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EVIDENCE FROM RENEWABLE PORTFOLIO STANDARDS

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ABSTRACT

Many US states have set ambitious renewable portfolio standards (RPS) that require utilities to switch from fossil fuels toward renewables. RPS increases the renewables capacity, bond issuance, maturity, and yield spreads of investor-owned utilities compared to municipal producers that are exempted from this climate policy. Contrary to stranded-asset concerns, the hit to overall firm financial health is moderate. Falling cost of renewables and passthrough of these costs to consumers mitigate the burden of RPS on firms. Using a Tobin's q model, we show that, absent these mitigating factors, the impact of RPS on firm valuations would have been severe.

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1 Introduction

Many jurisdictions around the world have started to implement climate policy, such as carbon taxes, emissions trading systems, or renewable power standards, to address the effects of global warming. Yet, we know relatively little about the impact of climate policy on the economy in practice. Indeed, a number of financial regulatory bodies worry that they can lead to a dramatic deflation of asset market valuations for emissions-intensive firms (e.g., fossil fuel reserves infrastructure, power plants), resulting in a stranded asset scenario that can then lead to a financial crisis through impaired balance sheets.[1] Put another way, what is the cost of climate policy to capital in these sectors?

We develop a novel approach to address these issues in the power sector. In nearly 40% of the major carbon-emitting countries globally, including the US, India, and South Korea, utilities are subject to renewable portfolio standards (RPS) that require them to switch from fossil fuels toward more expensive renewables, typically solar and wind farms.[2] Since utilities typically issue debt to finance their investments, this allows us to measure investors' required rate of return to fund spending on renewable capacity. However, an empirical challenge is that the enactment of climate policy is endogenous and dependent on underlying economic conditions that also affect firms' cost of capital.

A key step in our approach is to exploit institutional features of the RPS system in the United States to estimate the causal effect of climate policy on firm financial health. Of the 32 states in the US that enacted RPS over the period of 1991-2020, 14 of them require investor-owned producers to meet RPS targets, but exempt municipal producers. The municipal producer exemption allows us, in a panel regression setting,

[1] Some of the institutions that have written reports this stranded-asset scenario include Task Force Climate-Related Financial Disclosures, European Systemic Risk Board, and De Nederlandsche Bank.

[2] Emissions trading systems and renewable portfolio standards are two types of regulations used for emissions-intensive sectors, while national carbon taxes are enacted to address gaps for other sectors (see, e.g., Carhart et al. (2022) for overview of climate policy globally).

to address implementation timing or endogeneity concerns by using firm and state-by-year fixed effects.

For these states with municipal exemptions, we find that the passage of RPS legislation leads to economically and statistically significant changes in the treated utilities' outcomes of interest compared to municipal producers. Treated utilities gradually increase their renewables capacity by more than untreated utilities. To fund this increase, treated utilities issue more bonds, particularly in the first five years following RPS implementation. Consistent with the long length of their renewable investments, treated utilities also issue bonds that are of longer maturities.

Characteristics-adjusted bond yield spreads of treated utilities increase by around 66 bps compared to non-treated municipals in the state.[3] This is roughly an 11% increase in yield spreads relative to a base of around 6% for a typical corporate bond issue. However, the hit to yield spreads is transitory — lasting for around 4–5 years following implementation of RPS. The fall in spreads lines up with a significant increase in electricity prices for investor-owned utilities compared to municipal producers. Indeed, in the years coinciding with the reversion of these bond yield spreads and onset of higher electricity prices, there is actually an improvement in the credit ratings of treated utilities compared to non-treated utilities.

Although the distributions of the characteristics-adjusted yield spreads are comparable across investor-owned and municipals, one might nevertheless be concerned about whether small municipal producers are a good control group for large investment-owned power companies. To address these concerns, we run the same analyses for the other 18 states, which had no such exemptions. We expect and indeed find in our placebo analysis that the effects we documented in the states with municipal exemptions are absent in these states without exemptions.

[3] These yields are adjusted for issue-level characteristics including credit ratings, maturity, and in the case of municipal debt, its purpose and tax treatment.

In other words, the cost of climate policy to capital, while economically and statistically significant, is far from the stranded-assets scenario for emissions-intensive sectors that is often discussed by financial regulators. Despite the ambition of RPS reforms, the impact on firm valuations does not appear to be large enough to trigger cascading concerns for bank or institutional-investor portfolios.

Why is this the case? Our findings suggest two mitigating factors that ease the implicit tax burden of being required to use higher cost renewables by RPS. The first is the pass through of the higher cost of renewables to consumers in the form of higher electricity prices. The other is that the cost of installing renewables falls over time. Wind and solar capacity, which cost two to three times more than fossil fuel plants, falls significantly post RPS, to as little as 1.2 to 1.8 times at the end of the sample.

To quantitatively assess the importance of these two mitigating factors on the cost of climate policy to capital, we calculate the implicit revenue tax induced by RPS by calculating the extra cost of adhering to a state's RPS and to meet a state's electricity needs after netting out the costs that is passed onto consumers via higher electricity prices over time. The average tax burden as a fraction of firm capital each year is around 2.5%. If the costs of renewables do not fall or if firms cannot pass through the higher costs of building renewable capacity to consumers, the owners of capital effectively face a higher tax post RPS, which we estimate can be as high as around 7%.

To conservatively assess how these mitigating factors affect firm valuations, we calibrate a Tobin's q model from Pindyck and Wang (2013) that can tractably match key moments from the power sector. We omit credit constraints from our analysis as introducing these financial frictions will only worsen the effects we will obtain as we remove these mitigating factors.

Our model does a reasonable job of fitting a number of key moments from the post RPS sample, including output-to-capital ratio (24.8%), investment-to-capital ratio

(5.6%), depreciation rate (2.46%), revenue growth (1.26%), dividend yield (4.38%), and asset pricing moments. The Tobin's q implied from this data is around 1.53 for our firms, in line with estimates of US firms from the literature.

Our model generates a prediction for the Tobin's q difference between treated and untreated firms. This difference can be retrieved by comparing the Tobin's q in an RPS equilibrium with a laissez-faire equilibrium where producers are not subject to the tax. A key assumption in this comparison is that municipal producers are small relative to the investor-owned firms (which as we will show is reasonable) and compete in segmented markets. We find a moderate drop of around 18%, which as we will discuss, is in line with our reduced-form yield spread findings.

We then use our model to quantify the hit to Tobin's q when firms are subject to a counterfactual higher tax due to: (1) the cost of renewables remaining the same as pre-RPS, but there is cost passthrough; (2) the cost of renewables falling, but there is no passthrough; and (3) the cost of renewables not falling and also there being no cost passthrough. The hit to Tobin's q under counterfactual (3) is severe — around a 44% decline in Tobin's q. That is, the decline in Tobin's q is more than doubled — 2.5 times larger than if there were no mitigating factors. Of the additional decline, one-quarter of it is attributable to removing consumer-price passthrough and three-quarters of it to removing the falling cost of renewables.

In Section 4.6, we consider an extension of our quantitative analysis where we allow for aggregate mitigation benefits of RPS, i.e. we endogenize RPS within an integrated assessment model (Nordhaus (2017), Golosov et al. (2014), Jensen and Traeger (2014), Barnett et al. (2020)). These mitigation benefits can offset to a degree the direct effect of the tax on firm profitability by reducing climate disaster risks. Such mitigation benefits are likely to be small in our sample, since addressing global warming requires a collective global effort among major polluting countries. We find that our quantitative conclusions remain robust even when accounting for these aggregate mitigation benefits.

Related literature. Our paper is related to the literature on the impact of climate policy, such as the European emissions trading systems (ETS) (Känzig (2021)) and national carbon taxes (Metcalf and Stock (2020), Känzig and Konradt (2023)), on macroeconomic outcomes. In particular, our findings complement Känzig (2021), who shows that unexpected policy surprises in the European ETS lead to higher energy prices and larger declines in activity for demand-sensitive sectors than emissions-sensitive sectors. Papers in this literature, however, typically do not estimate the impact on firm cost of capital. But a direct assessment of firm cost of capital is called for in recent papers by academics on climate stress testing and transition risks (Jung et al. (2021), Bolton and Kacperczyk (2020), Pástor et al. (2022)).

Our paper is also related to work on the effects of RPS on the utilities sector in the US (Greenstone and Nath (2020), Upton Jr and Snyder (2017), Deschenes et al. (2023)). The literature uses synthetic controls to establish that RPS led to an expansion of renewable capacity and higher electricity prices, which are similar to our findings. However, we use a different identification scheme—a comparison of investor-owned versus municipal producers using state-by-year fixed effects. Moreover, the RPS literature has focused on the cost of RPS to consumers but not to capital owners. In this vein, our identification strategy is also conducive for our quantitative analysis. In a synthetic control design, the timing of staggered state adoption plays a role and differences of utilities across states that adopt and those that do not can be transitory.

Table 1: Summary of RPS Legislation in States with Municipal Exemptions

This table presents summary details of the passage of Renewable Portfolio Standards regulation in the 14 states that have thus far enacted the legislation with municipality exemptions. Note that Virginia also has an exemption for its small investor-owned producers. For the number of municipal and investor-owned suppliers, and their sales in gigawatt hours, we take the time series average.

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

2 Background, Data and Variables

2.1 Renewable Portfolio Standards at State Level

Our data on RPS in the US come from Barbose (2021). In Table 1, we report the RPS details for the 14 states that exempted their municipal producers. For each state, we report its year of implementation, the required amount of output that has to be produced from renewables, and the year when firms in that state are to have reached that requirement. Many states implemented their RPS in the mid-to-late 2000s. Investor-owned producers are allowed to gradually ramp up their mix of renewables before hitting the required or steady-state amount.

Consider the state of Illinois, which implemented its RPS in 2007. It gave firms a runway of around 20 years to reach a required renewable mix of 25% of output. Hence, investor-owned producers had to increase their mix by roughly a percent a year.

Table 2: Summary of RPS Legislation in States without Exemptions

This table presents summary details of the passage of Renewable Portfolio Standards regulation in the 18 states that have thus far enacted the legislation without municipality exemptions. For the number of municipal and investor-owned suppliers, and their sales in gigawatt hours, we take the time series average for a given year.

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

States typically vary the length of the transition period to a steady-state requirement depending on how stringent those requirements are. There is variation across states in terms of this stringency, which can be as high as 100 percent in Hawaii (in 2045) and Virginia (in 2050).

In Table 2, we report summary statistics for the other 18 states that do not exempt their municipals. Other than the municipal exemption, the distributions of mandate start dates, maximum green requirements and year the maximum target is achieved are not dissimilar to those from the 14 states with exemptions.

The literature on the determinants of RPS finds that political ideology aligned with concerns about global warming and affluence of households in the state predict whether a state implements an RPS (Lyon and Yin (2010), Carley and Miller (2012)).

Local economic concerns play a minor role. That is, policymakers in these states are driven by a desire to contribute to carbon abatement to mitigate the risks of global warming. Justifications for the exemption include that municipal producers do not cause as much damage to the climate in the first place; or they might not have the resources to implement an aggressive abatement plan. Such ideological motivations are similar to the sorts of policy variations used in the studies of European climate policies by Känzig (2021) and Metcalf and Stock (2020) for identification.

2.2 Investor-owned versus Municipal Producers

Using the U.S. Energy Information Administration's Annual Electric Generator Report (Form EIA-860), we collect information on the electric utilities in the United States. This annual form gives information on ownership type, where the utilities operate, along with a host of variables including total sales, megawatt capacity in different types of fuel sources, and the cost of installing these different types of capacity.

Numbers and sales by producer type. In Table 1, we also report for each state the time-series average of the number of producers of each type and the time-series average of the total sales of the two types of producers. Investor-owned firms mostly operate in one state, but around 5.4% operate in more than one state. While there are a greater number of municipal producers compared to investor-owned ones, investor-owned producers' sales are much higher than those of the municipal producers. For instance, in the state of Illinois, there are on average in a typical year around 4.2 investor-owned producers who generate 15,599 gigawatt hours. There are 18.4 municipal producers who generate 3,580 gigawatt hours.

Table 3: Summary Statistics of Firm-State-Year Renewable Capacity

This table presents summary statistics for firm-state-year renewable capacity. Our data has 4,392 firm-state-year observations across the period of 2001 to 2020.

Variable	N	Mean	Std. Dev.	Min	Pctl. 25	Pctl. 75	Max
Year	4,445	2009.17	5.011	2001	2005	2013	2020
Year RPS Starts	4,445	2007.387	1.316	2001	2007	2008	2009
Observations in Post Period	4,445	0.626	0.484	0	0	1	1
Years Relative to Start of Mandate	4,445	1.783	4.961	-6	-2	6	11
Firms Covered by State Mandate	4,445	0.227	0.419	0	0	0	1
Non-Renewable Capacity (mw)	4,445	957.524	3,029.771	1	9.6	303.4	27,498.8
Renewable Capacity (mw)	4,445	9.792	55.255	0	0	0	578.1
Renewable/Non-Renewable Capacity	4,445	0.009	0.045	0	0	0	0.448

Renewable capacity. In order to meet RPS, these firms respond in two ways: buy renewables from a supplier, or build solar and wind farms. Data on the former is spotty, while we can precisely track firm investments in renewable plants.

Table 3 presents summary statistics for firm-state-year renewable capacity in the 14 states with municipal exemptions that will be the focus of our empirical analysis. That is, we have data over time on the capacity a given firm has in each state that it operates in. Our data covers 4,445 firm-state-year observations across the period of 2001 to 2020.

Electricity prices. We collect yearly data on the average retail price of electricity from investor-owned and municipal utilities (separately) from 2001 to 2021.[4] These data come from various years of EIA State Electricity Profiles and are measured as cents/KWhr.

2.3 Debt level data

To fund these new investments to meet RPS requirements as well as standard investments to deal with depreciating capital, both investor-owned and municipals have to issue debt.

[4]Data for electricity prices is not broken down at the producer level.

Corporate debt. To see how investor-owned firms' financial conditions responded to RPS, we draw our data for corporate bonds from Mergent FISD, a standard corporate bond database. This dataset contains information on the yields, maturity, issue amount, bond rating, industrial sector, and issuer name of corporate bond issues in the United States, plus a host of other issue-relevant variables.

We filter on firms in the power sector. Although this data contains information on the state of the head office of the issuer, it does not typically contain information on the state or states in which the issuer operates.

To address this issue, we integrate our bond data with our dataset on utility operations, the details of which are outlined in Section 2.1. We match these two databases using the legal name of the issuer, as given in the 'Bond Issuers' dataset within Mergent, and perform a string distance match to our dataset on production. We are able to perform an exact match to roughly a third of issuers from Mergent, though these issuers make up roughly 72% of all issues in our dataset. When we cannot match exactly, we assume that the state of operation is the same as the state of the head office.[5] In a robustness check, we run our analysis on only the issuers we are able to match exactly; our results are essentially unchanged.

One technical issue with analyzing at the issue level is that many investor-owned utilities operate across several states. To resolve this problem, and ensure that issues are appropriately assigned to states, we perform the following procedure: first, we calculate the average exposure of an investor-owned utility in each of the states where it has a presence by taking the time-series total of sales in each state and dividing by the total sales. For a utility with presence in only one state, this results in a value of 1.

We then replicate any issues for utilities that operate in multiple states, but weight

[5]By looking at the discrepancy between the state of operation and state of the head office in our exact matches, we find that this assumption is correct roughly 87% of the time.

that observation by the previously calculated exposure. Therefore, if utility 'A' operates in, for example, Kansas, Kentucky, and Tennessee, and has sold roughly 20%, 20%, and 60% of its output in each state respectively, then an issue from utility 'A' appears three times in our dataset, with one assignment to each state, where each observation is weighted by 0.2, 0.2, and 0.6 respectively.

After this process, we are left with 11,118 corporate bond issues across our sample period of 1990-2021, with 2,650 issued in states with differential treatment of municipalities. We restrict our analysis to issues that are within 15 years either side of the passage of RPS legislation, to give us a final sample of 1,739 corporate bond issuances.

Municipal bonds. For municipal bonds, we use the SDC Muni database. This dataset contains information on the yields, maturity, issue amount, bond rating, industrial sector, state, and issuer name of municipal bond issues in the United States, plus a host of other issue-relevant variables. Given our interest in assessing the impact of RPS, we restrict attention to municipal bond issues in the 'Electric & Public Power', 'Combined Utilities', and 'Gas' sectors. Across our sample period of 1990 to 2021, we find complete data on 2,049 municipal issues. Of these, 322 were issued in states with differential treatment of municipalities within 15 years either side of RPS passage. Given that this differential treatment is critical to our identification strategy, these 322 are the principal controls that we use in our analysis.

2.4 Comparing investor-owned versus municipal producer debt

Unsurprisingly, municipal bond issues differ in systematic ways from investor-owned bond issues. Table 4 reports the mean and standard deviation of the variables of interest by municipal versus investor-owned issues. First, we have 322 issues by municipals, versus 1,739 corporate issues. For both types of producers, we find there are more debt issues for investor-owned utilities than municipals post RPS — 39% compared to 27%.

The typical municipal debt issue is 54 million dollars with a standard deviation of 103 million dollars. For investor-owned, the mean is 241 million dollars, with a standard deviation of 231 million dollars. Municipals borrow at longer maturities — 19 years, compared to 16 years for investor-owned.

The mean yield of municipal issues is 4.3%, while it is 5.8% for investor-owned. The standard deviation of yields is also larger for investor-owned, 1.9% compared to 1.4% for municipals. This difference in yields reflects the fact that municipals typically have a higher Moody's rating, 1.3 compared to 6.7 for investor-owned.[6] All municipal debt is investment grade, while 95% of the investor-owned debt is investment grade.

Since systematic differences exist between municipal and investor-owned issues that could distort our findings, we perform an adjustment to bond yields, issue amounts, maturity, and bond rating at issuance using a characteristics-based benchmarking as in Daniel et al. (1997). Specifically, we form 5x5x5 portfolios based on Moody's ratings, maturity, and issue size for adjusting yields. For each of these 125 portfolios, we calculate the median yield at issuance. We then subtract this median yield from the yields of all bonds within the same grouping. The means and standard deviations of these characteristics-adjusted yields are also given in Table 4.

We conduct a similar benchmark adjustment for our other issue level variables. When adjusting issue amounts, we base the adjustment on on Moody's ratings, maturity, and yields. When adjusting bond maturities, we base it on Moody's ratings, issue amount, and yields. When adjusting bond ratings, we base it on issue amount, maturity, and yields. The resulting distributions are shown in Figure 1. This figure shows that in all four cases, the two distributions after adjustment are not too far apart from each other.

[6] Here a value of 1 corresponds to Aaa, and a value of 17 corresponds to Caa1. A value of 7 indicates a Moody's rating of A3.

Table 4: Summary Statistics of Bond Data

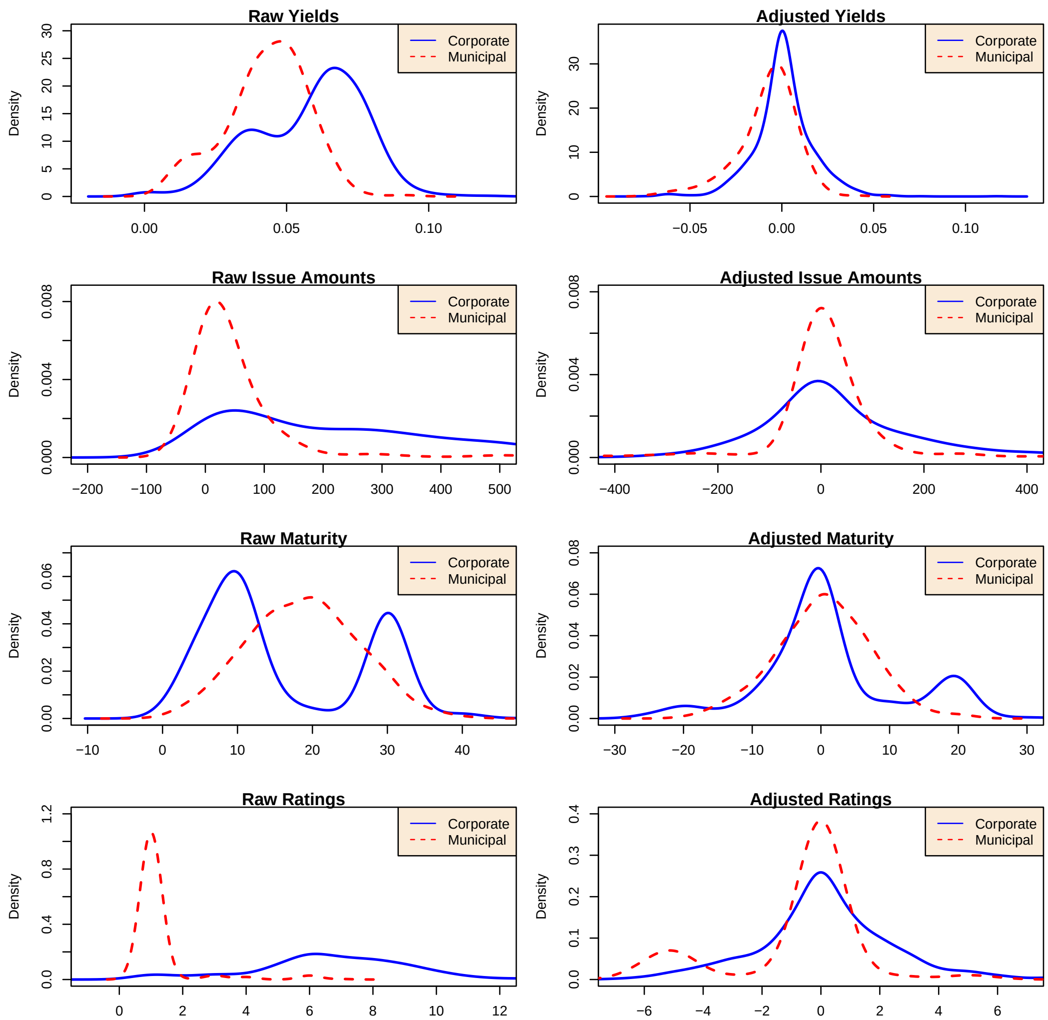
This table presents summary statistics on our final dataset of bond data. The data we collect runs from 1990 to 2021. Adjusted Yields are constructed using a characteristic benchmarking approach as described in Section 2.3. Tax code refers to one of four options: CB is taxable corporate bond, E is municipal bond exempt from federal tax, A is municipal bond taxable subject to AMT (Alternative Minimum Tax), and T is taxable municipal bond. Security Type refers to one of three options: CB is corporate bond, GO is general obligation municipal bond, and RV is revenue municipal bond.

	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%	

In addition to issue amount, maturity yield, and credit rating information, we also have information on the tax treatment of the various bonds as well as the security type. We include these additional variables as covariates in our issuance and yield regressions below.

Figure 1: Distributions of Adjusted Yields and Issue Amounts

This figure plots binned kernel density estimates of the distribution of the adjusted yield, issue amount, maturity, and rating of bond issues from municipal and investor-owned utilities, adjusted using a characteristic benchmark approach similar to Daniel et al. (1997). 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.



3 Reduced-Form Estimation of the Causal Effects of RPS

We are interested in assessing how RPS implementation impacts firm operating and financial conditions. A major concern in any setting that employs legislative change as a source of variation is the potentially endogenous nature of that legislative decision. By comparing outcomes across states that have passed RPS legislation for plausibly distinct and state-specific reasons, it is probable that any estimation results will be biased by the unobserved heterogeneity across states.

To address this problem, we take advantage of the institutional feature that exempted municipal producers and affords us a control group that offers within state-year variation. Hence, we can implement a restrictive identification procedure whereby we control for a state-year fixed effect. This inclusion directly addresses the concern that unlike states will be compared to one another.

3.1 Panel Regression Specifications

We conduct an event study estimation design to identify the dynamic effects of RPS passage. An added advantage of this approach is that it allows us to test for the presence of a pre-trend. We begin by looking at the impact on renewable power capacity at the producer level. We then look at how passage affected the bond issuance behavior of producers. With this in place, we investigate how the market priced these issuances by examining yields. We then turn to electricity prices.

Renewable power capacity at firm level. To assess the impacts of RPS passage on renewable to non-renewable power capacity at the producer level, we look at whether changes to the ratio of renewable to non-renewable capacity in the post passage period were different for corporate producers versus exempt municipal producers.

To do that, we estimate the following specification:

$$
\begin{aligned}
RKR_{i,s,t} = & \phi_{s,t} + \psi_i + \beta_{-5} D_{r_{s,t} \leq -5} \times corp_i \\
& + \sum_{-4 \leq r_{j,s,t} \leq -2} \beta_r D_r \times corp_i + \sum_{0 \leq r_{j,s,t} \leq 8} \beta_r D_r \times corp_i \\
& + \beta_9 D_{r_{j,s,t} \geq 9} \times corp_i + \Gamma \mathbf{X}_{i,j,t} + \epsilon_{i,j,t} \qquad (1)
\end{aligned}
$$

where $RKR_{i,t}$ is the renewable to non-renewable power capacity ratio of firm i, in state s, at year t; $\phi_{s,t}$ is a state-year fixed effect; ψ_i is a firm fixed effect; $corp_i$ is an indicator taking a value of 1 if the firm i is a corporate/investor-owned firm; D_r is an indicator that takes a value of one if the year of the issue t, is r years relative to the passage of the RPS legislation in state s; $\mathbf{X}_{i,t}$ is a vector of firm-level controls consisting of the log of the following variables: total customers, total revenues, and total sales in megawatt hours. In all cases, we include both the controls, and the controls interacted with the $corp_i$ indicator.

Note that we bin all observations 5 years before and all observations 9 years after passage. The coefficients of interest here are $\{\beta_{-5}, ..., \beta_9\}$. These track the differential response of corporate ratios to those of municipal ratios.

Bond issue level variables: issue amount, time-to-maturity, yield-to-maturity and credit rating. We now turn to an investigation of the bond market reactions to RPS passage, both on the supplier and market demand side. We test whether corporate bond issues differ from municipal bond issues along four dimensions: issue amount, maturity, yields, and bond ratings.

We run the following issue-level regression, where $r_{j,s,t}$ denotes the year of the issue relative to the passage of RPS in state s:

$$
\begin{aligned}
y_{i,j,s,t} = & \phi_{s,t} + \alpha_i + \varphi_j + \tau_j + \beta_{-5} D_{r_{s,t} \leq -5} \times corp_i \\
& + \sum_{-4 \leq r_{j,s,t} \leq -2} \beta_r D_r \times corp_i + \sum_{0 \leq r_{j,s,t} \leq 8} \beta_r D_r \times corp_i \\
& + \beta_9 D_{r_{j,s,t} \geq 9} \times corp_i + \Psi \mathbf{K}_{i,j,t} + \varepsilon_{i,j,t}
\end{aligned} \tag{2}
$$

Here $y_{i,j,s,t}$ is a measure of the issue j, by firm i, operating in state s, in year t; $\phi_{s,t}$ is a state-year fixed effect; ψ_i is a firm fixed effect; φ_j and τ_j are fixed effects for security type and tax code of issue j respectively. The security type of issue j takes a value of CB for corporate bonds, GO for general obligation municipal bonds, and RV for revenue municipal bonds; the tax code takes a value of CB for corporate bonds, A for municipal bonds taxable subject to AMT (Alternative Minimum Tax), E for municipal bonds exempt from federal tax, and T for taxable municipal bonds.; $corp_i$ is an indicator taking a value of 1 if the firm i is a corporate/investor-owned firm; D_r is an indicator that takes a value of one if the year of the issue t, is r years relative to the passage of the RPS legislation in state s. Note that, as before, we bin all observations 5 years before and all observations 9 years after passage.

We also include a vector of issue-level controls, $\mathbf{K}_{i,j,t}$. We control for the log of the maturity in years of the debt issuance, the log of the value of the issuance in \$mns, and an indicator for the rating band that the bond is assigned by Moody's, $\mathbb{I}(rating_{j,s,t} \in g)$.[7] These bands group bond ratings into similar risk profiles, and allow us to non-linearly control for the impact of bond rating on yield. These bands distinguish between high investment grade, low investment grade, and various junk bond statuses, which are likely to have strongly discontinuous impacts on bond yields,

[7] We make one adjustment to these bands, which is to include 'Aaa' rated bonds with 'Aa1', 'Aa1', and 'Aa3' bonds.

thus justifying the use of the non-linear specification. We remove a control when it measures the same bond level characteristic as the dependent variable, i.e. the regression for issue amounts does not include the log of the issue amount as a control. Again, in all cases, we include both the control, and the control interacted with the $corp_i$ indicator.

For our measures of the issue, we use the benchmark-adjusted issue amount in $mn, maturity of the issue in years, yield-to-maturity at issue, and Moody's bond rating that are described in Section 2.4.

Electricity prices. Finally, we consider the differential impact of RPS passage on electricity prices for corporate versus municipal producers. Here we only have observations for average prices for corporate and municipal sectors at the state level. We estimate the following specification:

$$\begin{aligned}\log(p)_{c,s,t} =& \phi_{s,t} + \beta_{-5} D_{r_{s,t} \leq -5} \times corp_c \\ &+ \sum_{-4 \leq r_{j,s,t} \leq -2} \beta_r D_r \times corp_c + \sum_{0 \leq r_{j,s,t} \leq 8} \beta_r D_r \times corp_c \\ &+ \beta_9 D_{r_{j,s,t} \geq 9} \times corp_c + \Phi \mathbf{C}_{s,t} + \nu_{i,j,t} \end{aligned} \tag{3}$$

Here $\log(p)_{c,s,t}$ is the log of the average annual price of sector c, in state s, in year t; $\phi_{s,t}$ is a state-year fixed effect; $corp_c$ is an indicator taking a value of 1 if the sector c is the corporate/investor-owned sector; D_r is an indicator that takes a value of one if the year of the issue t, is r years relative to the passage of the RPS legislation in state s.

We also include the following state-level variables as controls, captured by $(\mathbf{C}_{s,t})$: an indicator for the climate classification of the state, as defined by the National Oceanic and Atmospheric Administration; quantile bins of total power capacity, green capacity,

CO_2 emissions, electricity generation in megawatt hours, electricity generated by non-renewable sources, and electricity generated by renewable sources.

3.2 Empirical Findings

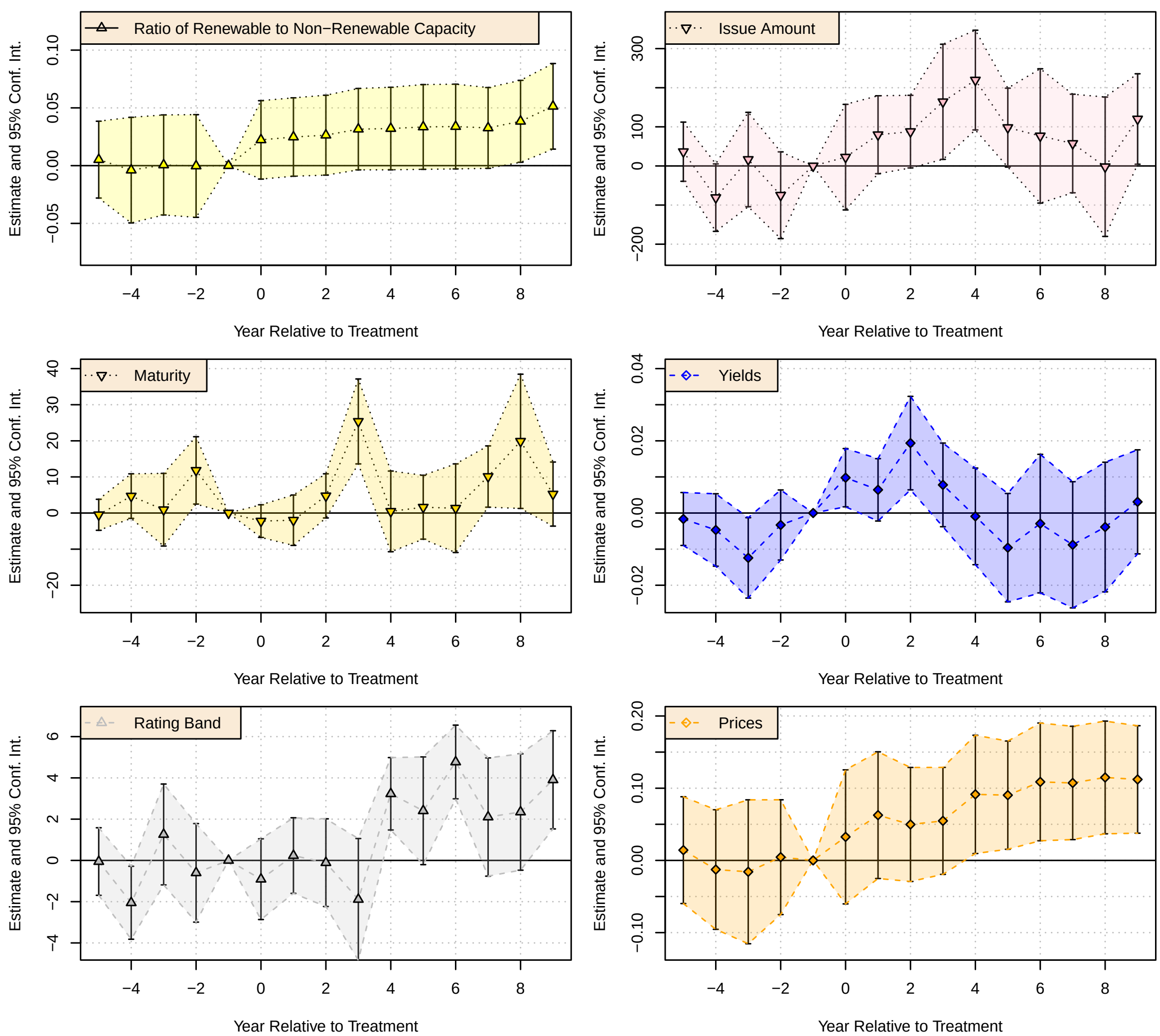
We plot the event studies from our estimations in Figure 2. Specifically, we plot the values of the fitted coefficients, $\{\beta_{-5}, ..., \beta_9\}$, that capture the differential response of corporate (treated) to municipal producers (exempted) from the RPS mandates. In the top left panel, we plot coefficients for the ratio of renewable to non-renewable capital specification (Equation 1); in the top right panel, we plot coefficients for the bond issue amount; in the center left, we plot for the maturity of the issue; in the center right, we plot for the yield-to-maturity at issue; in the bottom left, we plot for the bond rating (Equation 2); and in the bottom right panel we plot coefficients for electricity prices (Equation 3). Reassuringly, we find limited evidence of significant pre-trends in all six of our specifications.

Gradual rise of renewable capacity. Consistent with RPS passage driving an increase in renewable capacity, we find positive and statistically significant coefficients on our first regression involving the ratio of renewable to non-renewable capacity. In the years before the RPS treatment, the point estimates are exactly zero. After the RPS treatment, we see coefficients gradually increase from 0.03 to 0.05. The standard error bands include zero in the early years but do not include zero in the later years.

Higher bond issuance, maturity and yields. For our bond level regressions, we see economically and statistically significant impacts across all variables of interest. First, bond issuance increases significantly following RPS treatment. In the years before treatment, the coefficient of interest is close to zero, indicating that bond issuance by

Figure 2: States with Exemptions —Event Study

In this figure we plot the results of six event studies that assess the impact of RPS passage. In all cases, our coefficients represent the differential impact on corporate producers compared to municipal producers in states that passed RPS legislation with municipal exemptions. The top left panel takes the ratio of renewable to non-renewable capacity as the dependent variable, and uses a firm level specification as defined in Equation 1. In the top right, center left, center right, and bottom left panels, we use the issue amount ($mn), maturity (years), yield, and Moody's rating of bond issuances respectively as the dependent variable, with an issue level regression defined by Equation 2. For Moody's ratings, positive coefficients denote an improvement in ratings, and we use a linear ranking of ratings as the dependent variable, with 1 being Aaa and 17 being Caa1. Finally, in the lower right panel, we take average electricity prices as the dependent variable, using a state level specification as defined by Equation 3. We winsorize all dependent variables at the 5% level. Confidence bands are given at the 95% level.



investor-owned firms did not differ from their municipal counterparts. But there is a very rapid increase in bond issuance following treatment, peaking at around 4 years after treatment. There is a reversion in years 6 to 9 from the peak, but the mean of these years is still far above the pre-treatment years. However, the standard error bands on these later years are wider than the early years following treatment.

Second, the bond increase in bond issuance following RPS treatment is of long-maturity debt. We see that years 3 and 8 are associated with particularly long-dated debt. Third, there is a spike in characteristics-adjusted bond yields coinciding debt issuance in the early years. However, the increase in yields is transitory as they revert to normal in the long run. Hence, our results suggest that, relative to exempt municipal producers, non-exempt corporate firms issue debt with higher issue amounts and longer maturity, and face temporarily higher yields on that debt.

Eventual passthrough to consumers and long-run credit ratings. Fourth, we find that RPS led to an increase in electricity prices of the treated firms. There is a wide standard error band in the early years. But by the later years, it is clear that these treated firms were able to obtain higher consumer prices for their electricity. Our electricity-price increase finding are consistent with other work on RPS legislation (Greenstone and Nath (2020), Upton Jr and Snyder (2017)).

The drop in the adjusted yield coefficients at around four years post passage coincides with a significant increase in the electricity prices of investor-owned producers relative municipal suppliers. That is, what our findings in Figure 2 collectively demonstrate is a link between these electricity price increases and bond market yields. Once corporate producers are able to access higher electricity prices for providing renewable power, the initial increase in the cost of capital documented in the immediate post-passage period falls away.

To further support the point that this link is not coincidental, we find that credit ratings do not change in the early years post RPS treatment but improve in the later years (recall that positive coefficients imply improvements in the bond rating). The rise in the bond rating of investor-owned firms also coincides with the higher electricity prices. These findings suggest that the passthrough of the higher cost of renewables is a relevant mitigating factor in the impact of RPS on firm financial health.

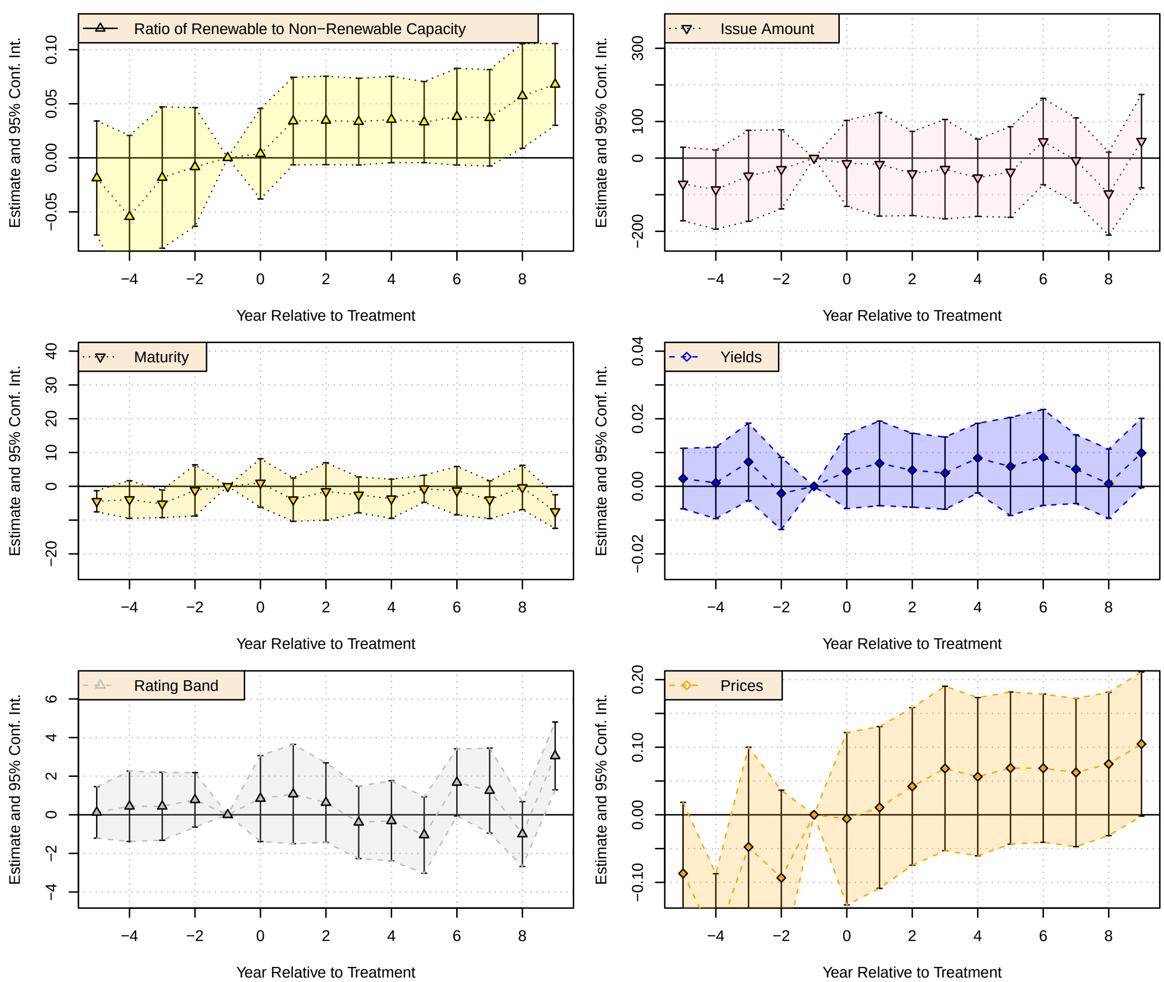
3.3 Placebo Analysis: States without Municipal Exemptions

Our identification strategy supposes that investor-owned issuers affected by RPS legislation are comparable to municipal issuers in the same state year that are exempt from the legislation. As a test of the validity of this result, we run the same exercises as in our main analysis, but restrict to the states that did not allow municipal exemptions. If our main finding is robust, we should not see a significant difference in the yields of investor-owned relative to municipalities in the same state-year in the wake of the RPS legislation.

There are 18 states that enacted RPS legislation without municipality exemptions, so in this exercise we restrict to municipal and investor-owned bond issues in these 18 states. Our specification is the same as in our main analysis. We include the results from the event study in Figure 3. We find essentially flat responses in all but the renewable to non-renewable capital ratio and electricity price cases. Here the results are difficult to interpret due to the presence of a significant pre-trend. However, in all other cases we find no appreciable change in the corporate to municipal spread, consistent with our identification argument.

Figure 3: States without Exemptions —Event Study

In this figure we plot the same set of results of six event studies that assess the impact of RPS passage in states without exemptions for municipal suppliers. As in Figure 2, the coefficients represent the differential impact on corporate suppliers compared to municipal suppliers. The top left panel takes the ratio of renewable to non-renewable capacity as the dependent variable, and uses a firm level specification as defined in Equation 1. In the top right, center left, center right, and bottom left panels, we use the issue amount ($mn), maturity (years), yield, and Moody's rating of bond issuances respectively as the dependent variable, with an issue level regression defined by Equation 2. For Moody's ratings, positive coefficients denote an improvement in ratings, and we use a linear ranking of ratings as the dependent variable, with 1 being Aaa and 17 being Caa1. Finally, in the lower right panel, we take average electricity prices as the dependent variable, using a state level specification as defined by Equation 3. We winsorize all dependent variables at the 5% level. Confidence bands are given at the 95% level.



3.4 Mitigating Factors

While economically and statistically significant, the cost of climate policy to capital is overall moderate, contrary to financial regulatory concerns regarding stranded assets about valuation ratios in emissions-intensive sectors. This despite the fact that RPS is considered by economists to be a quite ambitious climate policy, and which has also been adopted by other major polluting countries. Hence, a natural question of interest to financial regulators concerned about financial stability is why this is the case?

Our reduced-form empirical findings already suggest that one mediating factor is cost pass through via electricity price increases for households. Another factor is that the cost of installing renewable capacity fell over the decade of 2010. We plot in Figure 4 the price of installing a kilowatt of capacity for the difference fuel sources.[8] In 2012, the cost of installing solar and wind was much more expensive than installing brown capacity. In 2012, wind was twice as expensive as fossil fuel, while solar was three times as expensive, By the last year of our sample, 2020, solar and wind are only 50-60% more expensive than fossil fuel. Since most of the RPS initiatives are concentrated in the late 2000s and beginning of the 2010s, the fall in these prices can also contribute to falling yields over time.

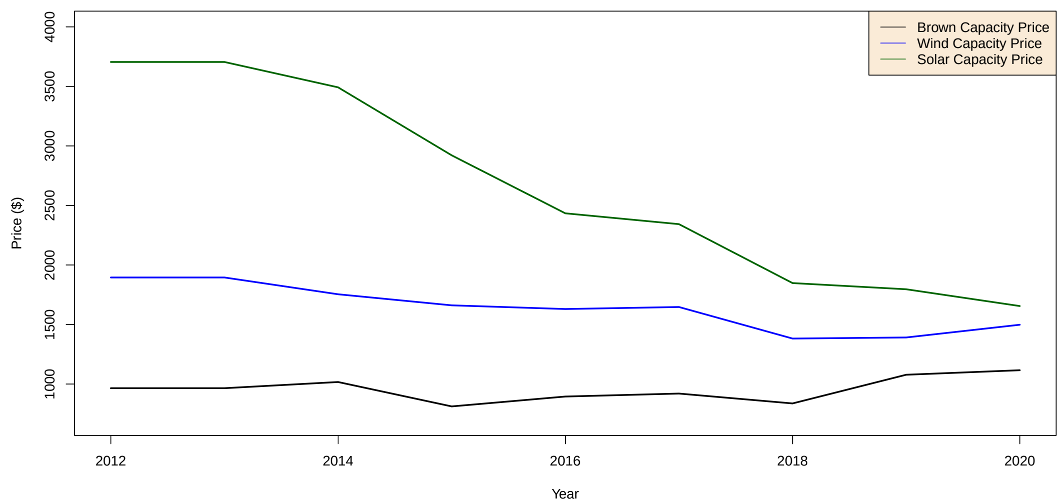
4 Quantitative Analysis of Mitigating Factors

To quantitatively assess the importance of these two mitigating factors on the cost of climate policy to capital, we use a Tobin's q model. We assess the impact of the implicit tax burden from RPS (i.e. lower firm profitability) on Tobin's q. Counterfactual taxes depending on these two mitigating factors then allow us to quantify their roles in

[8]Our data for constructing the price of installing renewables versus non-renewables comes from US EIA.

Figure 4: Cost of Renewable Capacity over Time

This figure plots the price of Renewable and Non-Renewable power capacity, in terms of $s per kilowatt, from 2012 to 2020.



impacting Tobin's q. We leave our credit constraints out of this analysis as adding financial frictions would merely magnify the already severe effects we obtain when we remove these mitigating factors.

4.1 Implicit Tax Burden of RPS

To calculate the implicit tax burden of the RPS, we create a data set that includes all investor-owned utilities that provide electricity to consumers in our sample of states. We have yearly historical data on these utilities from 2001 to 2022 to calculate the tax for those years; for the years beyond 2022, we use forecasts of future outcomes of these utilities to calculate future tax rates.

We first calculate yearly the net cost to a utility of installing renewable vs. non-renewable capacity to both meet the electricity needs of consumers and also adhere to a state's RPS mandates. As this net cost is the additional expenditure above what is required to provide power to consumers, this value is a natural analogue to a tax on firm revenues.

This net cost has two components. First, given that renewable generating capacity is typically more expensive than its non-renewable counterpart, there is an extra cost to the utility to build the capacity to meet energy and RPS requirements. However, as our reduced form evidence shows, the passage of RPS also has significant implications for the electricity prices that consumers pay. If consumer prices increase post passage of RPS, then this may offset the additional costs associated with more expensive renewable capacity. The sum of these two components give us the net cost to suppliers of RPS passage.

Extra cost of renewable vs. non-renewable capacity. To calculate the extra cost of using renewable vs. non-renewable generating capacity, we need to calculate how much renewable capacity is required to meet RPS mandates. We suppose that, for each firm i in state j in each year t, the required renewable capacity to meet the state RPS mandate is given by the following expression:

$$Cap^R_{i,j,t} = \frac{Y_{i,j,t} \times RPS_{j,t}}{\eta^R} \tag{4}$$

where $Cap^R_{i,j,t}$, measured in MW, is the renewable generating capacity that an investor-owned utility needs to meet the state's RPS mandate, assuming that the utility produces all the renewable electricity that they sell. $Y_{i,j,t}$ is the total retail sales of investor-owned utility i in state j and year t (measured in MWhr); $RPS_{j,t}$ is the renewable mandate in state j and year t (measured as a percent), and η^R is the average amount of time the renewable capacity is expected to be operating in a year (measured in hours). [9][10]

Similarly, we calculate for each firm i in state j and year t the non-renewable generating capacity ($Cap^N_{i,j,t}$) an investor-owned utility would need if they were to produce the amount electricity mandated to be green by the RPS by non-renewable means instead:

$$Cap^N_{i,j,t} = \frac{Y_{i,t} \times RPS_{j,t}}{\eta^N} \tag{5}$$

Because $\eta^N > \eta^R$, the utility has to buy more renewable capacity to generate the green electricity required by the RPS than the amount of non-renewable capacity they would need to generate the same amount of electricity by non-green means. This efficiency gap coupled with the higher price per unit of green capacity than brown capacity creates the extra cost of the RPS.

We can describe this extra capacity cost to an investor-owned utility i in state j and year t of the RPS mandate as:

$$C^R_{i,j,t} = [(p^R_t(Cap^R_{i,j,t} - Cap^R_{i,j,t-1})) - (p^N_t(Cap^N_{i,j,t} - Cap^N_{i,j,t-1})] + \delta[(p^R_t Cap^R_{i,t-1} - p^N_t Cap^R_{i,t-1}] \tag{6}$$

where p^R_t is the price per MW of renewable capacity and p^N_t is the price per MW of non-renewable generating capacity; and δ is a depreciation term.[11]

[9] $Y_{i,j,t}$ is obtained from the EIA (Annual Electric Power Industry Report, Form EIA-861 detailed data files, various years). These reports provide historical data from 2001 to 2022. For subsequent years, we use forecasts of electricity demand growth by state from Barbose (2021). We use the 2022 values of electricity production by firm from the EIA and multiply them by these forecasted growth rates to estimate future consumption.

[10] The EIA calculates a capacity factor by energy type: the average percentage of time plants of various fuel types produce electricity in a year. This is available in the EIA's Electric Power Annual. Based on these estimates we assume that renewable plants produce electricity 30% of the year and non-renewable plants produce electricity 55% of the year. Therefore, η^R is equal to 30% multiplied by 8760 (approximately the total number of hours in a year).

[11] Data on the price of green and brown capacity comes from the EIA (Form EIA-860). Yearly information on the cost of building a MW of capacity of different energy sources is available from 2013 to 2019. For brown capacity, we use the price of building a MW of natural gas generation. For green capacity, we use the average of the price of building a MW of wind and solar generation. For observations before 2013, we use the 2013 prices. For observations after 2019, we use the 2019 prices.

This extra cost measure has two terms. The first term measures the extra cost to utilities of having to build more renewable capacity that year to meet the requirements of the RPS. The second term measures the extra cost of having to keep up the utilities' existing stock of renewable capacity, which depreciates at the rate δ.[12]

Consumer Price impact of RPS passage. To calculate the net cost to utilities of the RPS requirements, we also need to adjust for any extra revenue that investor-owned firms might receive after the RPS mandate due to changes in the retail price. Note that in our data, we only observe the actual prices that consumers paid post RPS passage. We therefore need to construct an alternative price that consumers would have faced, had RPS passage not occurred.

We do this by comparing the growth rate of investor-owned and municipal utility prices before and after the passage of the RPS mandate. Our approach here is similar in principle to our reduced form exercises: we run a regression designed to capture the differential response of corporate vs. municipal electricity prices in the wake of the RPS passage. We then take our estimate of this differential response, and subtract it from observed prices to create a new alternative price path that does not contain the RPS effect. This new path then captures the prices investor-owned suppliers would have charged had RPS passage not occurred.[13]

With this alternative retail price, we can then calculate the extra revenue investor-owned utilities receive after the RPS mandate:

$$R_{i,j,t} = (Ret^{A}_{i,j,t} - Ret^{C}_{i,j,t}) \times Y_{i,j,t} \tag{7}$$

where $Ret^{A}_{i,j,t}$ is the actual retail price an investor-owned utility i receives in state

[12]For this analysis, we assume a depreciation rate of 3%.

[13]See Appendix A for full details, including the regression specification.

j in year t; $Ret^{C}_{i,j,t}$ is the estimated alternative price if there was no change in the relationship between investor-owned and municipal retail prices in the state after the RPS mandate. $Y_{i,j,t}$ is the total retail sales of an investor-owned utility i in state i and year t.

Summarizing the net cost. With the extra costs associated with renewable capacity (Equation 6), and the price effects of RPS passage in hand (Equation 7), we can calculate the net cost to investor-owned firms of the RPS mandate using the following expression:[14]

$$F^{R}_{i,j,t} = C^{R}_{i,j,t} - R_{i,j,t} \tag{8}$$

Constructing K. To calculate K for each utility i in state j and year t, we first measure the yearly cost to a utility in a state of providing non-renewable generation to meet demand:

$$F^{NR}_{i,j,t} = p^{NR}_{t}[TotalCap^{NR}_{i,j,t} - TotalCap^{NR}_{i,j,t-1}] + p^{NR}_{t}[TotalCap^{NR}_{i,j,t-1} \times \delta] \tag{9}$$

where $TotalCap^{NR}_{i,j,t}$ is the total amount of non-renewable capacity a utility needs to meet total demand:

$$TotalCap^{NR}_{i,j,t} = \frac{Y_{i,j,t}}{\eta^{N}} \tag{10}$$

This yearly cost equation has two terms. The first measures the cost to utilities of the extra non-renewable generating capacity they would have to build that year to meet demand. The second term measures the cost to the utilities of replacing depreciated non-renewable generating capacity they have already built. With this yearly cost, we

[14]In the firm/year observations in which the price effect is larger than the extra cost of the RPS, we do not allow the net cost to be negative. For those observations, we set the net cost to zero.

can calculate K:

$$K_{i,j,t} = K_{i,j,t-1} + F^{NR}_{i,j,t} \tag{11}$$

Because this is a recursive equation, we need to consider the initial value of K. We assume that, for the initial year in our sample (2001), K is equal to $TotalCap^{NR}_{i,j,2001} \times p^{NR}_{2001}$.

We now have all of the components we need to calculate a firm tax rate. For each firm/year observation, we just take the net cost of meeting the RPS mandate (Equation 8) divided by the capital of the utility (Equation O1).

4.1.1 Aggregating State Taxes

Finally, we aggregate firm-level taxes. We consider two options: an unweighted average, and a weighted average using the firm-level sales in megawatt hours as the weights.

The final results of this exercise are documented in Figure 5. This figure documents the estimated average taxes associated RPS mandates.[15] We overlay these average plots over the state level averages, shown in light gray. In the top left panel, we highlight both the average, and weighted average of our baseline case, where we adjust the tax to account for consumer and capacity price changes in the wake of RPS legislation. The average yearly tax rate associated with this case is 2.57% of capital, or 2.52% using a weighted average.

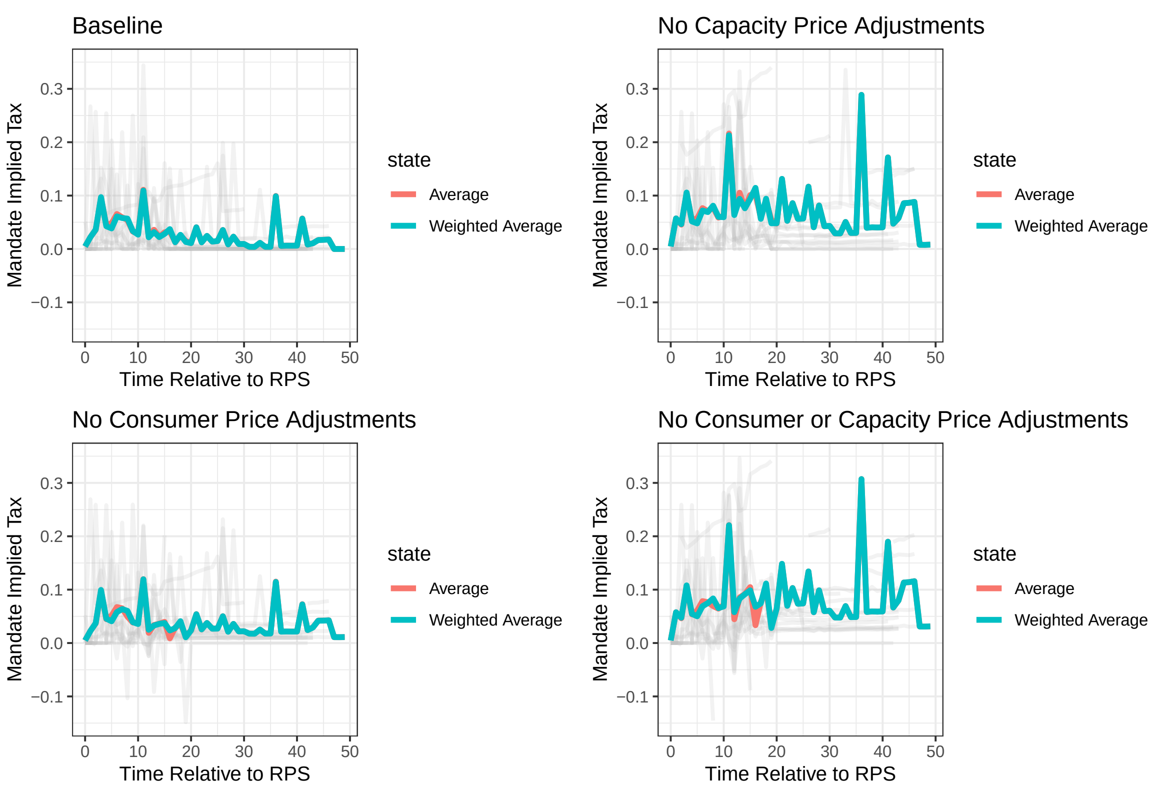
In the bottom left panel, we show the counterfactual path of taxes calculated without accounting for higher consumer prices. The tax in this case is slightly increased, averaging at an annual rate of 3.56% of capital, or 3.58% using a weighted average.

In the right two panels, we consider two other counterfactual cases in which capacity

[15] We exclude data from Iowa for this exercise; in Iowa, only two large investor owned firms are affected by the law, and other producers are exempt, but the law only mandates 105MW of green production. That is, they do not mandate a percentage of green production but a flat amount, and that flat amount is tiny, at less than 1% of production.

Figure 5: Implicit Tax Burden of RPS: Baseline and Counterfactuals Regarding Passthrough and Costs of Renewables

This figure shows the results of our data exercise on the path of firm-level taxes implied by RPS mandates. We include both our baseline construction, where we account for the pass-through of higher electricity prices to consumers and lower capacity costs for firms (top left panel), and also three counterfactual cases where we remove price benefits (top right and bottom panels). The bottom left panel corresponds to a counterfactual with no consumer price changes in the wake of RPS, the top right to a case with no capacity price changes, and the bottom to a case with neither consumer nor capacity price changes. As our data ends in 2021, all future values are calculated by extrapolation.



prices did not adjust after RPS passage. In the top right panel, we allow for consumer price adjustments, and in the bottom right we also eliminate these price changes. The average annual tax rates in these two cases are 6.95% and 6.89% of capital respectively, or 8.01% and 8.08% using a weighted average.

4.2 Model

To understand the impact of these taxes on Tobin's q, we use the model of Pindyck and Wang (2013). There is a continuum of identical firms and each firm's output is AK_t, where A is a productivity constant. The dynamics of $\mathbf{K}_t$ is given by:

$$\frac{dK_t}{K_{t-}} = \phi(I_{t-}/K_{t-})dt + \sigma d\mathcal{W}_t - (1-Z)d\mathcal{J}_t. \tag{12}$$

where $\phi(\cdot)$ is increasing and concave. The first term captures the gradual adjustment of capital from investments, where $i_t = I_t/K_{t-}$[16] The second term captures continuous (Brownian motion) shock to capital $\{\mathcal{W}_t\}$ (common to all firms) and the parameter σ is the diffusion volatility. The third term in (12) captures the damage to capital from weather disasters, where $\{\mathcal{J}_t\}$ is a (pure) jump process driving weather disaster arrivals with an arrival rate λ. The stochastic recovery fraction of capital upon the arrival of a weather disaster is $Z \in (0,1)$, which has the following cumulative density function: $\Xi(Z) = Z^\beta$ with $\beta > 0$ being a constant.

Household preferences. The representative household has Epstein-Zin preferences (Epstein and Zin (2013), Duffie and Epstein (1992)) , which are characterized by three parameters: ρ is the rate of time preference, ψ the elasticity of intertemporal substitution (EIS), γ the coefficient of relative risk aversion. The representative household

[16] We will also use $t-$ to denote these stock variables right before the arrival of a disaster.

dynamically chooses consumption and asset allocation among the stock portfolio and the risk-free asset.

Competitive market equilibrium with a tax. The competitive equilibrium is defined as follows. The firm chooses investments I_t to maximize firm value:

$$\max_{I} \mathbb{E}\left(\int_0^{\infty} e^{-\int_0^t r_v dv} CF_t \, dt\right) , \tag{13}$$

taking as given r_t the expected cum-dividend return for a firm in equilibrium and firm's cash flow at t given by

$$CF_t = AK_t - I_t - X_t. \tag{14}$$

At any time t, the firm uses its output AK_t to finance investment I_t, pay cash flows (dividends) CF_t to shareholders, and make mitigation spending (i.e. the revenue tax per period of X (determined by government). The tax is a fraction of the firm's capital stock K_t is given by α, i.e. $X_t = \tau K_t$. This means that $CF_t = (A - \tau)K_t - I_t$.

Due to the model's homogeneity property, the equilibrium value of a firm, Q_t, at time t must satisfy:

$$Q_t = qK_t \, , \tag{15}$$

where q is Tobin's q. The competitive equilibrium with revenue tax is given by a set of nonlinear equations given in Appendix D.

4.3 Calibration

We now turn to our calibration exercise. Our goals here are twofold. First, we aim to show that the model is capable of simultaneously matching key moments pertaining

Table 5: Parameters and Estimates

This table contains the values of our parameters from calibrating our model. We calibrate all parameters in the model except the productivity (A), depreciation rate (δ), and power-law exponent (β) parameters. For the first two values, we use firm-level data from the Federal Energy Regulatory Commission (FERC) to measure these parameters directly. For the power-law exponent, we draw on the work in Dell et al. (2012) and set this value equal to 39, which implies a reduction of GDP growth conditional on a disaster arrival of 2.5% per annum.

Parameter	Symbol	Value	Source
Elasticity of intertemporal substitution	ψ	2	Calibrated
Time rate of preference	ρ	0.043	Calibrated
Coefficient of relative risk aversion	γ	2.79	Calibrated
Productivity for K	$A-\tau$	0.123	Data from FERC
Depreciation rates for K	δ	0.0246	Data from FERC
Diffusion volatility	σ	0.14	Calibrated
Adjustment cost parameter	η	6.13	Calibrated
Jump arrival rate of disaster	λ	0.121	Calibrated
Power-law exponent for damage	β	39	Data from Dell et al. (2012)
Revenue Tax Representation of RPS	τ	0.0257	Section 4.1

to utilities and generating capital market impacts from an RPS tax that are roughly in line with our reduced form findings. Second, our model should allow us to consider counterfactual cases in which the consumer prices of electricity and/or the cost of new capacity did not vary in the aftermath of the policy.

Parameters. There are a total of ten parameters in the model. Three parameters govern risk preferences: ρ is the rate of time preference, ψ the elasticity of intertemporal substitution (EIS), and γ the coefficient of relative risk aversion. Four parameters govern capital: A is the productivity, δ is the depreciation rate, σ is the diffusion volatility, and η is the adjustment cost. Two parameters govern disasters: λ is the jump arrival rate of disasters that destroy capital, and β is the power-law exponent that determines the distribution of disaster damage wrought on capital. Finally, τ captures the revenue tax representation of RPS.

We calibrate our parameters in the following manner. The tax parameter (τ), which is 0.0257, is from our calculations in Section 4.1. We can then back out A by combining this tax parameter with the output-to-capital ratio, which is from Federal Energy Regulatory Commission data (FERC).[17] We also adjust the output-to-capital ratio to account for operating expenditures, which are absent from our model.[18]

Specifically, we construct the firm-level ratio of total operating revenues minus total operating expenditures to plant, property, and equipment, and then average these values across all firms in our sample, using data post passage of RPS. We arrive at a productivity of 0.123 ($A - \tau$) using this approach. To measure δ, we take a similar approach. We construct firm-level ratios of depreciation to plant, property, and equipment, and then average these values as before. We find a value of 2.46% for δ using this approach.

For the power-law exponent, we calibrate β in the following way. For the median country in the Dell et al. (2012) sample, extreme weather disasters in the form of excessively high temperatures reduces the GDP growth rate by 2.5% per annum. To match this value, we set $\beta = 39$, which implies a reduction of GDP growth conditional on a disaster arrival of $1/(\beta + 1) = 1/40 = 2.5\%$ per annum.

Moments. To calibrate our remaining six parameters, we target six moments: the investment-to-capital ratio, the dividend yield, the revenue growth rate, the risk-free rate, the risk premium, and the volatility of market returns.

For the investment-to-capital ratio and revenue growth rate, we use firm-level data from FERC on capital expenditures, revenue growth, and plant, property, and equipment to construct average values for these variables.[19] As in the case with our mea-

[17] See Appendix C for more details on the FERC data used to construct these target values.

[18] Operating expenses in FERC include depreciation to capital which is picked up by investment. We remove depreciating expenses from operating expenses in our calculation.

[19] Note that 'plant, property, and equipment is our 'capital' variable. This value is taken from FERC data, rather than the capital values we describe in Section 4.1. We use the FERC values here to maintain consistency in the calculation of ratios.

Table 6: Calibration Results

This table shows the results our calibration exercise. We first show the data moments that we seek to match, followed by the calibrated model moments from our baseline case.

Variable	Data	Calibrated
Investment	5.60%	5.13%
Dividend Yield	4.36%	4.91%
Growth Rate	1.26%	1.56%
Risk-Free Rate	0.88%	0.74%
Risk Premium	6.60%	5.58%
Volatility	14.1%	14.1%

surement of A and δ, we use only data post RPS passage to construct these averages. This process gives us an investment-to-capital ratio of 5.6%, and a revenue growth rate of 1.26% to target.[20]

For the risk-free rate and risk premium, we target 0.88% and 6.6% respectively, which are roughly in line with the literature. For the dividend yield and the volatility of market returns, we use data from CRSP-Compustat. We use data on dividends, stock prices, and stock returns for firms operating in the Electric Services sector (i.e. any firm with SIC code '4911'), during our sample period of 1990-2021. We first take the median values of dividend yields and annual returns in each year of our sample. We then take the mean of the median dividend yields and the standard deviation of the median returns as our targets. We find values of 4.36% and 14.1% respectively.[21]

Our calibrated parameters can be found in Table 5. We find an elasticity of intertemporal substitution (ψ) of 2, a time rate of preference (ρ) of 0.043, a coefficient of relative risk aversion (γ) of 2.79, a diffusion volatility (σ) of 0.14, an adjustment cost parameter (η) of 6.13, and a jump arrival rate of disaster (λ) of 0.121.

[20]As above, see Appendix C for more details on the data used to construct these target values.

[21]See Appendix C for illustrations of the time series of median dividend yields and annual returns.

Table 7: Model-Implied Hit to Tobin's q and Counterfactuals

This table shows the results our counterfactual exercises. In the first column, we show the moments generated by firms exempt from the mandate, who do no face the revenue tax. In the second column, we repeat our calibrated baseline case, with the tax. In the final three columns, we showcase moments generated from our three counterfactuals (CF (1) through CF (3)). In the first counterfactual case (CF (1)), we eliminate the pass through of RPS mandate requirements to consumers through changes in consumer prices. In the second (CF (2)), we remove the cost reductions in renewable capacity that occured in most states post RPS passage. Finally, in the third counterfactual (CF (3)), we remove both the consumer price and capacity price effects.

Variable	Exempt	Non-Exempt	CF (1)	CF(2)	CF (3)
Investment	7.22%	5.13%	4.23%	0.89%	-0.23%
Tobin's q	1.79	1.46	1.35	1.06	0.99

4.4 Fit of Our Model

These parameters generate model moments that roughly match their data equivalents, as can be seen in Table 6. The model's investment-to-capital ratio is 5.13% compared to 5.60% in the data. The model's dividend yield is 4.91% compared to 4.36% in the data. The model's growth rate at 1.56% is also a bit higher than in the data (1.26%). The model overshoots a bit in these moments, but the differences are still relatively small. For a couple of the asset pricing moments, the model undershoots a bit compared to the data — risk-free rate of 0.74% compared to 0.88% in the data and risk premium of 5.6% compared to 6.6% in the data. The model's volatility of stock returns of 14.1% matches exactly the 14.1% we observe in the data.

Beyond generating a reasonable fit of these key moments, we can conduct another check of the reasonableness of our model by comparing the model-implied hit to Tobin's q with that implied by our reduced-form finding on yield spreads.

Tobin's q in our sample. First, we can back out Tobin's q for our the firms in our sample by using the definition of a dividend yield — firm payout-to-capital ratio divided by q. We can calculate the payout-to-capital ratio for a firm as the output-to-capital ratio minus the investment-to-capital ratio and operating expenses-to-capital ratio. We calculate the median output-to-capital ratio, the median capital expenditure-to-capital (0.248), the median operating expenses to capital (0.125) and the median investment-to-capital ratio (0.056) using data on the FERC sample that occurs after the passage of RPS legislation.

Using the following expression:

$$q = \frac{\textit{Payout-to-capital ratio}}{\textit{Div. Yield}}, \tag{16}$$

we can back out q given that we observe the dividend yield. For the dividend yield, we use CRSP data, and take the median dividend yield of firms operating in the Electric Services industry across our sample period, which we find to be 4.36%.[22] (See Section 4.3 for details of the calculation of these moments.) Putting everything together, these values imply an average Tobin's q of 1.53, which is in line with estimates from the literature for US corporations (Philippon (2009)).

Model-implied hit to Tobin's q In Table 7, we show that our calibrated model can also match the change in Tobin's q implied by our reduced-firm findings (Section E). In this table, we report the model's output for non-exempt or treated firms' investment-to-capital ratio (5.13%) and Tobin's q (1.46). The Tobin's q of around 1.46, is very close to the 1.53 value we calculated above. We can construct the same outputs for firms not subject to the tax by simply using our calibrated model, but removing the tax τ. We get an investment-to-capital ratio of 7.22% and a Tobin's q of 1.79. Notice that the difference in q between exempt and non-exempt firms is around 0.33 in our model

[22]Here we denote a firm as operating in the Electric Services sector if it has SIC Code '4911'.

Comparing to reduced-form yield spread findings. We can then compare the model-implied hit to Tobin's q to that implied by our reduced-form yield spread findings. In our main reduced form results, we estimate event studies that map out the impact of RPS passage on issue-level variables. For this analysis, we restrict attention to the average effect of RPS. As such, we require a measure of this average effect, rather than the dynamic results outlined in Section 3. To arrive at this estimate, we employ a triple difference-in-differences estimation design (see Appendix B).[23] We arrive at an estimate of the average yield spread effect post RPS passage of 66bps, significant at the 5% level. For our set of firms, this 66bps finding implies a hit to Tobin's q of around 0.263 (see Appendix E). This estimate is lower than our model's implied hit because it assumes that firms mostly issue short-term debt. Nonetheless, our calibrated model's implied hit to Tobin's q is close to that implied by our reduced-form yield spread findings.

4.5 Counterfactuals.

In the remaining columns of Table 7, we consider three counterfactuals. In the first counterfactual (CF(1)), we remove the pass-through of RPS mandates to consumer pricing. The Tobin's q drops from 1.46 to 1.35 and investment-to-capital ratio drops from 5.13% to 4.23%.

In the second counterfactual (CF(2)), we do not account for falling capacity prices across the sample, i.e. we set the price of renewable and non-renewable capacity in each state to the prices in the year of RPS passage. We see a drop in Tobin's q from 1.46 to 1.06 and a decline in the investment-to-capital ratio from 5.13% to 0.89%. This

[23] There are at least two advantages to using a triple difference-in-differences approach here. First, we are able to use the entire sample of issuances to estimate the RPS effect, rather than just those from firms operating in states with municipal exemptions. Second, we reduce the concerns around systematic differences between municipal vs. corporate issuers, as we compare the difference in the difference across states, rather than just between corporate and municipal suppliers.

is a much more sizeable decline.

In the third counterfactual (CF(3)), we perform both adjustments — Tobin's q now drops from 1.79 to 0.99 and investment-to-capital ratio drops to -0.23%. In other words, we would have seen a decline in Tobin's q that is much more severe — around 44% — absent cost passthrough and falling cost of renewables. That is, the decline in Tobin's q is more than double if there were no mitigating factors. Of the additional decline, one-quarter of it is attributable to removing consumer-price passthrough and three-quarters of it to removing the falling cost of renewables.

4.6 Endogenizing RPS

There is a straightforward way for us to extend our quantitative analysis to endogenize RPS by introducing a second capital stock N following Hong et al. (2023b). This second capital stock is non-productive and provides carbon removal services for the economy. We denote the aggregate of this second capital stock by $\mathbf{N}$ and the aggregate of the productive capital stock by $\mathbf{K}$. A higher ratio of $\mathbf{N}$ to $\mathbf{K}$, which we denote by $\mathbf{n}$ reduces the arrival of climate disasters (Hong et al. (2023a)), i.e a climate tipping point. The tax on firms from RPS can be thought as their contributions to the accumulation of decarbonization capital.

There is a gradual increase in the ratio of decarbonization to productive capital stock until it reaches a steady-state level that is determined by the planner. This climate policy lowers the firm's Tobin's q, but the extent to which it does so depends on the mitigation benefits of decarbonization capital. The social planner chooses an optimal path of such investments in order to maximize welfare.

This extension increases the number of parameters of our model to include an adjustment cost for the decarbonization capital stock, a parameter to capture the mitigation benefits of this decarbonization capital stock and two extra parameters to describe the climate tipping point. We can then calibrate the model to fit the aggregate or average decarbonization path, summarized by the evolution of the ratio of decarbonization to productive capital, $\mathbf{N}/\mathbf{K}$, in addition to the rest of the aforementioned moments. This calibration is in the Online Appendix. Our quantitative results continue to hold in this general setting where RPS is endogenous.

5 Conclusion

A question of broad interest to both policymakers and market participants is the extent to which climate policy impact capital markets, particularly firm valuation. We first answer this question with reduced-form evidence from the implementation of renewable portfolio standards (RPS) in the United States that applied to investor-owned but exempted municipal producers. We find that investor-owned firms are hit with lower valuations from the hit in profits to build more expensive solar and wind farms than gas plants. Our reduced-form evidence suggests that the financial hit is moderate but smaller than in stranded-asset scenarios of concern to financial regulators. Two factors likely mitigated the hit to valuations: utilities were able to eventually pass through the higher cost of renewables to consumers and they also benefited from falling costs of renewables.

To quantify the importance of these mitigating factors for firm valuations, we then use our findings to calibrate a Tobin's q model. Counterfactuals show that the effect of RPS on valuations would have been severe absent renewables cost pass-through and falling costs of renewables. Our work can be used by policymakers to generate more realistic assessments of climate policy on firm valuations.

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Appendix

A Adjusting RPS Decarbonization Targets for Electricity Price Increases

For our calculations of the net cost to investor-owned utilities of meeting the RPS decarbonization targets, we need to estimate how the retail price of electricity changed for investor-owned firms relative to municipal utilities after the implementation of RPS. We describe here our methodology for measuring these price changes.

Note that there are many similarities here with our reduced form approach detailed in Section 3. Where this approach differs is that rather than estimating differential effects for each individual year post passage, we instead pool across all post periods to arrive at a single coefficient.

We estimate the following regression model:

$$log(p_{j,s,t}) = \beta_1 \times corp_j \times F_{s,t} + \delta_s \times \phi_s \times corp_j + \theta_s \times corp_j \times F_{s,t} + \gamma_{s,t} \times \phi_s \times \nu_t + \epsilon_{j,s,t} \quad \text{(A1)}$$

where $p_{j,s,t}$ is the retail electricity price for sector j (investor-owned or municipal) in state s in year t. $corp_j$ is an indicator that the sector is investor owned. $F_{s,t}$ is a variable that measures the number of years since the RPS was implemented in state s; the variable takes on a value of zero before the RPS implementation. ϕ_s is a set of state fixed effects. ν_t is a set of year effects, and $\epsilon_{j,s,t}$ is an error term. The coefficient of interest is β_1, which measures how the retail electricity prices of investor-owned firms changed differently after the implementation of a state RPS than the electricity prices of municipal utilities.

Estimating this model on data from our sample of 13 states, we find that the coefficient for β_1 is 0.0020, indicating that on average retail electricity prices of investor-owned utilities increased by about 0.20% per year more than the prices of municipal utilities in the years after the RPS.

With this price growth estimate, we can calculate for each state an alternative retail price for investor-owned utilities for the years after the RPS was implemented. That is, for the 2001 to 2021 sample, we can calculate what the retail electricity price would have been for investor-owned firms in a state had there been no difference in the price growth between investor-owned and municipal utilities after the RPS was implemented. For years after 2021 when we are projecting our data, we assume that the alternative retail price of investor-owned utilities stays the same as it in our last year of data (2021). We can then use this alternative retail price to calculate the revenue change that investor-owned utilities experienced because of the RPS.

B Triple Difference Estimate of the Effect of RPS on Yield Spreads

To perform our triple difference-in-differences, we compare the yield spread between corporate and municipal suppliers post RPS passage of states with exemptions, versus states without exemptions. Specifically, we estimate the following expression, using all issuances in the 32 combined states:

$$\begin{aligned} y_{i,j,s,t} =& \phi_{s,t} + \alpha_i + \varphi_j + \tau_j + \beta_0 \times corp_i \times post_{s,t} \\ &+ \beta_1 \times exempt_s \times corp_i \times post_{s,t} + \Lambda \mathbf{K}_{i,j,t} + \nu_{i,j,t} \end{aligned} \tag{B1}$$

where $y_{i,j,s,t}$ is the yield of issue j, by firm i, operating in state s, in year t; $\phi_{s,t}$ is a state-year fixed effect; ψ_i is a firm fixed effect;φ_j and τ_j are fixed effects for security type and tax code of issue j respectively; $corp_i$ is an indicator taking a value of 1 if the firm i is a corporate/investor-owned firm; $post_{s,t}$ is an indicator that takes a value of one if the issue occurs after RPS passage in that state; $exempt_s$ is an indicator that takes a value of 1 if the state that the firm operates in instituted a municipal exemption as part of RPS legislation; and $\mathbf{K}_{i,j,t}$ is a vector of issue level controls identical to those in our main specification (Equation 2).

The key coefficient of interest is β_1, i.e. the one associated with interaction term, $exempt_s \times corp_i \times post_{s,t}$. This coefficient tells us the difference in corporate-to-municipality spreads/issue amounts between states with and without exemptions. Note that the coefficient β_0 captures the impact of RPS legislation on corporate to municipal yield spreads in states without municipal exemptions. A test of our identification strategy is that β_0 is not statistically different from zero.

Our results are presented in Table B1. Consistent with our identification, we do not find a significant impact on corporate to municipal spreads in states without exemptions. By contrast, we find a positive and statistically significant coefficient in the case of adjusted yields of 66bps. It is this average spread in the post period that we will convert into a Tobin's q adjustment using the approach outlined above.

Table B1: Triple Difference-in-Differences for States with and without Exemptions

This table presents results of our triple difference-in-differences estimation. Here we pool issue level observations from all 32 states that passed RPS legislation. We include an indicator, $exempt_s$, that takes a value of 1 if the state instituted a municipal supplier exemption. The coefficient on $corp \times post$ captures the change in post RPS legislation spreads between corporate and municipal suppliers in states without municipal exemptions, and the coefficient on $exempt \times \times post$ captures the differential effect in states with exemptions.

Dependent Variables:	Adjusted Yields
Variables	
corp × post	0.0029
	(0.0018)
exempt × corp × post	0.0066**
	(0.0032)
Controls	Yes
Fixed-effects	
state-year	Yes
issuer	Yes
sec_type	Yes
tax_code	Yes
Fit statistics	
Observations	6,668
R^2	0.77530
Within R^2	0.13156

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

C Additional Data for Calibration Exercise

To construct data moments and parameters for our calibration exercise, we draw on two additional sources of data: the Federal Energy Regulatory Commission data (FERC), and CRSP-Compustat.

FERC Data. The data from FERC is captured from 'Form 1' submissions from utility companies. This form consists of a comprehensive financial and operating report submitted annually for electric rate regulation, market oversight analysis, and financial audits by Major electric utilities, licensees and others.

Utilities are required by law to submit this form if at least one of the following criteria is met for three consecutive years prior to reporting: (i) 1 million MWh of total sales, (ii) 100MWh of annual sales for resale, (iii) 500MWh of annual power exchanges delivered, or (iv) 500MWh of annual wheeling for others (deliveries plus losses).

We use this data to construct the output-to-capital, investment-to-capital, revenue growth, depreciation rate, and leverage values used in our calibration exercise. We define these variables using FERC data labels in the following way:

1. Output-to-capital is: $\frac{total\_operating\_revenues - total\_depreciation\_expense}{utility\_plant}$.
2. Investment-to-capital is: $\frac{cash\_flows\_provided\_from\_used\_in\_investment\_activities}{utility\_plant}$.
3. Revenue growth is the log difference in $total\_operating\_revenues$.
4. The depreciation rate is: $\frac{total\_depreciation\_expense}{utility\_plant}$.
5. Leverage is: $\frac{long\_term\_debt + current\_and\_accrued\_liabilities}{long\_term\_debt + current\_and\_accrued\_liabilities + common\_stock\_issued + retained\_earnings}$.

To construct the summary statistics used in the calibration exercise, we take the median values using all observations in post RPS passage years, using utilities operating in the 14 states we consider in our main analysis. This is simple using FERC data, as the data contains information on which states the utilities operate in, which also allows us to match the state-specific RPS passage year to the appropriate utilities.

In Figure C1, we represent state-level median values for each of the five variables above, with the sample median overlaid as a dashed blue line.

CRSP-Compustat Data. CRSP-Compustat offers firm and market fundamentals for all publicly traded U.S. firms. We restrict to firms in the dataset that have SIC Code '4911', which corresponds to 'Electric Services'.

We use this data to construct: (i) the dividend-yield, and (ii) the market volatility. We proceed by calculating median values of the dividend yield and annual stock return for each year in our sample, then take the mean/standard deviation of these median dividend yields/returns.

Figure C1: Representation of FERC Data

This figure shows state-level medians of the variables calculated using the Federal Energy Regulatory Commission data (FERC). We also include the full sample median as a dashed blue line, to indicate the values we use when performing the calibration exercise.

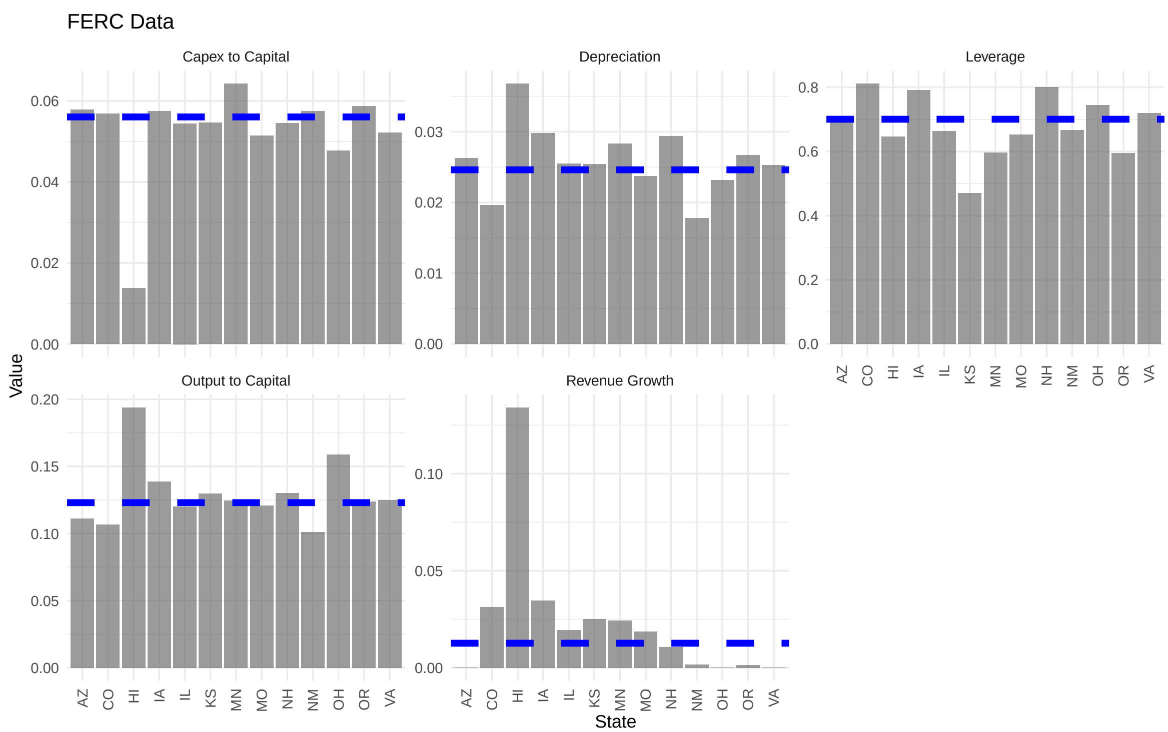
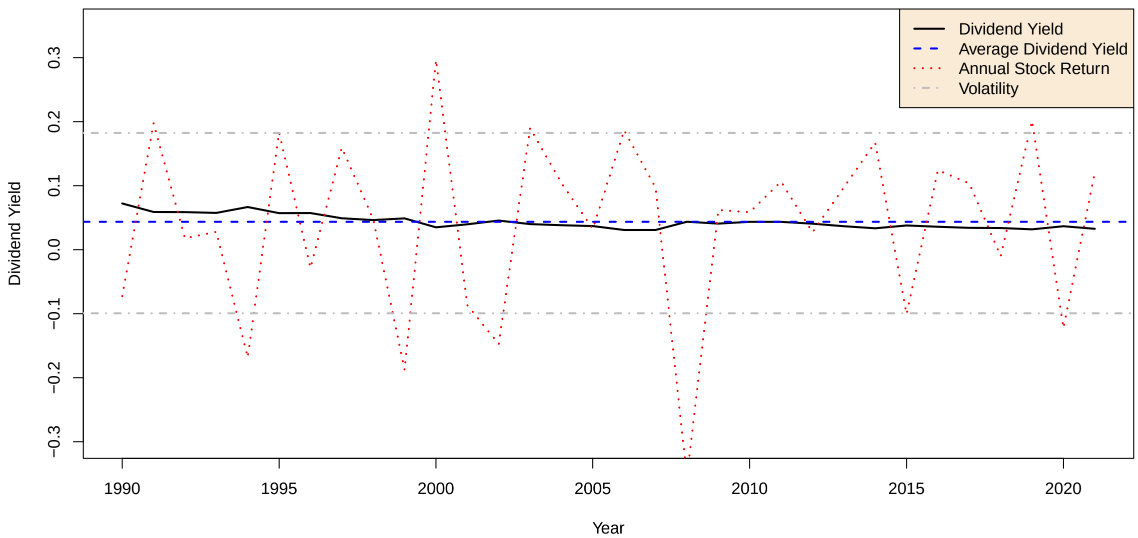


Figure C2: Representation of CRSP-Compustat Data

This figure shows data from CRSP-Compustat used in our calibration exercise. We restrict attention to firms operating in SIC Code '4911' (Electric Services) during our sample period of 1990 to 2021. We plot the median dividend yield (black solid line), the average of the median dividend yield across the whole sample (black dashed line), the median annual return (red dotted line), and the standard deviation (volatility) of the median annual return across the whole sample.



To construct the dividend yield, we take the ratio of Compustat item $DVPSX\_F$ (Dividends Per Share using Fiscal Year) over Compustat item $PRCC\_F$ (Price at Close of Fiscal Year). To construct market volatility, we calculate annual returns as the log change in $PRCC\_F$.

In Figure C2, we show the time series of the median dividend yield, the median annual stock return, the average of the median dividend yields, and the standard deviation (Volatility) of the median annual returns.

D Key Equations for Model Solution

To solve the model we outline in Section 4.2, we follow the procedure in Pindyck and Wang (2013). we begin by finding the equilibrium investment-over-capital, i^*. This value is the solution to the following non-linear equation (equivalent to Equation 12 in Pindyck and Wang (2013)):

$$A - i = \frac{1}{\phi'(i)} \left[\rho + (\psi^{-1} - 1) \left(\phi(i) - \frac{\gamma\sigma^2}{2} - \frac{\lambda}{1-\gamma} \mathbb{E}[1 - Z^{1-\gamma}] \right) \right] \tag{D1}$$

where ψ is the elasticity of intertemporal substitution, γ is the coefficient of relative risk aversion, ρ is the rate of time preference, σ is the diffusion volatility, λ is the jump arrival rate of disasters, and Z is a random variable with a power distribution over $(0, 1)$ that determines the loss of capital when a disaster arrives.

The function $\phi'(i)$ is the adjustment cost function, and is given by $\phi'(i) = 1 - \eta i$. The distribution of Z is determined by the following equation:

$$\zeta(Z) = \beta Z^{\beta-1}; \qquad 0 \leq Z \leq 1 \tag{D2}$$

where β captures the degree of damage implied by the shock realization. Given this distribution, the expectation term in Equation D1 is given by the following expression:

$$\mathbb{E}[1 - Z^{1-\gamma}] = 1 - \frac{\beta}{\beta + (1-\gamma)} \tag{D3}$$

Once we solve this non-linear expression to find i^*, the remaining moments are calculated using the following expressions:

$$q = \frac{1}{1 - \phi(i^*)} \tag{D4}$$

$$\frac{c}{q} = \frac{A - i^*}{q} \tag{D5}$$

$$r = \rho + \psi^{-1} g - \frac{\gamma\,(\psi^{-1} + 1)\,\sigma^2}{2} - \lambda \left[\frac{(\psi^{-1} - \gamma)(\beta - \gamma) + \gamma(\beta - \gamma + 1}{(\beta - \gamma)(\beta - \gamma + 1)} \right] \tag{D6}$$

$$rp = \gamma\sigma^2 + \lambda\gamma \left[\frac{1}{\beta - \gamma} - \frac{\beta}{(\beta + 1)(\beta + 1 - \gamma)} \right] \tag{D7}$$

$$g = r + rp - \frac{c}{q} \tag{D8}$$

E Mapping Reduced-form Yield Spread Findings to Change in Tobin's q.

Philippon (2009) shows that, to a first-order approximation, Tobin's q is a linear function of the relative yields of corporate and government bonds, as specified in Equation D9:

$$q_t \approx \frac{\psi}{\delta(1+r)} \frac{1+r_t^{\$}}{1+y_t^{\$}} + \text{constant} \tag{D9}$$

where ψ is the average book leverage, δ is the risk-neutral default rate, r is the real risk-free rate, $r_t^{\$}$ is the nominal risk-free rate, and $y_t^{\$}$ is the nominal yield on corporate bonds.[24] Using this formula, we can convert the estimated reduced form yield spread effects of RPS passage into an equivalent change in Tobin's q. Hence, we can assess the change in q_t with a change in $y_t^{\$}$ and change in debt issuance. The change in debt issuance is picked up by changes in book leverage ψ.

We just need data equivalents for the variables in Equation D9 to perform our transformation. We use a combination of the issue-level data from our reduced form exercises, and several additional sources of data. For risk-free rates, we use market yields of U.S. Treasury securities at 10-Year and 30-Year constant maturities, as measured by the Federal Reserve Economic Data (FRED) platform. To construct real risk-free rates, we divide these nominal returns by annual U.S. inflation, again as measured by FRED. We then split our issue-level dataset into two subsets, containing bonds issued at 10 and 30 year maturities respectively, and match the appropriate government bond yield to each sample.

For the risk-neutral default rate, we use values from Hull et al. (2005) that map Moody's ratings into default rates. We then take the weighted average of these rates, using the number of bonds in our reduced form dataset in each rating category as weights. We find a risk-neutral default rate across our sample period of 1.81% for bonds issued at 10-year maturity, and 1.45% for those issued at 30-year maturity.

Finally, for average book leverage, we use balance sheet data from the Federal Energy Regulatory Commission (FERC).[25] Using the definition of leverage in Philippon (2009), we find an average value of 0.70 across our sample period. The book leverage is not much different across the pre versus post RPS periods, suggesting that the major effect on Tobin's q is coming from yield spreads as opposed to changes in book leverage.

[24] This approximation is derived for firms issuing short-term debt. The quantitative analysis in Philippon (2009) for long-term bonds to adjust for long-term debt would not

[25] Specifically, we draw data on equity and debt from FERC Form 1 submissions. This form constitutes a comprehensive, firm-level financial and operating report, submitted annually for electric rate regulation, market oversight analysis, and financial audits by Major electric utilities, licensees and others.

Decline in Tobin's q. We calculate, for each issue, the following expression, where $_t^{RPS}$ is the Tobin's q of a firm after RPS passage:

$$\Delta q_{i,t} = q_{i,t}^{RPS} - q_{i,t} = \frac{\psi(1+r_t^{\$})}{\delta(1+r_t)} \left[\frac{1}{1+y_{i,t}^{\$}+0.0066} - \frac{1}{1+y_{i,t}^{\$}} \right] \tag{D10}$$

where the risk-free rates, $\{r_t, r_t^{\$}\}$, are the corresponding real and nominal market yields of U.S. Treasury securities with maturities that match that of issue i.

We then calculate the mean value of Δq_t across all issues. We find that the 66bps yield spread induced by RPS passage corresponds to a fall in Tobin's q of roughly 0.263. This is a conservative approximation for firms since the hit would be bigger if they issue longer-term debt, which our firms do. An adjustment for longer-term debt would yield a hit to Tobin's q more in line with our model's prediction.

Online Appendix

This online appendix describes the details for the endogenous RPS model from Hong, Kubik and Shore (2023), "The Cost of Climate Policy to Capital: Evidence from Renewable Portfolio Standards".

Calculating the ratio of decarbonization to productive capital $\mathbf{n} = \mathbf{N}/\mathbf{K}$. We can calculate $\mathbf{n}$ by constructing the ratio for each firm and taking the average for firms across the sector. From Equation 8, for each firm, we can calculate its N using the following equation:

$$N_{i,j,t} = N_{i,j,t-1} + F^{R}_{i,j,t} \tag{O1}$$

As this is a recursive equation, we need to consider the initial value of N. We assume that, for the initial year in our sample (2001), N is equal to zero. We then take the ratio of N/K for each firm and year and average it across firms in our sample. This average, which we take to be a measure of the average of aggregate decarbonization path $\mathbf{n} = \mathbf{N}/\mathbf{K}$ is shown in Figure O1.

Climate tipping point. The economy starts from the good climate state $\mathcal{G}$ characterized by less-frequent weather disasters) and stochastically transitions to the absorbing bad state $\mathcal{B}$ characterized by more-frequent weather disasters) at a stochastic rate of $\zeta_t > 0$ that is endogenous depending on decarbonization in the economy that is set by regulators.

$\{\mathcal{J}_t\}$ is now a (pure) jump process driving weather disaster arrivals with a climate-state-dependent arrival rate $\{\lambda_t^{\mathcal{S}_t}\}$ process. In a given climate state $\mathcal{S}_t$ ($\mathcal{B}$ or $\mathcal{G}$) at time t.

Non-productive capital stock. Let $\mathbf{X}_t$ denote the aggregate mitigation spending (investment), which equals the sum of mitigation spending contributions by all firms: $\mathbf{X}_t = \int X_t^{\nu} d\nu$. The aggregate decarbonization capital stock $\mathbf{N}$ evolves as follows:

$$\frac{d\mathbf{N}_t}{\mathbf{N_{t-}}} \;=\; \omega(\mathbf{X}_{t-}/\mathbf{N_{t-}})dt + \sigma d\mathcal{W}_t - (1-Z)d\mathcal{J}_t\,. \tag{O2}$$

That is, absent jumps, $\omega(\mathbf{X}_{t-}/\mathbf{N_{t-}})$, the drift of $d\mathbf{N}_t/\mathbf{N}_{t-}$, is analogous to $\phi(I_{t-}/K_{t-})$, the drift of dK_t/K_{t-}. We assume that $\omega(\,\cdot\,)$ is increasing and concave as we do for $\phi(\,\cdot\,)$. This specification captures the idea that changing $\mathbf{N}$ rapidly is more costly than changing it slowly.

Let $\mathbf{n}_t = \frac{\mathbf{N}_t}{\mathbf{K}_t}$ denote the aggregate decarbonization-productive capital ratio, which follows:

$$\frac{d\mathbf{n}_t}{\mathbf{n}_{t-}} = \left[\omega(\mathbf{x}_{t-}/\mathbf{n}_{t-}) - \phi(\mathbf{i}_{t-})\right]dt\,. \tag{O3}$$

There is no uncertainty for the dynamics of $\mathbf{n}_t$ in our model since productive and decarbonization capital stocks are subject to the same jump-diffusion growth and disaster shocks. Similarly, at the aggregate level, we assume that the controlled drift for the aggregate decarbonization capital stock $\mathbf{N}$ takes the same form as that for firm-level capital stock K:

$$\omega(\mathbf{x}/\mathbf{n}) = (\mathbf{x}/\mathbf{n}) - \frac{\eta_{\mathbf{N}}\,(\mathbf{x}/\mathbf{n})^2}{2} - \delta_{\mathbf{N}}\,, \tag{O4}$$

where $\mathbf{x} = \mathbf{X}/\mathbf{K}$, $\eta_{\mathbf{N}}$ is the adjustment cost parameter for the aggregate decarbonization capital $\mathbf{N}$, and δ_N is the depreciation rate.[26]

By accumulating decarbonization capital stock, regulators decrease the tipping-point arrival rate from $\zeta_0 > 0$ to

$$\zeta(\mathbf{n}; \mathcal{G}) = \zeta_0(1 - \mathbf{n}^{\zeta_1})\,, \tag{O5}$$

where $0 < \zeta_1 < 1$. (Recall that $\zeta(\mathbf{n}; \mathcal{B}) = 0$.) For a given $\mathbf{n}$, the lower the value of ζ_1 the more efficient the decarbonization capital stock is at curtailing the tipping-point arrival.

In a given climate state $\mathcal{S}$, decarbonization capital $\mathbf{N}$ can also ameliorate the damage to economic growth by reducing the frequencies of weather-disaster (e.g., high-temperature) events. Specifically, we use the following specification for the weather-disaster arrival rate $\lambda(\mathbf{n}; \mathcal{S})$ in state $\mathcal{S}$:

$$\lambda(\mathbf{n}; \mathcal{S}) = \lambda_0^{\mathcal{S}}(1 - \mathbf{n}^{\lambda_1})\,, \tag{O6}$$

where $\lambda_0^{\mathcal{S}} > 0$ is the arrival rate absent any decarbonization capital stock ($\mathbf{n} = 0$) in climate state $\mathcal{S}$ and $\lambda_1 \in (0, 1)$ measures how efficient the aggregate decarbonization capital stock reduces the weather-disaster arrival rate $\lambda(\mathbf{n}; \mathcal{S})$. For brevity, we assume that λ_1 is the same in the two climates states $\mathcal{G}$ and $\mathcal{B}$. Similar to the effect of ζ_1 on the tipping-point arrival, a lower value of λ_1 is associated with a more efficient decarbonization technology reducing the weather disaster arrival rate, *ceteris paribus*. Finally, to capture the idea that weather disasters are more frequent in the $\mathcal{B}$ state than in the $\mathcal{G}$ state conditional on $\mathbf{n}_t$, we assume $\lambda_t(\mathbf{n}_t; \mathcal{G}) < \lambda_t(\mathbf{n}_t; \mathcal{B})$ for all $\mathbf{n}_t$.

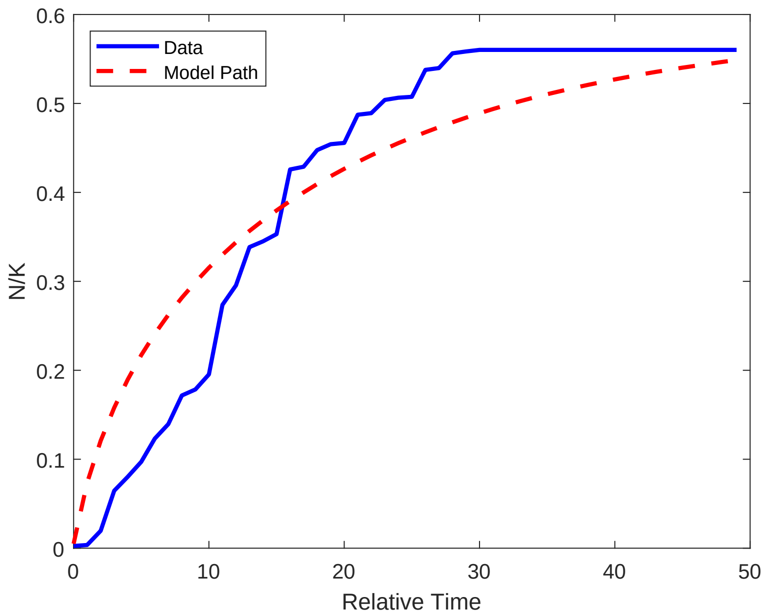
Optimal mandate. Decarbonization targets are optimally set by the government to maximize social welfare and are of the form $X_t = m(\mathbf{n}_t; \mathcal{S})K_t$. The fraction of total wealth allocated to meet the decarbonization targets is the scaled aggregate mitigation spending, $\mathbf{x}_t$, which is given by

$$\mathbf{x}_t = \frac{\mathbf{X}_t}{\mathbf{K}_t} = \frac{\alpha X_t}{K_t} = x_t = m(\mathbf{n}_t; \mathcal{S}_t)\,. \tag{O7}$$

[26] We assume that $\eta_{\mathbf{N}}$ and δ_N are equal to $\eta_{\mathbf{K}}$, and δ_K from our main model.

Figure O1: Model and Data Path for $\mathbf{N}/\mathbf{K}$

This figure shows the path of the ratio of decarbonization to productive capital ($\mathbf{N}/\mathbf{K}$), both from the data (solid blue line), and from the calibrated model with endogenized RPS mandates (dashed red line).



Due to the model's homogeneity property, the equilibrium value of a type-j firm, Q_t, at time t must satisfy:

$$Q_t = q(\mathbf{n}_t; \mathcal{S}_t) K_t \,, \tag{O8}$$

where $q(\mathbf{n}_t; \mathcal{S}_t)$ is Tobin's q for a firm as a function of $\mathbf{n}_t$ and climate state $\mathcal{S}_t$. The competitive equilibrium with a welfare-maximizing target is given by a set of ODEs given in Hong et al. (2023b). The programs to solve the ODEs can be obtained from the Review of Financial Studies Dataverse. In the model, since all firms are ex-ante identical, $q = \mathbf{q}$ and $i = \mathbf{i}$.

Calibration. We then perform the following calibration exercise. We take the parameters from Table 5 and then choose the additional four parameters to fit the path of $\mathbf{N}/\mathbf{K}$ given in Figure O1. The data is shown as a solid line and the model path is the dashed line. The additional parameters are reported in Table O1.

In Table O2, we report some key moments from our calibration exercise. Note that we have not recalibrated the entire model to refit all the moments. As such, some of the moments for investment and dividend yield differ more from the data. Nonetheless, we can see that there is still a sizeable gap in Tobin's q across non-exempt and exempt firms.

Table O1: Parameters and Estimates

This table contains the values of the additional parameters we introduce after endogenising the RPS mandates within the model from calibrating our model. Note that we assume that $\eta_{\mathbf{N}}$ and δ_N are equal to $\eta_{\mathbf{K}}$, and δ_K from our main model.

Parameter	Symbol	Value
Jump arrival baseline parameter from state G to B	ζ_0	0.6
Jump arrival sensitivity parameter from state G to B	ζ_1	0.92
Jump arrival baseline parameter with $\mathbf{n} = 0$ in state B in Bad State	λ_0^B	6.05
Mitigation technology parameter	λ_1	0.6

Table O2: Moments with Endogenised RPS

This table shows the generated moments from our calibrated model with endogenised RPS. We first show the data moments, followed by the implied moments for exempt and non-exempt firm.

Variable	Data	Non-Exempt	Exempt
Decarbonization Spending	2.57%	2.33%	0.00%
Investment	5.60%	3.79%	7.41%
Dividend Yield	4.36%	6.72%	4.05%
Volatility	14.1%	14.1%	14.1%
Tobin's Q	1.53	1.30	1.83