The Cost of Net Zero

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Abstract

Renewable Portfolio Standards (RPS) are increasingly adopted worldwide to accelerate the transition to renewable energy and net zero carbon emissions. Exploiting their staggered implementation in 32 U.S. states, we find that RPS explain higher bond yields and lower credit ratings. However, we observe opposite results when states introduce clean energy targets that include diverse energy sources. Consistent with our theoretical model, we find stronger effects in areas with political preferences for renewables. These results are robust in primary and secondary markets and extend to local municipalities. Our findings quantify the fiscal trade-offs facing taxpayers as governments administer the energy transition.

Countries around the world have proposed and adopted timelines for achieving net zero carbon emissions. Most countries have pledged net zero end targets for 2050, with some countries even setting deadlines for 2030 (Becht, Pajuste, Toniolo 2023). These new policies, while aspirational, often lead to hard decisions about investment and financing of new and existing projects. This paper finds that U.S. states that mandate renewable energy quotas face significantly higher borrowing costs and lower credit ratings, with municipal bond yields increasing by up to 18.7 basis points after implementing renewable portfolio standards. However, states adopting more flexible "clean energy" targets that include nuclear power and carbon capture technologies see the opposite effect - their borrowing costs decrease. These contrasting outcomes highlight the financial trade-offs facing taxpayers as state and local governments pursue net zero carbon emissions.

To guide our empirical analysis, we develop a theoretical framework that captures three economic forces affecting how renewable energy mandates impact municipal bond markets: (1) firms' production decisions under renewable requirements, (2) state governments' preferences over tax revenues and renewable adoption, and (3) the relationship between state finances and borrowing costs. The model shows that states face a fundamental trade-off - while they may have preferences for renewable energy adoption, pursuing aggressive renewable targets above private sector optima reduces tax revenues and increases borrowing costs. This creates tension between environmental goals and fiscal health that motivates our empirical predictions.

U.S. state governments have taken an active role in addressing climate change by adopting and enforcing Renewable Portfolio Standards (RPS) (Engel, 2006; Thombs and Jorgenson, 2020). RPS, also referred to as renewable electricity standards, are mandates that require utility providers to include a minimum percentage of electricity from eligible renewable sources. These sources include wind, solar, geothermal, biomass, and some types of hydroelectricity, and can also include landfill gas, municipal solid waste, or ocean energy. Notably, no national renewable or other clean energy policies are in place in the U.S. As a result, state-level RPS are the cornerstone of the U.S. renewable energy policy. These policies have set in motion a variety of economic changes through the integration of renewable energy into the electrical grid. The implementation of these policies shows that renewable energy targets are an effective policy tool and are responsible for significant growth in renewable energy generation in the U.S. (Deschenes, Malloy, and McDonald, 2023).

This paper examines the financial impact of renewable energy mandates. In particular, we ask whether renewable targets affect the financial health of states that adopt them. The answer to this question is unclear. On the one hand, our stylized model emphasizes inefficiencies that come from overinvesting in renewable energy. Existing evidence also shows that renewables raise the cost of electric systems and retail electricity prices (Barbose et al., 2015). These increases are non-trivial: Greenstone and Nath (2020) estimate that electricity prices increase by 11% seven years after the passage of RPS mandates and 17% twelve years later. Furthermore, Johnson (2014) estimates that the cost of CO_2 abatement from RPS is about four times higher than comparable cap-and-trade programs. While renewable targets achieve carbon reductions, these reductions come at a higher cost than the conventional estimates of the social cost of carbon. These higher costs may disrupt states' economies if they cause firms and residents to overinvest in renewables.

On the other hand, renewable targets could stimulate states' economies because they create demand for technology and infrastructure that supports new sources of energy. A study conducted by the Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory (NREL) estimates that RPS will generate 4.7 million jobs from 2015 to 2050. This study also estimates significant benefits associated with improved air quality, reduced greenhouse gas emissions, and reduced water use (Mai et al. 2016). State renewable targets also reduce uncertainty about future renewable energy production and consumption, and establish adopting states as leaders in the energy transition. Indeed, Zhou, Solomon, and Brown (2024) show that the energy policies of neighboring states reflect the enactment of RPS. Finally, it is also possible that RPS will not affect state financing. If energy markets can switch at a low cost to alternative sources of energy, then renewable targets will not affect the local economy and state financing costs.

Yields and credit ratings on bonds issued by U.S. states provide useful metrics for assessing the economic impact of renewable targets. Bond yields reflect the return investors expect to receive from state governments and credit ratings reflect the likelihood that states will default on their bonds over the long term. Both metrics convey comprehensive perceptions of states' economic conditions and are more indicative of the net effect of RPS on the local economy than other measures used in the literature to capture the economic consequences of renewable targets, such as job creation or electricity prices. We also extend our analysis to local issuers, like counties, cities, and school districts to test whether financing costs for lower levels of government also incorporate the effects of RPS.

We use state-level renewable mandates as our main treatment variable. For example, in 2007, the Illinois general assembly established the first version of the state's RPS. The Illinois mandate requires a minimum percentage of each utility's total supply to eligible retail customers be generated from renewable energy, with a prespecified schedule of "*at least 2% by June 1, 2008; at least 4% by June 1, 2009; at least 5% by June 1, 2010; at least 6% by June 1, 2011; at least 7% by June 1, 2012; at least 8% by June 1, 2013; at least 9% by June 1, 2014; at least 10% by June 1, 2015; and increasing by at least 1.5% each year thereafter to at least 25% by June 1, 2025*".[1]

[1] Illinois Public Act 095-0481. Illinois amended this law three more times, redefining the ultimate targets (from 25% in 2025 to 40% by 2030 and 50% by 2040), scope of affected customers, and the state funding behind their RPS

We study mandates for a total of 32 states, introduced in a staggered manner over the sample period, that require a steady increase in the percentage of renewable energy generation. Some states are aggressive in their targets (e.g., California has a target of 60% by 2030), while others have modest targets (e.g., Washington has a target of 15% by 2030). Further, some states let their renewable targets expire in response to changing energy priorities. Therefore, we use the realized renewable target for a particular year as a treatment variable. This measure adjusts both for whether a state has a renewable mandate and also for the intensity of the treatment.[2]

Our main outcome variables measure yields and credit ratings of state bonds. We also study yields and credit ratings for bonds from local issuers. We include state and year fixed effects to control for the influence of time-invariant state characteristics and macroeconomic fluctuations, and we use county fixed effects when studying local issuers. We use a stacked differences-in-differences approach with state- or county-cohort fixed effects and calendar month fixed effects. We control for a variety of bond characteristics and time-varying state and county characteristics.

Our main finding is that states' cost of capital increases and credit ratings deteriorate after mandates to increase renewable energy production and consumption. An implemented renewable mandate increases the yield of the state's bonds by about 18.7 basis points. We also find that a typical change in targeted renewable energy (going from a state with no renewable target to one with a target of 20%) results in an increase in the yield of the state's traded bonds of about 13 basis points. This effect is relative to any changes in adjusted yields of similar bonds issued by similar states. The increase is consistent with our stylized model. For credit ratings, the effect of renewable

program. Notably, the Public Act 102-0662 increased annual RPS funding from $235 million to over $580 million (Illinois Power Agency, 2022).

[2] We also use an alternative measure of renewable "demand" that adjusts for any transitional rules towards the target that affect the RPS electricity requirements.

targets is a reduction of 0.85 rating notches, with a 20% renewable target corresponding to a reduction of about 0.72 rating notches. These magnitudes are large relative to other factors shown to impact local bond yields. For example, Goldsmith-Pinkham, Gustafson, and Lewis (2023) find a 5.3-basis point effect of sea level rise on the yields of public debt in exposed areas. Ivanov and Garrett (2025) document a 10.3-basis point increase in yields for affected issuers after anti-ESG laws passed in Texas in 2021 led to the exit of five large municipal bond underwriters.

These results are robust in a variety of settings. For example, we verify the parallel pre-trends assumption in a dynamic, event time setting. We estimate effects relative to the announcement of a state's renewable mandate and relative to the actual adoption of renewable targets. In both tests, we find the effect emerges steadily over the years after the adoption and implementation of renewable targets. We also find that our results are robust to alternative ways of measuring bond yields, as well as an alternative measure of renewable targets that accounts for any transitional rules towards the target that affect electricity requirements.

We extend our analysis to the local level. On the one hand, local governments might be shielded from some of the fiscal consequences that come with renewable targets, as they will not bear the full costs of any state-level subsidies required to implement RPS. They may also not be obligated to compensate state governments for any tax shortfalls that arise due to spending on the implementation of renewable mandates. On the other hand, RPS could be particularly impactful to local governments that are proximate to changes in energy infrastructure. We find similar results among bonds issued by lower levels of government, including counties, cities, and school districts. However, the results are smaller in magnitude (44% to 79% of the effects for state bonds), indicating that the consequences of state-level energy policies are not shared equally at the local level.

We study the heterogeneity in state preferences for renewables (as proxied by the political process) as a major channel for the effect of renewable adoption. Our stylized model demonstrates that preferences for renewables will lead to higher targets, lower profits, and ultimately higher yields. Indeed, we find that yield increases are particularly high in areas that support Democratic candidates, a proxy for stronger political preferences for renewables. This result indicates that renewable energy mandates can be more expensive when preferences for renewable energy outpace its feasibility.

In recent years, some states have augmented their RPS with Clean Energy Standards (CES). CES are similar to RPS, in that they require utilities to provide electricity from clean sources. However, the definition of "clean" is more inclusive than "renewable" in that clean energy definitions are technology-neutral. CES allow nuclear energy, coal, or natural gas fitted with carbon capture and other technologies not on the list of renewable sources of energy. The majority of CES are aspirational, with goals of up to 100% clean energy, and are targeted at long-term time horizons, with many of them becoming fully effective in 2050. Although they are ambitious, they have limited bite during the period we study. In terms of our conceptual framework, the flexibility of CES effectively reduces the wedge between socially optimal and privately optimal renewable usage, explaining why these mandates might not increase borrowing costs. For these reasons, we expect clean energy mandates to have no effect or even opposite effects of renewable mandates because clean energy mandates introduce goals that are easier and cheaper to achieve.

We replicate our analysis after including a separate variable for whether states adopt clean energy mandates. The increase in yields and decrease in credit ratings due to renewable targets remains robust, both in the state and local issuer samples. However, we observe generally opposite results for clean energy mandates. Both state and local issuers' bond yields decrease after the adoption of clean energy mandates. Credit ratings are generally insensitive when states adopt clean energy targets. These results indicate states face contrasting economic consequences depending on the technologies they employ as they seek to reduce carbon emissions. The larger effects among state issuers compared to local issuers also suggest an asymmetry in terms of how mandates made at the state level affect the fiscal health of lower levels of government.

Finally, we also study the effect of renewable energy mandates on yields in primary markets. Initial bond issuances are important because they determine the cost of funding for state and local issuers. Unlike in secondary market transactions, issuers could potentially time these issuances to mitigate the effects of climate commitments. However, we find that the results in the secondary market continue to appear in the primary market, and the magnitudes for both state and local issuers are similar to their estimates in secondary market samples. These results suggest that municipal governments cannot time the market when issuing bonds to overcome the increased costs of funding associated with renewable energy targets.

Our paper is part of a growing literature on the costs and benefits of clean energy. Existing studies have primarily concentrated on expenses linked to high emissions, such as Matsumura, Prakash, and Vera-Muñoz (2014), who illustrate a decline in firm value associated with carbon emissions, Bolton and Kacperczyk (2021), who highlight investor demand for compensation due to exposure to carbon emission risk, and Ilhan, Sautner, and Velikov (2021), who provide evidence of the pricing of carbon risk in the options market. Hong, Kubik, and Shore (2024) demonstrate that renewable mandates increase the yield spreads and renewables capacity of corporations in the utility sector. Instead, we provide broad evidence that clean energy targets have consequences for the public. We also study clean energy mandates. Both states and local public issuers face a higher cost of funding when they opt for an aggressive push toward clean energy generation, and these effects are partially offset when states permit a more diverse range of energy technologies.

We contribute to the literature on the economic effects of renewable energy on the local economy. Deschenes et al. (2023) show that RPS are effective at incentivizing the installation of wind turbines. Cornaggia and Iliev (2024) show that the presence of natural resources in the form of wind and solar energy reduces yields and increases credit ratings. We contribute to this literature by showing the costs and benefits to taxpayers of regulatory efforts to incentivize and harness renewable energy. We find mixed results depending on which technology(s) regulators are willing to include in the pursuit of net zero. We provide the first analysis of the impact of renewable energy and clean energy mandates on the credit ratings and cost of capital for state and local governments.

We also add to the literature on the determinants of the cost of municipal debt. Noteworthy determinants explored in previous research include state corruption (Butler, Fauver, and Mortal, 2009), population aging (Butler and Yi, 2022), corporate subsidies (Chava, Malakar, and Singh, 2023), medical marijuana (Cheng, Franco, and Lin, 2022), the opioid crisis (Cornaggia, Hund, Nguyen, and Ye, 2022), newspaper closures (Gao, Lee, and Murphy, 2020), sea level rise (Painter, 2020; Goldsmith-Pinkham, Gustafson, Lewis, and Schwert, 2023), climate risk (Acharya, Johnson, Sundaresan, and Tomunen, 2022; Kyung Auh, Choi, Deryugina, and Park, 2022), credit ratings (Cornaggia, Cornaggia, and Israelsen, 2018 and 2023), natural disasters (Jerch, Kahn, and Lin, 2023), and lax cybersecurity (Curti, Ivanov, Macchiavelli, and Zimmerman, 2024). Our contribution to this body of literature is an examination of the impact of state-level targets of renewable energy production, specifically renewable energy and clean energy mandates.

2. Conceptual Framework: A Stylized Model of Renewable Targets

We develop a simple theoretical framework to understand how renewable energy mandates affect state finances and bond yields. The model captures three economic forces: (1) the production decisions of firms subject to renewable requirements, (2) the state government's preferences over both tax revenues and renewable energy adoption, and (3) the relationship between state finances and borrowing costs. This framework helps motivate our empirical analysis by highlighting the channels through which renewable mandates can impact municipal bond markets.

We begin with firms' production decisions. Consider a representative firm that uses renewable energy (R) as an input in production. The firm's production function follows a Cobb-Douglas form with diminishing returns to renewable energy. The firm faces a linear price p for renewable energy and pays taxes at rate t on its profits.[3] Formally, the firm solves:

$$\max_{R}[(1-t)(AR^{\alpha}-pR)]$$

A represents productivity and α captures the diminishing returns to renewable energy use. This specification abstracts from other inputs like capital and labor to focus on the key renewable energy trade-off. The producer's optimal choice of renewable energy use R^P is:

$$R^{P}=\left[\frac{A\alpha}{p}\right]^{\frac{1}{1-\alpha}} \tag{1}$$

This solution has intuitive properties - firms use more renewables when they are more productive (higher A), when diminishing returns are less severe (higher α), and when renewable prices are lower (lower p). This result provides our first insight: in the absence of government intervention, firms will choose a privately optimal level of renewable energy that balances productive benefits against costs.

The state government, however, has broader objectives beyond just maximizing tax

[3] We define the ranges of parameters, verify optimality conditions, and derive static effects in Internet Appendix A.

revenue. We model the state's utility function as having three components:

[1] Tax revenues from firm profits: $t(AR^{\alpha} - pR)$

[2] Direct preference for renewable energy: βR

[3] Funding costs that decrease with tax revenue: $D - \gamma t(AR^{\alpha} - pR)$

The first term captures the state's fiscal interests - higher firm profits generate more tax revenue. The second term represents political preferences for renewable energy adoption, with β measuring the strength of this preference. The third term introduces a key financing channel - states with stronger tax revenues face lower borrowing costs (captured by the parameter γ).[4]

Combining these elements, the state chooses its renewable energy target R^T to maximize:

$$\max_R [t(AR^{\alpha} - pR) - (D - \gamma t(AR^{\alpha} - pR)) + \beta R]$$

Which simplifies to:

$$\max_R [t(1+\gamma)(AR^{\alpha} - pR) + \beta R - \mathrm{D}]$$

The optimal renewable target chosen by the state is:

$$R^T = \left[\frac{A\alpha}{p - \frac{\beta}{t(1+\gamma)}}\right]^{\frac{1}{1-\alpha}} \tag{2}$$

This solution provides several insights that motivate our empirical analysis:

[4] The state's utility function is driven by a desire to spend on state projects that increase the consumption of its population but also to balance out any preferences for renewables above its constituents. Hence, it is an aggregation of the utilities of its population who are implicitly assumed to have a utility function increasing in consumption and renewables.

1. The state's optimal renewable target (R^T) exceeds the private sector optimum (R^P) when $\beta > 0$, and is the same as the private sector optimum when $\beta = 0$. This result provides a rationale for why some states implement binding renewable portfolio standards.[5]

2. Combining equations (1) and (2): the wedge between R^T and R^P increases with the strength of renewable preferences β but decreases with the tax rate t and the sensitivity of borrowing costs to revenues γ. This comparison suggests that states face a trade-off while pursuing renewable energy goals between maintaining high revenues and low borrowing costs.

3. States with no preference for renewables ($\beta = 0$) will choose targets equal to the private sector optimum. This helps explain why some states adopt renewable standards while others do not.

4. Higher renewable targets that push consumption above private sector optima will reduce tax revenues and increase borrowing costs through the γ parameter. This motivates our empirical tests of how renewable mandates affect municipal bond yields.

While this model is intentionally stylized, omitting dynamics and uncertainty, it captures the core economic mechanisms we examine empirically. The framework predicts that the introduction of binding renewable standards should increase municipal borrowing costs, these effects should be stronger in states with higher renewable targets, the impact on yields should operate through reduced tax revenues, and the effects may vary based on state characteristics that

[5] The model will have a renewable target lower than the producer's optimum if the state has a negative preference for renewables ($\beta < 0$). We assume that states with ($\beta < 0$) cannot implement punitive targeting.

influence the β and γ parameters.

These predictions align with our empirical strategy of examining how municipal bond yields and credit ratings respond to the adoption and intensification of state renewable portfolio standards. The model also suggests examining heterogeneity based on political preferences for renewable energy, which we explore in our analysis.

3. Institutional Background: State Governments and the Pursuit of Net Zero

U.S. state governments have long been more proactive than the federal government in implementing policies to curb greenhouse gas emissions. The U.S. federal government only recently announced plans for the nation to have a fully clean electrical grid by 2035 and net zero carbon emissions by 2050.[6] These goals, however, are not supported by explicit and immediately escalating targets for renewable electricity production and consumption and are not enshrined in federal laws.[7] At least 76 proposals for a national portfolio standard have been introduced, but none has become law.[8] Observers view these goals as vague, with support from Congress as the most important remaining obstacle (Waldman 2021).

In the meantime, the goal of clean energy transition has been mostly left to states to regulate and enforce.[9] Engel (2006) notes, "Here it is the state governments that are actively pursuing programs to reduce emissions of greenhouse gases and sequester carbon while the federal

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[6] U.S. Department of Energy, U.S. Department of Transportation, U.S. Environmental Protection Agency, and U.S. Department of Housing (2023), "The U.S. National Blueprint for Transportation Decarbonization", URL: https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf

[7] The idea of national clean energy standards received bipartisan support in 2009 in the House but failed in the Senate. Subsequent attempts in 2010 and 2012 to pass a Clean Energy Standard Act also failed.

[8] Congressional Research Service (2021), "A Brief History of U.S. Electricity Portfolio Standard Proposals", URL: A Brief History of U.S. Electricity Portfolio Standard Proposals (congress.gov)

[9] Hundreds of cities and municipalities in the U.S. have pledged to reduce their carbon footprints by adopting climate action plans. However, the majority of these plans are viewed as aspirational rather than realistic (Pulver, Bowman, Harvilla, and Wilson, 2021).

government has adopted a nonregulatory approach, and, many would argue, a mostly do very little approach" (pp. 1015). Renewable Portfolio Standards (RPS) are states' most common policy tool for reducing greenhouse gas emissions (Thombs and Jorgenson, 2020). RPS are mandates that require electricity suppliers to provide their customers with a stated minimum share of electricity from renewable sources. RPS are exclusively a policy tool of state governments. RPS have been effective in that they are responsible for approximately half of the growth of renewable energy generation in the U.S.[10] Deschenes et al. (2023) find that RPS policies increase wind generation capacity by 44 percent, or an additional 600 to 1,200 megawatts.

A relatively new development, Clean Energy Standards (CES) are similar to RPS in that they require a certain percentage of electricity to come from renewable sources. However, CES differ from RPS in that they allow more energy sources, including nuclear power or fossil fuels fitted with carbon capture technologies.[11] CES are new policy tools and represent an evolution of RPS, as Massachusetts passed the first CES in 2017. Clean energy and renewable energy operate similarly in that they both allow energy producers to earn clean energy credits. These credits are tradable and retail suppliers of electricity must hold a particular amount of them at the end of each compliance period to meet clean energy and renewable energy targets.[12] For example, a retail electricity supplier must hold 1,000 megawatt-hours of clean energy credits if it delivers a total of 5,000 megawatt-hours of electricity over a year in a state with a clean energy target of 20%.

[10] Lawrence Berkeley National Laboratory, U.S. Department of Energy (2021), "U.S. Renewables Portfolio Standards 2021 Status Update Early Release", URL: https://eta-publications.lbl.gov/sites/default/files/rps_status_update-2021_early_release.pdf

[11] CES, however, have been criticized for their inclusivity. For example, Friends of the Earth President Erich Pica commented that, "There is no role for nuclear in a least-cost, low carbon world. Including these dinosaurs in a clean energy standard is going to incentivize industry efforts to keep aging, dangerous facilities online." (Muyskens and Eilperin, 2020).

[12] Bipartisan Policy Center (2020), "Pathways to Decarbonization: A National Clean Energy Standard", URL: bipartisanpolicy.org/download/?file=/wp-content/uploads/2020/03/BPC_Energy_Clean-Energy-StandardV2.pdf

Therefore, because clean energy targets are market-based and technology-neutral, they are potentially a cost-effective approach to pricing and restricting carbon emissions in the electricity sector (Cleary, Palmer, and Rennert, 2019). Because clean energy targets are similar to renewable energy targets in requiring investment in new electricity infrastructure, the passage of a clean energy target can pre-empt renewable targets and therefore reduce the burden of regulation and compliance that ultimately falls on taxpayers.

4. Data and Sample Description

This section details our data sources. It also explains how we merge and filter the data to arrive at the final sample, as well as the descriptive characteristics of the sample.

3.1. Data Sources

We study the relationship between municipal bond pricing and renewable energy and clean energy mandates. We collect secondary market yields from the Municipal Securities Rulemaking Board (MSRB). The trading data are available from 2005 to 2022. We merge this dataset with bond characteristics in the Mergent Municipal Bond Securities Database (Mergent). We include general obligation tax-exempt bonds that have credit ratings. We eliminate bonds that are related to energy projects.[13] We obtain a list of state bonds from the Electronic Municipal Market Access website. We use this list to create separate samples of bonds issued by state governments and local entities.

We compute credit spreads for each transaction by subtracting the maturity-matched Municipal Market Advisors (MMA) AAA-rated curve from the raw yield.[14] We weight

[13] We eliminate bonds with Mergent use of proceed codes CUTI, ELEC, OUTI, and GAS.
[14] Table BI in the Internet Appendix reports results with spreads relative to maturity matched treasury yields.

observations by the transaction amount and compute *Adjusted Yield*, the average credit spread for all trades for a bond over a month. *Adjusted Yield* and bonds' credit ratings at the time of the transaction are our main dependent variables. We use Mergent to obtain up to three credit ratings for each bond from Moody's, Standard & Poor's, and Fitch at the time of each transaction. We assign numerical values to ratings, where AAA or Aaa is equivalent to 21, AA+ or Aa1 is equivalent to 20, and so on. *Credit Rating* represents the lowest rating assigned to a bond.

We obtain a variety of bond characteristics that also come from Mergent. These include the bond's coupon rate, offer amount, remaining years to maturity, age, call features, and whether the bond is wrapped with third-party insurance. We measure time-varying characteristics, such as credit ratings and years to maturity, at the time of the trade. We merge state-year data from the U.S. Census and Bureau of Economic Analysis, including population, income per capita, real GDP, and real GDP growth. We employ the geolocation procedure outlined in Cornaggia, Hund, Nguyen, and Ye (2022) to allocate bonds to their respective counties. This approach allows us to merge and control for county-year characteristics from the U.S. Census, such as county income per capita, unemployment rate, and county population. We also include population age structure data from the U.S. Census. These data allow us to control for any effects of population aging on municipal bond yields, as in Butler and Yi (2022). We measure political preferences with state- or county-level data on U.S. presidential votes from the MIT Election Lab.

We separately examine the issuance of state and local debt in the primary market. We collect offer yields in the primary market from Mergent. To account for market conditions, we normalize offer yields by subtracting the MMA AAA-rated curve yield at the issuance date from the raw yield. Our analysis focuses on bonds issued between 2001 and 2021. The remaining variables remain consistent with those in the secondary market sample, with measurements taken at the point of initial bond issuance.

3.2. Sample Construction and Descriptive Statistics

Our key independent variables capture which states implement Renewable Portfolio Standards (RPS) and Clean Energy Standards (CES). We measure this with an indicator taking a value of one if the state has implemented an RPS standard as of a given year and zero otherwise (*Renewable Target*). We also measure the intensity of the implementation of these standards with the variable *Renewable Percentage*: the percentage of electricity that utilities must supply from renewable sources in a given state-year.[15] We collect this information from the supplementary data included with the June 2023 U.S. State Renewables Portfolio & Clean Electricity Standards report provided by the Lawrence Berkeley National Laboratory and U.S. Department of Energy.

Figure I plots examples of *Renewable Percentage* for several states. Conditional on adoption, most states gradually increase renewable energy targets over time. For example, California mandates that 60% of its electricity should derive from renewable sources by 2030 with an initial jump to a 10% target and then a gradual increase in the targets over time. Two states (Kansas and Ohio) repealed their active RPS targets during our sample. Many of the states with RPS targets are similar to Arizona, Colorado, Illinois, and Washington with increasing targets towards 15% - 25%. Figure BI in the Internet Appendix displays *Renewable Percentage* for all

[15] These values are referred to as "nominal" targets. Certain load-serving entities (LSE) in each state may be subject to lower targets or be even exempt from the RPS target (Barbose, 2023). We also provide analysis based on RPS targets that adjusts for these exemptions. These adjusted targets are referred to as "RPS Demand". Results are in Table BII in the Internet Appendix.

state-years, conditional on adopting an RPS at any point over the sample period.

[Insert Figure I here.]

States adopt renewable energy and clean energy at different times. Figure II shows the number of states that adopt each year of our sample. “Adoption” refers to a state government’s legislative passage of the mandate. Many renewable energy and clean energy mandates are not active – in the sense that they require actual changes to the electricity mix – until years after their adoption. Therefore, we also tabulate the first year when the state has a positive RPS target in effect. Eleven states adopted RPS before 2000, including Iowa, which adopted the first RPS in 1983. Since then, 21 more states adopted RPS for a total of 32 states. Kansas and Ohio repealed their RPS, hence there are 30 states with active RPS as of the end of our sample 2022. Arizona repealed its RPS after the end of our sample.[16] These developments show that adopting and preserving an RPS is a fragile political process. Once adopted, states frequently adjust their targets or repeal them outright. These changes demonstrate the significant policy uncertainty surrounding RPS, and motivate us to study the years when renewable targets become active.[17] Adopted RPS are hypothetical with significant policy uncertainty, whereas active RPS are solidified policies that market participants can potentially price.

Clean energy mandates are relatively new, with the first state, Massachusetts, adopting such a standard in 2017. Since then, 13 more states have adopted clean energy mandates for a total of 14 states. Figure BII in the Internet Appendix displays states’ clean energy targets, conditional on a state having adopted a clean energy mandate by the end of the sample. Only two states have

[16] “Arizona regulators vote to repeal state renewable energy target, efficiency rules”, Fargo (2024).
[17] We also provide analysis based on the first year when RPS laws are passed. However, the laws are often amended and sometimes eliminated before being implemented and therefore the main credible signal of renewable commitment is the actual implementation of renewable targets. Results based on the adoption dates are in Table BIII in the Internet Appendix.

active clean energy targets as of 2022, the end of our sample, with most targets expected to become active after 2030 and four of them becoming active only in 2050. Our main variable measuring clean energy pledges is *Clean Energy Target.* It is an indicator variable that takes a value of one in years after a state adopts a clean energy target and zero otherwise. Whereas *Renewable Percentage* takes non-zero values in the years renewable anergy mandates become active, *Clean Energy Target* captures the years clean energy are adopted. This information is from Barbose (2023). We use adoption years for clean energy targets because observations associated with active clean energy targets are scarce as of the end of our sample. We use *Clean Energy Target* as a key independent variable.

[Insert Figure II here.]

In our empirical analysis, we use a stacked sample of renewable adoptions. With this approach, we stack all event-specific data to calculate the average effect across all events and estimate a single treatment effect. (see Cengiz, Dube, Lindner, and Zipperer, 2019) for an early implementation of this approach. Specifically, we align all observations with the event-time of state renewable energy target implementations and stack all not-yet-treated observations as a control set in each cohort. This approach addresses the issues with staggered differences-in-differences designs (see Sun and Abraham, 2021). We construct nine stacks for the renewable energy data and do not use any pre-treated states (states that adopted renewable energy targets before the start of our trading data in 2005). We also perform an approach for our issuance dataset where we have a longer dataset going back to 2000.

Panels A and B of Table I display summary statistics for the stacked secondary market and primary market samples, respectively. Panel A includes about 1.8 million observations for state issuers and 8.7 million observations for local issuers from 2005 to 2022. Each observation in this panel is a cusip-month containing at least one transaction. Panel B includes about 94 thousand observations for state issuers and 1.7 million observations for local issuers from 2001 to 2021. Each observation in this panel is an issuance cusip. *Adjusted Yield* is a key dependent variable. In the secondary market sample, *Adjusted Yield* has a mean of 12.69 basis points for state issuers and 27.23 for local issuers. These amounts are smaller in the primary market sample, at 6.4 basis points and 13.61 basis points, respectively. Lower yields in the primary market could be due to market timing on the part of issuers, as municipalities are less likely to issue debt when it is expensive.

Credit Rating is another key dependent variable. In the secondary market sample, *Credit Rating* has a mean of 19.56 rating notches (≈AA+/Aa1) for state issuers and 18.29 rating notches (≈AA-/Aa3) for local issuers. These amounts are similar in the primary market sample, at 19.58 (≈AA/Aa2) and 17.98 (≈AA-/Aa3), respectively. Summary statistics for other bond characteristics, such as coupon rates, offering amount, maturity, callability, and insurance status are similar to samples appearing in other papers on the U.S. municipal bond market with sample periods that overlap ours. We also include summary statistics for state- and county-level characteristics.

[Insert Table I here.]

5. Results from Bond Trades

Our main approach features observations associated with secondary market transactions. This approach provides at least two advantages. First, it allows bonds to enter the sample every time the bond trades, potentially providing within-bond time-series variation in yields and credit ratings. Second, observations are not dependent on state and local governments' decisions to issue bonds, which are likely a function of market conditions. Trades provide updated market prices that reflect changes in bonds' risk profiles. Therefore, secondary market transactions provide an opportunity to observe the effects of time-varying renewable energy targets. In the next section, we will complement our analysis of secondary market observations with observations based on primary market transactions.

4.1. Secondary Market Yields

For each observation in a state with a passed renewable energy mandate, we use bond-months issued in states with no active renewable energy mandate in the month as a control group. This approach generates unique treatment and control samples for issuers associated with each state with a renewable energy standard at some point over the sample. We stack these samples to estimate the effects of renewable energy targets on municipal bond yields, similar to how Cengiz et al. (2019) create stacks of data corresponding to waves of phase-in dates. This approach discards observations associated with states that have active renewable energy targets prior to the beginning of our sample. Later in the paper, we use a simple, pooled regression that includes observations for all 50 states for robustness. We estimate the following OLS regression equation using the samples of secondary market observations for state and local issuers described in Table I Panel A:

$$\begin{aligned}&\text{Adjusted Yield}_{i(j,k),t(y)} = \alpha + \beta \text{ Renewable Target}_{j,y} + \text{Bond Controls}_{i,t} + \\ &\text{State Controls}_{j,y} + \text{County Controls}_{k,y} + \text{Month-YearFixed Effects}_{t} + \\ &\text{State- or County-Cohort Fixed Effects}_{j \text{ or } k,c} + \varepsilon_{i,t} \qquad (3)\end{aligned}$$

where i indexes bond (j indexes state and k indexes county), t indexes month (y indexes year), and c indexes cohort. We take logs of skewed variables, including bond characteristics such as offering amount and state characteristics such as population and real GDP. Year-cohort fixed effects remove time-series variation in yields that is common to issuers whose renewable targets become active in the same year. State- or county-cohort fixed effects remove variation in yields that is common to issuers in the same state or county with an active renewable energy mandate. We cluster standard errors by bond and month. Table II presents the results. We report coefficient estimates for all control variables for completeness. We suppress these estimates in tables hereafter to conserve space.

[Insert Table II here.]

Consistent with our model, the results reveal a positive and statistically significant relation between the adoption of renewable targets and state bond yields. In model (1), we estimate an 18.7 basis points increase in yields for state issuers after the state implements a renewable energy target. For local governments, the magnitude is about 8.3 basis points. The next two columns estimate the effect depending on the actual renewable energy target in place. The difference in *Renewable Percentage* between a state issuer without a target and a state issuer with a typical variation in the target of 10.24% (standard deviation). Model (3) shows that this change is associated with an increase in adjusted yield of about seven basis points (0.645 × 10.243 = 6.66).[18] For local governments, the magnitude is about five basis points (0.510 × 10.243 = 5.22). These results indicate that municipal issuers' fiscal health deteriorates when states implement renewable energy targets. The decrease is larger when these targets become active. The magnitude of the effect is large relative to findings in related literature. For example, Goldsmith-Pinkham et al. (2023) find a two-basis point increase in yields among municipal bond issuers in coastal areas at risk for sea level rise. They also argue that a moderate increase in bond yields corresponds to a large decrease

[18] A one-standard deviation increase in a state's targeted renewable energy consumption (3.784, per Table I Panel A) results in an increase in adjusted yield of about four basis points (1.104 × 3.784 = 4.17) relative to any changes in adjusted yields of similar bonds issued by similar states.

in the present value of the underlying issuer cash flows.

The dependent variable in Table II, *Adjusted Yield*, is a transaction amount-weighted measure of the spread between raw yields and the MMA AAA-rated curve. We test whether our results are sensitive to how we measure yields in Table BI in the Internet Appendix. Model (1) in Panel A of Table AI replicates model (1) from Panel A of Table II for ease of comparison. We compute three alternative yield measures. First, we compute yields based on equal-weighting rather than transaction-amount weighting. Second, we compute a yield spread that subtracts the maturity-matched treasury yield (similar to the approach in Cornaggia, Hund, Nguyen, and Ye 2022). Third, we compute a measure that is both equal-weighted and matched to the corresponding treasury yield. Models (2) through (4) in Panel A of Table BI in the Internet Appendix report results with each of these dependent variables. Across specifications, the coefficients on *Renewable Target* are similar in sign, statistical significance, and magnitude (if not larger for measures based on raw yields), indicating our results are not sensitive to how we measure yields. Panel B of Table BI in the Internet Appendix replicate this analysis for local issuers. Again, we find robust results across specifications.

Next, we test whether our results are sensitive to how we measure renewable energy targets. Some states provide exemptions from renewable energy mandates for certain load-serving entities (LSE). These exemptions affect the actual amounts of renewable energy that must be supplied. Figure BIII in the Internet Appendix provides examples of this effect for several states. *Renewable Percentage* is the same as before. *Renewable Demand* is *Renewable Percentage* net of exemptions and other state-specific adjustments. We obtain this measure from the Lawrence Berkeley National Laboratory and the U.S. Department of Energy. As expected, *RPS Demand* is generally lower than *Renewable Percentage*. For example, *Renewable Percentage* was 20% for

California in 2010, but *Renewable Demand* was only 16.8%. We replicate Table II after substituting *Renewable Demand* for *Renewable Percentage*. The results are in Table BII in the Internet Appendix. For state and local issuers, we find a robust, positive relation between *Renewable Demand* and adjusted yield, indicating our results are not driven by how we measure renewable energy mandates.

The results in Table II show that yields increase as states increase renewable energy targets. Next, we provide year-by-year estimates of the relation in event time to gain a clearer understanding of the dynamic relation between renewable targets and yields. Specifically, we estimate the following OLS regression equation using the sample of secondary market observations for state issuers described in Table I Panel A:

$$\text{Adjusted Yield}_{i(j),t(y),c} = \alpha + \beta_e \text{ Renewable Target}_j \times \text{Event Year}_e + \text{Bond Controls}_{i,t} + \text{State Controls}_{j,y} + \text{Month-Year Fixed Effects}_t + \text{State-Cohort Fixed Effects}_{j,c} + \varepsilon_{i,t} \quad (4)$$

where i indexes bond (j indexes state), t indexes month (y indexes year), and c indexes cohort. *Renewable Target* is an indicator for states that implement RPS after the start of the sample and *Event Year* is a set of indicators that indicate event time (indexed by e) relative to the year the renewable target is effective. We also present figures where we benchmark the timing relative to the year RPS standard is first adopted. We cluster standard errors by bond and month. Figure III presents the results.

[Insert Figure III here.]

The results indicate a gradual increase in yields following the introduction of renewable targets. This result echoes findings by Deschenes et al. (2023), who show that RPS have slow dynamic effects on investments in renewable energy capacity. These authors show that most renewable energy capacity additions occur more than five years after RPS legislation is passed. Importantly, we observe no clear trend in states' yields leading up to RPS adoptions. This pattern indicates the absence of different pre-trends in treatment and control groups. In this context, parallel pre-trends indicate that our stacked regression specification does an adequate job of controlling for any residual economic factors that affect the timing of states' decisions to adopt RPS targets.

In Panel B of Figure III, we instead use event time aligned with the first year when the RPS standard asks for a positive RPS target. This is the first year the utilities have to comply with the mandates. This is also a year when uncertainty is resolved as to whether the mandates will become effective and not be amended or repealed. Here we find a quicker increase in the yields of the affected issuers. Within two years, the effect's 95% confidence interval no longer overlaps with issuers' point estimates in the year the RPS first binds.

Next, we produce a similar analysis for local issuers. Specifically, we estimate the following OLS regression equation using the sample of secondary market observations for local issuers described in Table I Panel A:

$$\text{Adjusted Yield}_{i(j\text{ or }k),t(y),c} = \alpha + \beta_e \text{ Renewable Target}_j \times \text{Event Year}_e + \text{Bond Controls}_{i,t} + \text{State Controls}_{j,y} + \text{Month-Year Fixed Effects}_t + \text{County-Cohort Fixed Effects}_{k,c} + \varepsilon_{i,t} \quad (5)$$

where *i* indexes bond (*j* indexes state and *k* indexes county), *t* indexes month (*y* indexes year), and *c* indexes cohort. *Renewable Target* is an indicator for states that adopt an RPS after the start of the sample and *Event Year* is a set of indicators that indicate event time (indexed by *e*) relative to the year the renewable target becomes active. We cluster standard errors two ways, by bond and month. The results are similar to those in Figure III. We observe a gradual increase in yields following the introduction of renewable targets. Figure IV presents the results. As before, the increase is more pronounced once we align the observations in event time that benchmarks to the actual implementation of the laws.

[Insert Figure IV here.]

4.2. Credit Ratings

Credit ratings produced by the big three credit rating agencies (Moody's, Standard & Poor's, and Fitch) measure the long-term credit risk of bond issuers.[19] These metrics update slowly and avoid incorporating short-term fluctuations in credit risk (Cornaggia and Cornaggia, 2013; Bruno, Cornaggia, and Cornaggia, 2016). Therefore, credit ratings provide an alternative and less volatile measure of issuers' financial health. We test the relation between credit ratings and states' adoption of renewable energy targets. We use the specification from equation (3) and Table II with *Credit Rating* substituted as the dependent variable. Table III presents the results.

[Insert Table III here.]

The results for credit ratings are consistent with those for yield spreads in Table II. Model (1) shows that the introduction of a renewable standard is related to a decrease in the state credit rating by 0.85 notches. In model (3) we show a shift in *Renewable Percentage* equal to one standard deviation (10.243% in our sample) will result in a decrease in credit ratings of about 0.37 notches ($-0.036 \times 10.243 = 0.369$) relative to any changes in ratings of similar bonds issued by similar states. The magnitudes of these effects are in line with or larger than other determinants of

[19] We do not control for credit ratings when we study the effect of renewable or clean energy targets on yields. Credit ratings capture credit spreads relative to a risk-free asset. They are a predictor of yields that takes into account all covariates. Iliev and Vitanova (2024) demonstrate the challenges associated with using endogenous variables as controls. We report results that control for credit ratings in Table BIV in the Internet Appendix. The coefficient estimates on *RPS Standard* and *RPS Target* attenuate but remain robust. As expected, coefficients on credit ratings are large and negative. A one-notch increase in ratings is associated with reduction in yields of about ten to 13 bp.

credit ratings. For example, Becker and Milbourn (2011) find that increased competition among credit rating agencies leads to an increase in ratings of about 0.19 notches. Cornaggia, Cornaggia, and Xia (2016) find a "revolving door" effect of credit analysts who take jobs at investment banks of 0.18 to 0.23 notches. Cornaggia, Cornaggia, and Israelsen (2020) find that ratings increase by 0.09 to 0.13 notches due to a home bias on the part of analysts. Models (2) and (4) report similar effects for local issuers. The effect for local issuers is insignificant when measured at the adoption of *Renewable Target* but is significant when we account for the actual implementation of a renewable percentage. The results in model (4) indicate a decrease of about 0.38 notches (-0.047 × 8.1 = 0.3807). These results are similar in economic magnitude in comparison to the result for state issuers, and the magnitudes remain comparable to findings in other papers on the determinants of credit ratings.

4.3. Clean Energy Standards

Several states passed clean energy standards during our sample period. As described above, clean energy standards prescribe clean energy targets in the future, some of which do not become active until 2050. Most of these mandates take effect after the end of our sample. However, the passage of laws supporting these new standards is an important indicator of the road ahead. Such mandates may signal a ramping-up of the effects of renewable targets, as clean energy targets are generally more ambitious than renewable targets. Therefore, the adoption of clean energy could have stronger effects on yields compared to renewable targets and with the same sign. On the other hand, clean energy targets are technology-neutral, meaning that, unlike renewable targets, clean energy mandates are more inclusive. Clean energy welcomes a diverse group of energy sources, such as nuclear energy coal, or natural gas fitted with carbon capture technologies. Therefore, clean energy targets allow states more degrees of freedom to tackle the energy transition. This added flexibility may reduce constraints on states and will enable them to implement changes in ways that add value to the economy. In this case, clean energy targets could have opposite effects on yields compared to renewable energy targets. The impact of adopting clean energy standards, therefore, is an empirical question. Table IV presents the results when we include an indicator of state's adoption of clean energy targets.

[Insert Table IV here.]

The results in model (1) reveal a negative and statistically significant relation between clean energy and state bond yields. The adoption of a state clean energy targets is associated with a 7-basis point reduction in the yield of state bonds. Similarly, in models (2) and (4) we find that local yields also go down. Local issuers in state-years that have passed clean energy targets have yields that are 3.94 basis points lower than similar issuers in states that have not passed clean energy targets. These results indicate that municipal issuers' fiscal health improves when states pass clean energy targets. We also control for the direct effect of renewable targets, which remain large and positive.

Next, we test the relation between credit ratings and states' passage of clean energy targets. We use the specification from model (3) and Table IV with *Credit Rating* substituted as the dependent variable. Table V presents the results.

[Insert Table V here.]

The results are mixed with little evidence that clean energy standards affect credit ratings. We find a negative and insignificant relation between clean energy targets and credit ratings for states and local issuers. Combined, the results in Tables IV and V provide evidence that clean energy targets improve the financial health of state and local issuers while having no large negative effects on their credit ratings. This result supports the idea that market participants have contrasting views about how mandates made at the state level to use "renewable energy" versus "clean energy" will affect local economic outcomes. Market participants expect the energy transition will improve the fiscal health of municipalities that are allowed to use nuclear energy, coal, and natural gas.

4.4. Robustness

This section examines whether the main results are robust in a variety of settings. We use a pooled sample instead of a stacked regression approach. We also test whether the results are present in primary market transactions.

4.4.1. Yields and Credit Ratings in a Pooled Sample

Our main approach uses stacked samples. We generate unique treatment and control samples for each instance when a state's renewable target becomes active. This approach discards a lot of observations associated with states that have active renewable targets before the beginning of our sample (e.g., California). In this section, we use a simple, pooled regression based on the samples described in Table I. This approach allows each bond-month observation to enter the sample one time.[20]

We estimate the following OLS regression equation using the sample of secondary market

[20] In the stacked approach, some observations appear in multiple control samples. Other observations never appear in the analysis, e.g., those from states like California that have active RPS prior to the beginning of the sample. This is why the numbers of observations in Tables II through V differ from those reported in Table VI.

observations described in Table I Panel A:

$$\text{Adjusted Yield}_{i(j,k),t(y)} = \alpha + \beta \text{ Renewable Percentage}_{j,y} + \text{Bond Controls}_{i,t} +$$

$$\text{State Controls}_{j,y} + \text{County Controls}_{k,y} + \text{Month-Year Fixed Effects}_{y} +$$

$$\text{State or County Fixed Effects}_{j \text{ or } k} + \varepsilon_{i,t} \tag{4}$$

where *i* indexes bond (*j* indexes state and *k* indexes county) and *t* indexes month (*y* indexes year). We use state (county) and year fixed effects when studying bonds issued by states (local issuers). We cluster standard errors by bond and month. Panel A of Table VI presents the results.

[Insert Table VI here.]

The results are broadly similar to what we observe under the stacked approach. We observe a positive and statistically significant relation between renewable targets and state and local bond yields. Model (1) shows that the adoption of renewable targets increases the adjusted yield by about 15.8 basis points relative to adjusted yields of similar bonds issued. Model (2) repeat the analysis for bonds issued by local municipalities. We observe similar results to the sample of state-issued bonds, in terms of sign, magnitude, and statistical significance. The average increase in the renewable target between untreated and treated states is 9.48 basis points.

Next, we test whether the results for credit ratings from the stacked approach are robust when using a pooled sample. Panel B of Table VI repeats the analysis specified in equation (6) but with *Credit Rating* as the dependent variable. The results likewise indicate that renewable energy mandates are associated with deteriorating credit quality for state issuers but do not filter down to the credit ratings of local issuers. The passage of renewable targets explains a decrease in credit ratings of 0.28 notches for states.

4.4.2. Results from New Bond Issues

Our main approach features observations associated with secondary market transactions. Here we test the robustness of our results using observations associated with primary market transactions. Studying primary market transactions is useful because these transactions capture the realized costs issuers face as they raise capital. We re-estimate equation (3) using the sample of primary market observations for bonds issued by states and local governments, as described in Table I Panel B. As before, we use a stacked approach based on events when states' renewable targets are adopted. We include controls for bond characteristics and state-level economic activity. We include year-cohort fixed effects and state- or county-cohort fixed effects We cluster standard errors by bond and month. Table VII presents the results.

[Insert Table VII here.]

Models (1) and (2) report results for states and local issuers, respectively. These results are similar to the main results based on secondary market trades but the magnitudes are smaller. We observe robust evidence that RPS predicts higher offering yields for local governments. Models (3) and (4) replicate the analysis in Table IV for clean energy targets. The results are similar, if not stronger. Whether we consider bonds issued by states or local issuers, we find that clean energy targets predict lower offer yields. The economic magnitudes of the coefficients for state issuers are noticeably larger than those in Table IV. This comparison indicates that clean energy targets are particularly helpful for lowering the cost of capital for state issuers when they choose to issue new bonds. This result is intuitive, in that, unlike for secondary market observations, municipalities choose when to issue bonds. To the extent that clean energy targets cause investors to be more optimistic about the fiscal health of the state and municipalities, issuers will naturally capitalize on this perspective when enthusiasm for clean energy targets is particularly high and the financial benefits are particularly large.

6. RPS and Preferences for Renewables

Our theoretical framework suggests that states' preferences for renewable energy adoption (captured by parameter β) play a key role in determining both the implementation and impact of RPS policies. States with stronger preferences for renewables will choose higher renewable targets that deviate more from the private sector optimum and the larger wedge between socially mandated and privately optimal renewable usage should lead to greater reductions in tax revenue and larger increases in borrowing costs.

To test this prediction empirically, we examine how the effect of renewable target adoption on municipal bond yields varies with political preferences. We measure preferences using the support for Democratic candidates in presidential elections at both state and county levels, as Democratic support typically correlates with stronger environmental policy preferences. Table VIII presents the results.

[Insert Table VIII here.]

We measure political support with the percentage of votes cast in a given state or county for the Democratic candidate in the most recent presidential election. Model (1) in Table IX shows that our results are robust after controlling for these measures. Models (2) and (3) introduce interaction terms that test whether the relation between renewable targets and yields varies with political preferences. Coefficients on the interaction terms show that stronger support for Democratic candidates is related to significantly higher yields in states with renewable targets.

These results suggest that Democratic control of the state and county might signal preferences for RPS targets even when these are not economically beneficial or are related to over-investment in renewable energy.

These findings align with our model's prediction that stronger preferences for renewables (higher β) lead to more aggressive implementation of RPS policies that push further beyond private sector optima. The result is particularly striking at the county level, suggesting local political preferences influence how renewable mandates affect municipal borrowing costs even within states. Counties with stronger Democratic support may pursue additional local green initiatives that compound the fiscal impact of state RPS policies.

7. Conclusion

This paper examines the economic consequences of decisions by state governments to adopt renewable energy targets or clean energy targets. Our theoretical framework shows that states face a fundamental trade-off between environmental preferences and fiscal health - while they may desire higher renewable energy usage, pushing consumption above private sector optima reduces tax revenues and increases borrowing costs. The model predicts these effects will be larger in jurisdictions with stronger preferences for renewables, which choose more aggressive targets that deviate further from private sector optimal levels.

Consistent with these predictions, we find that states' bond yields increase and their credit ratings decrease after the adoption and enactment of renewable targets. The magnitudes of these changes are larger than those documented in the literature on climate change. These effects filter down to the local level, as we observe similar and robust evidence among issuers inside adopting states, such as counties, cities, and school districts.

However, we observe opposite results when states adopt clean energy targets. This comparison reveals that market participants take contrasting views as to the economic consequences of renewable energy versus clean energy. Investors and credit rating agencies interpret the use of “renewable” energy as a signal of declining financial health. However, the use of “clean” energy, which subsumes “renewable” energy and includes additional energy sources, has a positive effect on the financial health of states and local issuers. Overall, this study is the first to present evidence of the effects of Renewable Portfolio Standards and Clean Energy Standards on the cost of funding of state and local municipalities.

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Zhou, Shan, Solomon, Barry, and Marilyn Brwon, 2024, “The spillover effect of mandatory renewable portfolio standards”, *Proceedings of the National Academy of Sciences* 121 (25), e2313193121.

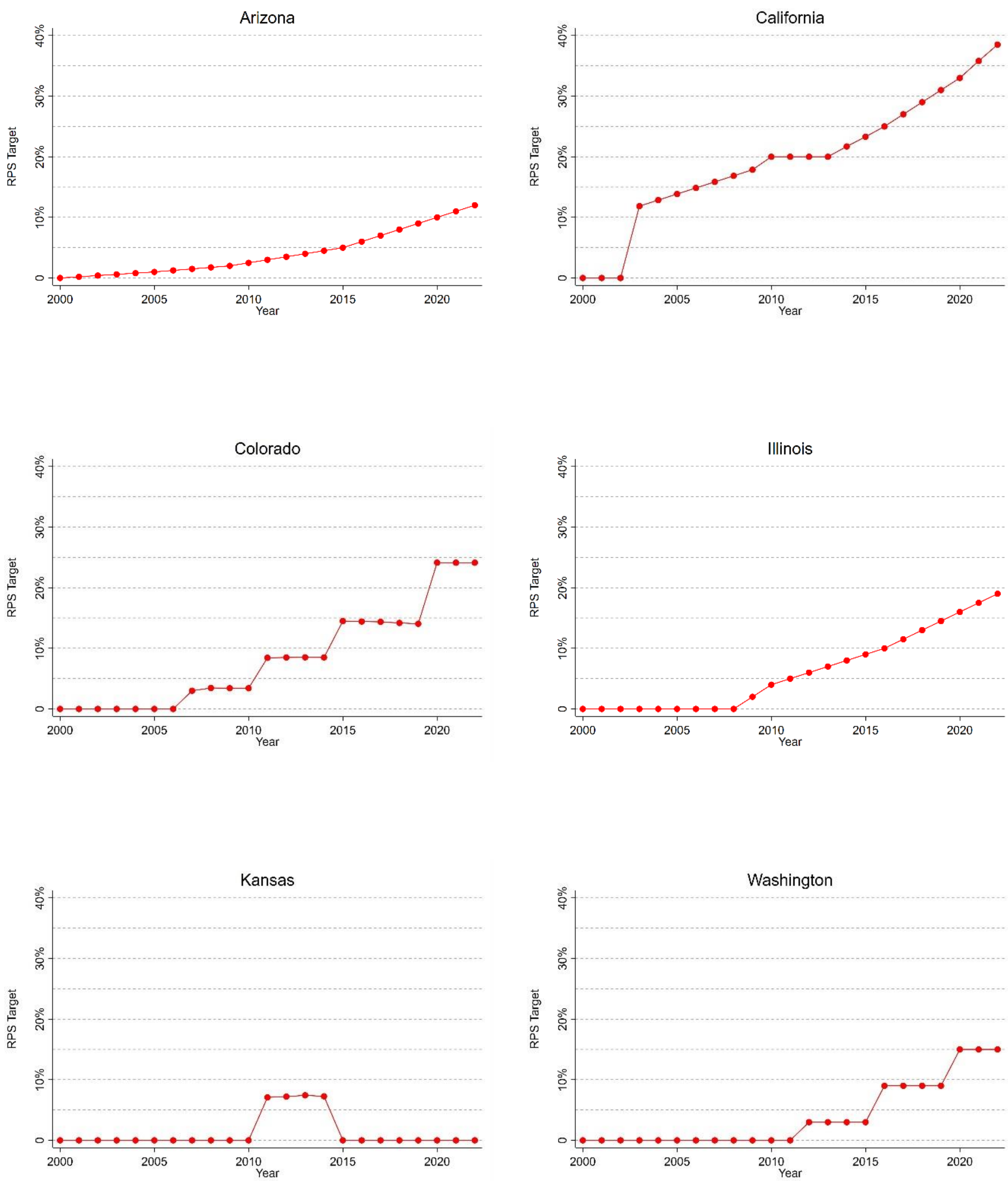


Figure I – Renewable Percentage Examples

This figure plots examples of states' RPS targets. *Renewable Percentage* is the state-year target for the percentage of electricity to be sourced from renewable sources as reported by the Lawrence Berkeley National Laboratory and U.S. Department of Energy.

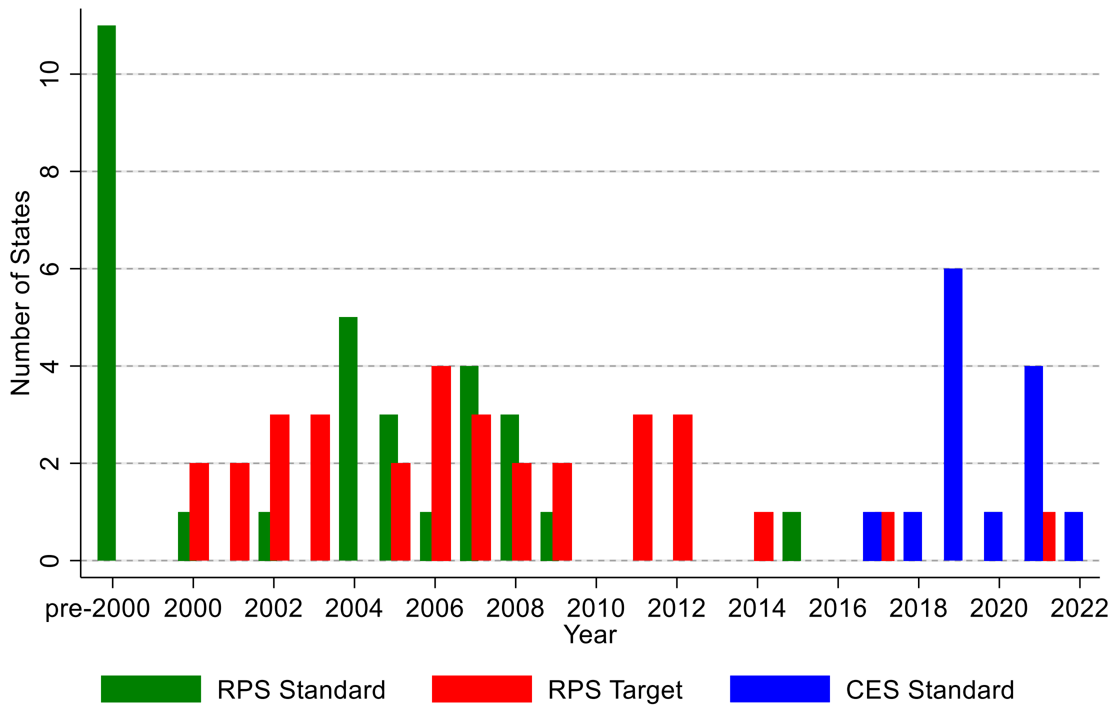
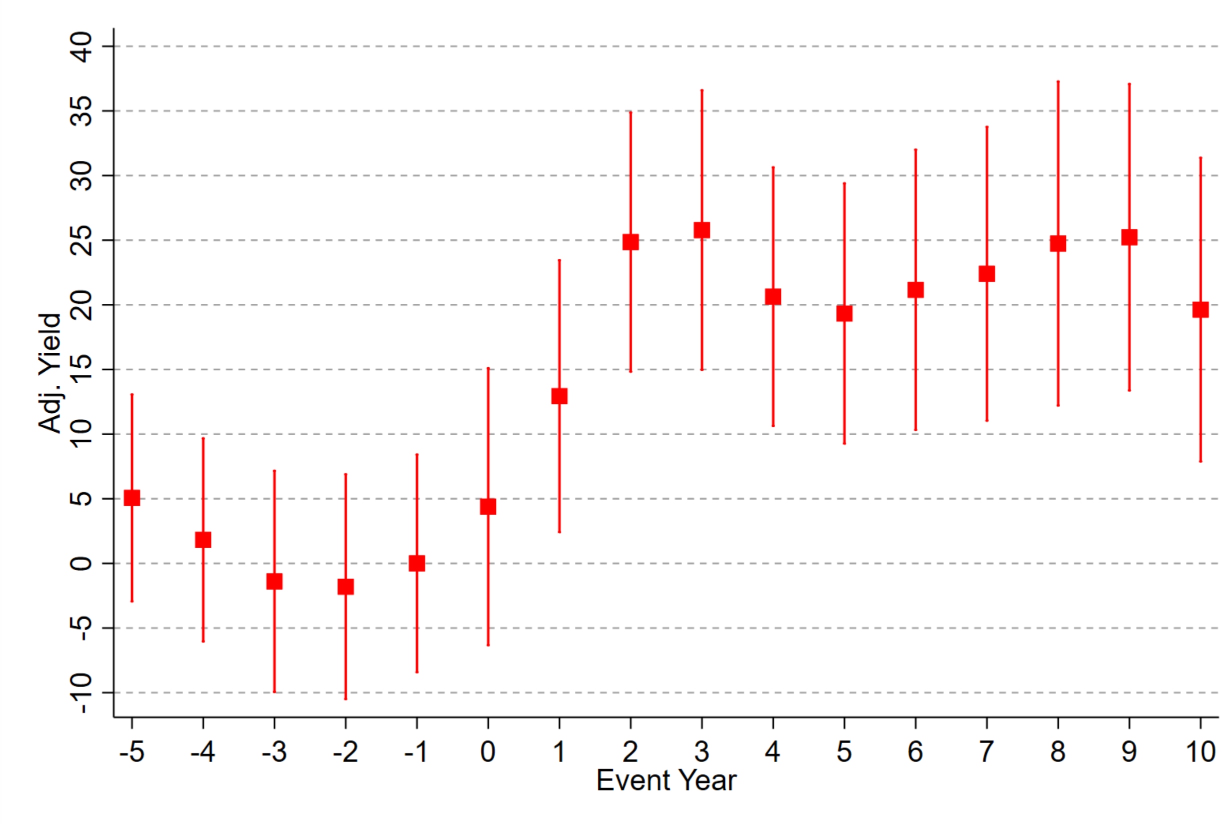
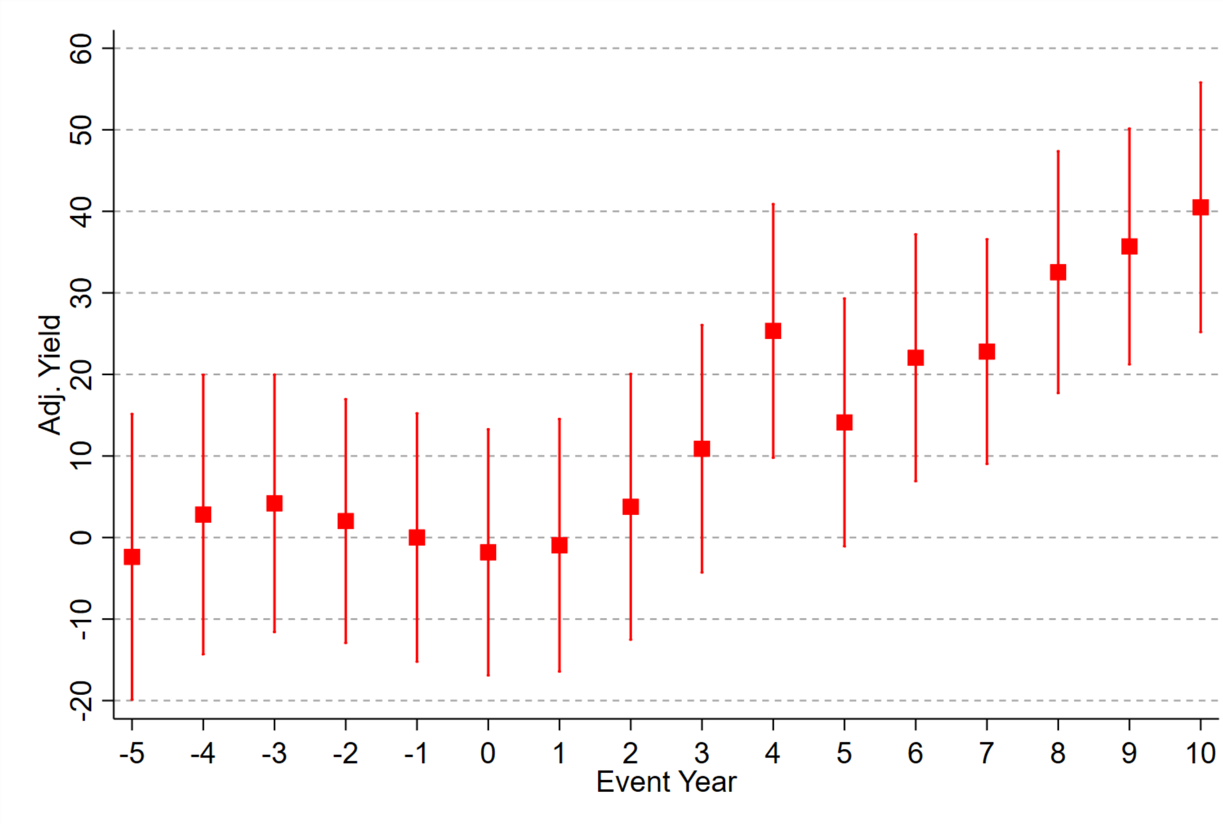


Figure II – Renewable Portfolio Standards and Clean Energy Standards Adoptions over Time

This figure plots the number of states that have adopted Renewable Portfolio Standards (RPS), implemented renewable targets, and adopted Clean Energy Standards (CES) over time. Data are from the Lawrence Berkeley National Laboratory and the U.S. Department of Energy.



Panel A: The Event is Renewable Target Effective



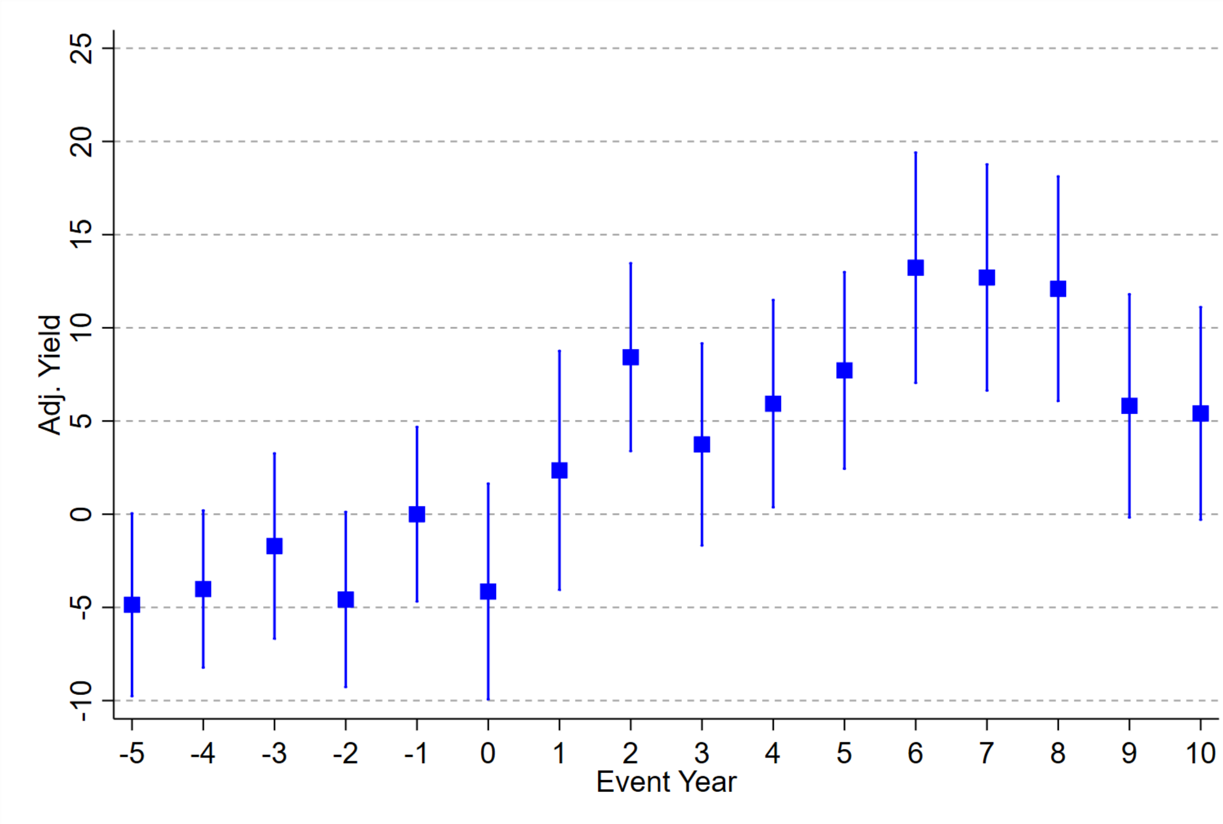
Panel B: The Event is Renewable Target Adoption

Figure III – States' Secondary Market Yields around Renewable Target Adoptions

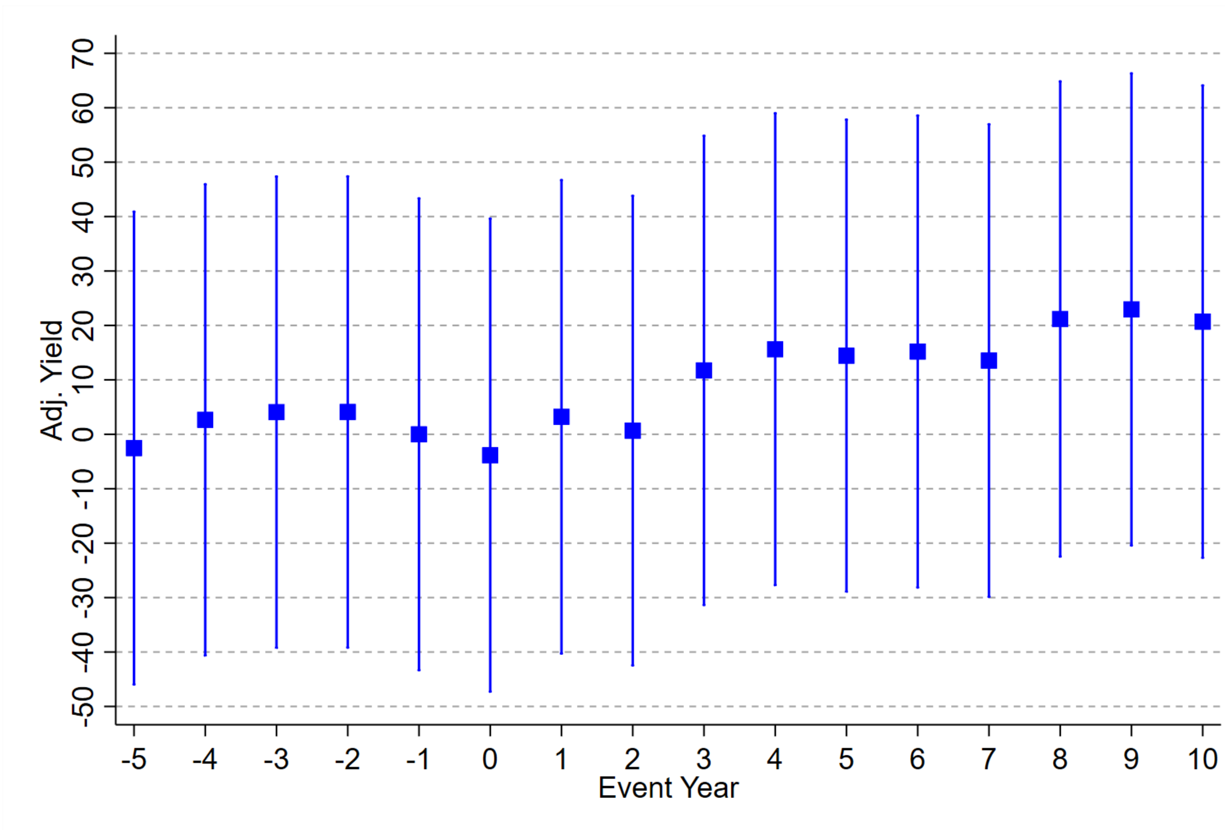
This figure plots estimates of β_{-5} through β_{+10} from the following OLS regression equation based on the sample of observations associated with state issuers in Table I Panel A:

$$\text{Adjusted Yield}_{i(j),t(y),c} = \alpha + \beta_e \text{ Renewable Target}_j \times \text{Event Year}_e + \text{Bond Controls}_{i,t} + \text{State Controls}_{j,y} + \text{State-Cohort Fixed Effects}_{j,c} + \text{Year-Cohort Fixed Effects}_{y,c} + \varepsilon_{i,t,c}$$

where *i* indexes bond (*j* indexes state), *t* indexes day (*y* indexes year), and *c* indexes cohort. In Panel A, *Event Year$_e$* represents a vector of indicator variables, one for each year *e* relative to the year a state's *Renewable Percentage* became non-zero for the first time. The time -1 estimate is set to zero. In Panel B, *Event Year$_e$* represents a vector of indicator variables, one for each year *e* relative to the year a state's *Renewable Target* is adopted for the first time. The time -1 estimate is set to zero. Other variable definitions are in the legend of Table I. Whiskers represent 95% confidence intervals.



Panel A: The Event is Renewable Percentage Takes Effect



Panel B: The Event is Renewable Target Adoption

Figure IV – Local Issuers' Secondary Market Yields around Renewable Percentages

This figure plots estimates of β_{-5} through β_{+10} from the following OLS regression equation based on the sample of observations associated with local issuers in Table I Panel A:

$$\text{Adjusted Yield}_{i(j),t(y),c} = \alpha + \beta_e \text{ Renewable Target}_j \times \text{Event Year}_e + \text{Bond Controls}_{i,t} + \text{State Controls}_{j,y} + \text{State-Cohort Fixed Effects}_{j,c} + \text{Year-Cohort Fixed Effects}_{y,c} + \varepsilon_{i,t,c}$$

where *i* indexes bond (*j* indexes state), *t* indexes day (*y* indexes year), and *c* indexes cohort. In Panel A, *Event Year$_e$* represents a vector of indicator variables, one for each year *e* relative to the year a state's *Renewable Percentage* became non-zero for the first time. The time -1 estimate is set to zero. In Panel B, *Event Year$_e$* represents a vector of indicator variables, one for each year *e* relative to the year a state's *Renewable Target* is adopted for the first time. The time -1 estimate is set to zero. Other variable definitions are in the legend of Table I. Whiskers represent 95% confidence intervals.

Table I – Summary Statistics

This table provides definitions and summary statistics for dependent and independent variables. Data sources are in parentheses. Panel A provides definitions and summarizes the secondary market variables measured at the time of the transaction, and Panel B summarizes the primary market observations at the time of issuance. *Renewable Target* is an indicator equal to one if the state has a Renewable Portfolio Standard in place. *Renewable Percentage* is the state-year target for the percentage of electricity to be sourced from renewable sources as reported by the Lawrence Berkeley National Laboratory and U.S. Department of Energy. *Clean Energy Target* is an indicator equal to one if the state has a Clean Energy Standard in place. *Adjusted Yield* is the difference in basis points between the bond yield to maturity reported by the Municipal Securities Rulemaking Board (MSRB) and the maturity-matched Municipal Market Advisors (MMA) AAA-rated yield curve (Bloomberg). *Credit Rating* is the lowest numerical rating issued by Moody's, Standard & Poor's, and Fitch (Mergent). Ratings are scaled so that "AAA" is 21 and "D" is 1. *Coupon Rate* is the coupon rate of the bond in percentage (Mergent). *Log Offering Amount* is the natural logarithm of the bond offering amounts in $ millions (Mergent). *Years to Maturity* is years left until the bond matures (Mergent). *Bond Age* is the number of years since the bond was issued, measured at the time of the observation. *Call Option* is an indicator equal to one if the bond has a call option (Mergent). *Insured* is an indicator equal to one if the bond is insured (Mergent). *Negotiated* is an indicator equal to one if the bond is a negotiable offering (Mergent). *State Population* is the state population in millions (U.S. Census Bureau). *State Income per Capita* is county per capita personal income in a given year (U.S. Bureau of Economic Analysis). *State Real GDP* is the state GDP in 2012 trillion dollars, and *Real GDP Growth* is the state real GDP growth in percentages (both from the U.S. Bureau of Economic Analysis). *State Age Dependency* is the ratio of the state population above age 65 to the population between ages 15 and 64 (U.S. Census). *County Income per Capita* is the average annual income per capita measured in thousands (Bureau of Economic Analysis), *County Unemployment Rate* is the unemployment rate measured as a fraction of the labor force (Bureau of Labor Statistics), *County Population* is the total county population measured in millions (U.S. Census). *County Age Dependency* is the ratio of the county population above age 65 to the population between ages 15 and 64 (U.S. Census).

Panel A: Trade Level Sample

	State Issuers (1,830,206 Obs.)			Local Issuers (8,746,311Obs.)		
	Mean	St. Dev.	Median	Mean	St. Dev.	Median
Renewable Target	0.202	0.401	0.000	0.201	0.401	0.000
Renewable Percentage	4.116	10.243	0.000	2.813	8.062	0.000
Clean Energy Target	0.027	0.162	0.000	0.022	0.147	0.000
Adj. Yield	12.694	80.654	10.700	27.234	89.690	22.000
Credit Rating	19.564	1.417	20.000	18.289	1.963	18.000
Coupon Rate	4.537	1.043	5.000	4.092	1.077	4.250
Log Offering Amount	16.021	1.215	16.193	14.368	1.241	14.417
Years to Maturity	7.279	5.408	6.000	7.863	5.873	7.000
Bond Age	5.167	3.666	4.819	4.205	3.313	3.863
Call Option	0.515	0.500	1.000	0.529	0.499	1.000
Insured	0.135	0.342	0.000	0.404	0.491	0.000
Negotiated	0.265	0.441	0.000	0.320	0.467	0.000
State Population	8.314	6.009	6.926	7.383	4.718	6.456
State Income per Capita	44.192	9.751	42.513	42.612	8.416	41.003
State Real GDP	0.438	0.366	0.388	0.373	0.294	0.304
Real GDP Growth	1.093	2.597	1.400	1.170	2.926	1.600
State Age Dependency	0.143	0.029	0.143	0.148	0.022	0.148
County Income per Capita				43.261	13.096	40.332
County Unemployment Rate				0.063	0.026	0.057
County Population				0.523	0.793	0.269
County Age Dependency				0.142	0.043	0.137

Panel B: Issuance Level Sample

	State Issuers (94,314 Obs.)			Local Issuers (1,688,755Obs.)		
	Mean	St. Dev.	Median	Mean	St. Dev.	Median
Renewable Target	0.086	0.281	0.000	0.121	0.326	0.000
Renewable Percentage	1.563	6.531	0.000	1.711	6.608	0.000
Clean Energy Target	0.003	0.058	0.000	0.003	0.059	0.000
Adj. Yield	6.409	27.795	4.000	13.612	30.651	11.000
Credit Rating	19.584	1.374	20.000	17.978	1.950	18.000
Coupon Rate	4.429	0.834	5.000	3.645	1.122	4.000
Log Offering Amount	15.076	1.607	15.363	13.173	1.250	13.092
Years to Maturity	10.794	5.863	10.000	9.954	5.816	9.000
Call Option	0.490	0.500	0.000	0.487	0.500	0.000
Insured	0.166	0.373	0.000	0.435	0.496	0.000
Negotiated	0.271	0.444	0.000	0.302	0.459	0.000
State Population	6.481	5.381	4.681	6.787	4.556	5.763
State Income per Capita	37.846	8.466	36.818	37.400	7.433	35.989
State Real GDP	0.326	0.308	0.235	0.335	0.279	0.266
Real GDP Growth	1.496	2.597	1.600	1.490	2.621	1.700
State Age Dependency	0.136	0.028	0.139	0.146	0.017	0.147
County Income per Capita				36.396	11.219	34.053
County Unemployment Rate				0.060	0.022	0.056
County Population				0.404	0.803	0.152
County Age Dependency				0.146	0.042	0.141

Table II – Renewable Commitments and Yields in Secondary Market Trading

This table reports results from stacked OLS regressions with *Adjusted Yield* as the dependent variable. The sample consists of monthly trading yields of bonds between 2005 and 2022. Models (1) and (3) use state-issued bonds, models (2) and (4) use local municipal bonds. *Renewable Target* is an indicator equal to one if the state has a Renewable Portfolio Standard in place. *Renewable Percentage* is the state target for renewable energy production for that year. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
	State Adj. Yield	Local Adj. Yield	State Adj. Yield	Local Adj. Yield
Renewable Target	18.658***	8.301***		
	(2.403)	(1.075)		
Renewable Percentage			0.645***	0.510***
			(0.091)	(0.075)
Coupon Rate	-7.021***	-8.547***	-6.950***	-8.542***
	(1.300)	(0.315)	(1.298)	(0.315)
Log Offering Amount	-5.344***	-2.922***	-5.357***	-2.930***
	(0.411)	(0.281)	(0.410)	(0.280)
Years to Maturity	-2.398***	-2.112***	-2.393***	-2.110***
	(0.184)	(0.131)	(0.184)	(0.132)
Bond Age	0.944**	0.911***	0.953**	0.914***
	(0.464)	(0.142)	(0.463)	(0.142)
Call Option	-17.567***	-10.798***	-17.592***	-10.790***
	(2.150)	(0.794)	(2.148)	(0.795)
Insured	-9.564***	9.718***	-9.622***	9.679***
	(2.061)	(1.628)	(2.060)	(1.629)
Negotiated Offering	1.585	4.114***	1.544	4.206***
	(0.966)	(0.783)	(0.966)	(0.777)
State Population	-11.241***	-5.709***	-11.576***	-5.822***
	(1.903)	(1.324)	(1.881)	(1.294)
State Income per Capita	0.709***	1.608***	0.736***	1.455***
	(0.268)	(0.238)	(0.270)	(0.240)
State Real GDP	-26.868*	-92.622***	-24.490	-93.636***
	(15.434)	(11.067)	(15.683)	(11.012)

Real GDP Growth	0.794***	0.691***	0.878***	0.747***
	(0.232)	(0.131)	(0.225)	(0.131)
State Age Dependency	-157.180	121.537**	-144.974	52.854
	(128.630)	(59.887)	(132.894)	(60.786)
County Income per Capita		0.228***		0.219***
		(0.064)		(0.063)
County Unemployment Rate		250.278***		237.558***
		(26.682)		(26.605)
County Population		-85.801***		-83.640***
		(12.490)		(12.447)
County Age Dependency		-68.198***		-66.664***
		(24.811)		(24.827)
State-Cohort Fixed Effects	Yes	No	Yes	No
County-Cohort Fixed Effects	No	Yes	No	Yes
Month-Year Fixed Effect	Yes	Yes	Yes	Yes
Adj. R-squared	0.17	0.13	0.17	0.13
Observations	1,830,206	8,746,311	1,830,206	8,746,311

Table III – Renewable Commitments and Credit Ratings

This table reports results from stacked OLS regressions with *Credit Rating* as the dependent variable. The sample consists of monthly ratings on traded state bonds between 2005 and 2022. Models (1) and (3) use state-issued bonds, models (2) and (4) use local municipal bonds. *Renewable Target* is an indicator equal to one if the state has a Renewable Portfolio Standard in place. *Renewable Percentage* is the state target for renewable energy production for that year. Bond Controls include *Coupon Rate*, *Log Offering Amount*, *Years to Maturity*, *Bond Age*, *Call Option*, *Negotiated Offering*, and *Insured* indicator. State Controls include *State Population*, *State Income per Capita*, *State Real GDP*, *Real GDP Growth*, and *State Age Dependency*. County Controls include *County Income per Capita*, *County Unemployment Rate*, *County Population*, and *County Age Dependency*. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
	State Credit Ratings	Local Credit Ratings	State Credit Ratings	Local Credit Ratings
Renewable Target	-0.849***	-0.262***		
	(0.095)	(0.033)		
Renewable Percentage			-0.036***	-0.015***
			(0.003)	(0.003)
Bond Controls	Yes	Yes	Yes	Yes
State Controls	Yes	Yes	Yes	Yes
County Controls	No	Yes	No	Yes
State-Cohort Fixed Effects	Yes	No	Yes	No
County-Cohort Fixed Effects	No	Yes	No	Yes
Month-Year Fixed Effect	Yes	Yes	Yes	Yes
Adj. R-squared	0.74	0.49	0.74	0.49
Observations	1,830,206	8,746,311	1,830,206	8,746,311

Table IV – Clean Energy Standards and Yields in Secondary Market Trading

This table reports results from stacked OLS regressions with *Adjusted Yield* as the dependent variable. The sample consists of monthly trading yields of bonds between 2005 and 2022. Models (1) and (3) use state-issued bonds and models (2) and (4) use local municipal bonds. *Clean Energy Target* is an indicator equal to one if the state has a Clean Energy Standard in place. *Renewable Target* is an indicator equal to one if the state has a Renewable Portfolio Standard in place. *Renewable Percentage* is the state target for renewable energy production for that year. Bond Controls include *Coupon Rate*, *Log Offering Amount*, *Years to Maturity*, *Bond Age*, *Call Option*, *Negotiated Offering*, and *Insured* indicator. State Controls include *State Population*, *State Income per Capita*, *State Real GDP*, *Real GDP Growth*, and *State Age Dependency*. County Controls include *County Income per Capita*, *County Unemployment Rate*, *County Population*, and *County Age Dependency*. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1) State Adj. Yield	(2) Local Adj. Yield	(3) State Adj. Yield	(4) Local Adj. Yield
Clean Energy Target	-7.000**	-3.946***	-4.982*	-2.999**
	(2.904)	(1.279)	(2.985)	(1.289)
Renewable Target	18.598***	8.345***		
	(2.407)	(1.076)		
Renewable Percentage			0.614***	0.501***
			(0.096)	(0.076)
Bond Controls	Yes	Yes	Yes	Yes
State Controls	Yes	Yes	Yes	Yes
County Controls	No	Yes	No	Yes
State-Cohort Fixed Effects	Yes	No	Yes	No
County-Cohort Fixed Effects	No	Yes	No	Yes
Month-Year Fixed Effect	Yes	Yes	Yes	Yes
Adj. R-squared	0.17	0.13	0.17	0.13
Observations	1,830,206	8,746,311	1,830,206	8,746,311

Table V – Clean Energy Standards and Credit Ratings

This table reports results from stacked OLS regressions with *Credit Rating* as the dependent variable. The sample consists of monthly ratings on traded state bonds between 2005 and 2022. Models (1) and (3) use state-issued bonds, models (2) and (4) use local municipal bonds. *Clean Energy Target* is an indicator equal to one if the state has a Clean Energy Standard in place. *Renewable Target* is an indicator equal to one if the state has a Renewable Portfolio Standard in place. *Renewable Percentage* is the state target for renewable energy production for that year. Bond Controls include *Coupon Rate*, *Log Offering Amount*, *Years to Maturity*, *Bond Age*, *Call Option*, *Negotiated Offering*, and *Insured* indicator. State Controls include *State Population*, *State Income per Capita*, *State Real GDP*, *Real GDP Growth*, and *State Age Dependency*. County Controls include *County Income per Capita*, *County Unemployment Rate*, *County Population*, and *County Age Dependency*. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
	State Credit Ratings	Local Credit Ratings	State Credit Ratings	Local Credit Ratings
Clean Energy Target	-0.059	-0.036	-0.185**	-0.065*
	(0.094)	(0.038)	(0.092)	(0.036)
Renewable Target	-0.850***	-0.261***		
	(0.095)	(0.033)		
Renewable Percentage			-0.037***	-0.015***
			(0.003)	(0.003)
Bond Controls	Yes	Yes		
State Controls	Yes	Yes		
County Controls	No	Yes		
State-Cohort Fixed Effects	Yes	No		
County-Cohort Fixed Effects	No	Yes		
Month-Year Fixed Effect	Yes	Yes		
Adj. R-squared	0.74	0.49	0.74	0.49
Observations	1,830,206	8,746,311	1,830,206	8,746,311

Table VI – Secondary Market Trading with a Pooled Sample Representing All States

This table reports results from OLS regressions with *Adjusted Yield* and *Credit Ratings* as the dependent variables. The sample consists of monthly trading yields of municipal bonds between 2005 and 2022. Models (1) and (3) use state-issued bonds, models (2) and (4) use local municipal bonds. *Renewable Target* is an indicator equal to one if the state has a Renewable Portfolio Standard in place. Bond Controls include *Coupon Rate*, *Log Offering Amount*, *Years to Maturity*, *Bond Age*, *Call Option*, *Negotiated Offering*, and *Insured* indicator. State Controls include *State Population*, *State Income per Capita*, *State Real GDP*, *Real GDP Growth*, and *State Age Dependency*. County Controls include *County Income per Capita*, *County Unemployment Rate*, *County Population*, and *County Age Dependency*. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
	State Adj. Yield	Local Adj. Yield	State Credit Ratings	Local Credit Ratings
Renewable Target	15.78***	9.48***	-0.28***	-0.09**
	(2.15)	(0.87)	(0.08)	(0.03)
Bond Controls	Yes	Yes	Yes	Yes
State Controls	Yes	Yes	Yes	Yes
County Controls	No	Yes	No	Yes
State Fixed Effects	Yes	No	Yes	No
County Fixed Effects	No	Yes	No	Yes
Month-Year Fixed Effect	Yes	Yes	Yes	Yes
Adj. R-squared	0.19	0.14	0.75	0.37
Observations	919,716	5,762,241	919,716	5,762,241

Table VII – Renewable Commitments and Offering Yields

This table reports results from OLS regressions with *Adjusted Yield* as the dependent variable. The sample consists of offering yields of state bonds between 2001 and 2021. Models (1) and (3) use state-issued bonds, models (2) and (4) use local municipal bonds. *Renewable Target* is an indicator equal to one if the state has passed a Renewable Portfolio Standard as of a given year. *Clean Energy Target* is an indicator equal to one if the state has a Clean Energy Standard in place. Bond Controls include *Coupon Rate*, *Log Offering Amount*, *Years to Maturity*, *Bond Age*, *Call Option*, *Negotiated Offering*, and *Insured* indicator. State Controls include *State Population*, *State Income per Capita*, *State Real GDP*, *Real GDP Growth*, and *State Age Dependency*. County Controls include *County Income per Capita*, *County Unemployment Rate*, *County Population*, and *County Age Dependency*. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1) State Adj. Yield	(2) Local Adj. Yield	(5) State Adj. Yield	(6) Local Adj. Yield
Renewable Target	5.744*	4.383***	5.270*	4.327***
	(2.956)	(0.837)	(2.963)	(0.836)
Clean Energy Target			-39.148*	-4.033
			(23.016)	(2.871)
Bond Controls	Yes	Yes	Yes	Yes
State Controls	Yes	Yes	Yes	Yes
County Controls	No	Yes	No	Yes
State Fixed Effects	Yes	No	Yes	No
County Fixed Effects	No	Yes	No	Yes
Month-Year Fixed Effect	Yes	Yes	Yes	Yes
Adj. R-squared	0.53	0.38	0.56	0.37
Observations	94,314	1,688,755	94,314	1,688,755

Table VIII – Preferences, Renewable Commitments, and Yields

This table reports results from stacked OLS regressions with *Adjusted Yield* of local municipal bonds as the dependent variable. The sample consists of monthly trading yields of local bonds between 2005 and 2022. *Renewable Target* is an indicator equal to one if the state has passed a Renewable Portfolio Standard as of a given year. *Democrat Support at the State* (*County*) *Level* is an indicator taking a value of one if at least fifty percent of votes cast in the state (county) in the most recent Presidential election were for the Democratic candidate. Bond Controls include *Coupon Rate*, *Log Offering Amount*, *Years to Maturity*, *Bond Age*, *Call Option*, *Negotiated Offering*, and *Insured* indicator. State Controls include *State Population*, *State Income per Capita*, *State Real GDP*, *Real GDP Growth*, and *State Age Dependency*. County Controls include *County Income per Capita*, *County Unemployment Rate*, *County Population*, and *County Age Dependency*. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)
	Local Adj. Yield	Local Adj. Yield	Local Adj. Yield
Renewable Target	8.157***	-26.333***	-30.974***
	(1.077)	(5.970)	(2.947)
Renewable Target × Democrat Support at State Level		0.682***	
		(0.121)	
Renewable Target × Democrat Support at County Level			0.754***
			(0.062)
Democrat Support at State Level	-0.460***	-0.569***	
	(0.119)	(0.105)	
Democrat Support at County Level	-0.025		-0.357***
	(0.065)		(0.061)
Bond Controls	Yes	Yes	Yes
State Controls	Yes	Yes	Yes
County Controls	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes
Month-Year Fixed Effect	Yes	Yes	Yes
Adj. R-squared	0.13	0.13	0.13
Observations	8,746,311	8,746,311	8,746,311

The Cost of Net Zero

Internet Appendix

Appendix A: Optimality Conditions and Comparative Statics for the Renewable Energy Mandate Model

This appendix provides mathematical foundations for the theoretical framework presented in Section 2. Section A1 defines the parameter space and establishes economic restrictions needed for the model's solutions. Section A2 verifies the optimality conditions by deriving first-order conditions and confirming second-order conditions for both the private sector optimization (A2.1) and the state government's problem (A2.2). Section A3 analyzes the gap between private and state optima, establishing conditions under which state mandates exceed private sector choices (A3.1) and develops comparative statics that show how renewable targets respond to changes in preferences (A3.2). These derivations provide the theoretical foundation for our empirical predictions about how renewable energy mandates affect municipal bond yields.

A1. Parameter Definitions and Ranges

The model's parameters must satisfy the following conditions to ensure economic relevance and mathematical consistency:

1. Production Parameters:
   - $A > 0$: Total factor productivity parameter
   - $0 < \alpha < 1$: Production elasticity parameter capturing diminishing returns to renewable energy
   - $p > 0$: Price of renewable energy input
   - $R \geq 0$: Quantity of renewable energy input
2. Government Parameters:
   - $0 < t < 1$: Tax rate on firm profits
   - $\gamma > 0$: Sensitivity of borrowing costs to tax revenues
   - $\beta \geq 0$: State preference parameter for renewable energy
   - $D \geq 0$: Base level of borrowing costs

Additional Parameter Restrictions:

1. For the state's optimization problem to be well-defined: $p > \frac{\beta}{t(1+\gamma)}$: Ensures finite optimal renewable energy usage.
2. For positive production: $AR^{\alpha} - pR$ at the optimum: Ensures profitable production.

A2. Verification of Optimality Conditions

A2.1. Private Sector Optimum

The private sector firm solves:

$$\max_{R}[(1-t)(AR^{\alpha}-pR)]$$

The first-order condition is:

$$(1-t)(A\alpha R^{\alpha-1}-p)=0$$

The optimal renewable target chosen by the state is:

$$R^P=\left[\frac{A\alpha}{p}\right]^{\frac{1}{1-\alpha}}$$

The second-order condition is:

$$(1-t)A\alpha(\alpha-1)R^{\alpha-2}<0$$

This inequality is satisfied since $\alpha < 1$ (diminishing returns assumption) and $t < 1$ (tax rate less than 100%).

A2.2. State Government Optimum

The state government's problem:

$$\max_R[t(AR^{\alpha}-pR)-(D-\gamma t(AR^{\alpha}-pR))+\beta R]$$

The first-order condition is:

$$t(1+\gamma)(A\alpha R^{\alpha-1}-p)+\beta=0$$

The optimal renewable target chosen by the state is:

$$R^T=\left[\frac{t(1+\gamma)A\alpha}{t(1+\gamma)p-\beta}\right]^{\frac{1}{1-\alpha}}$$

Which we can rewrite as:

$$R^T=\left[\frac{A\alpha}{p-\frac{\beta}{t(1+\gamma)}}\right]^{\frac{1}{1-\alpha}}$$

The second-order condition is:

$$t(1+\gamma)A\alpha(\alpha-1)R^{\alpha-2} < 0$$

This is satisfied since α < 1, t > 0, and γ > 0.

A3. Key Comparative Statics

A3.1. Gap Between Private and State Optima

The difference between state and private optima is:

$$R^T - R^P = \left[\frac{A\alpha}{p - \frac{\beta}{t(1+\gamma)}}\right]^{\frac{1}{1-\alpha}} - \left[\frac{A\alpha}{p}\right]^{\frac{1}{1-\alpha}}$$

This difference is:

- Positive when $\beta > 0$
- Zero when $\beta = 0$

The gap:

- Increases with β
- Decreases with t and γ

These characteristics validate the trade-off between renewable preferences and fiscal considerations.

A3.2. Effect of Renewable Preferences (β) and Fiscal Considerations (t,γ)

The optimal renewable target for the state government is:

$$R^T = \left[\frac{A\alpha}{p - \frac{\beta}{t(1+\gamma)}}\right]^{\frac{1}{1-\alpha}}$$

$$\frac{\partial R^T}{\beta} = \frac{1}{1-\alpha}\left[\frac{A\alpha}{p-\frac{\beta}{t(1+\gamma)}}\right]^{\frac{\alpha}{1-\alpha}} \frac{\frac{A\alpha}{t(1+\gamma)}}{\left(p-\frac{\beta}{t(1+\gamma)}\right)^2} > 0$$

This positive derivative confirms that stronger preferences for renewables lead to higher renewable targets.

Next, we consider the derivative with respect to the tax rate t:

$$\frac{\partial R^T}{t} = \frac{1}{1-\alpha}\left[\frac{A\alpha}{p-\frac{\beta}{t(1+\gamma)}}\right]^{\frac{\alpha}{1-\alpha}} \frac{-\frac{A\alpha\beta}{t^2(1+\gamma)}}{\left(p-\frac{\beta}{t(1+\gamma)}\right)^2} < 0$$

This derivative is negative because $\beta > 0$ (preference for renewables), $t > 0$ (positive tax rate), $\alpha < 1$ (diminishing returns), and the denominator $p - \frac{\beta}{t(1+\gamma)}$ must be positive for the solution to be well-defined.

The negative derivative confirms that higher tax rates lead to lower renewable targets, as increasing tax rates amplify the fiscal impact of reduced profits.

The derivative with respect to the borrowing sensitivity (γ) is similar.

Appendix B: Supplementary Analysis of Renewable Standards and Municipal Bond Markets

This appendix provides additional empirical analysis that complements the main results. We present expanded figures showing renewable portfolio standards across all adopting states (Figure BI), clean energy standards for adopting states (Figure BII), and comparisons between nominal renewable targets and actual demand requirements (Figure BIII). This appendix also includes supplementary tables examining alternative yield definitions (Table BI), renewable demand effects (Table BII), alternative timing specifications (Table BIII), and yield analyses conditional on credit ratings (Table BIV).

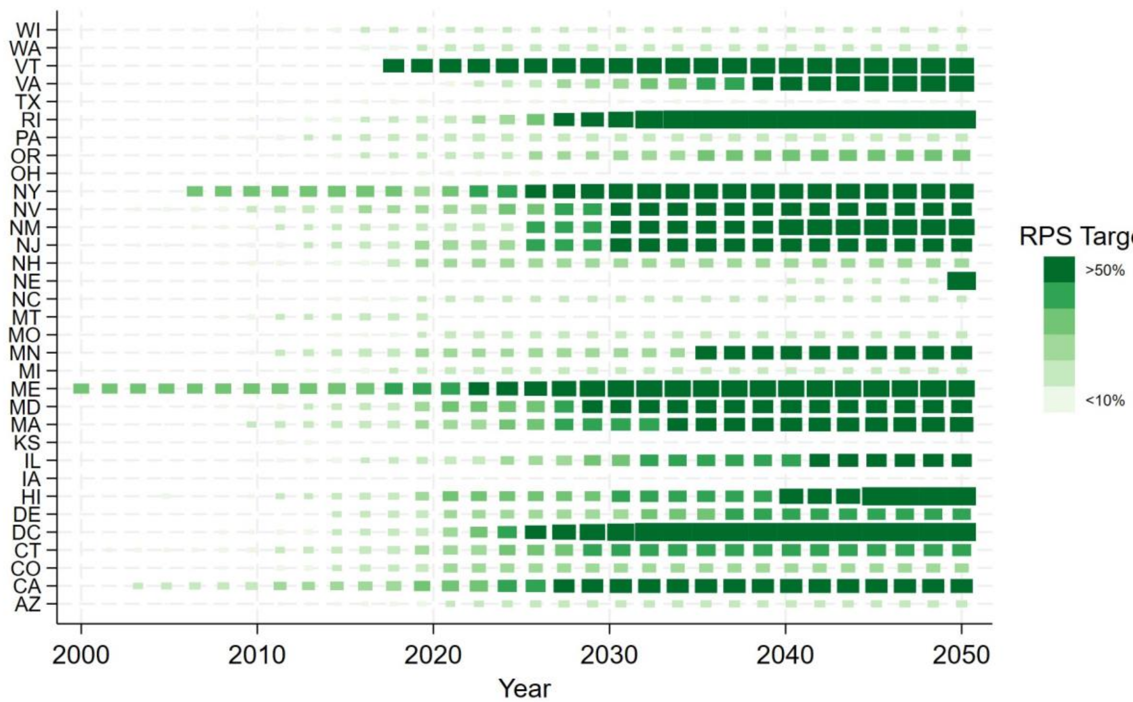


Figure BI – Renewable Portfolio Standards for Adopting States

This figure plots renewable percentages for the 32 states that implemented a renewable target at any point over the sample period. *Renewable Percentage* is the state-year target for the percentage of electricity to be sourced from renewable sources as reported by the Lawrence Berkeley National Laboratory and U.S. Department of Energy.

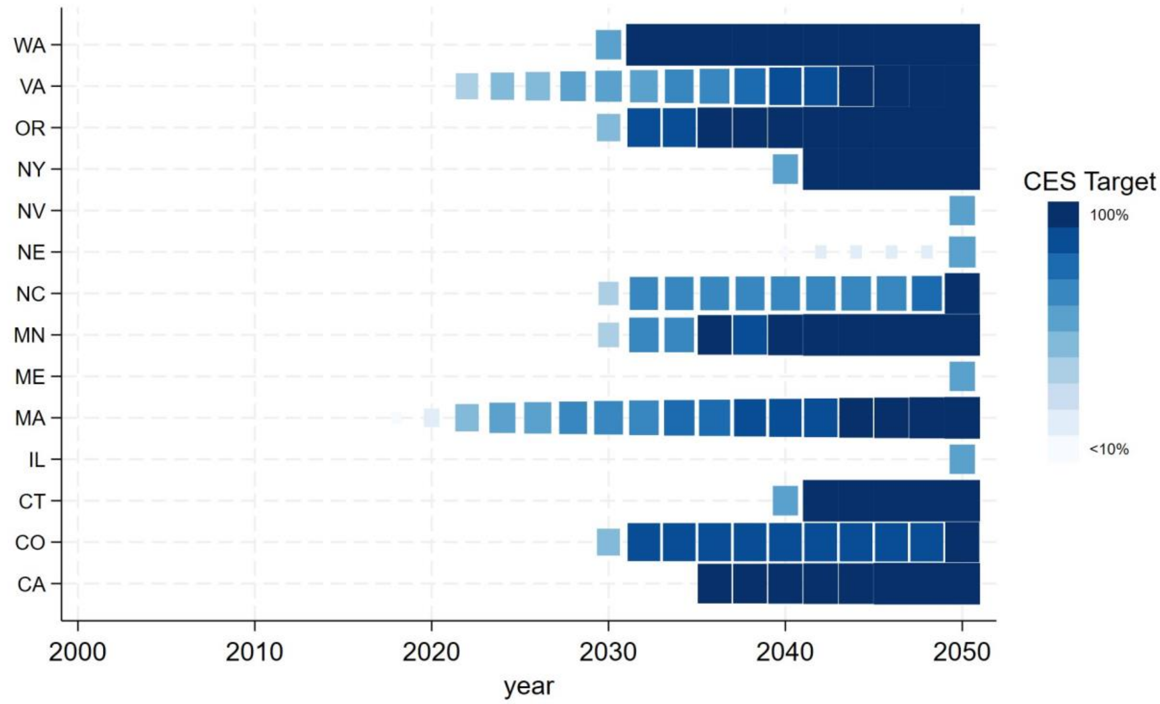


Figure BII – Clean Energy Standards for Adopting States

This figure plots clean energy targets for the 14 states that implemented a clean energy target at any point over the sample period. *Clean Energy Target* is the state-year target for the percentage of electricity to be sourced from technology-neutral renewable sources including nuclear power or fossil fuels fitted with carbon capture technologies. We collect this information from the Lawrence Berkeley National Laboratory and the U.S. Department of Energy.

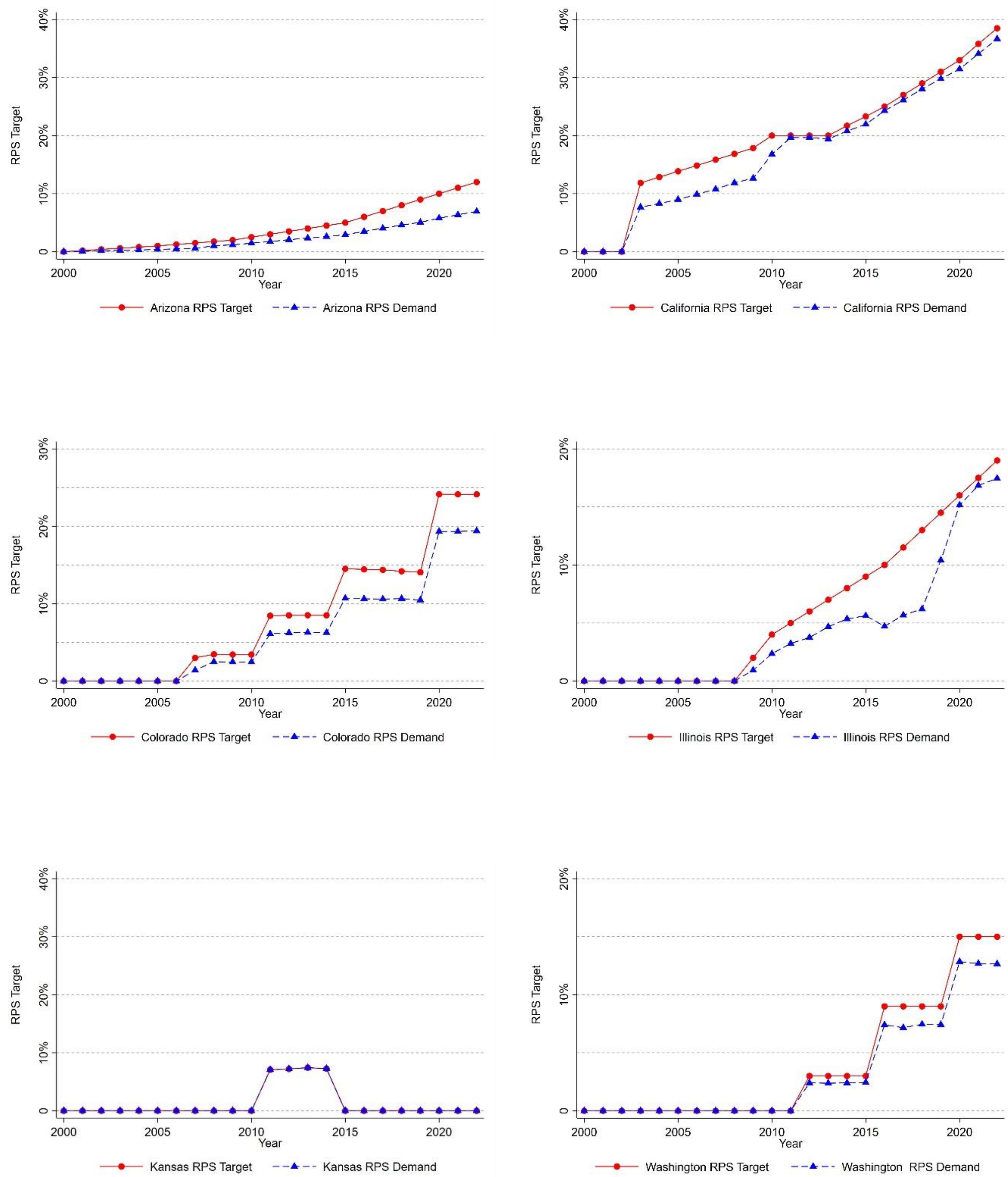


Figure BIII – Renewable Percentage vs. Renewable Demand

This figure plots examples of states' Renewable Percentages over time. It shows the percentage of electricity that RPS mandate to be derived from renewable sources (solid line) and the projected RPS demand as a percentage of electricity sales that adjusts for state exemptions and other provisions (dashed line). Data are from the Lawrence Berkeley National Laboratory and the U.S. Department of Energy.

Table BI – Renewable Commitments and Yields in Secondary Market Trading with Alternative Yield Definitions

This table reports results from OLS regressions with three alternative yield definitions for state yields as the dependent variable. Panel A reports results from the state issuer sample while Panel B reports results for the local issuer sample. In Panel A (Panel B), model (1) reports results with *Adjusted Yield* from Table II (Table IV) that uses transaction-amount weighted yield spreads relative to maturity-matched MMA yields. Model (2) in both panels reports results with *Equal-Weighted MMA Adjusted Yield* as the dependent variable. This dependent variable uses average equally weighted yield spreads relative to the MMA instead of weighting by transaction amount. Model (3) reports results with *Trade-Weighted Treasury Adj. Yield* as the dependent variable. This variable uses transaction-amount weighted yields and subtracts maturity-matched treasury bond yields. Model (4) reports results with *Equal-Weighted Treasury Adj. Yield* as the dependent variable. This variable uses average equally-weighted yields and subtracts maturity-matched treasury bond yields. *Renewable Target* is an indicator equal to one if the state has passed a Renewable Portfolio Standard as of a given year. Bond Controls include *Coupon Rate*, *Log Offering Amount*, *Years to Maturity*, *Bond Age*, *Call Option*, *Negotiated Offering*, and *Insured* indicator. State Controls include *State Population*, *State Income per Capita*, *State Real GDP*, *Real GDP Growth*, and *State Age Dependency*. County Controls include *County Income per Capita*, *County Unemployment Rate*, *County Population*, and *County Age Dependency*. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Panel A: State Issuers

	(1)	(2)	(3)	(4)
	Trade-Weighted State MMA Adj. Yield	Equal-Weighted State MMA Adj. Yield	Trade-Weighted State Treasury Adj. Yield	Equal-Weighted State Treasury Adj. Yield
Renewable Target	18.66***	18.40***	20.45***	20.24***
	(2.40)	(2.41)	(2.45)	(2.47)
Bond Controls	Yes	Yes	Yes	Yes
State Controls	Yes	Yes	Yes	Yes
Year-Cohort Fixed Effects	Yes	Yes	Yes	Yes
State-Cohort Fixed Effects	Yes	Yes	Yes	Yes
Adj. R-squared	0.17	0.17	0.34	0.34
Observations	1,830,206	1,830,206	1,830,206	1,830,206

Panel B: Local Issuers

	(1) Trade-Weighted Local MMA Adj. Yield	(2) Equal-Weighted Local MMA Adj. Yield	(3) Trade-Weighted Local Treasury Adj. Yield	(4) Equal-Weighted Local Treasury Adj. Yield
Renewable Target	8.30***	8.17***	9.75***	9.61***
	(1.08)	(1.06)	(1.08)	(1.06)
Bond Controls	Yes	Yes	Yes	Yes
State Controls	Yes	Yes	Yes	Yes
County Controls	Yes	Yes	Yes	Yes
Year-Cohort Fixed Effects	Yes	Yes	Yes	Yes
County-Cohort Fixed Effects	Yes	Yes	Yes	Yes
Adj. R-squared	0.13	0.13	0.29	0.29
Observations	8,746,311	8,746,311	8,746,311	8,746,311

Table BII – Renewable Demand and Yields in Secondary Market Trading

This table reports results from OLS regressions with *Adjusted Yield* as the dependent variable. The sample consists of monthly trading yields of state bonds between 2005 and 2022. Models (1) and (3) use state-issued bonds, models (2) and (4) use local municipal bonds. *Renewable Demand* is the demand for RPS electricity (adjusted for exempt load and other state-specific provisions) divided by the total electricity sales in the state. Bond Controls include *Coupon Rate*, *Log Offering Amount*, *Years to Maturity*, *Bond Age*, *Call Option*, *Negotiated Offering*, and *Insured* indicator. State Controls include *State Population*, *State Income per Capita*, *State Real GDP*, *Real GDP Growth*, and *State Age Dependency*. County Controls include *County Income per Capita*, *County Unemployment Rate*, *County Population*, and *County Age Dependency*. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1) State Adj. Yield	(2) Local Adj. Yield	(3) State Credit Ratings	(4) Local Credit Ratings
Renewable Demand	0.292**	0.302***	-0.022***	-0.019***
	(0.122)	(0.107)	(0.004)	(0.004)
Bond Controls	Yes	Yes	Yes	Yes
State Controls	Yes	Yes	Yes	Yes
County Controls	No	Yes	No	Yes
State-Cohort Fixed Effects	Yes	No	Yes	No
County-Cohort Fixed Effects	No	Yes	No	Yes
Month-Year Fixed Effect	Yes	Yes	Yes	Yes
Bond Controls	Yes	Yes	Yes	Yes
Adj. R-squared	0.17	0.13	0.73	0.49
Observations	1,830,206	8,746,311	1,830,206	8,746,311

Table BIII – Renewable Commitments with Alternative Timing

This table reports results from stacked OLS regressions with *Adjusted Yield* and *Credit Rating* as the dependent variable. The sample consists of monthly trading yields of bonds between 2005 and 2022. Models (1) and (3) use state-issued bonds, models (2) and (4) use local municipal bonds. *Renewable Standard* is an indicator equal to one if the state has passed a Renewable Portfolio Standard. Bond Controls include *Coupon Rate*, *Log Offering Amount*, *Years to Maturity*, *Bond Age*, *Call Option*, *Negotiated Offering*, and *Insured* indicator. State Controls include *State Population*, *State Income per Capita*, *State Real GDP*, *Real GDP Growth*, and *State Age Dependency*. County Controls include *County Income per Capita*, *County Unemployment Rate*, *County Population*, and *County Age Dependency*. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
	State Adj. Yield	Local Adj. Yield	State Credit Ratings	Local Credit Ratings
Renewable Standard	5.888***	5.581***	-0.374***	-0.021
	(2.218)	(1.281)	(0.090)	(0.030)
Bond Controls	Yes	Yes	Yes	Yes
State Controls	Yes	Yes	Yes	Yes
County Controls	No	Yes	No	Yes
State-Cohort Fixed Effects	Yes	No	Yes	No
County-Cohort Fixed Effects	No	Yes	No	Yes
Month-Year Fixed Effect	Yes	Yes	Yes	Yes
Adj. R-squared	0.20	0.14	0.74	0.49
Observations	997,888	5,173,448	997,888	5,173,448

Table BIV – Renewable Commitments and Yields in Secondary Market Trading Conditional on Credit Ratings

This table reports results from stacked OLS regressions with *Adjusted Yield* as the dependent variable. The sample consists of monthly trading yields of bonds between 2005 and 2022. Models (1) and (3) use state-issued bonds, models (2) and (4) use local municipal bonds. *Renewable Target* is an indicator equal to one if the state has a Renewable Portfolio Standard in place. *Renewable Percentage* is the state target for renewable energy production for that year. Bond Controls include *Coupon Rate*, *Log Offering Amount*, *Years to Maturity*, *Bond Age*, *Call Option*, *Negotiated Offering*, and *Insured* indicator. State Controls include *State Population*, *State Income per Capita*, *State Real GDP*, *Real GDP Growth*, and *State Age Dependency*. County Controls include *County Income per Capita*, *County Unemployment Rate*, *County Population*, and *County Age Dependency*. Variable definitions are in the legend of Table I. We cluster standard errors at the bond and month levels and report them below coefficient estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1) State Adj. Yield	(2) Local Adj. Yield	(3) State Adj. Yield	(4) Local Adj. Yield
Renewable Target	9.496***	5.832***		
	(1.962)	(0.974)		
Renewable Percentage			0.250***	0.368***
			(0.074)	(0.076)
Credit Rating	-10.790***	-9.435***	-10.951***	-9.440***
	(0.896)	(0.557)	(0.872)	(0.556)
Bond Controls	Yes	Yes	Yes	Yes
State Controls	Yes	Yes	Yes	Yes
County Controls	No	Yes	No	Yes
State-Cohort Fixed Effects	Yes	No	Yes	No
County-Cohort Fixed Effects	No	Yes	No	Yes
Month-Year Fixed Effect	Yes	Yes	Yes	Yes
Adj. R-squared	0.18	0.16	0.18	0.16
Observations	1,830,206	8,746,311	1,830,206	8,746,311