The Cost of Climate Policy to Capital: Evidence from Renewable Portfolio Standards

Harrison Hong, Edward Shore and Jeffrey Kubik

Columbia University and Syracuse University

Virtual Seminar in Climate Economics

April 16, 2024

Motivation

- Gradual implementation of climate policy targeting emissions-intensive sector
  - Carbon taxes, emissions trading systems, renewable portfolio standards,...
- Plentiful research on the benefits, but little on the costs to capital of firms in these sectors
- But having causal estimates of the effect on investors' forecasts of abatement costs and risks would be useful for ...
  - Understanding welfare and long-run investment in these sectors and guide climate modeling and policy (Nordhaus (2017), Jensen and Traeger (2014), Golosov et.al. (2014), Hong, Wang and Yang (2023))
  - Addressing financial regulatory concerns on transition risks (Task Force Climate Related Disclosures, European Systemic Risk Board)

Our Paper

- Estimate the response of bond markets to renewable portfolio standards (RPS), which cover power firms in 40% of major-emitting countries
  - Since power firms issue debt to fund investments, we have lots of bond yield data
  - Measure response to RPS requiring investor-owned producers to produce electricity with wind and solar
- Exploit institutional features of state-level RPS in the US (2001-2022) to identify effects of climate policy on capital
  - Municipal producer exemptions allow for state x year fixed effects
- Combine emissions, bond issue, and our novel identification strategy to estimate elasticity of credit spreads to a ton of carbon emissions reduction
- Use a structural bond pricing model (Merton (1974), Longstaff and Schwartz (1995), and Leland Toft (1996) to infer expected abatement costs
  - Distance to default: abatement costs reduce firm cashflows and asset value and lowers distance to default

Main Findings

- RPS leads to a reduction of carbon emissions of 2.7 millions tons per year for typical producer
  - More conservative than Greenstone and Nath (2020) and Deschenes et.al. (2023) who use cross state variation in RPS and plant/firm level emissions
  - We use within state comparison of investor-owned to municipals
  - We measure emissions at producer-type level from state enforcement of RPS to avoid missing emissions from purchases of renewable certificates (RECs)
- Comes at a cost of 66 bps (or around 24 bps per ton)
  - Difference-and-difference estimate is around 100 bps
  - No pretrends in dynamic DID
  - No effects in placebo sample of states without municipal exemptions
  - Triple difference estimate yields 66 bps
  - First causal estimates of elasticity of asset price to emissions reduction in the climate finance literature (Hong et.al. (2020), Giglio et.al. (2021))

Main Findings (Cont'd)

- RPS imposes an effective 1.3% tax as a fraction of asset value, corresponds to investors expecting \$50 per ton to reduce
  - GMM estimation of Longstaff and Schwartz (1995) to data on post-RPS credit spreads and difference in credit spreads between treatment and control
  - Use estimate of asset value using publicly traded debt and equity to then infer abatement cost per ton of emissions
  - Estimate larger than \$5-\$19 from Meng (2017) using 2009-2010 Waxman-Markey Bill
  - Renewables around 1.5 to 2 times more expensive for some of RPS sample
- Large effects consistent with marginally significant cost passthrough of 4% higher electricity prices
  - Differs from estimates in Europe where producer effects are mild and consumers bear the burden (Kanzig (2021)) depending on recycling of funds (Metcalf and Stock (2020).
  - Our estimates suggest that conclusions differ for the power sector where electricity price setting is determined by regulators as well.

Background: States with Municipal Exemptions

Table: Summary of RPS Legislation in States with Municipal Exemptions

State	Mandate Start	Maximum Renewable %	Year Max Achieved	No. Municipal	No. Investor-Owned	Municipal Sales (gwhrs)	Investor-Owned Sales (gwhrs)
Arizona	2001	15	2025	0	2.9	0	37,785
Colorado	2004	30	2020	8.4	1.65	4,780	28,987
Hawaii	2004	100	2045	0	3.1	0	9,393
Iowa	1991	1	2000	57.3	2.15	4,201	33,160
Illinois	2007	25	2026	18.4	4.2	3,580	15,599
Kansas	2009	20	2020	45.9	4	5,914	25,839
Minnesota	2007	30	2020	46.15	3.65	6,124	42,171
Missouri	2008	15	2021	2.05	2	427	22,663
North Carolina	2007	12.5	2021	2.95	3	2,490	96,816
New Hampshire	2007	12.8	2025	1	1.8	19	7,846
New Mexico	2004	80	2040	2.55	3	1,663	14,861
Ohio	2008	8.5	2026	14.75	8.25	5,148	85,027
Oregon	2007	50	2040	1	4.6	2,624	33,212
Virginia	2020	100	2050	8.55	3.2	3,397	90,430

Background: States without Municipal Exemptions

Table: Summary of RPS Legislation in States without Exemptions

State	Mandate Start	Maximum Green %	Year Max Achieved	No. Municipal	No. Investor-Owned	Municipal Sales (gwhrs)	Investor-Owned Sales (gwhrs)
California	2002	60	2030	13.15	7.55	38,027	190,115
Connecticut	1998	40	2030	1.65	1.7	387	2,718
District Columbia	2005	90	2041	0	0	0	0
Delaware	2005	21.5	2026	1.82	0	222	0
Maine	1999	84	2030	0	1.83	0	1,689
Maryland	2004	50	2030	1.6	0	284	0
Massachusetts	2002	100	2090	8.85	3.55	2,829	15,156
Michigan	2008	15	2021	18.05	8.75	4,631	91,907
Montana	2005	15	2015	0	2.1	0	1,076
Nevada	1997	50	2030	0	3.65	0	30,303
New Jersey	1999	52.5	2045	1	3.7	627	46,869
New York	2004	70	2030	4.25	9.25	951	95,247
Pennsylvania	2004	7.5	2020	1	7	292	27,979
Rhode Island	2004	100	2033	0	1	0	11
Texas	1999	5	2025	11.8	4.55	40,173	47,342
Vermont	2015	75	2032	4.75	2.2	529	4,244
Washington	2006	15	2020	3	3.95	14,204	32,038
Wisconsin	1999	10	2015	9.9	8	2,068	50,272

Data on Renewables, Emissions and Electricity Prices by Producer Type, 2001-2020

Table: Summary Statistics by Producer-Type-State-Year

	Investor-Owned			Municipal		
Variable	N	Mean	SD	N	Mean	SD
Number of Producers	200	2.4	1.1	167	23	21
Observations in Post Period	200	0.71	0.45	167	0.72	0.45
Renewable/Non-Renewable Capacity	200	0.014	0.039	167	0	0
Per Firm CO2 Emissions (metric tons)	200	5,998,148	4,685,296	167	253,942	476,152
Electricity Prices (per KWhr)	200	$0.10	$0.49	167	$0.11	$0.73

Effects of RPS on Renewables, Emissions and Electricity Prices

Table: Firm/Producer-Type Level Difference in Differences

Dependent Variables:	Renewable/Non-Renewable Ratio	Average Firm Emissions (CO2)	Log of Electricity Prices
Model:	(1)	(2)	(3)
Variables			
corp	0.0006**	7,756,508.5***	-0.0974***
	(0.0003)	(826,846.7)	(0.0175)
corp × post	0.0224***	-2,701,193.7***	0.0416*
	(0.0044)	(904,025.5)	(0.0237)
Fixed-effects			
State-Year	Yes	Yes	Yes
Fit statistics			
Observations	367	367	367
R^2	0.56537	0.77278	0.95976
Within R^2	0.18555	0.63509	0.15853

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Bond Issue Variables

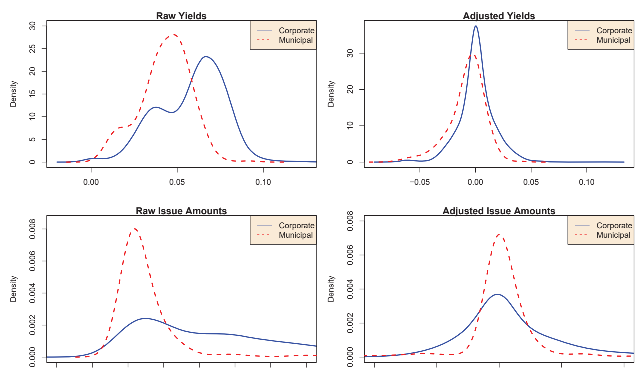
Table: Summary Statistics of Bond Data

	Municipal			Investor-Owned		
Variable	N	Mean	SD	N	Mean	SD
Yield	322	0.043	0.014	1739	0.058	0.019
Maturity (years)	322	19	7.1	1739	16	11
Issue Amount ($mn)	322	54	103	1739	244	233
Moody Rating (rank)	322	1.3	0.98	1739	6.7	2.5
Investment Grade	322	1	0	1739	0.95	0.21
Observations in Post Period	322	0.27	0.44	1739	0.39	0.49
Adjusted Yield	322	-0.0063	0.013	1739	0.0011	0.013
Adjusted Issue Amount ($mn)	322	15	84	1739	39	141
Year	322	2002	5.6	1739	2004	9.6
Security Type	322			1739		
... CB	0	0%		1739	100%	
... GO	32	10%		0	0%	
... RV	290	90%		0	0%	
Tax Code	322			1739		
... A	14	4%		0	0%	
... CB	0	0%		1739	100%	
... E	275	85%		0	0%	
... T	33	10%		0	0%	

Adjusted Yields and Issue Amounts

Figure: Distributions of Adjusted Yields and Issue Amounts

We construct benchmarks by forming 5x5x5 portfolios on Moody's rating, maturity, issue size, and yields. We then subtract the median yield/issue amount/maturity/bond rating in each portfolio from the actual value for each issue inside that portfolio.



RPS Increases Credit Spreads and Issue Amount

Table: Credit Spreads and Issuance Difference-in-Differences

Dependent Variables:	Adjusted Yields	Adjusted Issue Amount
Model:	(1)	(2)
Variables		
corp × post	0.0099***	51.66
	(0.0026)	(32.70)
Controls	Yes	Yes
Fixed-effects		
State-Year	Yes	Yes
Issuer	Yes	Yes
Security Type	Yes	Yes
Tax Code	Yes	Yes
Fit statistics		
Observations	2,050	2,050
R^2	0.76049	0.67895
Within R^2	0.19169	0.05921

Clustered (state-year) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Similar Estimates When Run State by State

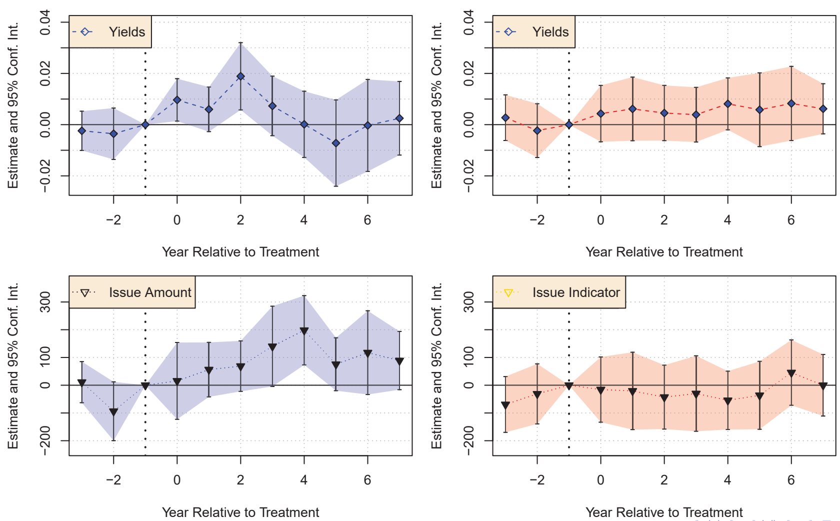
Table: State-by-State Results

Dependent Variables:	Adjusted Yields		Adjusted Issue Amounts	
Weighting:	Observations	Precision	Observations	Precision
Variables				
corp × post	0.0084*	0.0114***	28.74	104.69***
	(0.0044)	(0.0029)	(58.65)	(30.34)
Controls	Yes	Yes	Yes	Yes
Fixed-effects				
Year	Yes	Yes	Yes	Yes
Issuer	Yes	Yes	Yes	Yes
Security Type	Yes	Yes	Yes	Yes
Tax Code	Yes	Yes	Yes	Yes

Standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Panel Event-Study Results

Figure: Dynamic DID for States with and without exemptions



Triple Difference Estimates

Table: Pooling States with and without Exemptions

Dependent Variables:	Adjusted Yields	Adjusted Issue Amt.
Variables		
corp × post	0.0029	57.98***
	(0.0018)	(18.60)
exempt × corp × post	0.0066**	4.764
	(0.0032)	(35.96)
Controls	Yes	Yes
Fixed-effects		
State-Year	Yes	Yes
Issuer	Yes	Yes
Security Type	Yes	Yes
Tax Code	Yes	Yes
Fit statistics		
Observations	6,668	6,668
R^2	0.77530	0.70137
Within R^2	0.13157	0.03803

Clustered (State-Year) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Longstaff and Schwartz (1995) Model of Corporate Bond Yields

- The value of a firm's assets (V) evolves according to a geometric Brownian motion:

$$dV = \mu V dt + \sigma V dZ_1,$$

  where σ is a constant representing asset volatility, and Z_1 is a standard Wiener process.
- The short-term riskless interest rate is defined by the following process:

$$dr = (\zeta - \beta r)dt + \eta dZ_2$$

  where ζ, β, and η are constants and Z_2 is another standard Wiener process.

Distance to Default X

- Price of a risky discount bond, $P(X, r, T)$

$$P(X, r, T) = D(r, T) - \omega D(r, T)Q(X, r, T),$$

  - $D(r, T)$ is price of riskless bond
  - ω represents the proportion of the debt not recovered in the case of default
  - $Q(X, r, T)$ is a measure of the cumulative default probability
  - X represents the distance to default, which is defined as the ratio of firm value at issuance (V) to the constant lower bound value of the firm that triggers default ($\underline{V}$)
- Price of risky coupon bond $P^C(C, X, r, T)$ is a portfolio of risky discount bonds,from which we can invert the bond yield

$$y(C, X, r, T)$$

Abatement Costs Lower Distance to Default

- Let τ be the annual abatement costs to meet RPS expressed as a fraction of asset value
- We convert these abatement costs into a lump sum impact on the initial value of firm assets V_0

$$V_0^\tau = (1 + \delta^\tau)V_0$$

where

$$\delta^\tau = \tau \sum_{t=1}^{N} (1 + r)^{-t}$$

- Given that the expected value of V is linearly related to V_0, and X is simply the ratio of V to the constant default boundary, $\underline{V}$, this adjustment can then be directly applied to X to give the implied distance to default of the firm after RPS

$$X^\tau = (1 + \delta^\tau)X$$

- The yield spread impact of RPS relative to the counterfactual bonds that are not taxed (i.e. municipal bonds) is then given by the following expression:

$$\Delta y^{RPS} = y(C, X, r, T) - y(C, X^\tau, r, T)$$

Parameters

Table: Parameters

Parameter	Symbol	Source
Risk-free interest rate	r	Sample average from reduced form dataset (4.03%)
Debt not recovered after default	ω	Huang and Huang (2012) (0.5131)
Coupon Rate	C	Sample average from reduced form dataset (5.8%)
Volatility	σ	Calculated using daily returns in power sector (15.9%)
Distance to Default	$\{X^{Aaa}, \ldots, X^{B}\}$	Estimated in the Paper
Implied Tax Rate of RPS	τ	Estimated in the Paper

Estimation Approach

- We estimate our parameters using GMM as it allows us to incorporate both bond-level data on yields, and also our reduced form finding of the impact of RPS on credit spreads.
- Search for parameters that minimize the squared gap between our model moments and our observed data moments, $\hat{\theta}$:

$$\hat{\theta} = \arg\min_{\theta \in \Theta} (g(\theta)' W g(\theta))$$

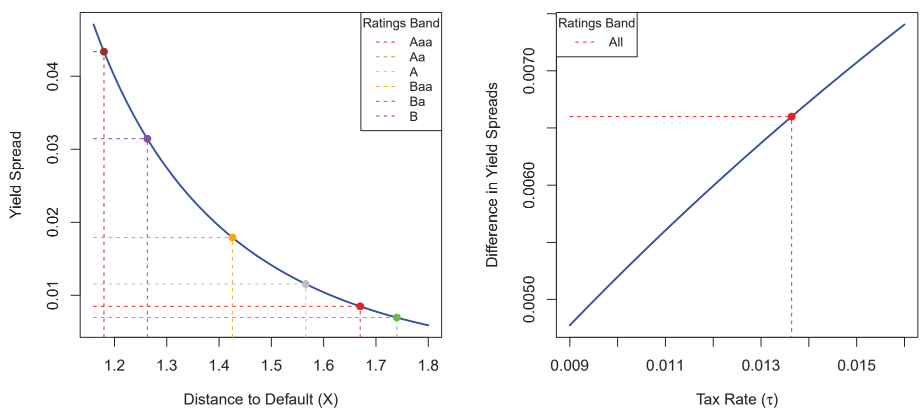
  where $g(\theta)$ is the squared distance between the model moments implied by θ and the data moments, and W is the weighting matrix (we use the identity matrix).
- Construct standard errors using the typical sandwich formula:

$$Var(\hat{\theta}) = (G'WG)^{-1} G'W\Omega WG(G'WG)^{-1}$$

  where G is the Jacobian of $g(\theta)$, evaluated at $\hat{\theta}$, and Ω is the covariance matrix of $g(\theta)$.
- Ω obtained by bootstrapping the construction of our data moments 1,000 times, and then calculating the covariance matrix across these simulations.

Identification

Figure: Identification of Model Parameters



Estimation Results

Table: Model Estimation Results

Panel A: Distance to Default

Ratings Band	X	Data Yield Spread	Model Yield Spread
Aaa	1.67 (0.21)	85bps	85bps
Aa	1.74 (0.02)	69bps	69bps
A	1.57 (0.03)	115bps	115bps
Baa	1.43 (0.04)	179bps	179bps
Ba	1.26 (0.02)	314bps	314bps
B	1.18 (0.01)	434bps	434bps

Panel B: Tax Rate

Ratings Band	τ	Data Diff in Yield Spreads	Model Diff in Yield Spreads
All	1.36% (0.16%)	66bps	66bps

Panel C: Cost to Firm Value

Ratings Band	Cost to Firm Value
All	$53.81 ($6.30)

Average Abatement Costs

- Use Enterprise Value (EV) for US utilities to construct Asset Value using Compustat data and a common EV multiple of EBITDA for the power sector
- Collect income statement data from FERC on firms operating in the Utilities sector and construct EBITDA, and back out a proxy of asset value for each firm using common EV multiple
- Once we have this measure of asset value, we can then establish in dollar terms the annual impact of RPS using our estimated tax parameter, τ

$$\mathbb{E}[\textit{Abatement Cost (\$)}] = \sum_{i \in N} \sum_{t \in T} \frac{\tau \times \textit{Asset Value}_{i,t}}{\beta^{CO2}}$$

where *Abatement Cost ($)* is the cost to the firm in dollars of eliminating one metric ton of CO2, and β^{CO2} is our estimated coefficient of the total absolute annual drop in CO2 induced by RPS

Putting Abatement Costs into Perspective

- We perform some simple calculations that link CO2 reduction to power generation
- Power sector generates an average of 0.86lbs of CO2 for every KWhr of electricity produced
- Therefore, every ton of CO2 generated corresponds to roughly 2.56 megawatt-hours of power
- Price of 1KWhr $\sim$\$0.11 $\implies$ ratio of revenue from electricity generation to CO2 production $\sim$\$281.60 per ton of CO2

Conclusions

- Using a novel identification strategy for renewable portfolio standards (RPS) in the US that govern investor-owned utilities but exempt municipal producers, we find that the reduction in carbon emissions of 2.7 million tons per producer from RPS comes at a cost of 66 bps wider credit spreads
- This trade-off can be explained with a structural corporate-bond pricing model in which RPS narrows distance to default by reducing firm cashflows.
- We use the model to infer that the abatement costs that firms have to bear is $50 per ton of emissions abated.
- Firms in the power sector bear more of the tax burden of RPS as there is only a small pass through of higher renewable costs to consumers.