{i,t} - Y_{i,13}$, emissions reduction in year t compared to 2013; $E_{i,13} = A_{i,13} - Y_{i,13}$, allowance surplus in 2013
- **Challenges**: unobserved factors could affect both allowances and emissions
- **To address this**: use past emissions shocks $e_{i,11} = Y_{i,11} - \widehat{Y_{i,11}}$ as an IV for allowance surplus in 2013
- $\widehat{Y_{i,t}}$ counterfactual emissions, predicted with an AR(1) model, estimated with system GMM (Blundell and Bond, 1998)

$$Y_{i,t} = \widehat{Y_{i,t}} + e_{it} = \lambda_0 + \lambda_1 Y_{i,t-1} + \sum_{t=0}^{s} \gamma_s X_{i,t-s} + \eta_t + \eta_i + e_{it} \tag{4}$$

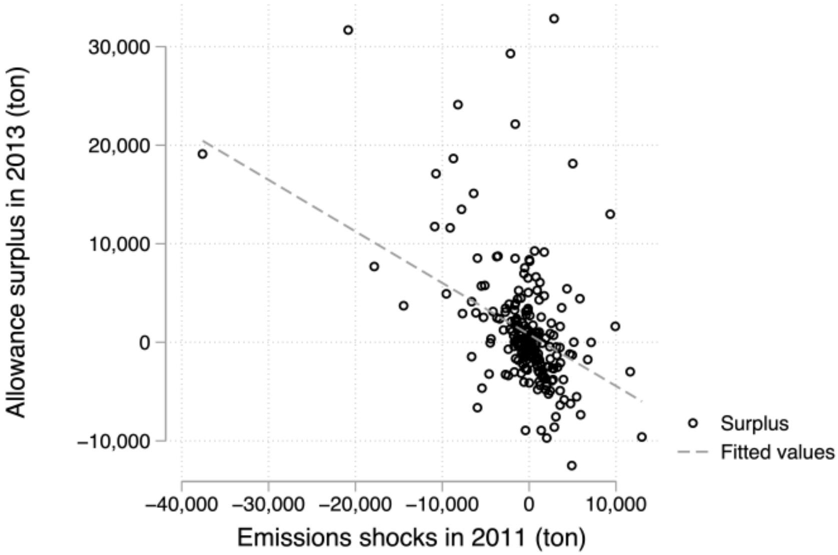
- Key assumption: no serial correlation in the error term, i.e. $E(e_{it}e_{is}) = 0, t \neq s$.

An example



- positive shock in 2011
  - increase the firm's average emissions 2009-2012——increase its emissions allowances
  - increase the firms's emissions level in subsequent years after 2011

First stage: shock and surplus



Overall effects

	(1) 2014	(2) 2015	(3) 2016	(4) 2017
Panel A: OLS ($N = 220$)				
allowance surplus	-0.07	-0.07	-0.02	0.01
	(0.09)	(0.11)	(0.12)	(0.13)
R-squared	0.15	0.21	0.22	0.23
Panel B: IV, all ($N = 220$)				
allowance surplus	0.07	0.10	0.08	0.13
	(0.09)	(0.13)	(0.15)	(0.17)
1st stage F stat.	62.25	62.25	62.25	62.25
p-value of Hansen J	0.62	0.18	0.15	0.18
Panel C1: IV, by sector: service ($N = 131$)				
allowance surplus	0.14^{**}	0.18	0.21	0.23
	(0.07)	(0.15)	(0.14)	(0.18)
1st stage F stat.	68.52	68.52	68.52	68.52
p-value of Hansen J	0.28	0.23	0.27	0.47
Panel C2: IV, by sector: industry ($N = 89$)				
allowance surplus	-0.07	-0.12	-0.17	-0.06
	(0.18)	(0.21)	(0.25)	(0.26)
1st stage F stat.	18.33	18.33	18.33	18.33
p-value of Hansen J	0.37	0.92	0.79	0.47
Panel D1: IV, by size: below ($N = 111$)				
allowance surplus	0.14	0.30^{*}	0.31^{*}	0.40^{*}
	(0.12)	(0.16)	(0.17)	(0.22)
1st stage F stat.	36.83	36.83	36.83	36.83
p-value of Hansen J	0.35	0.44	0.41	0.43
Panel D2: IV, by size: above ($N = 109$)				
allowance surplus	0.12	0.02	0.01	0.06
	(0.16)	(0.18)	(0.22)	(0.21)
1st stage F stat.	22.95	22.95	22.95	22.95
p-value of Hansen J	0.16	0.66	0.56	0.69

Discussions (1/2)

On the mitigation effect of the policy,

- Firms in different sectors respond to the policy differently.
  - No significant effect on firms in the service sector.
  - Emissions in 2015 for firms in industry sector decreased – coal consumption decreased.
- Different sectors have distinct potential of reducing carbon emissions.

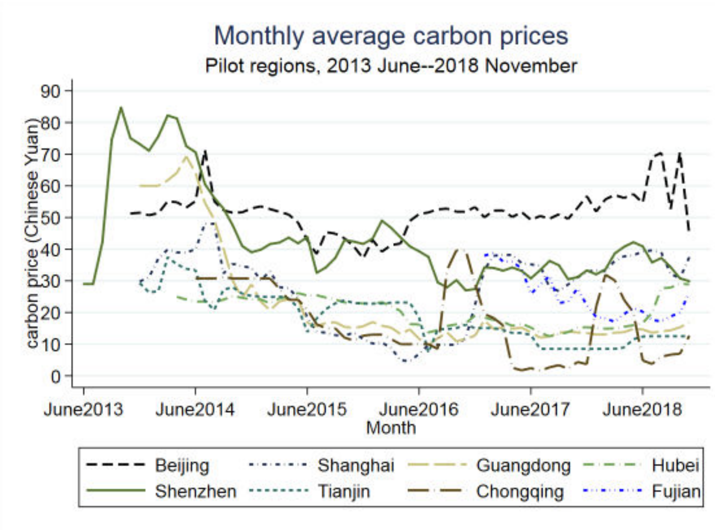
Discussions (2/2)

Overall, the allocated allowances don't significantly affect the pilot firms' emissions.

However, the effects differ by sector and firm size.

- The independence property likely holds but not among smaller firms and firms in the service sector: free allowances likely dampen their mitigation potential.
- Interpretation: non-trivial transaction cost for these firms. Industrial firms might know more about their energy consumption and production info, and therefore likely plan better.

Appendix: carbon price



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Appendix: McCrary density test

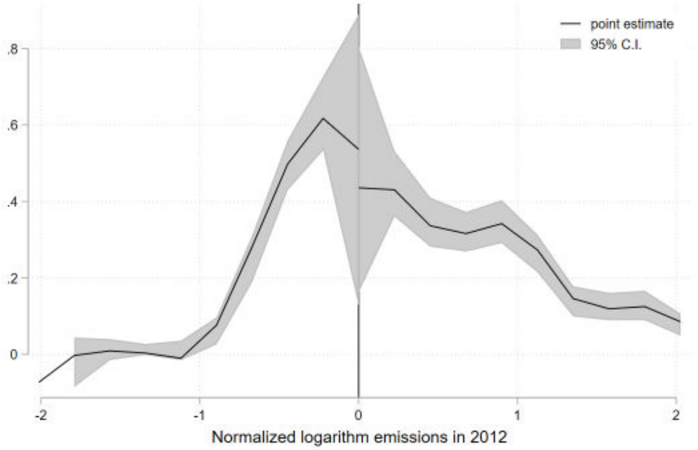

Figure: McCrary density test: p-value of the test is 0.92

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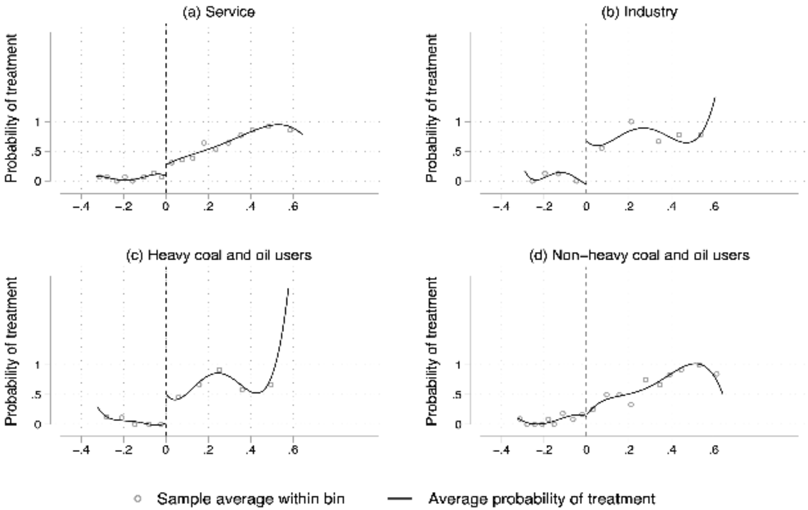
Likelihood of being treated: by subsample



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Robustness

Table: Effect of pilot ETS in Beijing on carbon emissions, linear, by different bandwidth selectors, triangular kernel

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	msetwo	msesum	mserd/msecomb1	msecomb2	cerrd/cercomb1	certwo	cersum	cercomb2
treat	-0.49*	-0.65	-0.65	-0.65	-0.53	-0.51	-0.50	-0.53
	(0.29)	(0.46)	(0.46)	(0.46)	(0.55)	(0.39)	(0.53)	(0.55)
Observations	328	272	268	268	193	258	197	193
Mean dependent var.	9.14	9.08	9.08	9.08	9.08	9.14	9.08	9.08
Sd. of dependent var.	0.39	0.37	0.37	0.37	0.36	0.37	0.36	0.36
1st stage F stat.	10.33	5.06	5.02	5.02	2.74	5.93	2.79	2.74
Bandwidth-left	.336	.359	.354	.354	.254	.242	.258	.254
Bandwidth-right	.641	.359	.354	.359	.254	.461	.258	.258

This table reports the RD estimations on the effect of Beijing ETS on CO_2 emissions in 2015 using different bandwidth selectors. Robust standard errors are reported in parentheses. Estimations on sector dummies are not presented in the table however included in all the columns. All estimations are estimated using triangular kernel. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

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Robustness

Table: Placebo tests, Effect of pilot ETS in Beijing on carbon emissions, 2009

	All	Sector		Heavy coal and oil users		State-related firms	
		Industry	Service	Yes	No	Yes	No
treat	1.64	4.08**	0.12	3.00	-2.20	-5.96	3.08
	(2.03)	(2.03)	(2.82)	(2.52)	(5.58)	(27.78)	(2.05)
Observations	328	76	252	103	225	151	177
1st stage F stat.	10.33	12.68	5.02	14.09	0.74	0.08	23.13

* $p < 0.1$

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Robustness

Table: Placebo tests, Effect of pilot ETS in Beijing on carbon emissions, 2010

	All	Sector		Heavy coal and oil users		State-related firms	
		Industry	Service	Yes	No	Yes	No
treat	0.29	3.13	-1.53	1.40	-2.62	-9.70	1.50
	(1.77)	(1.98)	(2.41)	(2.34)	(5.54)	(38.12)	(1.79)
Observations	328	76	252	103	225	151	177
1st stage F stat.	10.33	12.68	5.02	14.09	0.74	0.08	23.13

* $p < 0.1$

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Robustness

Table: Placebo tests, Effect of pilot ETS in Beijing on carbon emissions, 2011

	All	Sector		Heavy coal and oil users		State-related firms	
		Industry	Service	Yes	No	Yes	No
treat	-0.25	0.08	-0.51	0.37	-1.12	-1.60	-0.12
	(0.84)	(0.33)	(1.41)	(0.25)	(4.04)	(14.29)	(0.38)
Observations	328	76	252	103	225	151	177
1st stage F stat.	10.33	12.68	5.02	14.09	0.74	0.08	23.13

* p <0.1

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The ETS effect, 2013-2015 included

Table: Effect of pilot ETS in Beijing on carbon emissions, with firms involved since 2013, 2014 or 2015 included

	All	Sector		Heavy coal and oil users	
		Industry	Service	Yes	No
treat_plus	-0.42*	-0.91	-0.19	-0.51**	-0.21
	(0.23)	(0.60)	(0.21)	(0.22)	(0.43)
Observations	414	111	303	118	296
1st stage F stat.	15.59	5.12	10.15	26.32	3.23

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

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Robustness: uniform kernel

Table: Effect of pilot ETS in Beijing on carbon emissions, linear, uniform kernel

	All	Sector		Heavy coal and oil users		State-related firms	
		Industry	Service	Yes	No	Yes	No
treat	-0.45*	-0.54*	-0.37	-0.67**	0.02	-1.01	-0.34*
	(0.25)	(0.29)	(0.32)	(0.31)	(0.53)	(1.61)	(0.19)
Observations	328	76	252	103	225	151	177
1st stage F stat.	13.11	11.58	6.99	16.18	1.49	0.59	24.77

This table reports the RD estimations on the effect of Beijing ETS on CO_2 emissions in 2015 suing uniform kernel and triangular kernel. Robust standard errors are reported in parentheses. Estimations on sector dummies are not presented in the table however included in all the columns. All estimations use sample selected by msetwo bandwidth selector.
* p <0.1, ** p<0.05, *** p<0.01

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Robustness: matched-DID

Table: Effect of pilot ETS in Beijing on carbon emissions in 2015, matched-DID

	All	Heavy coal/oil users		Sector		Non state-related		State-related	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
treatpost	-0.14	-0.42	-0.08	-0.37***	-0.07	-0.31**	-0.13	-0.60***	-0.05
	(0.10)	(0.41)	(0.09)	(0.12)	(0.12)	(0.15)	(0.36)	(0.15)	(0.08)
Observations	2597	371	2226	469	2128	336	665	133	1463
1st stage F stat.									
Sample	Full	Yes	No	Industry	Service	Industry	Service	Industry	Service

* p <0.1, *** p<0.01

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Dynamic panel model on carbon emissions

A system generalized method of moments (GMM) estimator (Blundell and Bond, 1998). Take first-difference transformation of the model,

$$\Delta Y_{it} = \lambda_1 \Delta Y_{i,t-1} + \sum_{s=0}^{k} \gamma_s \Delta X_{i,t-s} + \Delta \eta_t + \Delta e_{it}. \tag{5}$$

IV: $Y_{i,t-2}$ for $\Delta Y_{i,t-1} = Y_{i,t-1} - Y_{i,t-2}$, and $\Delta Y_{i,t-1}$ for $Y_{i,t-1}$

Assumptions: no serial correlation in the error term, i.e. $E(e_{it} e_{is}) = 0, t \neq s$.

Moment conditions:

$$\begin{aligned} E[Y_{i,t-s}, \Delta e_{i,t}] &= 0, s = 2, 3, ..., t; \\ E[X_{i,t-s}, \Delta e_{i,t}] &= 0, s = 2, 3, ..., t; \\ E[\Delta Y_{i,t-1}(\eta_i + e_{i,t})] &= 0, t = 2, 3, ..., T; \\ E[\Delta X_{i,t-1}(\eta_i + e_{i,t})] &= 0, t = 2, 3, ..., T. \end{aligned} \tag{6}$$

Data: emissions data for non-pilot firms between 2009 and 2015 and for pilot firms between 2009 and 2012

Validity of IV Arellano-Bond test (Arellano and Bond, 1991), absence of higher-order serial correlation: $corr(\Delta e_{it}, \Delta e_{i,t-2}) = 0$ and $corr(\Delta e_{it}, \Delta e_{i,t-3}) = 0$; $corr(\Delta e_{it}, \Delta e_{i,t-1}) \neq 0$ by construction. (p-values= 0.48, 0.43, and 0) Back

Allowances and Emissions Reduction(2SLS)

$$
\begin{aligned}
R_i &= \zeta_0 + \zeta_1 \hat{E}_i + W_i\theta + u_i; \ \text{(Second stage)} \\
E_i &= \delta_0 + \delta_1 e_{i,11} + \delta_2 e_{i,12} + W_i\lambda + v_i. \ \text{(First stage)}
\end{aligned}
\tag{7}
$$

- $e_{i,11}$ and $e_{i,12}$: emissions shocks for firm i in 2011 and 2012
- E_i : the allowance surplus (or deficit, if negative) for firm i in 2013
- W_i : a set of control variables, including sector dummy, ownership dummy, and firm i's average emissions before 2013

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Monotonicity

$$propensity_i = \gamma_0 + \gamma_1 e_i + \gamma_2 avgemi_i + s_i + o_i + \epsilon_i, \quad (8)$$

Table: Tests for the monotonicity assumption

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
iv11 (emissions in ton)	-0.43***	-0.61***	-0.20	-0.39***	-0.47***	-0.41***	-0.33	-0.43***	-0.40**
	(0.11)	(0.15)	(0.24)	(0.13)	(0.14)	(0.09)	(0.22)	(0.11)	(0.17)
iv12 (emissions in ton)	-0.49***	-0.60***	-0.74***	-0.53***	-0.76***	-0.46***	-0.79***	-0.59***	-0.73***
	(0.16)	(0.17)	(0.15)	(0.12)	(0.17)	(0.10)	(0.18)	(0.11)	(0.15)
Observations	74	73	73	131	89	111	109	113	107
Mean dependent var.	-1.42	451.94	3310.10	602.69	2197.42	1432.49	1059.78	1530.90	948.89
Sd. of dependent var.	5813.16	4235.48	7956.44	5219.54	7621.89	5273.34	7278.91	6534.16	6133.86
Sample	1st tertile	2nd tertile	3rd tertile	Service	Industry	Below median	Above median	State related	Non-state related
R-squared	0.59	0.49	0.55	0.58	0.50	0.66	0.63	0.63	0.46

Note: First-stage estimations on the test of monotonicity assumption of emissions shocks (in ton) in 2011 and 2012 as instrumental variables by the propensity score of having allowance surplus (columns 1–3), sector (columns 4–5), firm size (columns 6–7), and ownership (columns 8–9).Emissions shocks are constructed as the realized emissions and predicted emissions in 2011 and 2012; the propensity score equals 1 if a firm had an allowance surplus in 2013, and 0 otherwise. Specifications in all the columns include sector dummies, ownership dummies, and the average emissions between 2009 and 2012. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

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