Supply Reduction vs. Tax: China's Coal Industry

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Motivation

- How do we regulate externalities?
  - Pigouvian tax
  - Quota (cap and trade)
- Very few cases of cap-and-trade in developing countries
  - Weak institutional capacity/difficulty to build exchanges and monitor production
  - Instead: command-and-control supply reductions
  - Examples: factory shutdowns, moratorium on fishing/logging
- Resource tax more common
- Practical policy choices:
  - **Supply reduction** vs resource **tax**

Ambiguous Efficiency Ranking

- Policy maker chooses a policy instrument before uncertainty realizes
  - Uncertainty about demand, supply or external loss
- Classic Weitzman (1974) tradeoff based on relative slopes of MB, MC
  - Linear loss: use tax
  - Highly convex loss: use quota
- Supply reduction: similar to a quota, but allocatively inefficient
  - Steeper supply curve
- Efficiency ranking is an empirical question!

Reform of China's Coal Industry

- China: largest producer and consumer of coal (>50%)
- Coal: energy security, pollution, economic stability
- Reform: 2016-2019
  - Reduce capacity: close small mines and suspend new approval
  - **Constraints on production**
  - 35% YoY price increase in 2016
- We will take as capacity (entry & exit) as given and focus on the effects of production constraints

What do We Do?

- Estimate an equilibrium model of coal demand and supply
  - Production constraints as rotations of **supply** functions
- Quantify the effects of the supply reduction policy
  - Economic surplus
  - Environmental impact
- Develop a **criterion** to rank the policy with a tax
  - With very mild assumptions on the loss function

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1. Observed policy: economic surplus $\downarrow$, environmental cost $\downarrow$, total effect ≈ 0
2. A tax would be more efficient

Contributions & Literature Review

- New empirical evidence on Weitzman type tradeoff
  - Estimated equilibrium model
  - Prior work often uses IAM or calibrated models (Pizer, 2002; Muller and Mendelsohn; 2009; Newell and Pizer; 2003; Fell et al., 2012)
- Retrospectives on a large industrial policy; economic effects of environmental policies (Ryan, 2012; Fowlie et al., 2016; Chen et al., 2025; among many)
  - A novel ranking criterion: **minimal** assumptions on the objective, **no** assumption on the optimality of the observed policy
- China's coal industry matters a great to the world
  - New estimates on demand and supply elasticities
  - Prior work often uses older data (Burke and Liao, 2015; Shi et al., 2018; Teng et al., 2019); takes production function approach (Zhou et al., 2019; Zheng, 2024)

Road Map

1. Illustrative model
    1.1 Efficiency trade off
    1.2 Idea of the ranking criterion
2. Background and Data
3. Estimation of Supply and Demand
4. Counterfactual simulations
    4.1 Welfare relative to no supply reduction policy
    4.2 Welfare ranking between supply reduction and tax

Illustrative Model

Setup

- Supply function $P^S = a_0 + a_1 Q$
- Demand $P^D = b_0 + b_1 Q + \varepsilon$
- External marginal loss $MD = r_0 + r_1 Q$,
- $a_1 > 0, b_1 < 0, r_1 > 0$. Shock ε: mean 0; variance: σ^2
- Welfare

$$W = E\left(\int_0^{\max(Q^\star,0)} \left(P_D\left(q\right) - P_S\left(q\right) - MD\left(q\right)\right) dq\right)$$

$Q^\star$: equilibrium quantity

Tax vs Supply Reduction

- Tax: choose τ

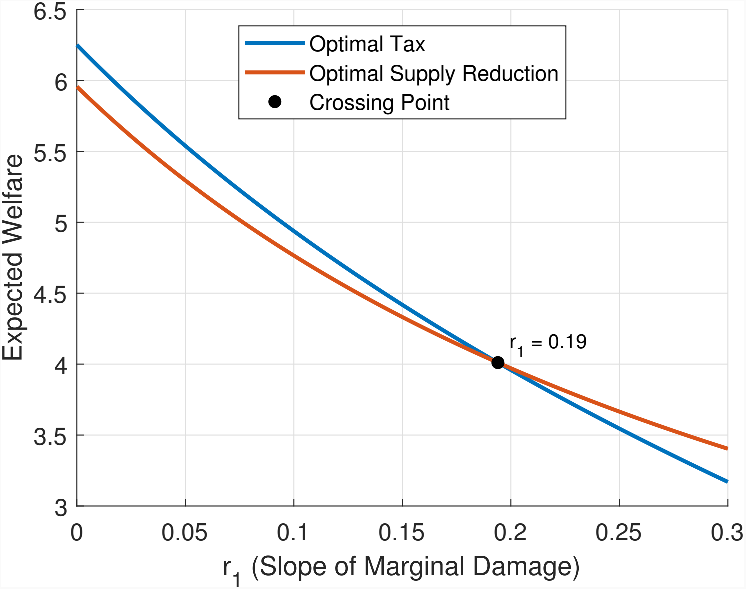
$$Q^\star = \max\left(0, \frac{b_0 + \varepsilon - a_0 - \tau}{a_1 - b_1}\right)$$

- Supply reduction: choose supply curve rotation $\alpha_1 > a_1$

$$P^S = a_0 + \alpha_1 Q,$$

$$Q^\star = \max\left(0, \frac{b_0 + \varepsilon - a_0}{\alpha_1 - b_1}\right)$$

Supply Reduction More Efficient When Loss Function is More Convex



Is There a Tax Better Than A Given Supply Reduction Policy?

- What happens if we do not know the loss function?
  - Environmental impact, forcing coal users to switch to renewables, reducing coal mining deaths, ...

$$W = \underbrace{E\left(\int_0^{\max(Q^\star,0)} \left(P_D(q) - P_S(q)\right) dq\right)}_{S} - \underbrace{E\left(\int_0^{\max(Q^\star,0)} MD(q)\, dq\right)}_{E(L(Q^\star))}$$

- Given an observed supply reduction policy, is there a tax that
  - matches the economic surplus S
  - has a smaller $E(L(Q^\star))$?

Ranking Criterion

Theorem
On a finite support, if L is finite, increasing and differentiable, and Q_1 stochastically dominates Q_2, then $E\left(L\left(Q_1\right)\right) \geqslant E\left(L\left(Q_2\right)\right)$

We can claim a tax is better, if

1. For a given supply reduction policy, compute S (eg., based on estimated model)
2. Find a tax $\tau^\star$ that matches S
3. Verify that the quantity distribution under the supply reduction policy stochastically dominates that under $\tau^\star$

We call $\tau^\star$ an SMD tax (**S**urplus-**M**atching with a **D**ominated quantity distribution)

(Non-)Existence of SMD Tax

- Finding an SMD tax is a sufficient condition: show the superiority of tax
  - Failure to find SMD tax does not say which one is better
- Supply reductions for many demand and supply functions have an SMD tax
- A tax does not admit SMD supply reduction
- No SMD tax for a quota and vice versa

Background and Data

Coal Industry in China

- Anthracite (high purity coal): 23%; bituminous: 70%
  - Majority use: electricity, coking, cement
  - Power plants in China adapt to mixed grades
- Reforms before 2014 create a national coal market connected by rails, rivers and sea
- Long-term contracts
  - Promised delivery quantity
  - Allow prices to move based on the spot market

Economic Policies

- Five-year plan in 2016 (13th): limit production to
  - improve coal industry profitability
  - improve worker welfare and safety
  - reduce environmental impact
- Alternative: resource tax
  - Started in 2014; low rates (2-8%)

Main Data Sources

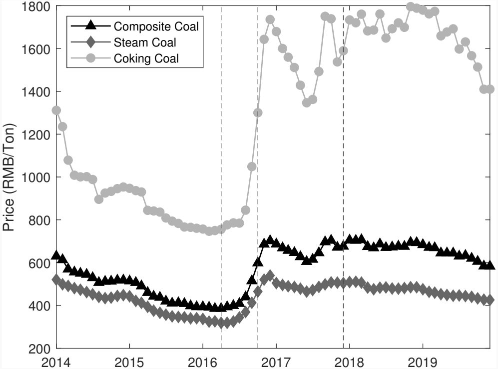
- Cross-province shipment 2012-2016: China Coal Transportation and Distribution Association (CCTDA)*
- Mining capacity 2014-2018: National Energy Administration
- Monthly consumption 2014-2017: China Coal Resources* and imputation
- Monthly production 2014-2019: CCTDA* and National Bureau of Statistics (NBS)
- Monthly provincial coal prices: National Development and Reform Council
- High frequency station level air quality 2014-2017: Ministry of Environmental Protection

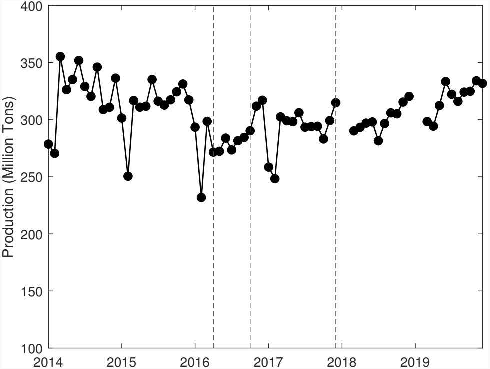
*: commercial data vendors

Summary Statistics

	Mean	SD	p25	Median	p75
Panel A. Coal-Consuming Provinces					
Quantity (Million Tons/Month/Province)					
Consumption	1016.15	762.98	462.04	746.56	1329.72
Price (RMB/ton)	532.01	133.87	430.21	523.03	615.45
N=1440; based on 30 coal-consuming provinces in 2014-2017					
Panel B. Coal-Producing Provinces					
Quantity (Million Tons/Month/Province)					
Supply	1130.13	1991.28	119.92	361.51	997.66
Capacity	1121.09	1784.84	158.92	517.61	1239.99
N=1200; based on 25 coal-producing provinces in 2014-2017					
Panel C. Foreign Import					
Quantity (Million Tons/Month)	60.4	90.3	0	11.13	98.57
N=48; 2014-2017					

Price and Quantity





Key Data Patterns

1. Major provinces and large SOEs drive quantity reduction
   - Inner Mongolia, Shanxi
2. A province's share of coal shipped to another province has remained stable
   - Possible reasons: long-term contract fixed shipping capacity; power plant preferences

Demand and Supply

Demand

- In province j and month t, coal consumption

$$\ln q_{jt} = \alpha \ln p_{jt} + \alpha_{wind} \ln e_{jt}^{wind} + FE_j^{\text{demand}} + FE_{m(t)}^{\text{demand}} + \varepsilon_{jt}$$

  Wind power generation; province and month fixed effects
- Instruments
  - Shift-share IVs accounting for differences in policy **timing** and **exposures**
  - SOE shift-share: average lagged (2012-3) province i's SOE production weighted by transportation shares to j, interacted with policy start indicator
  - Capacity shift-share: weighted average of small coal mine capacity in 2014 (at risk of closure in 2016) in province i by transportation shares, interacted with policy start indicator
- Elasticity: -0.534

Supply

- Province i's production in month t

$$\ln MC_{it} = \gamma \frac{q_{it}}{K_{it}} + FE_i^{\text{supply}} + FE_{m(t)}^{\text{supply}} + \text{policy effect}_{it} + \eta_{it}$$

  K_{it}: approved mining capacity

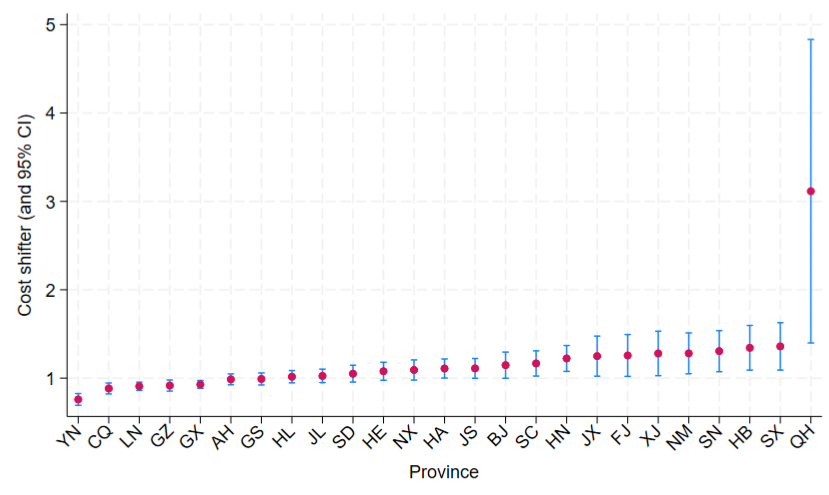
  P_{it}: average destination prices

  Policy effect rotates the MC curve

- Instruments:
  - Weighted average of wind production in destination provinces; demand residuals
- Elasticities:
  - Shanxi: 0.83, Inner mongolia: 0.66, average: 1.13

Policy Increases MC

$$MC^{\text{policy}} = \text{shifter} \cdot MC^{\text{pre-policy}}$$



Welfare Effects and Policy Ranking

Counterfactual Simulations

- Assume
  - policy maker chooses the rotation of the supply curve before knowing the demand and supply shocks in 2017
  - capacity (mine closures) are taken as observed in the data
  - shocks are AR1
- Main simulations
  - What is the effect of the observed policy?
    - Welfare changes relative to a no-policy counterfactual
  - What is the welfare cost of misallocated reduction?
    - Economic surplus changes relative to a uniform tax with the same expected quantity
  - Is tax better under any increasing loss function?
    - Does there exist an SMD tax?

Welfare Effects of the Observed Policy

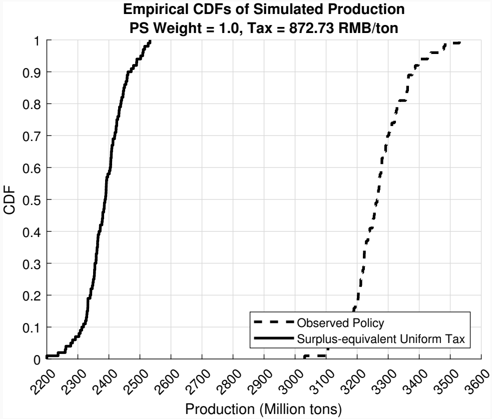
Observed Policy - No Policy	Mean	95% Range
Changes in		
Delivery price (RMB/Ton)	160.80	[150.14, 171.07]
Production (Million Tons)	-606.17	[-625.14, -586.85]
Consumption (Million Tons)	-550.17	[-569.64, -531.84]
Surplus Changes (Trillion RMB)		
Consumer	-0.60	[-0.65, -0.56]
Producer	0.06	[0.05, 0.07]
Total Economic Surplus	-0.54	[-0.58, -0.50]
Saved Environmental Costs (Trillion RMB)		
Aerial Pollution	0.29	[0.27,0.31]
Production Process	0.08	[0.08,0.08]
Carbon	0.16	[0.16,0.17]
$\triangle$Total	-0.01	[-0.05,0.04]

Welfare Costs of Misallocation

Output-equivalent Tax - Observed Policy	Mean	95% Range
Changes in		
Delivery price (RMB/Ton)	26.14	[12.68, 43.96]
Production (Million Tons)	0.00	-
Consumption (Million Tons)	-89.56	[-159.42, -46.02]
Surplus Changes (Trillion RMB)		
Consumer	-0.07	[-0.13, -0.03]
Producer	-0.35	[-0.38, -0.32]
Tax Revenue	0.89	[0.86, 0.94]
Total Economic Surplus	0.47	[0.43,0.52]
Saved Environmental Costs (Trillion RMB)		
Aerial Pollution	0.04	[0.02,0.08]
Production Process	0.00	[0.00,0.01]
Carbon	0.03	[0.01,0.05]
ΔTotal	0.54	[0.52, 0.58]

There is an SMD Tax

$$Obj = CS + PS + tax - E(loss)$$



Conclusion

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- SMD tax as a ranking criterion to compare the efficiency of a supply reduction and a tax
- Estimate an equilibrium model of China's coal market
- Supply reduction significantly increases PS and total welfare
- Existence of SMD tax shows that a tax can do better than the observed policy
    - More nuanced if the policy maker weighs PS more