Carbon Markets with Chinese Characteristics: From Design to Consequences

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March 13, 2026

Motivation

- China's national carbon market uses a **Tradable Performance Standard (TPS)**: allowances allocated per unit of output based on emission-intensity benchmarks (Fischer, 2001; Goulder et al., 2022).
- **Benchmarks** determine whether firms receive subsidies or penalties $\Rightarrow$ shape firm behavior and aggregate emissions (Pizer and Zhang, 2018).
- Power sector is **highly concentrated**, dominated by five large SOE generation groups (Zhang et al., 2023).
- **Key question**: Are carbon costs transmitted to electricity prices?

This Paper

- **Theory**: How does rate-based carbon trading interact with imperfect competition in the power sector?
- **Empirics**: Micro evidence on carbon cost pass-through to electricity prices across three provinces.
- **Finding**: No carbon cost pass-through — lenient benchmarks subsidize most generators, eliminating the price signal.
- **Discussion**: Evidence consistent with **regulatory capture** — SOE-dominated sectors receive more lenient benchmarks.

Contribution

1. First rigorous empirical evaluation of carbon cost pass-through in China's **national** ETS using unit-level data.
2. Advances TPS theory by incorporating **imperfect competition** and strategic bidding.
3. New evidence on **regulatory capture** in China's carbon-electricity nexus.
4. Reconciles puzzling patterns: low carbon prices, low liquidity, no economic impact.

Carbon and Electricity Markets in China

Carbon Market

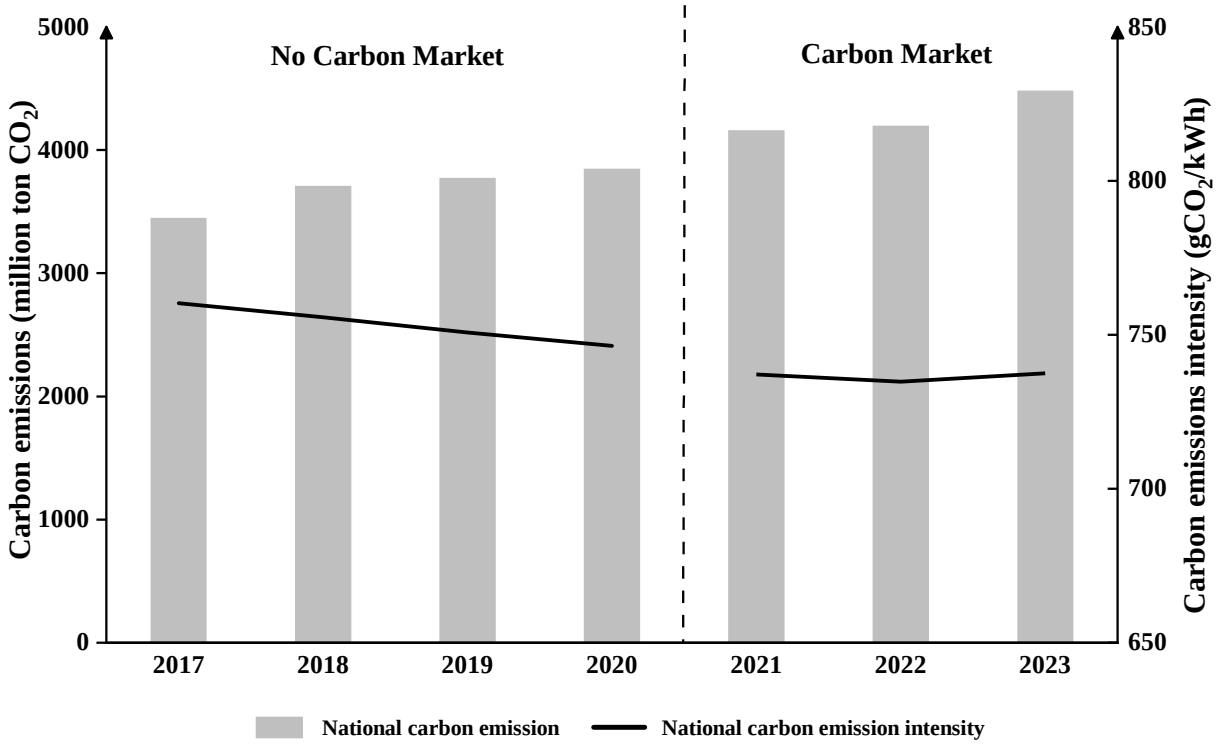
- 2013–2021: Regional pilots (cap-and-trade based on historical emissions).
- 2021–present: **National ETS** covering power sector only; **rate-based** allocation (Goulder et al., 2022).

Electricity Market

- 2015 reform ("No. 9 Document"): real-time spot markets in pilot provinces (Guo et al., 2020).
- Data: Shandong, Shanxi, Guangdong — provinces with active spot trading.

Carbon Market Has Not Reduced Emissions

China's national carbon market has **contributed nothing** to controlling total carbon emissions or emission intensity.



Model: Rate-Based Scheme and Carbon Cost

Generator i's profit under TPS with benchmark B:

$$\pi_i = \bar{p}_i \bar{q}_i + p(q_i - \bar{q}_i) - C_i(q_i, a_i) - \lambda(E_i(q_i) - a_i - Bq_i) \tag{1}$$

FOC w.r.t. output q_i:

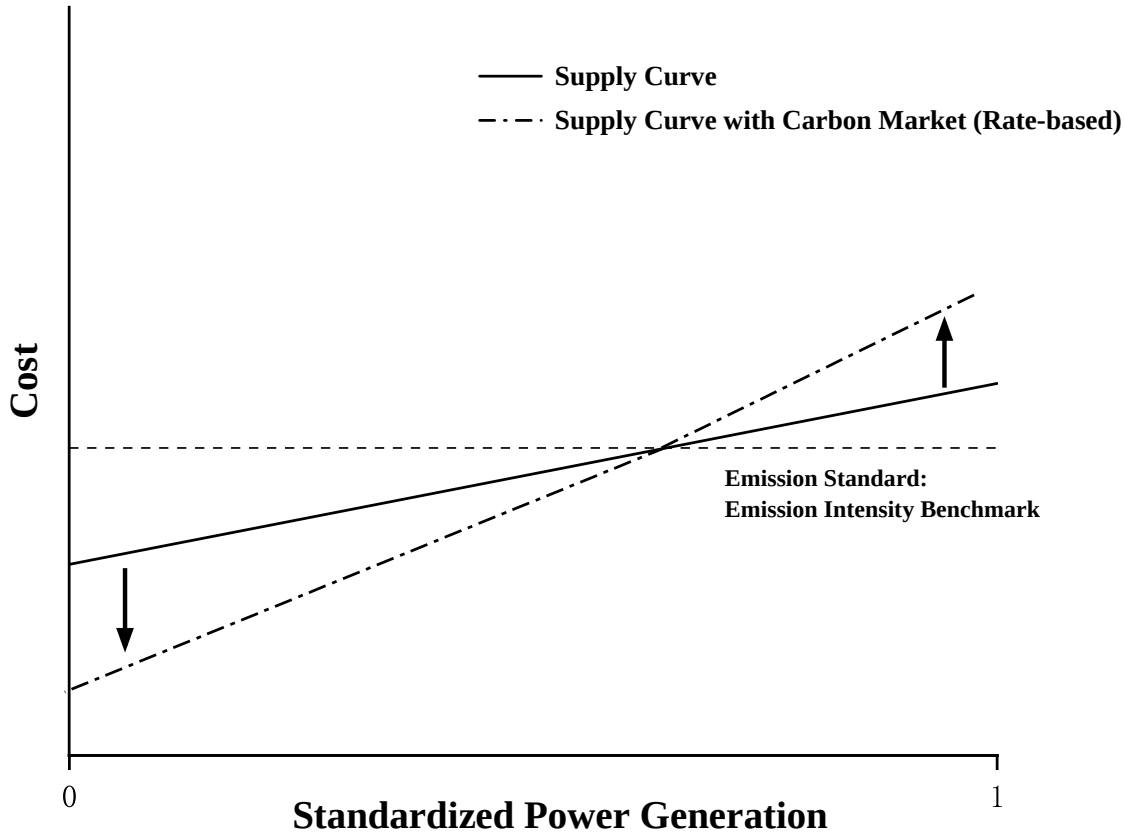
$$p = C_q' + \lambda \underbrace{(E_q' - B)}_{\text{carbon cost component}} \tag{2}$$

Key insight:

- If $E_q' > B$ (dirty unit): carbon **tax** $\Rightarrow$ cost increases.
- If $E_q' < B$ (clean unit): carbon **subsidy** $\Rightarrow$ cost decreases.
- Lenient $B \Rightarrow$ most firms subsidized $\Rightarrow$ no upward price pressure.

TPS Rotates the Supply Curve

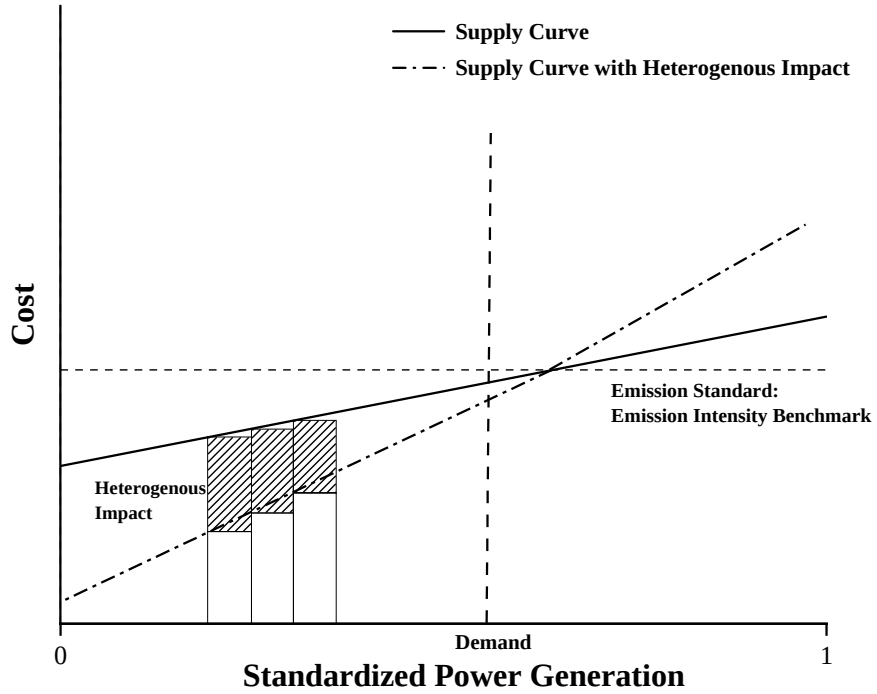
Unlike cap-and-trade (shifts curve up), rate-based scheme rotates the supply curve around the benchmark.



Clean units (below benchmark): cost ↓ Dirty units (above): cost ↑

Heterogeneous Costs and Strategic Bidding

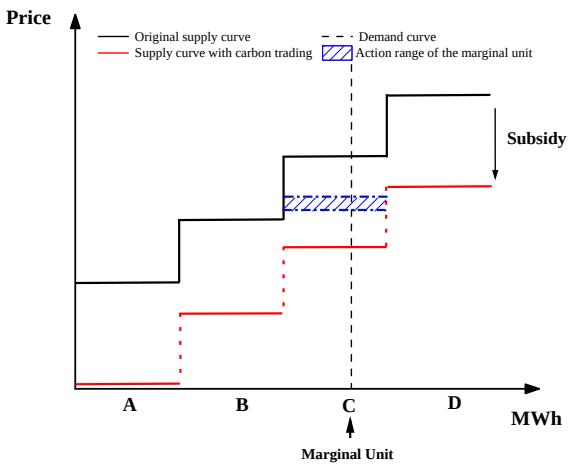
Generators face heterogeneous cost impacts (subsidy vs. tax):



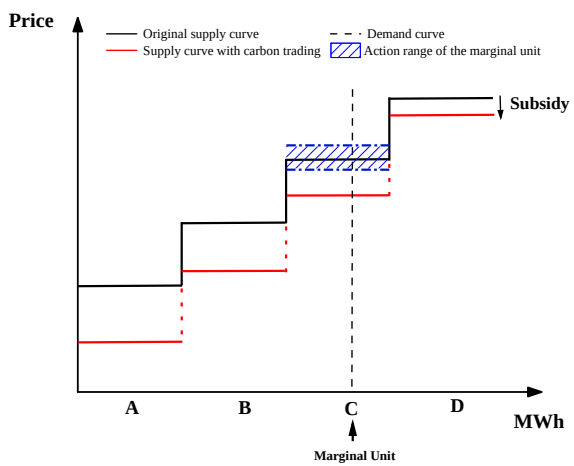
Under imperfect competition (Kim, 2022): firms adjust markups strategically $\Rightarrow$ heterogeneous pass-through rates.

Three Cases of Carbon Cost Pass-Through

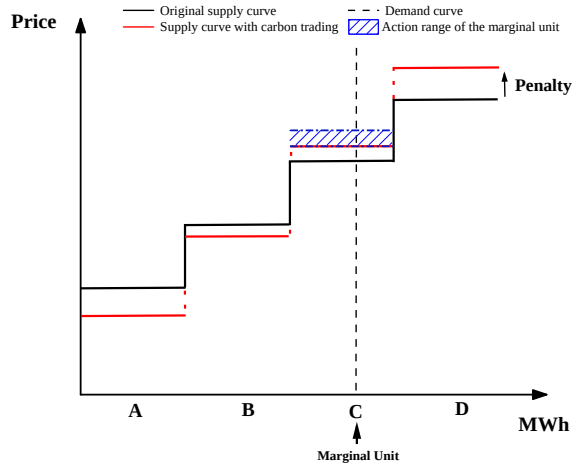
Depending on whether the marginal generator receives a subsidy or penalty:



(a) Subsidy $>$ cost diff.



(b) Subsidy $<$ cost diff.



(c) Penalty for marginal unit

Data preview: Marginal generators received subsidies in **90%** of cases $\Rightarrow$ Cases (a) or (b) dominate.

Data

Three provinces: Shandong, Shanxi, Guangdong (2021–2023)

- **Electricity prices**: Real-time spot prices from Provincial Trading Centers (hourly & 15-min)
- **Carbon price**: National ETS daily price (Wind Database)
- **Fuel prices**: Coal (Shanghai Harbor Index), Gas (NY futures)
- **Unit-level data**: Capacity, fuel type, emission intensity, ownership for all generators

Key advantage: Can identify marginal generators and calculate unit-level carbon costs.

Carbon and Electricity Prices

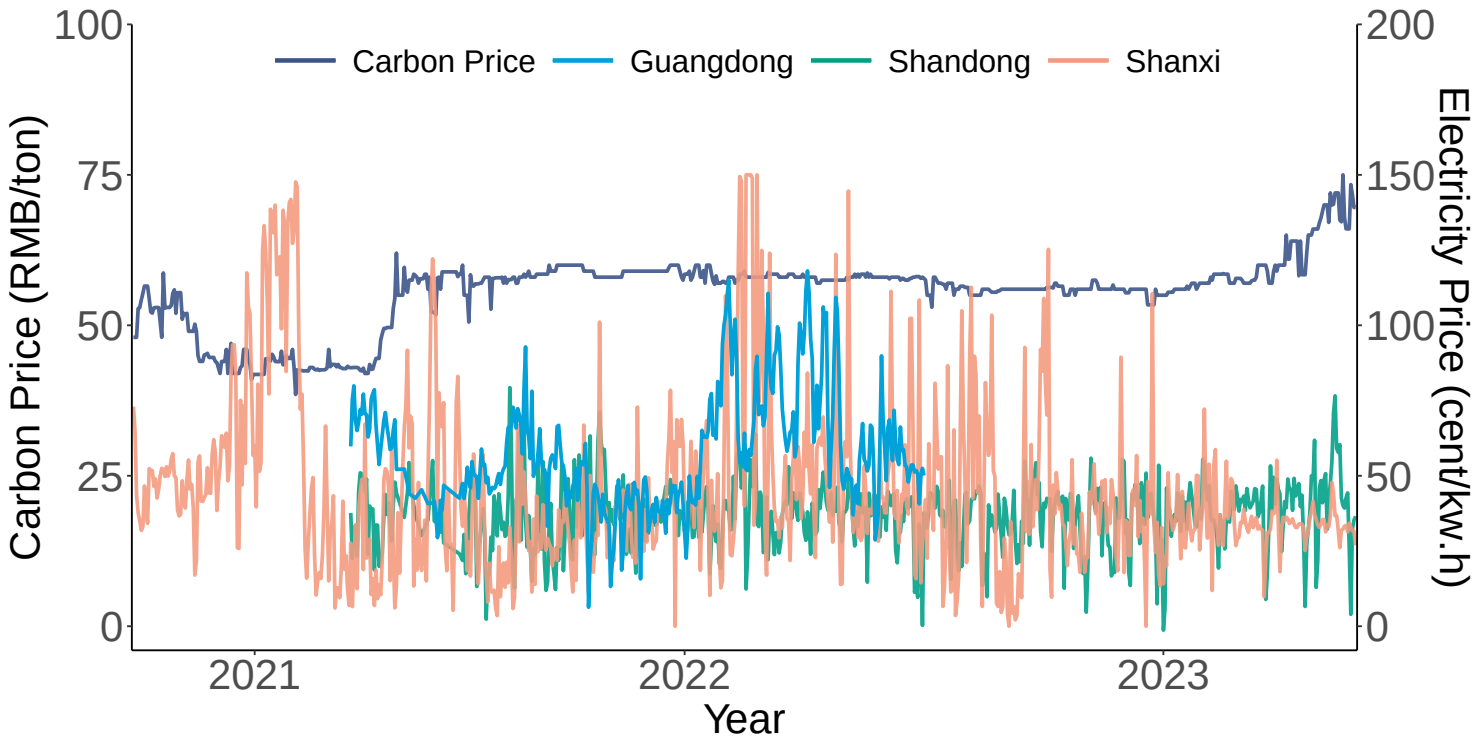
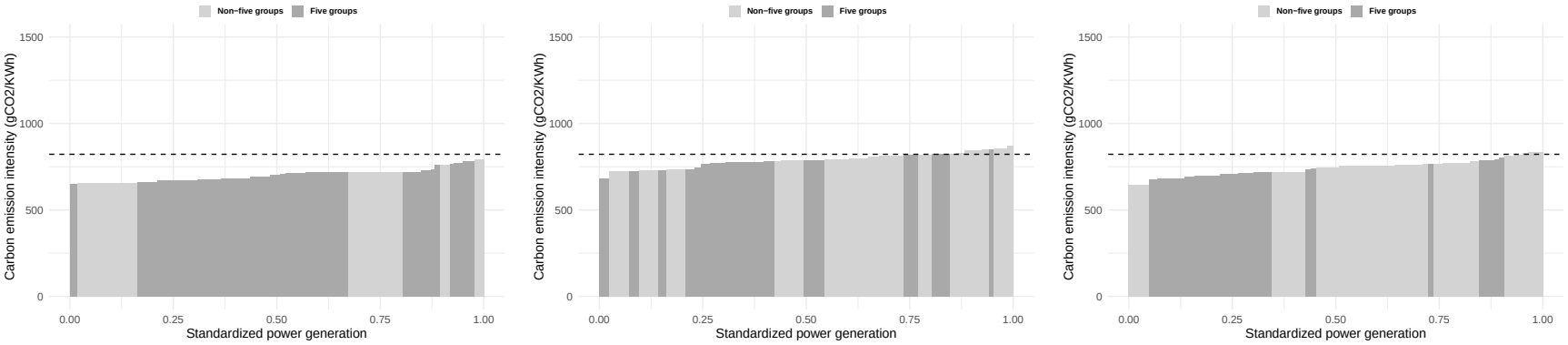
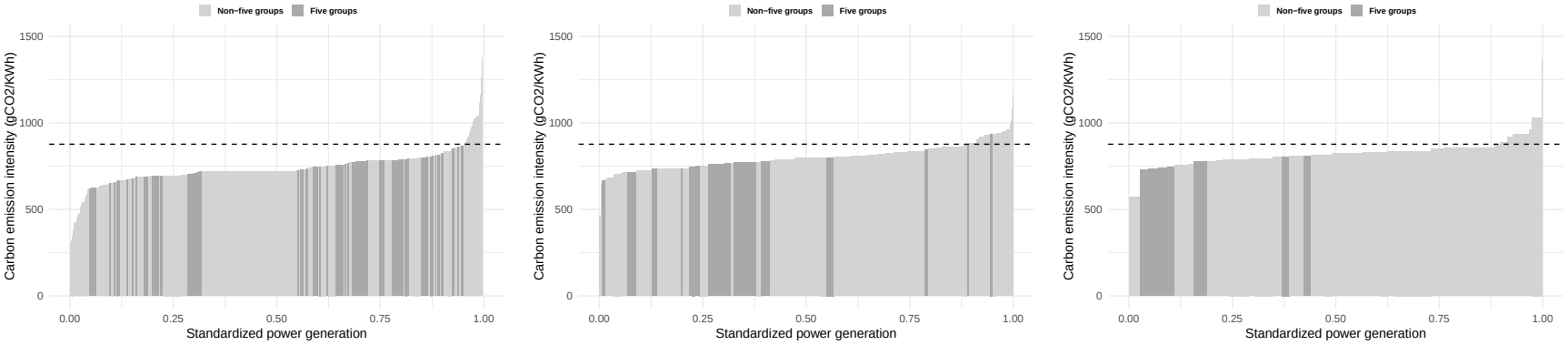


Figure: Carbon and electricity prices in Shandong, Shanxi, and Guangdong

Benchmark and Emission Intensity



(a) Shandong: Over 300MW (b) Shanxi: Over 300MW (c) Guangdong: Over 300MW

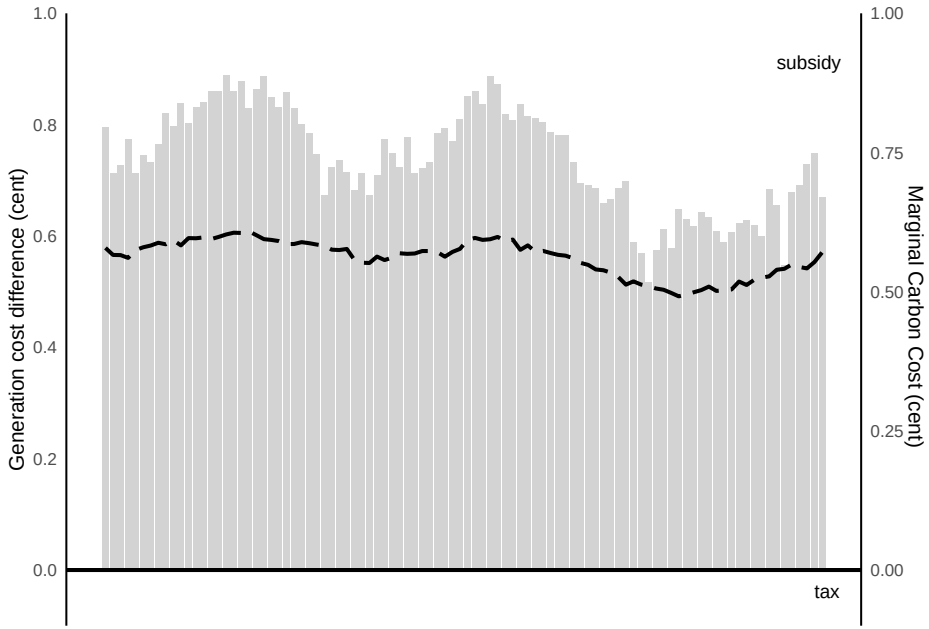


(d) Shandong: Under 300MW (e) Shanxi: Under 300MW (f) Guangdong: Under 300MW

Figure: Ordered Carbon Intensity of Generators

Carbon Costs vs. Generation Cost Gaps

- Most generators receive **subsidies** under the current benchmark.
- Carbon costs/subsidies are **too small** to bridge the marginal generation cost gap.



$\Rightarrow$ Carbon cost pass-through is missing under current conditions.

Pass-Through Estimation

Regress electricity price on marginal fuel cost and marginal carbon cost:

$$P_{jth} = \beta_1 C_{fuel,jth} + \beta_2 \underbrace{CC_{jth}}_{\text{carbon cost}} + X^D_{jth}\beta^D + X^S_{jth}\beta^S + \theta_j + \lambda_{th} + \epsilon_{jth} \quad (3)$$

- $CC_{jth} = \lambda_t(\alpha \cdot ec_{jth} - B)$: carbon cost of marginal generator
- Controls: load demand, renewable generation, transmission
- Province FE + Time FE; hourly & 15-minute frequency

Key coefficient of interest: β_2 — carbon cost pass-through rate.

Results: Zero Carbon Cost Pass-Through

	Hourly Results		Minute Results	
	(1)	(2)	(3)	(4)
Carbon	0.020	0.691	0.056	−0.035
	(0.664)	(0.596)	(0.276)	(0.254)
Fuel	1.141***	1.207***	0.997***	0.988***
	(0.093)	(0.135)	(0.042)	(0.062)
Renewables	−0.008***	−0.008***	−0.008***	−0.008***
	(0.0002)	(0.0003)	(0.0001)	(0.0001)
Load	0.004***	0.003***	0.004***	0.004***
	(0.0001)	(0.0002)	(0.0001)	(0.0001)
Transmission	−0.002***	−0.002***	−0.002***	−0.002***
	(0.0002)	(0.0002)	(0.0001)	(0.0001)
Indi-FE	N	Y	N	Y
Time-FE	Y	Y	Y	Y
Adjusted R^2	0.362	0.362	0.357	0.357

Carbon coefficient: insignificant across all specifications.

Fuel cost: passes through ≈1:1 as expected.

Observations with "floor" and "cap" prices removed (Jha & Leslie, 2022; Weber & Woerman, 2024).

Provincial Heterogeneity

Table: Heterogeneous Pass-through Rate in Different Provinces

	Hourly Results			Minute Results		
	Shandong	Shanxi	Guangdong	Shandong	Shanxi	Guangdong
Carbon	−0.958	−0.472	4.147	−0.814	−0.497	1.195
	(1.918)	(1.150)	(1.284)	(1.145)	(0.566)	(0.550)
Fuel	0.256**	1.035**	0.645***	0.236***	1.037**	0.610***
	(0.026)	(0.168)	(0.0004)	(0.013)	(0.166)	(0.004)
Time-FE	Y	Y	Y	Y	Y	Y
Observations	9,485	7,940	5,647	33,754	26,742	22,290
Adjusted R^2	0.394	0.632	0.609	0.375	0.619	0.604

Carbon pass-through is **insignificant in all provinces**. Control variables suppressed for space.

Why No Pass-Through? Regulatory Capture

- Carbon costs are NOT transmitted ⇒ **By design**, not by accident.
- **Regulatory capture**: agencies meant to serve the public interest become influenced by the industries they regulate (Stigler, 1971; Peltzman, 1976; Laffont & Tirole, 1991).
- China's regulatory environment is deeply intertwined with **SOE interests** (Xu, 2011): banking (Ping, 2013), stock market (Ren, 2022), electricity (Lin & Purra, 2019).
- China's power sector:
  - **Market power**: Five SOE groups dominate generation.
  - **Revolving door**: Experts move between industry and regulation.

Evidence 1: SOE Share and Benchmark Leniency (Pilots)

Sectors with **higher SOE share** face **less stringent** benchmark tightening.

↑10pp SOE share ⇒ ↓0.38pp benchmark decline rate.

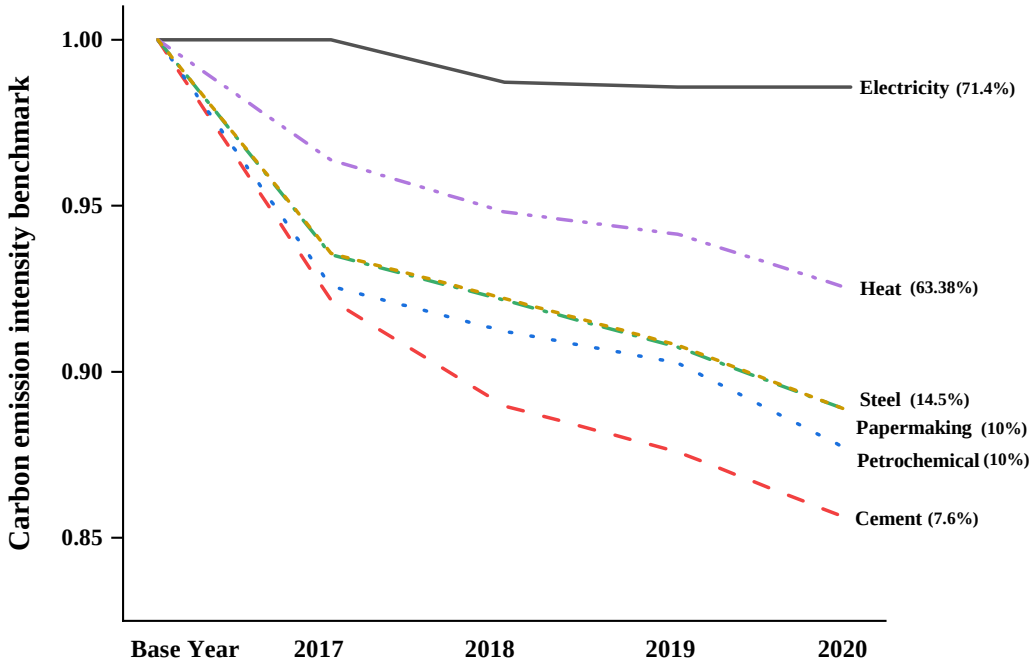


Figure: Trends of Carbon Emission Benchmarks in Different Industries

Evidence 2: SOE Dominance and Compliance Rates (Pilots)

Regions with **higher SOE dominance** $\Rightarrow$ **fewer penalized** generation units.

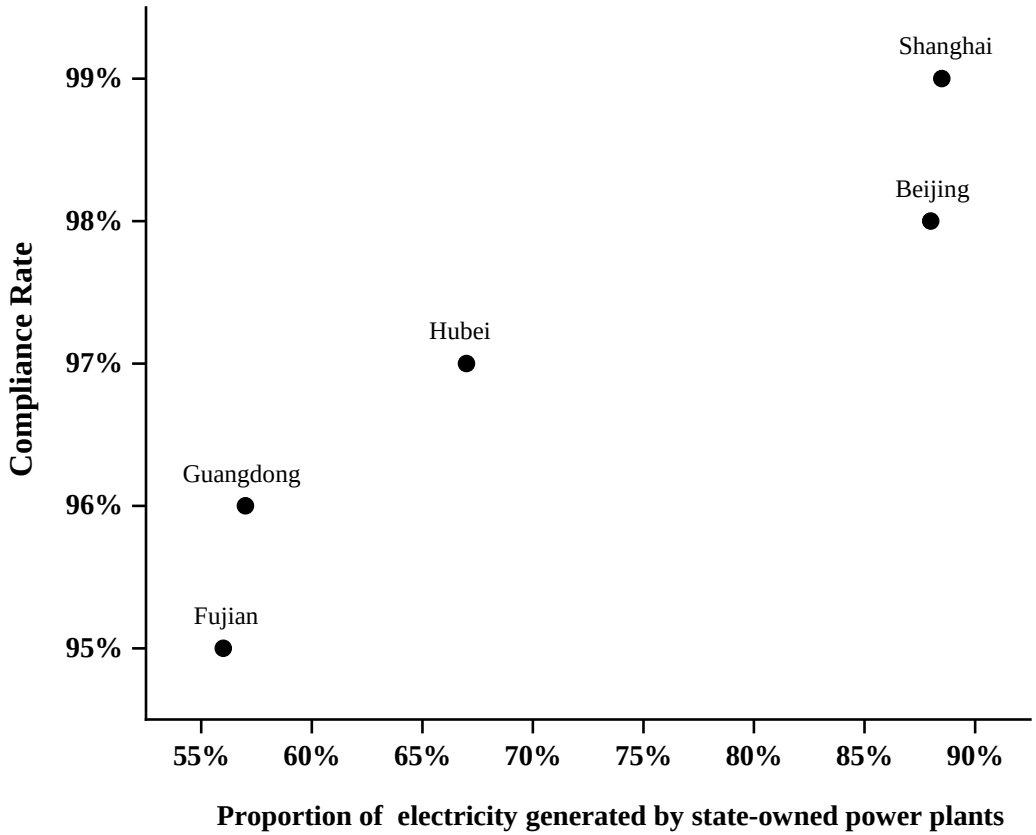


Figure: Market Power and Benchmark Stringency in Pilot Carbon Markets

Evidence 3: National ETS Benchmark Trends by Ownership

Benchmarks **decrease more slowly** in categories with **larger shares** of the top 5 groups.

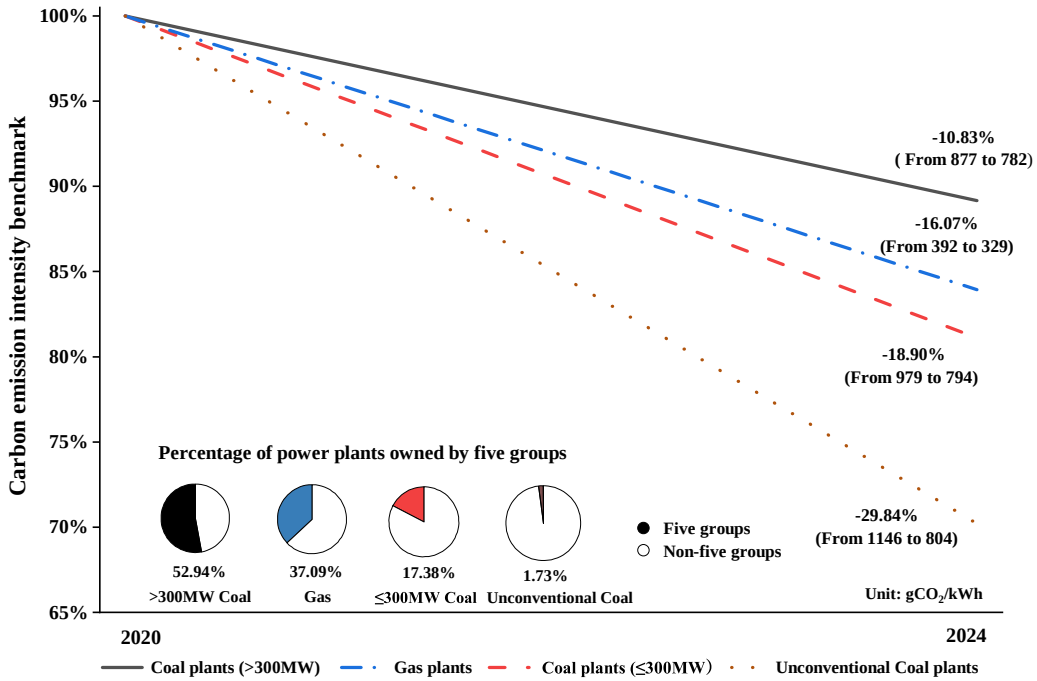


Figure: Trend of Standardized ETS Benchmarks and Ownership Structure

Evidence 4: Who Gets Penalized?

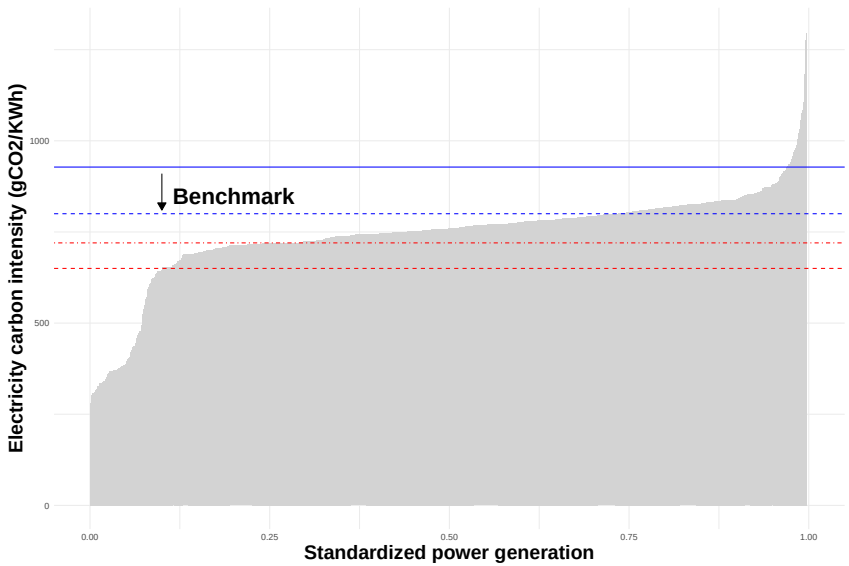
Only **2–5%** of top-5-group units are taxed vs. **19–23%** of others.

		2021	2022	2023	2024
Number of penalized units					
	Five groups	46 (2%)	51 (2%)	74 (4%)	92 (5%)
	Non-five groups	364 (19%)	371 (20%)	409 (22%)	431 (23%)
Penalized capacity (MW)					
	Five groups	35,061 (3%)	40,521 (4%)	60,719 (5%)	73,522 (7%)
	Non-five groups	81,052 (7%)	86,060 (8%)	118,324 (11%)	129,883 (12%)

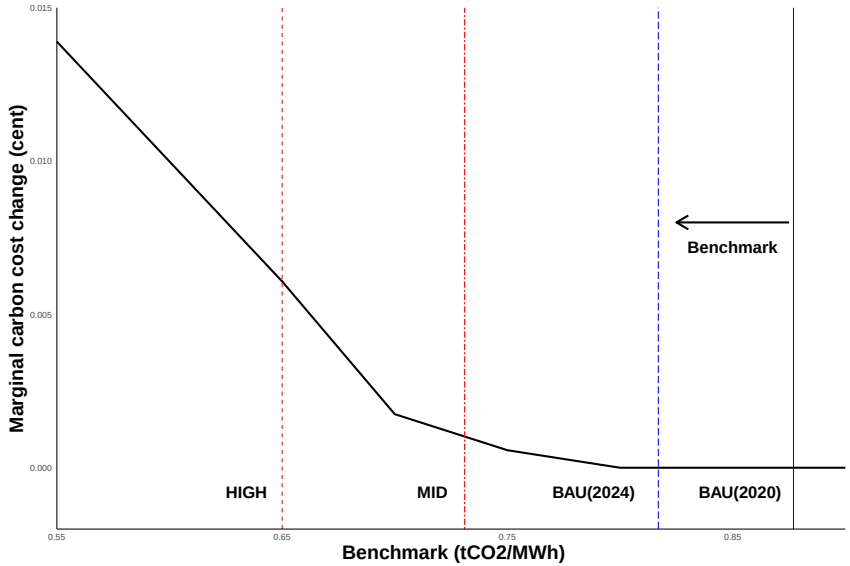
$\Rightarrow$ ETS design systematically favors large SOE-owned generators.

When Will Carbon Cost Pass-Through Occur?

Counterfactual: tighten benchmarks until the marginal unit faces a **tax** (not subsidy).



(a) Benchmark and penalized generators



(b) Marginal carbon cost change

Pass-through begins at ≈0.71 tCO_2/MWh (large coal), ≈0.80 (small coal), ≈0.33 (gas). Consistent with Goulder et al. (2026): current benchmarks are below efficiency-maximizing level.

Conclusion

1. Rate-based ETS **rotates** the supply curve ⇒ heterogeneous cost impacts.
2. Lenient benchmarks **subsidize** most generators ⇒ no carbon cost pass-through.
3. Evidence consistent with **regulatory capture**: SOE-dominated categories receive systematically more lenient benchmarks.
4. China's carbon market currently has **minimal economic impact**.
5. **Policy implication**: Significant benchmark tightening is needed before carbon pricing can affect the economy.

Thank  *You*

Appendix Slides

A1: Emission in the Energy Sector

Different from previous papers that analyze TPS (e.g., Goulder et al., 2018), we introduce emission abatement a_i instead of net emissions e in the model.

Express **total emissions** e_i as follows,

$$e_i = E_i(q_i) - a_i \tag{4}$$

E_i is the emission function of total generation q_i for generator i.

The total emission level is determined by both the generation and emission abatement means.

A2: Profit of Generator Under Imperfect Competition

Following Kim (2022), the market clearing profit is:

$$\pi_i = P(p_i, q_i, \mathbf{p_{-i}}, \mathbf{q_{-i}})(Q_i(P(p_i, q_i, \mathbf{p_{-i}}, \mathbf{q_{-i}})) - \bar{q}_i) + \bar{p}_i\bar{q}_i - C_i(Q_i, a_i) - \lambda(E_i(Q_i) - a_i - BQ_i) \tag{5}$$

Q_i: Quantity won by generator i in market competition

p_{-i} and q_{-i}: Bidding strategy of other generators
The marginal generator decides the market clearing price.

A3: Electricity Market in China

Phase I: before 2002

- State monopoly, with government-set electricity prices.

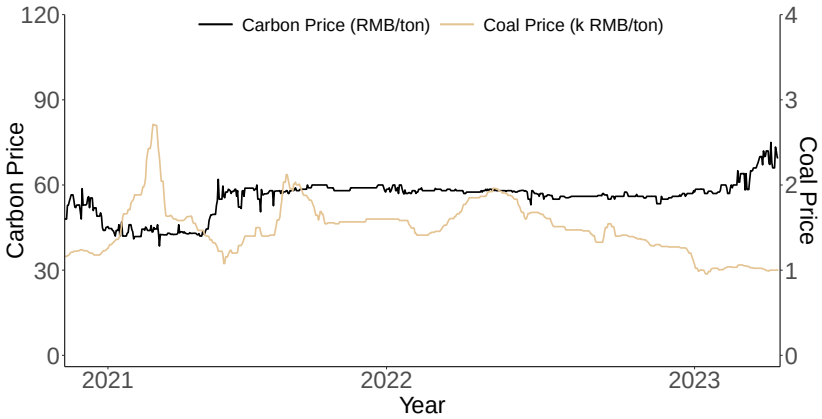
Phase II: 2002 - 2015

- "Separation of generation from the grid" policy (Ngan et al., 2010).

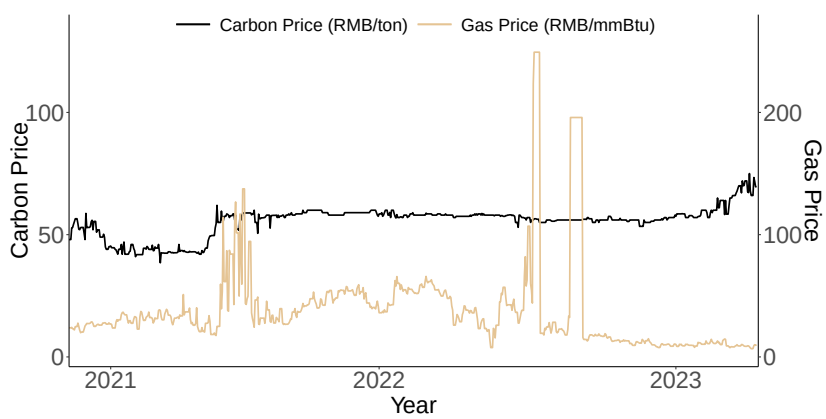
Phase III: 2015 - present

- "No. 9 Document" reform (Guo et al., 2020).

A4: Carbon, Coal, and Gas Prices

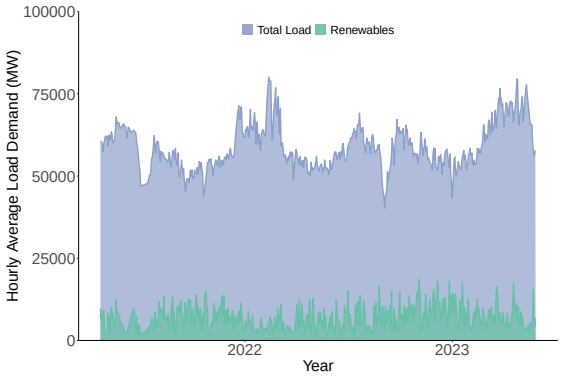


(c) Carbon and coal prices

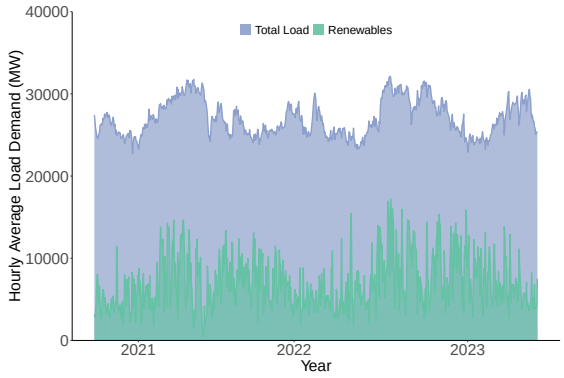


(d) Carbon and gas prices

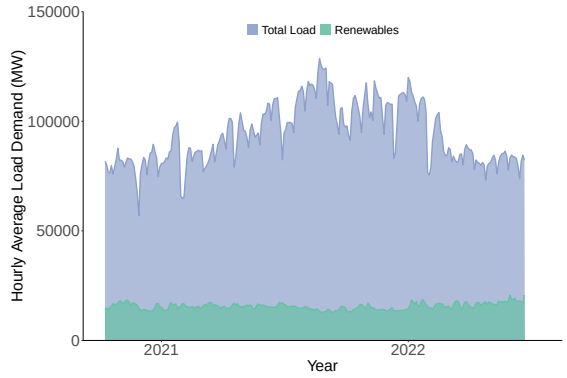
A5: Electricity Demand and Renewable Generation



(e) Shandong



(f) Shanxi



(g) Guangdong

Figure: Average Load Demand and Renewable Generation

A6: Data Source

Data	Source
Real-time Electricity Price	*Provincial Electric Power Trading Center*
Carbon Price	*Wind Database*
Gas Price	*NY future market*
Coal Price	*Coal Price Indexes at Shanghai Harbor*
load Demand	*Provincial Electric Power Trading Center*
Renewable generation	*Provincial Electric Power Trading Center*
Unit-level information	*Compilation of Statistics on the Electric Power Industry & National Unit Energy Efficiency Competition Data*

A7: Marginal Cost Calculation

- **Marginal generation cost difference between i and $i+1$**

$$\Delta C_{th}^{diff} = C_{i+1,th} - C_{i,th} \tag{6}$$

- **Marginal carbon cost of generator $i+1$**

$$CC_{i+1,th} = \lambda_t(\alpha ec_{i+1,th} - B) \tag{7}$$

- λ_t: daily carbon price; α: emission coefficient; $ec_{i+1,th}$: coal consumption/kWh.

A8: Marginal Generator Identification

Fuel cost of the marginal generator:

$$C_{fuel,jth} = \begin{cases} p_t^{Coal} FC_{jth} & \text{If generator type is Coal} \\ p_t^{Gas} FC_{jth} & \text{If generator type is Gas} \end{cases} \tag{8}$$

- p_t^{Coal} and p_t^{Gas}: coal/gas price
- FC_{jth}: fuel consumption per kWh of the marginal generator

A9: Who Benefits From the Carbon Market?

Table: Provincial Total Carbon Cost (million CNY)

	Province	2021	2022	2023
Shandong				
>300MW	Five groups	-902.55	-1001.15	-1086.43
	Non-five groups	-443.51	-492.43	-534.40
≤300MW	Five groups	-638.56	-709.13	-515.83
	Non-five groups	-1352.83	-1505.47	-1129.13
Shanxi				
>300MW	Five groups	-144.06	-190.69	-217.04
	Non-five groups	-96.44	-124.51	-141.52
≤300MW	Five groups	-248.16	-349.88	-241.33
	Non-five groups	-319.36	-436.74	-145.41
Guangdong				
>300MW	Five groups	-487.06	-603.49	-686.93
	Non-five groups	-478.84	-579.51	-658.83
≤300MW	Five groups	-76.48	-94.89	-66.82
	Non-five groups	-181.28	-212.64	-8.72
Gas-fired	Five groups	-15.98	-19.15	18.89
	Non-five groups	-33.12	-37.11	114.12

Notes: Negative = net subsidies; positive = net carbon taxes.

A10: Subsidies or Taxes under Alternative Benchmarks

Scenario	Coal >300	Coal ≤ 300	Gas	Carbon cost
1	0.80	0.88	0.37	subsidy
2	0.77	0.86	0.36	subsidy
3	0.75	0.84	0.35	subsidy
4	0.73	0.82	0.34	subsidy
5	0.71	0.80	0.33	tax

Notes: Tighten benchmarks until the marginal unit pays a tax.