

# Renewable Portfolio Standards, Vertical Structure, and Investment

April 25, 2026

## **Abstract**

Policy effectiveness within industries depends on market structures. We provide evidence of this by examining how vertical structure influences renewable capacity investments under Renewable Portfolio Standards (RPS). RPS link the upstream and downstream electricity sectors by mandating downstream firms to procure a fraction of sales from renewables. Considering various channels through which downstream firms can source investment to comply, we show that RPS-driven investments vary across states with different degrees of vertical integration in their electricity sector. We find lower investments in more vertically separated states, suggesting that the policy provides different incentives depending on the underlying market structure.

JEL codes: L42, L94, Q42, Q48

Keywords: Renewable Portfolio Standards, vertical relations, renewable energy, electricity markets, market structure

# 1 Introduction

A central question in economics is how to design effective policies based on an understanding of the incentives of the parties involved. This becomes particularly challenging since the efficacy of the policy may depend on whether the incentives it creates align with the firms’ own objectives under the prevailing market structure. This paper highlights the importance of the market structure as a factor influencing policy outcomes, exploiting an empirical setting where one can observe the same regulation in action under different market structures. Specifically, we quantify the effects of the Renewable Portfolio Standards and how this outcome depends on the extent to which the market is vertically related.

The Renewable Portfolio Standards (RPS) are a set of policies in the United States that have the objective to increase the generation capacity from renewable sources. The RPS require that a minimum percentage of electricity supply in a state be met by generation from renewable sources. The policy is enacted at the state level, and as of August 2024, 29 states and the District of Columbia had established an RPS.<sup>1</sup> The Energy Information Administration claims that half of the growth in renewable generation since 2000 is due to RPS mandates alone.<sup>2</sup>

While previous studies have examined the effects of the RPS policy, we contribute to the literature by evaluating its effectiveness in driving renewable capacity investment, with particular attention to the role of vertical market structure, which varies across states. We argue that this interaction is crucial to understanding how the policy creates investment incentives, especially given that the electricity industry operates as a vertical supply chain.

We focus on the fact that the RPS place an obligation on the downstream sector – electric utilities or other retail electric providers, in general load-serving entities – to achieve the goal of an increased renewable share in the upstream generation sector. Since downstream retail companies are responsible for inducing new investment upstream, the effectiveness of the policy in achieving the goal may depend on the closeness of the vertical relationship between the retail and wholesale sectors.<sup>3</sup>

An interesting aspect of the US electricity industry is that the degree and prevalence of vertical

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<sup>1</sup>In addition, seven other states have put in place “renewable energy goals”, they do not have the same stringency level as the RPS and therefore, we only focus on the RPS states (<https://t.ly/e7RID>). To date, there is no federal RPS or similar policy in place.

<sup>2</sup>“Roughly half of all growth in U.S. renewable electricity generation and capacity since 2000 is associated with state RPS requirements” (Barbose (2024) and <https://t.ly/PPXYK>).

<sup>3</sup>While exhibiting important variations, several other policies share an incentive mechanism similar to that of Renewable Portfolio Standards (RPS). Zero-emission vehicle (ZEV) mandates compel manufacturers to sell a specific percentage of ZEVs to avoid penalties. Low-carbon fuel standards (LCFS) establish targets for the average carbon intensity of transportation fuels. Plastic recycling quotas mandate that a certain percentage of plastic products or packaging must be composed of recycled content or must be recycled. In all these examples, the mandates apply uniformly to all market participants; however, vertically integrated and vertically separated entities coexist within these markets.

ties between retail and wholesale vary significantly between states. Historically the US electricity sector was dominated by vertically integrated companies serving as a local monopolist handling both generation and retail (distribution), but the restructuring process aimed at separating these vertical ties to create competitive markets, though this was not completely achieved and not uniformly across states.<sup>4</sup> As a result, we observe a mix of cases where a retail company also operates in the generation sector, referred to as the vertically integrated case, and cases where a retail company is completely separated from generation – the vertically separated case. These two types of vertical relationship coexist in most states, including those that underwent restructuring, creating varying degrees of vertical relations at the state level. This is the main source of variation that we use in our empirical analysis.

We explore two channels through which the policy can induce new investments. The first is the *contracting channel*, where a retailer enters a contract with an upstream firm that plans to invest in new renewable capacity, or directly invests in capacity itself, in order to use the generation from this new capacity to comply with the RPS requirement.<sup>5</sup> The second channel is through a new market created by the policy itself, where retailers can purchase Renewable Energy Credits (RECs) from renewable generators to comply with the RPS, which we term as the *REC market channel*.<sup>6</sup>

Although these two channels may coexist, we assume that the extent to which policy-driven investments at the state level differ by the vertical structure is determined by investments sourced through the contracting channel. That is the case if the vertical relationship between the downstream retailer and upstream generators is stronger, and therefore the retailer’s compliance needs are aligned with upstream investment incentives. This alignment gives the retailer an advantage in establishing and enforcing investment contracts, ultimately resulting in more investment through the contracting channel.<sup>7</sup> Alternatively, investments made through the REC market channel are likely to respond only to the incentives created by the REC market. To assess the validity of these assumptions we test whether the investments –specifically those sourced through the contracting channel– are more effective in vertically integrated settings than in vertically separated environments towards compliance.

To quantify this relationship, it is important to identify the contractual links between invested renewable capacity and retail firms. Although firm-level contract data are often confidential, we

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<sup>4</sup>For example, California suspended the restructuring process after experiencing an electricity crisis in 2001. This incident also influenced restructuring processes in other states.

<sup>5</sup>Note that we group direct investments made by a vertically integrated retail firm as part of the contracting channel since vertical integration is a case where the contracting process is fully internalized.

<sup>6</sup>As explained later in the paper, the implementation of the RPS policy relies on the issuance of a Renewable Energy Credit (REC) for each unit of electricity produced from approved renewable sources. RECs can be traded under certain rules, and firms that need to comply with the policy must acquire RECs through their own production or through the REC market.

<sup>7</sup>Establishing and enforcing contracts for renewable energy projects is particularly challenging due to the variability in generation, which makes long-term commitments harder to secure (Ryan (2023)).

compiled a novel dataset on contractual agreements (e.g, power purchase agreements) between retail firms and renewable generators from the Federal Energy Regulatory Commission (FERC Form 1). Although exact details of these contracts are not available, we were able to identify the renewable generators that established contracts with retail firms at the start of their operations. The capacities of renewable generators that are identified to have contractual links with the retail firm are defined (or categorized) as investments sourced through the contracting channel. These data are complemented with several datasets from the Energy Information Administration (EIA), including data on generators (EIA Form 860), retail electricity providers (EIA Form 861), and state electricity sector characteristics (EIA Electric Power Annual).

The electricity sector data were then combined with the RPS dataset compiled by the National Renewable Energy Laboratory ([Barbose \(2024\)](#)). For each state that has enacted an RPS and for each year, we observe the annual minimum percentage requirement (i.e., RPS target levels) for renewable energy sales, which are announced and publicly known several years in advance. The database also reports each state’s compliance status, indicating whether the state fully complied with the RPS requirements that year, and if not, by how much it did not meet the requirements.

Our empirical strategy explores the relationship between annual state-level renewable investments attached to the RPS policy and the state’s vertical structure. Since RPS requirements are published in advance, retail firms can plan to ensure that their investments and the respective generation output are online by the compliance year. We aggregate the new wind and solar generation capacities contracted by retailers within each state that come online each year. By using state-level investments that are contractually tied to retailers within the state, our analysis focuses on the aggregate-level outcomes of a state’s regulation, rather than an individual generating firm’s decisions to invest. This suits our analysis well as our focus is on how effectively the states that vary in vertical structures source investment to meet the state-level requirement.

However, identifying whether the new capacity is driven by the policy presents a challenge. To address this, we leverage the exogenous variation in RPS requirements over time along with the variation in annual compliance status. In particular, regarding the investments that occur in the non-compliance years, we exploit the observation that if the state did not achieve compliance, all new renewable investment must have been used to comply with the policy. Therefore, we expect a stronger influence of the RPS policy on renewable investments during non-compliance years. By focusing on these years, we implicitly assume a causal relationship between policy and investment.

We use three different measures to characterize a state’s vertical market structure. First, a binary indicator that identifies restructured states from the rest. This has often been used in the literature as restructuring resulted in separating the generation sector from the retail sector. We contribute to this literature by introducing two new continuous measures of vertical separation in

the electricity sector, using firm-level vertical linkage data. The first measure takes the capacity share of upstream generators not owned by companies with a presence downstream. The second measure, our preferred measure, computes the market share of sales from retailers that do not own generation assets. This effectively captures the varying degrees of existing firm-level vertical linkages across states.

Our empirical analysis estimates the relationship between new annual renewable capacity investments used for RPS compliance and the interaction of the measure of vertical separation with an indicator showing whether a state is non-compliant. We find that investments tied to RPS compliance are lower in states with a more vertically separated structure than those states with closer vertical links, by a factor between 0.6 and 1.5 times the overall annual average investment in renewables capacity. The results suggest that states with stronger vertical links may be more effective in sourcing investments for compliance.

As mentioned above, we assume that differences in investment outcomes between vertical structures are mainly driven by the contracting channel. However, investments through the REC market channel could affect these differential impacts if the REC market channel serves as a viable alternative to the contracting channel for investors. Although this indirect effect via the REC market could be controlled for by including REC spot market variables in our main regression, we are unable to do so because REC market data are not publicly available for the entire set of states. Therefore, we theoretically quantify the potential bias of omitting the REC market channel in our analysis. We find that the direction of this bias depends on whether wholesalers perceive the REC market as a reliable source for making investment decisions. We then empirically verify the direction of the bias using a subsample of states within the PJM interconnection, where REC market data are publicly available, confirming that the REC market channel may be less reliable and thus less explored by investors compared to the contracting channel.<sup>8</sup> This subsample analysis also indicates that there may be a positive bias in our main results due to the inability to control for the REC market channel, but that the magnitude of this bias is small and, therefore, not a major concern.

Overall, our main finding is that RPS-driven investment through the contracting channel is significantly lower in more vertically separated states than in more integrated ones. Although this result does not by itself establish a causal relationship, it suggests that in the electricity sector there may be a potential misalignment in investment objectives when policies are not tailored to the state’s prevailing vertical structure – likely the case given that the policy’s general design is uniform despite market structure differences. Altogether, our study emphasizes the need to account for market structure when designing or reforming policies targeting clean energy investment.

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<sup>8</sup>PJM, a regional transmission organization coordinating wholesale electricity supply and demand in 13 states and D.C. publishes monthly statistics for solar REC (SREC) prices. More details are provided in Section 4.5.

**Related literature.** There is a relatively small set of studies that explicitly examine the interplay between RPS and renewable capacity investment. [Yin and Powers \(2010\)](#) study the relationship between renewable capacity and RPS stringency, finding a positive effect, though without accounting for market structure. More recently, [Deschenes et al. \(2023\)](#) have addressed a similar question using staggered differences-in-differences methods, finding a causal effect of RPS on wind investments, but also do not consider market structure or vertical relationships. Our paper is the first to explore the role of vertical relationships in conjunction with RPS-driven investment, suggesting that its effects may not be entirely technology-specific but may also depend on market structure.<sup>9</sup>

Our paper also relates to the literature exploring vertical integration and investment. Transaction cost theory suggests that the difficulty of specifying and enforcing a contract is an important factor that determines to what extent firms are vertically integrated ([Joskow \(2003\)](#), [Lafontaine and Slade \(2007\)](#)). Our paper is broadly related to this theory as we draw on this literature to argue that a stronger vertical relationship leads to a more effective contract specification as well as enforcement. There is also a stream of the literature that focuses on the fact that investments in power plants are relationship-specific, thus prone to hold-up problems. [Joskow \(1987\)](#) studies the relation between investments in coal power plants and the extent of the vertical relationship between input coal suppliers and coal plants. More recently, [Ryan \(2023\)](#) showed that the hold-up problem arising from the counterparty risk of investing in solar capacity can be significant, especially for renewable assets, and can result in inefficient levels of investment (procurement). [Fabra and Llobet \(2025\)](#) also study the implications of counterparty risk defaults in this type of relationship. [Brown and Sappington \(2022\)](#) is close to our paper from a conceptual point of view, as they provide theoretical predictions that vertical integration would increase capacity investment in electricity markets.

Lastly, our paper is broadly related to empirical studies exploring the market effects of vertical integration, deregulation, and restructuring in electricity markets. Deregulation has been associated with significant reductions in maintenance costs ([Davis and Wolfram \(2012\)](#)), and labor and fuel costs ([Fabrizio et al. \(2007\)](#), [Cicala \(2015\)](#)), implying a reduction in electricity prices. [Leslie \(2018\)](#) shows that in the context of a carbon tax in electricity markets, the market structure is an important factor in the impact of the tax. [Mansur \(2007\)](#) finds that market power is exercised to a lesser extent in vertically integrated markets than in restructured markets, and [MacKay and Mercadal \(2024\)](#) find that in some cases, deregulation has resulted in higher prices than in regulated markets.

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<sup>9</sup>There have been several other studies on a variety of aspects of the policy. [Greenstone and Nath \(2021\)](#) find that the implementation of RPS reduces emissions but leads to higher electricity prices. Similarly, [Feldman and Levinson \(2023\)](#) find that RPS reduced emissions and natural gas generation, although the impacts are small. [Wolverton et al. \(2022\)](#) focuses on the manufacturing sector and finds that electricity prices are slightly higher in RPS states than in non-RPS states. [Fullerton and Ta \(2025\)](#) use a general equilibrium model around the RPS policy in addition to reduced-form evidence of the effect of RPS on market outcomes including retail prices. [Hollingsworth and Rudik \(2019\)](#) examine the spillover effect of the RPS policy and measure the reduction of emissions associated with it. [Abito et al. \(2025\)](#) examines a cost-effective REC market trading mechanism.

## 2 Institutional Background and the Importance of Market Structure

### 2.1 The Renewable Portfolio Standards

The RPS is a state-level policy that sets a minimum requirement for the share of the in-state electricity supply coming from designated renewable energy sources by a certain date (EIA (2022)). Specifically, the policy requires the *retail* electricity providers (electric utilities) to source a certain percentage of their electricity sales (load supplied to final consumers) from renewable sources. These resources can include wind, solar, geothermal, biomass, and some types of hydroelectricity and, in some cases, even landfill gas, municipal solid waste, and ocean energy. The energy source considered renewable differs by state, but wind and solar are the dominant sources. Some states impose a minimum requirement separately for solar and the rest of renewables.<sup>10</sup>

The RPS policy exists in 29 states and the District of Columbia as of late 2024, which implies that the policy applies to 58% of total U.S. retail electricity sales (Barbose (2024)). Adoption times vary between states. Figure 1 shows a timeline of these adoption events. When a state decides to adopt an RPS policy, the annual minimum percentage requirements (i.e., targets) and their scheduled increases over time are set and announced several years in advance. Usually, the target levels for the decade or several upcoming years are established upfront, meaning that they do not flexibly adjust based on the state’s investment progress. Thus, retail electricity companies typically know the target levels of subsequent years at the time of the state’s RPS adoption. The magnitude and growth rate of the annual target levels differ by state. Therefore, the annual RPS target levels can be viewed as fairly exogenous.<sup>11</sup>

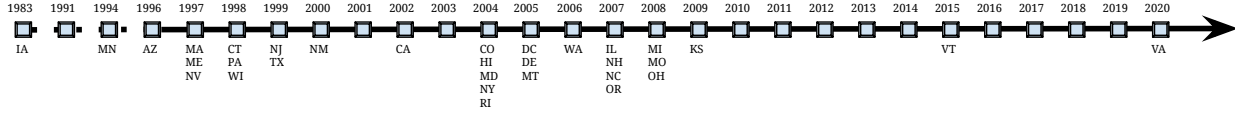
Figure 2 shows the annual RPS mandate as a percentage of total sales for four states: Arizona, DC, California, and New York. Each state enacted its RPS policy at different points in time and with different speeds in the changes in their target levels. Arizona was an early adopter with a very gradual increase in the size of the target and with a maximum target level under 20% to be reached in 2026. A much more aggressive set of schedules can be found in DC, where the RPS was enacted in 2008 initially at a target under 10% but with a very steep curve to reach a target of 100% by 2033. New York and California exhibit a behavior in between the two first examples but once again with different enactment years. These schedules are public information and are announced prior to the enactment of the policy in the state.

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<sup>10</sup>RPS solar carve-outs are state-specific minimum requirements that must be fulfilled with solar generation. In those states, the Renewable Energy Credits (RECs) generated this way are known as SREC (solar RECs), see Barbose (2024).

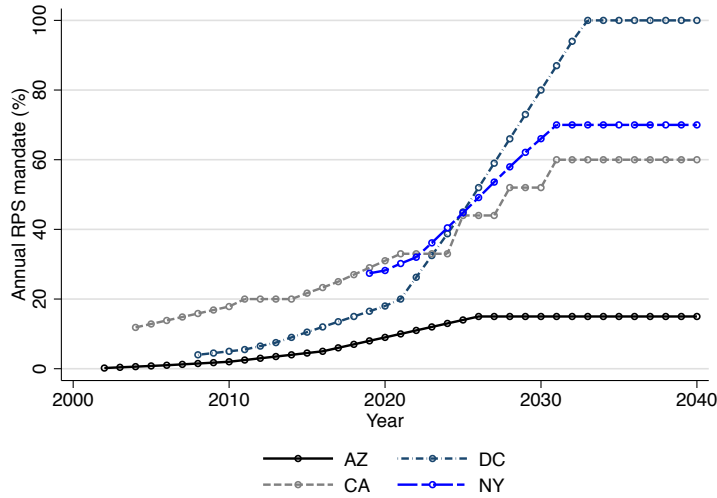
<sup>11</sup>For example, the Arizona legislature passed the full schedule of RPS targets, one for each year for the period 2006 - 2024 on 14 November 2006 as it can be verified in this document of the state legislature <https://t.ly/QtKUw> (p. 85-86).

Figure 1: RPS Enactment by State



Notes: Year in which the state implemented an RPS policy for the first time. Data from Barbose (2024).

Figure 2: RPS Targets Per Year (Selected States)



Notes: The annual RPS mandate is a minimum requirement of electricity sales that must be generated using renewable sources. The requirements are expressed as percentages of annual sales. Different states have enacted the RPS policy at different points in time and with different levels of stringency. Data from Barbose (2024).

## 2.2 RPS compliance and Renewable Energy Certificates (RECs)

At the end of a compliance year, the state calculates each retail electricity provider’s required amount of Renewable Energy Certificates (RECs), based on the share of the state’s total electricity consumption sold by the provider. If the retail provider fails to meet the requirement for that year, the provider must pay a penalty in the form of Alternative Compliance Payments (ACP), which allows it to make a payment at a pre-established price for the amount of the unfulfilled requirements. Table A.1 in the Appendix summarizes the ACP values reported in 2014 for each state. The penalty value is about 50 \$/MWh, with some variation across states. This value is in the middle of the range of average spot prices in the US for that year, implying that the penalty was a true financial burden to be avoided.<sup>12</sup>

<sup>12</sup>According to the EIA, the average spot wholesale electricity price in 2014 was above 50 \$/MWh in the northeast US markets and California. Other markets had averages slightly below that threshold but above 38 \$/MWh. See <https://t.ly/2Uu1J>

There are several ways in which retail electricity providers can obtain RECs to comply with the RPS policy. First, the retail electricity provider can generate the required amount from their own renewable generators or by establishing a long-term contract (Power Purchase Agreement or PPA) with renewable generators upstream. For each MWh of electricity generated, the provider receives a credit.<sup>13</sup> Second, retail electricity providers can purchase credits in the spot market for renewable energy credits (i.e., REC market).<sup>14</sup> Any renewable generator, regardless of whether it is owned by Independent Power Producers (IPPs) or retail providers, can sell its unbundled generation on the spot market if the state has enacted an RPS and has a deregulated generation sector.<sup>15</sup>

Many states require RECs produced within the state to meet their RPS goals, with the aim of increasing in-state renewable generation. However, some states allow credits from other states to be used for compliance, which could lead to spillover effects across state lines (Hollingsworth and Rudik (2019)). Even then, these states typically limit eligible credits to those produced within the same interconnection as the state (Abito et al. (2025)). When determining a retailer’s or state’s compliance status, all RECs –whether bundled, unbundled, sourced in-state, or out-of-state – are counted, provided the sourcing channel is state-approved.

A state implementing an RPS policy does not always comply with its target levels, and as a result the compliance status can vary over time. If a certain year is designated as a ‘non-compliance’ year, it indicates that the total RECs procured by the state’s retail providers fell short of the state’s minimum RPS requirement.

### 2.3 Restructuring and deregulation of the electricity sector

The electricity sector consists of three main segments: generation, transmission, and retail (distribution).<sup>16</sup> A common market structure prevailing until the 1990s consisted of a single company owning assets in all three segments, corresponding to what is known as a vertically integrated market. However, several states went through deregulation and restructuring processes in their

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<sup>13</sup>REC credits obtained through direct investment or contract are referred to as a bundled REC, as the credit is bundled with the actual generated electricity.

<sup>14</sup>RECs supplied on the spot market are referred to as unbundled credits, as they do not require the retailer to purchase the electricity that produced the credit.

<sup>15</sup>A renewable generator must choose between selling its credits bundled with electricity through a contract or selling the credit unbundled in the spot market. Once a credit is bundled, it cannot be resold as unbundled on the spot market. Thus, the spot market for RECs applies only to unbundled RECs. Prices are typically reported separately for each REC type, indicating that they are treated as distinct credits with separate markets. More information can be found in <https://www.epa.gov/lmop/unbundle-electricity-and-renewable-energy-certificates>.

<sup>16</sup>There is a distinction between retail and distribution services, where in some markets retail has been open to competition and in others it is vertically integrated with distribution. However, distribution services are still mostly legacy local monopolies managed by electric utilities. When there is a retail choice program, final consumers are typically billed by their local electric utility or by a company focused exclusively in the retail sector; in either case, we will refer to them as retailers. Since retail is the sector directly affected by the RPS, we refer to the retail sector throughout the paper with the understanding that, in some cases, it is vertically integrated with some distribution company.

electricity sector from the late 1990s. The main objective was to eliminate the inefficiencies of vertically integrated monopolies and introduce competition into the electricity sector.

The deregulation and restructuring process targeted both wholesale and retail sectors. First, deregulation of the wholesale generation sector refers to opening the generation segment to competition by allowing independent power producers (IPPs) and other firms to participate. Prior to these reforms, the regulated electric utilities serving retail customers generated electricity using their own assets rather than purchasing from other generation companies. Wholesale deregulation was accompanied by the implementation of spot wholesale markets to facilitate electricity trade between retail providers and independent power producers.<sup>17</sup>

Second, deregulation and restructuring of the retail electricity sector refer to opening the retail service market to retailers other than the legacy electric utilities. This restructuring is often accompanied by ‘Retail Electricity Choice’ programs, which allow end-use customers (including residential, industrial, and commercial customers) to choose their electricity provider from either the legacy utilities or competitive retail suppliers, such as retail marketers.<sup>18</sup>

As our focus is on the extent to which a retail firm interacts with the wholesale generation sector – with vertical integration as the strongest form – wholesale generation sector deregulation/restructuring is more relevant to our analysis. Although deregulation aimed to break vertical ties between the retail and wholesale sectors, firm-level vertical integration has not been completely eliminated after the deregulation process. Even in states with restructured wholesale sectors, legacy retail firms may still own generation assets in the wholesale market (e.g., *PG&E* in California and *Reliant* in Texas).

We define vertical integration as a retail firm’s capability to source electricity from its own generation assets in the wholesale market. Hence, we need to explore the firm-level links between the wholesale and retail sectors to derive a measure of vertical integration that accurately reflects the market structure. Once firm-level integration status is considered, the degree of vertical integration at the state level can vary across states, even between states with the same binary indicator for a restructured market. Therefore, our notion of vertical integration does not refer to historically regulated vertically integrated monopolies.

## 2.4 Vertical structure and renewable investment

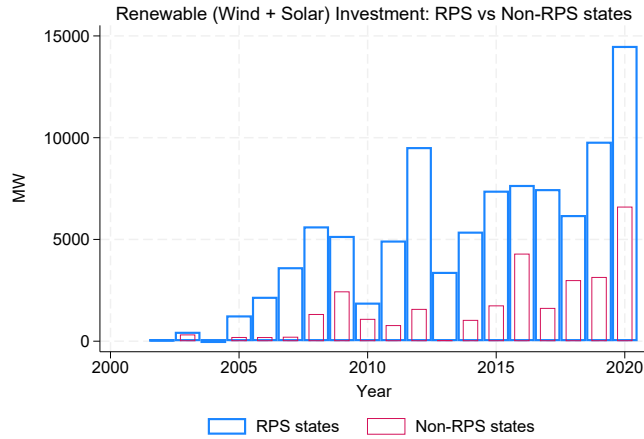
Since the RPS target level increases over time, retail electricity providers cannot comply with the policy unless new renewable generation investments are made over time. Especially given the small

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<sup>17</sup>This spot market is operated by “Independent System Operators (ISO)” or “Regional Transmission organizations”.

<sup>18</sup>However, the specifics of these retail choice programs differ across states. In 2018, 13 states and the District of Columbia had active statewide *residential* retail choice programs. Source: <https://www.nrel.gov/docs/fy18osti/68993.pdf>.

Figure 3: Renewable Investment: RPS states vs. Non-RPS states



*Notes:* Renewable resource includes wind and solar generation capacities. The bar graphs shows the addition of new investment each year, separately for states that have eventually enacted RPS policy and those that have not.

share of renewable generation capacity at the time of enactment, along with their small capacity factor, inducing new investments in renewable generation is the critical and ultimate goal of the RPS policy.<sup>19</sup> Figure 3 shows a steady growth in invested renewable capacities over time, with significantly larger capacity additions in states that adopted an RPS compared to those that did not.<sup>20</sup>

Because the policy is designed in such a way that downstream retail companies are in charge of inducing the investment upstream, how effectively the investment can occur depends on the vertical relationship between the downstream and upstream firms.

#### 2.4.1 Two investment channels for RPS compliance

There are two channels through which the RPS policy can induce new investments in renewable generation capacity: the contracting channel and the REC market channel. The two coexist in the current electricity market. Figure 4 illustrates the two channels.<sup>21</sup>

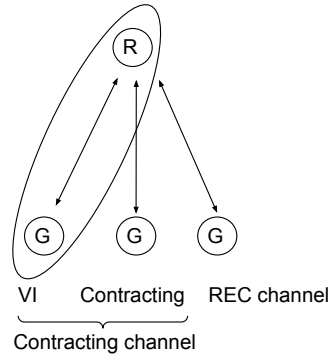
The *contracting* channel investment involves retail firms investing in new renewable generation capacity through contracts with upstream firms planning to build such facilities. This channel also

<sup>19</sup>Moreover, one of the main reasons that the state legislation cited for passing the RPS policy was the expected in-state employment gains from strengthening the green power industry (Hollingsworth and Rudik (2019)), which cannot be achieved without continuously large investments in renewable generation within the state.

<sup>20</sup>Figure E.4 presents a summary of renewable capacity investments by state vertical structure (as defined by  $VS_{\text{binary}}$ ), shown separately for RPS and Non-RPS states. The figure suggests that vertically integrated states invest more in renewable generation. However, this is based only on raw data. We examine this pattern more rigorously in the empirical analysis section, controlling for other relevant factors.

<sup>21</sup>These channels serve as additional revenue sources, alongside tax credits or other national support available to renewable capacity developers.

Figure 4: Two channels to comply with the RPS policy



*Notes:* Two channels through which a retailer can meet the RPS regulation. The contracting channel implies building new capacity to meet the requirement. In the REC channel the retailer waits for the market forces to “induce” new investment from a generator that is not vertically integrated with this retailer and purchase REC credits from it.

includes cases of vertical integration, where a retail firm invests directly through its own affiliate in the upstream sector. Although vertical contracting and vertical integration are not the same concepts, vertical integration can be viewed as an extreme form of contracting. Moreover, contracting can achieve outcomes similar to vertical integration, provided that the issues related to incomplete contracts are not severe (Lafontaine and Slade (2007); Joskow (2003)).

Therefore, the contracting channel here encompasses both vertical contracting and vertical integration. The contract usually takes the form of a long-term purchasing power agreement (PPA) at a specified price per MWh generated by the renewable facility, allowing the developer to recover the investment cost. The documentary evidence on the relationship between the policy implementation and the decision to build new capacity supports our claim that for a retailer entering into a contract with renewable generators can be interpreted as that specific generator’s investment decision to be strongly influenced by the needs of the retailer.<sup>22</sup> In the case of vertical integration, the retail company builds its own renewable generation assets by incurring the investment cost. In both cases, the retailer acquires the bundled credits (RECs) for each unit of renewable electricity generated by the new facilities.

The *REC market* channel investment refers to investments driven by incentives created by the REC spot market, where upstream renewable generators supply credits and earn revenue by selling them to retail firms needing credits for RPS compliance. In this case, retail firms have no control over upstream investment decisions and must rely on the REC market to incentivize new renewable

<sup>22</sup>A PWC report on PPAs and RPS notes that “[A]s utilities get closer to meeting their RPS requirements, their need to enter into PPAs for new renewable energy projects diminishes.” (<https://t.ly/v6hzu>). In the specific context of California, there is an annual report that documents how the procurement expenses through PPAs on renewable generation due to the RPS have changed over time (<https://t.ly/-zyoe>).

investments. If an upstream firm finds REC market revenues sufficient to cover investment costs, it will proceed with the investment.

#### 2.4.2 The effect of vertical structure on investment

A close vertical relationship makes it easier for retail firms to induce new investments in renewable capacity, particularly through the contracting channel. For instance, a vertically integrated retailer can directly build new renewable generation to meet RPS requirements. Even when not directly investing but instead contracting with an upstream firm, having an integrated upstream affiliate offers an advantage in negotiating contracts with wholesalers developing renewable generation. This advantage arises from the upstream firms' awareness that retailers with direct investment options and a good understanding of wholesale operations can more effectively draft and enforce long-term contracts, which often involve complex terms related to quantity, pricing, and duration.

In contrast, a greater separation between the retail and wholesale sectors makes it harder to establish contracts that align their investment incentives. When vertically separated, retail firms without a wholesale market presence cannot directly invest in capacity and must rely on upstream firms, particularly in non-compliance years. This dependency weakens their bargaining position during contract negotiations. Combined with their lack of experience in the wholesale sector, these challenges can lead to incomplete contracts, which, in turn, may incentivize upstream firms to hold up investment, and ultimately resulting in suboptimal levels of contracting and investment.

Note that investments tied to the REC channel – driven by revenue incentives from selling or buying unbundled credits in the REC spot market– are not relationship-specific and are therefore unlikely to be directly affected by vertical structure. That is, any upstream company, even without a contractual relationship with a downstream firm, can choose to invest if the REC market channel profits are sufficient.<sup>23</sup> This implies that any differences in overall investments across distinct vertical structures, which are used towards compliance, are primarily due to differences in investments through the *contracting channel*.

Therefore, separating investments specifically sourced through the contracting channel would be ideal for our analysis. However, this is challenging, in general, due to the difficulty of observing contract data. We address this challenge by using a unique dataset that provides information on contractual relationships between retail firms and renewable generators. However, even in the absence of these data and under the assumption that the investments in the contracting channel are influenced by the vertical structure suggests that the effect can still be identified from aggregate investment data, provided there is sufficient variation in the degree of vertical structure.

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<sup>23</sup>However, REC market channel can also indirectly affect the contracting channel investment, which we discuss in Section 4.5.

Due to the policy’s complexity and the multiple interaction channels between sectors, the existing literature on modeling these interactions is limited and not fully aligned with our context. However, it still informs our understanding of vertical relations. Therefore, building on the existing literature, we present a simple model of investment and vertical relationships between a retailer and a generation plant in Online Appendix E.1. Under certain assumptions, we find that renewable investment is higher when both downstream and upstream parts of the industry are integrated within the same firm, compared to a vertically separated structure. We aim to test, using data, the predictors suggested by theory and our reasoning in this section, while accounting for real-world vertical structures and policy-relevant variables.

### 3 Data

**Renewable generation capacity and investment data: EIA 860.** We use EIA Form 860 to obtain generator-level information, including nameplate capacity, location (state), operating status (e.g., operating, proposed, retired), ownership type, and energy source. We focus on wind and solar generators, which are consistently classified as renewable across all states.<sup>24</sup>

We categorized generators that changed their status from ‘proposed’ to ‘in operation’ as newly invested generators and aggregate their nameplate capacities at the state( $s$ )-year( $t$ ) level, where  $t$  denotes the year in which construction is completed and operations begin. We use the start-of-operation year rather than the proposal year, as industry reports suggest that the involved parties typically determine the operational year when negotiating contracts or at the start of construction.<sup>25</sup>

**Vertical relations and contract data: FERC Form 1.** Using the ownership information in EIA Form 860, we identify generators directly invested in by retail companies (e.g., electric utilities), which correspond to vertically integrated investments. However, retail companies may also establish long-term power purchase contracts with renewable generators owned and invested by Independent Power Producers (IPP). Although these IPP-owned generators are contractually linked to retail firms, they are recorded as IPP-owned in EIA Form 860, making such contractual relationships difficult to identify using EIA data alone.

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<sup>24</sup>The RPS policy primarily targets these sources, as other renewables – such as hydroelectric power – have largely reached capacity limits and can be expanded in limited areas. Consistent with this, Figure E.2 in the Online Appendix shows that capacities of other renewables, including biomass and hydro, have remained relatively flat over time, with investment levels substantially smaller than those for wind and solar.

<sup>25</sup>Construction durations, calculated from EIA 860 as the time between initial proposal and operation, vary substantially across projects, with an average of roughly two or three years. Industry accounts indicate that developers and project commissioners agree on a target completion year early on and adjust construction timelines accordingly. Moreover, RPS targets are published well in advance (often up to ten years), allowing retail and wholesale firms to plan investments ahead of the compliance year  $t$  based on anticipated renewable shortfalls. Additional discussion of renewable project development is available at [power-technology.com](http://power-technology.com).

To address this limitation, we use the FERC Form 1 (Yearly Purchased Power and Exchanges) to identify contractual links between major retail companies and renewable generators invested by IPPs.<sup>26</sup> While contract-level information is generally difficult to obtain, this dataset allows us to identify renewable generators with long-term purchasing contracts with major retail companies. If a retailer establishes a power purchase agreement with a renewable generator and purchases power from it on an ongoing basis, we categorize that generator as being contracted with the retailer. Because power purchase agreements are commonly arranged during the planning stage of renewable projects as part of project financing, we treat such capacity as investment occurring through the contracting channel. We then combine this information with EIA data to construct state-level investment capacity sourced through the contracting channel. Our final renewable investment measure therefore includes (i) new IPP-invested generators that are contractually linked to retail firms (identified using FERC data) and (ii) new generators vertically integrated with retail firms (identified using EIA 860). A more detailed discussion of the FERC data and variable construction is provided in Online Appendix [E.2.1](#).

Another advantage of using contract data is that it captures cross-state spillovers in RPS-driven investments, which arise when an RPS policy in one state induces renewable generation in neighboring states. Our measure of state-level contracted capacity aggregates the capacities of all generators contracted to retail firms in a state, regardless of whether those generators are located in-state or out-of-state.<sup>27</sup> As a result, our renewable investment measure accounts for out-of-state capacity induced by a state’s policy – an effect that is difficult to capture without firm-level contracting data.<sup>28</sup>

**RPS policy data.** Data on RPS policies are publicly available. We primarily use a dataset constructed by [Barbose \(2024\)](#), which reports the states that have enacted an RPS, the year RPS was implemented, RPS target levels (in %), and annual RPS requirements (in MWh) for each state over time. We also use annual state-level RPS compliance rates from [Barbose \(2024\)](#), which measure actual compliance as a ratio of total MWh of renewable generation (credits) to requirement. Although RPS policy compliance is verified at the retail-firm level, the data are reported only at the state level. Consequently, unless a state’s compliance rate is 100%, we cannot identify the compliance/non-compliance status at the firm level. This does not pose a major limitation, however,

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<sup>26</sup>FERC Financial Report Form 1 (Annual Report of Major Electric Utilities) is an annual regulatory filing that collects financial and operational information from major electric utilities.

<sup>27</sup>For example, retail firms in Arizona may source capacity from IPPs located in Arizona, New Mexico, or California. Because these out-of-state capacities are still induced by Arizona’s RPS, they are included in Arizona’s contracted capacity.

<sup>28</sup>We also include a measure of net electricity flows between states to account for generation spillovers, similar to the approach in [Hollingsworth and Rudik \(2019\)](#). The identified spillover patterns and their magnitudes are presented in Online Appendix [E.3.1](#).

as our analysis is conducted at the state level.

**State-level control variables.** We further construct a set of state-level market variables to control for differences across states, drawing on several data sources, primarily the EIA Electric Power Annual. Specifically, we include total annual net summer capacity and total net generation to capture differences in generation scale across states. We also control for the average profitability of a megawatt of renewable generation capacity in each state to account for cross-state differences in weather conditions that affect capacity utilization and investment returns. Finally, we use annual net interchange (net flow) data among states within the same interconnection to account for any physical electricity trades, including renewable generation transfers potentially induced by RPS. Additional details on data sources and the construction of state-level variables are provided in Online Appendix [E.2.2](#).

## 4 Empirical Analysis

Our goal is to explore how the patterns of new investments in renewable generation, specifically aimed at meeting the RPS compliance requirements, differ across states with varying degrees of integration between retail firms and wholesale generators.

### 4.1 Non-compliance years: Variation in compliance status

#### 4.1.1 Importance of RPS targets and regulatory compliance motives

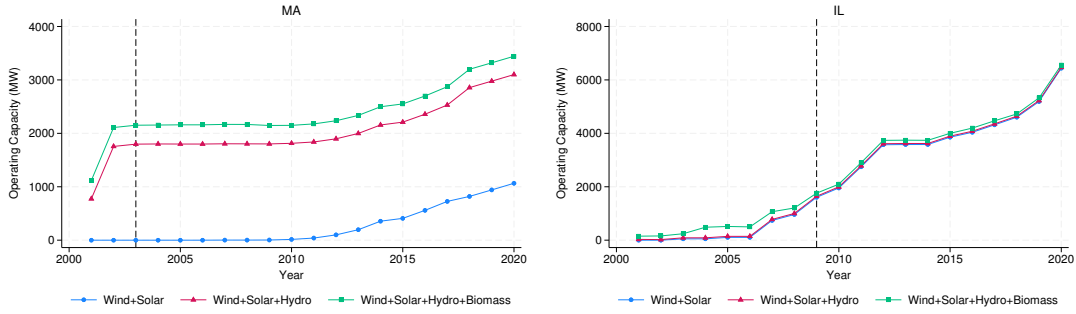
Several studies examining the RPS policy employ a (staggered) differences-in-differences (DiD) analysis, with RPS adoption as the treatment, leveraging the staggered nature of state-level adoption. Although we have implemented a staggered DiD regression similar to the literature, with results presented in [Table A.2](#) in the Appendix, we find this method less suitable for our analysis for the following reasons. First, our focus is on the impact of the vertical structure on renewable investments induced by RPS, which requires a triple difference-in-differences design that is generally not supported by the staggered DiD framework. Second, wind and solar capacity investments were nearly non-existent in most states before the RPS, resulting in limited pre-treatment variation. In addition, the small number of treated states within the same cohort (calendar year) poses challenges for implementing a staggered DiD estimation.<sup>29</sup>

Moreover, there is considerable heterogeneity in states' investment responses to the RPS policy, even in the post-RPS years, due to differences in initial stocks of renewable generation eligible

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<sup>29</sup>The lack of pre-treatment variation weakens the power to test parallel trends, which is crucial for establishing causality. Moreover, a small treated sample within each calendar year (cohort) creates the sparse dummy problem ([Hansen \(2022\)](#)), leading to imprecise parameter estimates.

Figure 5: Operating Capacities: Eligible Renewables in Three Categories



*Notes:* Figures show the existing capacities in MA and IL, summarized by different fuel categories. “Wind+Solar” shows the existing wind and solar generation capacities, with hydro (“Wind+Solar+Hydro”) and biomass (“Wind+Solar+Hydro+Biomass”) added subsequently. RPS adoption dates indicated with vertical dashed lines.

for compliance and RPS target levels.<sup>30</sup> Figure 5, which plots cumulative capacities by renewable energy sources, illustrates how investment patterns differ between Massachusetts (MA) and Illinois (IL), which have different levels of initial renewable stock and target levels. In MA (left panel), wind and solar capacities remain stagnant for several years after RPS adoption (indicated by the vertical dashed line) because the state’s cumulative renewable capacity, including hydro and biomass, was sufficient to meet the low initial RPS requirements. However, as the requirements steadily increased, the investment also began to increase. On the other hand, IL (right panel) had a relatively small initial stock of renewable capacity, with minimal wind and solar capacities. In addition, the RPS target in IL in the first year of adoption was more than twice as large as in MA.<sup>31</sup> Thus, new wind and solar investments began shortly after RPS adoption in IL.

We observe similar heterogeneous investment responses across states. Thus, pre- and post-RPS adoption variation alone cannot explain this rich heterogeneous pattern of investments. This is another reason why difference-in-differences is not suitable for our analysis, as these RPS-related variables are not defined for states that do not have the policy in place.<sup>32</sup> Therefore, we leverage the variation in RPS targets and retailers’ compliance needs in our analysis.

<sup>30</sup>The importance of accounting for preexisting renewable capacity in the analysis has been noted in other studies (Greenstone and Nath (2021), Deschenes et al. (2023)).

<sup>31</sup>Although the pre-existing capacity in the RPS start year appears similar in both states, MA had an RPS requirement of 498,344 MWh while IL had a requirement of 1,210,441 MWh in 2009.

<sup>32</sup>Despite the limitation, we implemented a simple difference-in-differences estimation using pre- and post-enactment, where we interacted the treatment with the vertical structure variable. Table E.3 in the Online Appendix shows the results, which are qualitatively similar to our main analysis, finding that vertical separation is associated with lower renewable capacity investment. Its equivalent placebo test using new fossil-fueled capacity as the dependent variable is shown in Table E.4, the sign of the main coefficient is positive in that case.

Figure 6: RPS Requirement, RPS Goal, and Non-compliance: Connecticut



*Notes:* The graph shows the annual minimum requirement set by the RPS policy in Connecticut (CT). The RPS requirement is a minimum percentage target requirement set by RPS multiplied by the annual generation within CT, which is equivalent to the total sales of retail providers in CT. RPS goal is the amount of annual generation unfulfilled by the state for that fiscal year, and the values are plotted only for the Non-compliance variable, which is a variable that indicates the years when the state was in full compliance with the RPS policy.

#### 4.1.2 The use of compliance status to link investments to policy

We introduce a binary measure of non-compliance status, termed ‘Non-compliance’, constructed from state-level annual compliance data. This variable indicates the years when a state fails to fully comply with the RPS, capturing variation in the post-RPS period for states that have adopted the policy. A state is designated to be in Non-compliance if total renewable generation within the state eligible for compliance – whether from existing or new capacity, contracted capacities, or REC market purchases, in-state or out-of-state – falls short of the requirement level.<sup>33</sup>

The non-compliance status is used to link observed investments to the policy. If full compliance is not reached in a given year, all new renewable capacities available during that year, regardless of the sourcing channel, are expected to be used by retail firms for compliance purposes, yet the state still fails to meet the requirement. For a retailer facing non-compliance penalties, it would be inefficient not to use available renewable energy from new capacity in that year. Therefore, the RPS policy’s influence on renewable investments is expected to be stronger in non-compliance years, allowing us to attribute the observed investments to the policy with greater confidence. This serves as a complement to our analysis, where some econometric methods face challenges in estimating a clear causal relationship between policy and investment.<sup>34</sup> We elaborate more on this non-compliance

<sup>33</sup>Some states allow renewable energy (RECs) generated out-of-state to count toward compliance, leading retail companies to contract with out-of-state capacities or purchase out-of-state credits. For a detailed discussion of RPS spillover effects across states and the REC trading scheme, see [Hollingsworth and Rudik \(2019\)](#) and [Abito et al. \(2025\)](#). We also summarize documented spillovers in capacity contracting in Tables [E.1](#) and [E.2](#), with further discussion in the Online Appendix [E.3.1](#).

<sup>34</sup>Our identification strategy does not require investment in noncompliance years to be greater than in compliance years. Although there is a positive correlation between noncompliance and investment, the relationship is not

measure, as well as the variable’s exogeneity, in Section 4.3.

To account for the degree of incomplete compliance, we introduce the *RPS Goal* variable, which measures the shortfall from the target in a given year. For example, if the compliance percentage is 80% with a total target of  $X$  MWh, the RPS goal is 20% of  $X$  MWh. This variable complements our Non-compliance indicator, which is binary and does not capture the extent of the deficit. Figure 6 provides an example of the Non-compliance and RPS Goal variables for Connecticut. The solid line represents the annual RPS requirement, calculated as RPS target (%) multiplied by total electricity sales (MWh), with Non-compliance and RPS Goal variables plotted together.

## 4.2 Different measures of vertical structure

We construct a variable, termed *VS* (Vertical Separation), to measure the degree of vertical separation between the generation and retail sectors at the state level. Although vertical structure at the firm level is binary, representing vertical integration or separation at the state level requires more than a simple binary indicator. We introduce two additional versions of this variable: a generation-sector-based measure and a retail-sector-based measure. We discuss the relationship between these measures, as well as the details on the construction of these variables, in Appendix C.

### 4.2.1 Binary indicator for vertical separation.

The first measure is a binary variable indicating each state’s restructuring status. Although restructuring can occur in wholesale or retail markets, or both (as discussed in Section 2.3), wholesale market restructuring is more relevant to the vertical relationships we examine. That is, wholesale restructuring increases separation between generation and retail, as retail firms must purchase electricity from the market rather than generating it themselves. Therefore, we assigned  $VS_{\text{binary}} = 1$  to states that have restructured their wholesale sectors.<sup>35</sup> This categorization closely resembles the list of generation-based restructured states used in the literature as well as policy reports (Fabrizio et al. (2007), Borenstein and Bushnell (2015), MacKay and Mercadal (2024), and the EPA<sup>36</sup>).

The restructuring process began in the mid-1990s, before the launch of RPS policies, with a focus on reforming inefficient monopolies that primarily relied on fossil fuel generation, rather than on renewables, which were not yet prevalent. For this reason, the vertical structure – and thus the *VS* measure – is exogenous to the RPS policy.

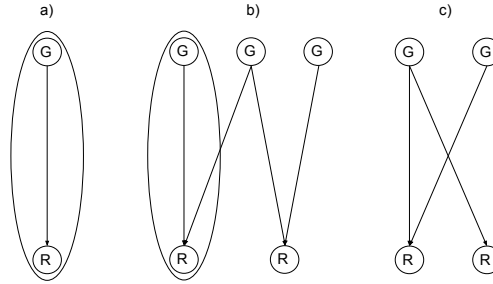
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statistically significant.

<sup>35</sup>We assigned  $VS_{\text{binary}} = 1$  to the following states: NY, RI, NH, MA, ME, CT, DE, MD, NJ, PA, IL, OH, MI, OR, TX, VA, and CA.

<sup>36</sup><https://www.epa.gov/greenpower/understanding-electricity-market-frameworks-policies>

Figure 7: Different market structures and their vertical separation nature



*Notes:* Arrows represent sales of power from generation entities to retailers. Ovals represent joint ownership. a) Fully vertically integrated: A classic electricity utility company where both generation and retail are owned by the same company. b) Partial vertical separation: A wholesale generator that sells also to an independent retailer. c) Fully vertically separated structure.

#### 4.2.2 Continuous measures using firm-level information

While a binary indicator for state-level restructuring is common in many studies, it has limitations due to the lack of a unified definition, with restructuring and deregulation often used interchangeably and not clearly distinguishing between wholesale and retail sectors (Borenstein and Bushnell (2015)). In practice, restructuring did not always lead to complete separation between generation and retail, as utilities in restructured states often continue to own and operate generation assets (see Section 2.4).

To illustrate the need for a continuous measure of vertical separation, Figure 7 depicts three possible configurations in the electricity sector, all of which can coexist within the same state. The simplest configuration is full vertical integration, where all generators and retail assets belong to the same company. Another case is partial vertical integration, where a retail firm generates electricity using its own assets while also purchasing electricity from an independent upstream firm. Finally, there is full vertical separation, where the generation and retail sectors share no common ownership.

Given the varying degrees of vertical ties across states, we develop continuous measures of vertical separation using firm-level data on these relationships, which are then aggregated at the state level for our analysis.

**Vertical separation measure using generation capacity data.** The first continuous vertical separation variable,  $VS_{gen}$ , measures the extent to which generation capacities in the wholesale market are not owned by retail firms. Using EIA 860 data, we calculate the share of generation capacity within a state that is not vertically integrated – not directly owned by firms operating in the retail sector.<sup>37</sup> To address potential endogeneity in shares as new investments occur, we fix the

<sup>37</sup>This share is based on total available capacity, not the utilized capacity (i.e., share or sales), and includes all fuel types.

variable at its 2002 value, before most states adopted RPS, for all subsequent years.

**Vertical separation measure using the retail provider and generator.** The previous measure,  $VS_{\text{gen}}$ , focused on the wholesale sector and did not incorporate retail sector information. Since the RPS primarily affects retail electricity providers, we develop a continuous measure of vertical separation,  $VS_{\text{retail}}$ , which accounts for retail market conditions. This measure captures the presence of retail firms that do not have direct vertical linkages with the wholesale sector. Using data from EIA Form 861, which includes information on retail firms – such as total sales and revenues – in each state, we identified retail firms without generation assets and computed their share of retail sales (total annual electricity sales in MWh) within the state.<sup>38</sup> To address potential endogeneity from changes in market shares driven by retailer compliance strategies and new investments, we fix the variable at its 2002 value, before most states adopted RPS. Nevertheless, our VS measure remains relatively stable over time, as summarized in [Table E.13](#), suggesting that vertical structure is not substantially affected by additional investments.

### 4.3 Main specification

Taking into account all of the previous considerations, we estimate the following regression model:

$$\begin{aligned} \text{Renewable Investment}_{s,t} &= \alpha_0 + \alpha_1 \text{RPS Goal}_{s,t} + \alpha_2 \text{Non-compliance}_{s,t} \\ &+ \beta VS_s \times \text{Non-compliance}_{s,t} + \sum_{l=-2}^{l=+2} \lambda_l D_{s,t^*+l} \\ &+ \sum_{l=-2}^{l=+2} \gamma_l D_{s,t^*+l} \times VS_s + \gamma' \mathbf{X}_{s,t} + \varepsilon_{s,t}. \end{aligned} \quad (1)$$

To that end, we use only states that have adopted RPS. Thus, our empirical analysis differs from a standard difference-in-difference estimation, where RPS-adopting states are considered treated and non-adopting states serve as the control group. As discussed in [Section 4.1](#), we adopt this modified approach because increasing policy target levels and retailers' regulatory compliance motives, which are present only in states that have adopted an RPS, better explain changes in state investments than the RPS adoption event alone.<sup>39</sup>

The dependent variable  $\text{Renewable Investment}_{s,t}$  represents the aggregate level of new investments in wind and solar generation capacity in state  $s$  and year  $t$ , as explained in [Section 3](#).<sup>40</sup> Note

<sup>38</sup>We include only retail firms with at least 5% of the market share in terms of total annual sales.

<sup>39</sup>We implemented a staggered difference-in-differences analysis using the [Callaway and Sant'Anna \(2021\)](#) estimator to investigate the causal relationship between RPS adoption and renewable investment, as presented in [Table A.2](#) in the Appendix. The results are consistent with those of [Deschenes et al. \(2023\)](#), showing that the adoption of an RPS policy increases renewable investments.

<sup>40</sup>Since there is no investment in some years in some states, we cannot use a logged investment variable to address a potential scaling problem. However, incorporating state-level capacity and RPS requirement sizes in the specification partially mitigates this issue.

that our focus is not on analyzing individual firms’ decisions to invest in renewable generation, which would require using firm-plant level data as the primary variable. Instead, we examine the outcomes of individual-level decisions in an aggregate sense. We use the year  $t$  when the new capacity starts operations and match that year with the RPS variables of that same year. Since the schedule of annual RPS targets is set up several years in advance, the typical process of contracting for investment is that the plant construction is planned and decided years in advance so that the plant can go online at the time needed to comply with the RPS. For these reasons, we believe that new investments strategically planned for RPS compliance and that come online in year  $t$  are relevant to the RPS requirement for that year.

The main variable of interest is the interaction of the state’s market structure measure ( $VS$ ) and the Non-compliance status.<sup>41</sup> Therefore, the coefficient  $\beta$  captures to what extent the changes in investment in renewable assets differ across different vertical structures conditional on non-compliance. We also control for RPS Goal, which captures how far the state is from complying with the policy.  $\mathbf{X}_{s,t}$  includes state-level controls, such as total capacity and total net generation, net import flows into the state from neighboring states, average profitability of a MW renewable capacity, as well as year fixed effects and market (Regional Transmission Organization) fixed effects.<sup>42</sup> Note that we included state fixed effects to control for any policy changes that occurred within the state that could potentially affect the investment. In all specifications, standard errors are clustered at the state level. To capture time trends that are common to all states but that only occur around the point in time of non-compliance in certain states, we added time dummies  $D_{s,t^*+l}$  associated with each year  $l$  before and after the event – the year  $t^*$  in which the state is non-compliant – in a separate set of robustness specifications as well as the interaction of these dummies and the vertical separation measure.<sup>43</sup>

The data span from 2002 to 2020, including the states that have eventually adopted RPS by 2020.<sup>44</sup> We use only the years after the state enacted the RPS policy because the compliance variable cannot be defined for years before the RPS policy started. Since each state enacted RPS in different years, we have an unbalanced panel data set. Note that most states, a total of 18 states,

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<sup>41</sup>We do not include  $VS$  as a separate regressor since we include state fixed effects.

<sup>42</sup>The average profitability of 1 MW of renewable capacity is directly related to the total generation per MW within the state, similar to a capacity factor. Since states with favorable weather conditions achieve higher utilization of their renewable capacity, this variable reflects the profitability of renewable assets based on weather conditions.

Total capacity and net generation capture the size differences of the electricity sectors across states. Capacity and generation values associated with the contemporaneous year’s capacity investment are excluded from these control variables.

<sup>43</sup>We used a window of two years before and after the event. These dummy variables are different from the year fixed effects. This is inspired by some of the specifications in [Greenstone and Nath \(2021\)](#) and from the use of similar dynamic effects specifications in a different context in [Vanmutelli \(2022\)](#).

<sup>44</sup>We do not use investment data prior to 2002 because the restructuring process was completed in most of the states by 2002 and those investment data prior to 2002 are contaminated with the investment boom that resulted from restructuring.

adopted an RPS policy between 2002-2008, and the data are not significantly unbalanced.<sup>45</sup>

**Identification.** We discuss several issues related to identifying our empirical model. First, our objective is not to identify the underlying drivers of investment decisions. In general, identifying the motives or determinants of investment using observed data is challenging and requires entirely different empirical methods along with strong assumptions.

Our focus, instead, is on investments that can plausibly be linked to the RPS policy. To narrow the sample in a way that strengthens this link, we take several steps. We restrict attention to states that are required to comply with the policy, and we isolate investments that are contractually tied to retail companies subject to those compliance obligations. To further address the concern that some contracted capacities may not actually be used for compliance, we focus on investments occurring in non-compliance years (see Section 2.2). The key assumption is that when a state is classified as non-compliant in a given year, all new renewable capacity that came online during that year was used toward compliance, yet the state was still unable to fully comply. Under this assumption, investments made in these years are more closely linked to the RPS policy. Therefore, while we do not claim to identify a causal effect in the traditional sense, our empirical approach is designed to focus on cases where the link between the policy and the observed investments is most credible, and to examine how the differences in vertical structures explain the investment patterns.

The estimation of the interaction term in Equation (1) relies on these two assumptions: that the residuals are uncorrelated with the state’s market structure ( $VS$ ) and uncorrelated with whether or not the state is non-compliant. For the former, the vertical market structure in each state evolved primarily due to the deregulation movement that preceded the relatively recent RPS policy. We also keep the level of  $VS$  fixed over time, using the value of the year prior to the policy enactment in each state.

The exogeneity of the Non-compliance variable follows from noting that the Non-compliance variable for state  $s$  in year  $t$  can be represented as:

$$\text{Non-compliance}_{s,t} = \mathbf{1}(G_{s,t} < \tau_{s,t}R_{s,t}),$$

where  $\tau_{s,t}$  is the RPS target rate and  $R_{s,t}$  is total retail electricity sales, both of which are exogenous variables determined outside the wholesale sector.  $G_{s,t}$  represents the total annual generation from renewable sources used for compliance, including the generation from newly installed capacity that comes online in year  $t$ , which is our dependent variable  $Y_{s,t}$ . Since the generation from this year’s new capacity is included in  $G_{s,t}$ , one might think that the Non-compliance variable could be endogenous. However, note that the variable is an indicator function, and the inequality  $G_{s,t} < \tau_{s,t}R_{s,t}$  defining

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<sup>45</sup>Although our sample spans over the period 2002 to 2020, the RPS compliance data do not exist for latter years of the sample in some states.

this function holds even when excluding the generation from the new capacity  $Y_{s,t}$ . In other words, if  $G_{s,t}$  (including the generation from  $Y_{s,t}$ ) falls below the target requirement ( $\tau_{s,t}R_{s,t}$ ), the inequality will also hold when the generation from  $Y_{s,t}$  is excluded. We have also verified that the inequality for full compliance (i.e.,  $G_{s,t} \geq \tau_{s,t}R_{s,t}$ ) continues to hold when excluding the generation from newly installed capacities. This implies that the Non-compliance variable, as an indicator function, is not determined by  $Y_{s,t}$  and is therefore exogenous with respect to  $Y_{s,t}$ . More details on this argument can be found in [Appendix B](#).

#### 4.4 Results

The results of regression (1) using the three different measures of vertical separation (binary, generation capacity, and retail sales) are shown in [Table 1](#) and in detailed form in Appendix Tables [A.3](#), [A.4](#), and [A.5](#). In the three cases, our variable of interest ( $VS \times$  Non-compliance) has a negative and statistically significant coefficient except for the specifications without the full set of covariates included, which we show in the Appendix. In other words, our coefficient of interest reveals that renewable investment is lower when there is no compliance and the retail sector is more separated from the generation sector relative to states that are more integrated. The positive coefficient for the Non-compliance variable confirms that investments sizes are larger in years of deficits, which corresponds to retail firms planning more investment for years in which generation will fall short of the RPS requirement.

Although our preferred measure of vertical separation is the retail sales measure, shown in column (3), estimates for  $VS \times$  Non-compliance in all three columns in [Table 1](#) are qualitatively similar, ranging between  $-270.1$  and  $-112.9$ . On average, conditional on being non-compliant in a given year, states with a more vertically separated structure invest less in renewable capacities than their more vertically integrated counterparts by a factor between 0.6 and 1.5 times the overall average investment in renewables, with the latter factor being the one associated with our preferred measure. Our findings correspond to the differential impacts by vertical structure in investment in the contracting channel as discussed in [Section 2.4](#).

As previously mentioned, we estimated specifications where we also included time dummies corresponding to each year before and after a non-compliance year. These results can be found in [Appendix A](#). Across all the different measures of vertical separation, this type of specification gives estimates that are also consistent with our main results. In addition, in [Tables E.5 - E.7](#) in the Online Appendix we report the same regressions as in this section but without using contract-linked data but only data from the EIA. The results are largely similar but slightly larger standard errors.

Table 1: Renewable investment and compliance using different measures of vertical separation

	(1)	(2)	(3)
	Binary VS	Generation VS	Retail VS
	Renewable Investment		
VS x Non-compliance	-112.9** (49.73)	-216.0** (100.3)	-270.1** (108.1)
Non-compliance	104.6** (48.12)	184.2** (87.83)	153.8** (62.11)
RPS goal (GWh)	0.00308 (0.0167)	-0.00004 (0.0192)	-0.00112 (0.0210)
Net summer capacity (MW)	0.0955*** (0.0333)	0.0933*** (0.0322)	0.0910*** (0.0294)
Net generation (GWh)	-0.00702 (0.00786)	-0.00632 (0.00765)	-0.00657 (0.00725)
Renewable per cap. lag (GWh per MW)	-0.00600 (0.0178)	-0.00659 (0.0174)	-0.00986 (0.0186)
Net flow lag (GWh)	2.056 (3.725)	2.518 (3.836)	1.244 (3.854)
Constant	-4078.3*** (515.4)	-4155.0*** (482.3)	-3900.5*** (411.8)
$N$	388	388	388
Adj. $R^2$	0.61	0.62	0.62
Dep. var. mean	183.27	183.27	183.27
Market FE	✓	✓	✓
State FE	✓	✓	✓
Year FE	✓	✓	✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New renewable capacity (MW). Each column corresponds to the results obtained using each of the three different measures of vertical separation: binary, continuous-generation, and continuous-retail. The data combine EIA and FERC information, see main text for further details. For each state, only years when RPS policy had been put in place. Standard errors clustered at the state level.

**Placebo test.** Natural gas-fired generators dominated the new fossil fuel capacity investment in the past few decades. As a placebo test, we run the same regressions using the state-level investment in natural gas-fired generation only as a dependent variable. Investment in natural gas and coal plants is not affected by the RPS regulation; thus, these additional regressions serve as a natural placebo test for the vertical structure’s effects on the RPS-induced renewable investment.

Tables E.8, E.9, and E.10 in Online Appendix show the result of the regression specification in Equation (1) with the dependent variable replaced with the aggregate state-level investment in fossil fuel generation. We combine the investments in natural gas, coal, and oil generation to construct this variable. In all of the twelve specifications (three measures of vertical separation and four specifications each) we find a positive coefficient and only two of them are statistically significant. In other words, there is not a relationship between the RPS policy and investments in non-renewable capacity conditional on the market structure. However, the coefficient on Non-compliance has a negative and statistically significant sign in Column (4) of the three tables, indicating that in the absence of compliance, there is less investment on fossil-fuel capacity due to a substitution effect towards investment in renewables.

**Wind and solar investments.** One potential concern is that our results may be driven by a specific type of technology. To address this question, Tables E.11 and E.12 in the Online Appendix show the results of the same model of this section but with a dependent variable that measures the investment in wind and solar capacity, respectively. This specification isolates the effect that the RPS policy has on each of the two most commonly adopted renewable technologies in the US conditional on market structure. In this case, we use  $VS_{\text{retail}}$ . Similarly to the results when aggregating both types of investment, the estimate for the  $VS \times$  Non-compliance is negative and significant in our preferred specifications, with a combined effect that roughly corresponds to the effect using total renewable capacity.

#### 4.5 The effect of the Renewable Energy Credits (RECs) market on investment

Section 2.4 discussed the two main channels through which investments can occur: the contracting channel and the Renewable Energy Credit (REC) market channel. We assumed that the differential effect of vertical structure on investment is primarily driven by the contracting channel and that investments through the REC market channel do not significantly differ by vertical structure. Although the best way to empirically verify this is to include REC spot market variables in our main regression to control for investment variation explained by REC market conditions, we cannot include these variables due to data limitations. REC market data, especially spot prices of credits, are not publicly available, and only a few states report monthly statistics for solar REC

(SREC) prices.<sup>46</sup>

Omitting REC market variables could bias our estimate if investments through the REC market channel do occur and affect the differences in investment patterns attributable to the vertical market structure, which is captured by our main coefficient of interest (for the variable  $VS \times \text{Non-compliance}$ ). In this subsection, we discuss whether attractive REC market conditions – characterized by high REC price levels – could either crowd out or enhance investments occurring through the contracting channel and examine the direction of bias associated with each case when not accounting for the REC market related variables in the analysis. We then empirically confirm the direction of the bias from an analysis using a subsample for which REC market data are available.

**The effect of the REC market channel on the contracting channel investment.** We explain how the existence of a REC market channel investment may indirectly affect contracting channel investments, considering the incentives of both retail and wholesale firms. We first discuss the effects separately for vertical separation and vertical integration and then compare the two.

On the retailer’s side, attractive REC market conditions for renewable project developers in the wholesale sector – high REC prices – are unfavorable for retailers since they are buyers of these credits. Therefore, a retail firm is more likely to comply through the contracting channel when REC spot prices are high, regardless of its vertical structure.

When considering a wholesale firm’s incentive, two possible cases arise under vertical separation, depending on whether the REC market channel is perceived as a reliable source for a wholesale firm planning to invest, providing stable revenue for recovering investment costs – that is, as an alternative to contracting.

First, if wholesalers view the REC market as a reliable investment channel, they are more likely to shift away from the contracting channel toward the REC market to finance their investments, particularly if contracting is more challenging and commitment to contracts is weaker than in the integrated case. However, as retailers are more inclined to choose the contracting channel when REC market conditions favor wholesalers, a misalignment in upstream and downstream incentives emerges, further reducing contracting channel investments compared to a scenario without the REC market option. This suggests that attractive REC market conditions (e.g., high REC prices) could crowd out contracting channel investments in vertically separated environments.

Second, if the REC market channel is not well established, that is, wholesalers do not view it as a reliable source comparable to the contracting option, they would not switch to the REC market channel even under attractive REC market conditions. At the same time, since retailers prefer the

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<sup>46</sup>For example, the PJM Interconnection provides summary statistics for REC prices for states within the market through the PJM-GATS (Generation Attribute Tracking System) platform, which includes weighted average prices from both long- or mid-term contracts and spot prices for solar capacity (See <https://www.pjm-eis.com/>).

contracting channel, overall contracting channel investment may increase, or at least not be crowded out by an attractive REC market.

In the vertically integrated case, where upstream and downstream incentives are aligned, investment decisions are driven by retailer’s needs, making the reliability of the REC market to wholesaler irrelevant. Since retailers prefer the contracting channel when REC market prices rise, contracting channel investments in vertically integrated environments are not crowded out by an attractive REC market.

Since our main focus is on differential impacts across vertical structures, we now summarize whether the presence of an attractive REC market channel intensifies or reduces the investment differences. This depends on the direction of the crowd-out effects discussed above. In summary, if the REC market channel is a reliable source of investments for wholesalers, the presence of an attractive REC market is expected to further intensify differences in contracting channel investments between vertically integrated and separated structures. On the other hand, if the REC market channel is not well established, an attractive REC market would not intensify these differences but instead reduce the gap in contracting channel investment between the two vertical structures.

**REC market variable as an omitted variable and the direction of bias.** Based on the previous discussion, we know that while the REC market channel ( $Z$ ) itself does not affect the contracting channel investment ( $Y$ ) directly, it could change the differential effects across vertical structures, our main coefficient for  $X = VS \times \text{Non-compliance}$ . We can formalize this problem as

$$Y = \beta_0 + (\beta_1 + \beta_2 Z) X + \varepsilon,$$

where the effect of  $X$  could be affected by  $Z$ . If  $Z$  is present, the effect of  $X$  on  $Y$  is more intensified if  $\beta_1$  and  $\beta_2$  have the same sign, and more subdued if  $\beta_1$  and  $\beta_2$  have different signs. Since we do not include  $Z$  in the analysis, we can assess the direction of the bias for  $\beta_1$  in this case. In [Appendix D](#) we obtain that the expression for this bias is  $\beta_2 E[Z]$ .<sup>47</sup>

The sign of  $\beta_2$  depends on whether the REC market channel works or not, as discussed earlier. Thus, we can test whether this channel amplifies the difference between vertical structures (for crowding out the contracting channel) or reduces the gap between vertical structures. If it amplifies the difference, this implies that the signs of  $\beta_1$  and  $\beta_2$  are the same, while in the case where the difference is reduced,  $\beta_1$  and  $\beta_2$  must have opposite signs. Since  $\beta_1 < 0$ , this indicates that the bias will be negative if the REC market is working well, and the bias is positive if not. In other words, in the former case, our main regression without the REC market channel variable ( $Z$ ) would estimate a  $b_1$  that is larger in magnitude than when including  $Z$ . If the bias is positive, the estimate would be smaller in magnitude than when including  $Z$ .

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<sup>47</sup>The sign of  $E[Z]$  is positive since we use REC prices as our variable for  $Z$ .

Table 2: With REC price as a control: Solar investment in PJM (using  $VS_{\text{retail}}$ )

	(1)	(2)	(3)
	Solar Cap Investment		
VS x Non-compliance	-60.96*	-69.26*	-80.83**
	(31.56)	(36.88)	(30.98)
Non-compliance	35.56	38.31	34.39
	(26.41)	(27.87)	(28.70)
RPS goal (GWh)	0.00120	0.00149	0.00239
	(0.00352)	(0.00364)	(0.00343)
Net generation (GWh)	0.00307*	0.00328*	0.00335*
	(0.00154)	(0.00172)	(0.00177)
Net summer capacity (MW)	0.0160	0.0157	0.0169
	(0.00953)	(0.00969)	(0.0101)
REC price( $t$ ) x VS x Non-compliance		0.00481	
		(0.1000)	
REC price( $t - 1$ ) x VS x Non-compliance			0.0587
			(0.0884)
Constant	9.858	13.39	10.13
	(10.89)	(9.629)	(11.51)
$N$	93	88	86
$R^2$	0.64	0.64	0.64
Dep. var. mean	32.35	34.17	34.97

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable is the new solar capacity (MW) that enters each state every year. This analysis includes only PJM states. All regressions include state, year FE. Standard errors are clustered at the year level. REC price ( $t$ ) variable is the first month price of the contemporaneous year and REC price ( $t - 1$ ) variable is the average price of the previous year (lagged value). The Non-compliance variable has been adjusted to capture compliance for solar-specific requirements in states that have a separate requirement for solar.

**Subsample regression including REC market variables.** We empirically verify the direction of bias using a small sample of states within the PJM interconnection, where REC market data are available. PJM publishes summary statistics of solar renewable credits traded within the region, but only for the solar renewable credits (SRECs). Thus, we restrict our analysis to investments in *solar* generation capacity within these states. We use the state-level (weighted-average) prices of individually transacted solar RECs from 2008 to 2020, averaging the monthly prices to the yearly level to make the time consistent with our main dataset. The ‘Non-compliance’ variable is adjusted for states that have separate RPS target levels and compliance statuses for solar generation capacity.

We use the same specification as in Equation (1) using solar investment capacities as the dependent variable. Results are presented in Columns (1)-(3) in Table 2. Column (1) shows the result when not including the REC market variables. In Columns (2) and (3) regressions, we specify REC price variable interacted with our main variable, to capture differential impacts across vertical

structure further being impacted by the REC market channel. We use the contemporaneous year’s REC price (but of the first month) in Column (2) regression and one-year lagged REC price in Column (3).<sup>48</sup> Given that RECs can be traded between states within PJM, the standard errors are clustered at the year level.<sup>49</sup>

Comparing the results of Column (1) to Columns (2) and (3), we find that the coefficient of our main variable,  $VS \times \text{Non-compliance}$ , changes from  $-60.96$  to  $-69.26$  and  $-80.83$ , respectively after adding the REC price control variables. This indicates a positive bias, since column (1) estimate is smaller in magnitude than in (2) and (3), which would occur if the REC market investment channel is not active and wholesale firms not making investment decisions based on REC market signals. It also implies that the results from our main estimation, which omits this variable due to data limitations, might be biased towards zero; the negative estimate for the  $VS \times \text{Non-compliance}$  variable would likely be larger in magnitude if REC market variables were included. However, note that the size of bias is not substantially large, so while our main analysis may have underestimated the true effect of vertical structure, the potential bias is not worrisome.

While the sample size is small to make a definitive statement about REC market channel investment, both the sign and the magnitude of bias from our small sample analysis hints on that the REC market investment channel may not be working properly and not serving as an alternative of contracting option. This may be attributed to the unattractive REC market conditions, which do not offer a reliable basis for wholesalers’ investment decisions. For instance, REC prices are heavily influenced by the state’s compliance status and can vary considerably.<sup>50</sup> This is particularly true for solar renewable credits (SRECs). In our sample, SREC prices are significantly higher in non-compliance years by about 24.7% on average. Moreover, Table 3 summarizes monthly SREC prices in the PJM market from 2008 to 2020, showing substantial volatility – from \$0 to about \$700/MWh, even within the same month.<sup>51</sup> The high variability in credit prices suggests that renewable project developers are unlikely to base their investment decisions solely on revenues from selling RECs in the spot market, as these revenues are uncertain and heavily influenced by a state’s compliance status.

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<sup>48</sup>Because new investments could affect the spot prices of RECs within the same year, we used the average monthly REC price of the first month (January) of each calendar year to avoid simultaneity in REC price determination.

<sup>49</sup>Most states require retailers to acquire credits issued within the same state, but some allow purchases from other states to meet RPS requirements. For example, Pennsylvania allows credits purchased within the PJM interconnection to be used for compliance (Abito et al. (2025)). Additionally, due to the small sample size, clustering at the state level would result in very small cluster sizes.

<sup>50</sup><https://www.nrel.gov/docs/fy14osti/61042.pdf>

<sup>51</sup>A price of zero occurs when there is excess supply relative to demand (with very low or zero demand for credits).

Table 3: Summary Statistics: Solar Renewable Energy Credits (SREC) Price – PJM states

Price (\$/MWh, monthly)	mean	med	min	max	s.d.	N
Weighted average price	181.25	156.49	0	654	145.23	1,594
Lowest price	76.14	16.75	0	648	107.39	1,594
Highest price	431.28	460	0	715	131.87	1,594

*Notes:* Data from PJM states only, 2008 - 2020.

## 5 Conclusion

This paper examines one of the major U.S. policies promoting renewable generation – the Renewable Portfolio Standards. We carefully analyze the structure of the policy and the incentives it creates in the energy sector, acknowledging that the effectiveness of compliance through investment may depend on the vertical relationship between the upstream generation and downstream retail sectors. Our findings show that the amounts of investment in renewable generation capacity resulting from restrictions imposed by the Renewable Portfolio Standards largely differ depending on the vertical structure of the electricity sector in a given state.

Although we find that investments made to comply with the policy are larger in states with closer vertical relationships, this does not imply that the historical form of vertical integration in this sector should be preferred over vertical separation. Vertically integrated and regulated structures are well known to generate inefficiencies, such as excessive investment, many of which have been mitigated by separating the generation and retail sectors. Nevertheless, when the objective of the policy is to stimulate substantial investment in a particular technology, the traditionally inefficient structure may, in some cases, be more effective at achieving policy goals. For the RPS policy – where retail firms are responsible for inducing upstream investment – a closer vertical relationship appears more effective for meeting policy goals. The variation in policy effectiveness across different vertical structures suggests that policy design and implementation should account for these differences. By applying a uniform, market structure-neutral approach, current policies may have inadvertently hindered efforts to decarbonize the electricity sector.

While our analysis is subject to certain caveats – primarily the lack of granular data and the complex institutional environment created by a state-level policy, which limits the ability to apply clean causal identification strategies – we believe that the core message of the paper – that market structure plays a critical role in shaping policy outcomes – offers valuable insights for the design of future energy policies.

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# Appendices

## A Tables and Figures

Table A.1: Alternative Capacity Payments (ACP): by state, year 2014

State	ACP payment (\$/MWh)
CT	\$55 (class 1 and class 2)
DC	\$50 (Tier 1 and Solar), \$10 (tier 2)
DE	\$80 (non-solar), \$500 (solar)
IL	Average rec price paid by IPA
MA	\$73.7 (class 1 non-solar), \$30.3 (class 2 existing re), \$12.1 (class 2 -waste energy), \$384 (class 1 solar -Srec 1 program), \$316 (class 1 solar-SREC 2 program)
MD	\$40 (tier 1 non-solar), \$15 (tier 2), \$50 (tier 1 solar)
ME	\$70.9 (new renewables tier)
NH	\$62.1 (class 1 new RE), \$28.2 (class 1-thermal), \$62.1 (class 2 -solar), \$40.1 (class 3- existing biomass), \$33.8 (class 4 – existing small hydro)
NJ	\$50 (tier 1 and 2), \$239 (solar)
OH	\$61.0 (non-solar), \$50 (solar)
OR	Established bi-annually by Oregon PUC (\$110 for 2014 and 2015)
PA	\$45 (tier 1 non-solar and tier 2), 2x market value of RECs (tier 1 solar)
RI	\$73.9
TX	Financial penalty (\$50/MWh)

Source: [Heeter et al. \(2014\)](#).

Table A.2: Staggered differences-in-differences analysis

	(1)	(2)
Overall ATT	100.98 (79.72)	29.26 (59.54)
Average over 1-5 years post	31.61 (26.19)	-6.36 (47.34)
<i>N</i>	940	940
Controls		✓

*Notes:* Dependent variable: New renewable capacity (MW). [Callaway and Sant'Anna \(2021\)](#) estimator. Standard errors in parentheses.

Table A.3: Renewable investment and compliance using binary measure of vertical separation

	(1)	(2)	(3)	(4)
Non-compliance x VS	-88.41 (206.1)	-89.90 (208.9)	-112.9** (49.73)	-120.1** (45.19)
Non-compliance	71.51 (60.37)	69.41 (60.74)	104.6** (48.12)	97.75*** (32.74)
RPS goal (GWh)		0.00613 (0.0201)	0.00308 (0.0167)	-0.00947 (0.0218)
Net summer capacity (MW)		0.0955***	0.0921*** (0.0333)	(0.0291)
Net generation (GWh)		-0.00702	-0.00504 (0.00786)	(0.00647)
Renewable per cap. lag (GWh per MW)			-0.00600 (0.0178)	-0.00755 (0.0171)
Net flow lag (GWh)			2.056 (3.725)	3.320 (3.752)
Constant	1117.4*** (130.2)	1111.7*** (116.0)	-4078.3*** (515.4)	-4388.6*** (775.5)
<i>N</i>	388	388	388	388
Adj. <i>R</i> <sup>2</sup>	0.47	0.47	0.61	0.61
Dep. var. mean	183.27	183.27	183.27	183.27
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New renewable capacity (MW). The data combine EIA and FERC information, see main text for further details. For each state, only years when RPS policy had been put in place. Dynamic effects with a window +/-2 years. Standard errors clustered at the state level.

Table A.4: Renewable investment and compliance using a continuous measure of vertical separation (generation capacity)

	(1)	(2)	(3)	(4)
Non-compliance x VS	-250.4 (162.5)	-249.6 (164.6)	-216.0** (100.3)	-183.7*** (63.09)
Non-compliance	181.3 (153.6)	179.4 (163.2)	184.2** (87.83)	147.8** (55.80)
RPS goal (GWh)		0.00298 (0.0204)	-0.0000413 (0.0192)	-0.00680 (0.0227)
Net summer capacity (MW)			0.0933*** (0.0322)	0.0939*** (0.0317)
Net generation (GWh)			-0.00632 (0.00765)	-0.00621 (0.00747)
Renewable per cap. lag (GWh per MW)			-0.00659 (0.0174)	-0.00525 (0.0162)
Net flow lag (GWh)			2.518 (3.836)	2.757 (3.816)
Constant	1074.9*** (62.37)	1072.0*** (50.68)	-4155.0*** (482.3)	-4243.3*** (599.8)
<i>N</i>	388	388	388	388
Adj. <i>R</i> <sup>2</sup>	0.47	0.47	0.62	0.61
Dep. var. mean	183.27	183.27	183.27	183.27
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New renewable capacity (MW). The data combine EIA and FERC information, see main text for further details. For each state, only years when RPS policy had been put in place. Dynamic effects with a window +/-2 years. Standard errors clustered at the state level.

Table A.5: Renewable investment and compliance using a continuous measure of vertical separation (retail sales)

	(1)	(2)	(3)	(4)
Non-compliance x VS	-444.7* (236.5)	-445.3* (241.8)	-270.1** (108.1)	-213.4*** (75.89)
Non-compliance	201.9 (139.1)	203.0 (151.6)	153.8** (62.11)	115.4*** (38.83)
RPS goal (GWh)		-0.00167 (0.0254)	-0.00112 (0.0210)	-0.0101 (0.0269)
Net summer capacity (MW)			0.0910*** (0.0294)	0.0916*** (0.0285)
Net generation (GWh)			-0.00657 (0.00725)	-0.00692 (0.00741)
Renewable per cap. lag (GWh per MW)			-0.00986 (0.0186)	-0.0122 (0.0192)
Net flow lag (GWh)			1.244 (3.854)	1.019 (4.152)
Constant	967.5*** (81.06)	969.0*** (65.65)	-3900.5*** (411.8)	-3871.5*** (545.8)
<i>N</i>	388	388	388	388
Adj. <i>R</i> <sup>2</sup>	0.49	0.49	0.62	0.61
Dep. var. mean	183.27	183.27	183.27	183.27
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New renewable capacity (MW). The data combine EIA and FERC information, see main text for further details. For each state, only years when RPS policy had been put in place. Dynamic effects with a window +/-2 years. Standard errors clustered at the state level.

## B Identification

In Section 4.3 we discuss the identification of the main parameter  $\beta$  with a particular focus on the Non-compliance variable of state  $s$  in year  $t$  which can be formally represented as follows:

$$\text{Non-compliance}_{s,t} = \mathbf{1}(G_{s,t} < \tau_{s,t}R_{s,t}).$$

The RPS target percentage  $\tau_{s,t}$ , is determined by state legislation independently of actual wholesale and retail market conditions. Moreover, the target levels are set and published in advance, allowing market participants to observe the targets for the coming years. The variable  $R_{s,t}$  represents the total electricity sales within the state, which are determined by consumers and subject to various exogenous shocks. For this reason, the right-hand side of the inequality is exogenous from the investor or generators' point of view.  $G_{s,t}$  represents the total annual generation from renewable sources used for compliance, including the generation from newly installed capacities, Renewable Investment $_{s,t}$ , which refer to as  $Y_{s,t}$  throughout the discussion.

Now we argue that while the value of  $G_{s,t}$  itself is not independent of  $Y_{s,t}$ , as it contains generation sourced from  $Y_{s,t}$ , the inequality condition that determines the Non-compliance variable – an indicator function – is independent of  $Y_{s,t}$ . To clarify, let  $G_{s,t}^*$  represent the total annual renewable generation *excluding* the generation from new capacities coming online in year  $t$ ,  $Y_{s,t}$ . When denoting the generation from  $Y_{s,t}$  as  $\tilde{G}_{s,t}$ , the variable  $G_{s,t}^* = G_{s,t} - \tilde{G}_{s,t}$ . Then, if  $G_{s,t} < \tau_{s,t}R_{s,t}$ , it follows that  $G_{s,t}^* < \tau_{s,t}R_{s,t}$ , meaning the same inequality condition that determines the Non-compliance variable can be satisfied without  $Y_{s,t}$ .

We also verify whether the inequality condition in the opposite direction – namely,  $G_{s,t} \geq \tau_{s,t}R_{s,t}$ , which corresponds to full compliance – is preserved when excluding the generation from new capacities in year  $t$ . The situation of concern is a full-compliance year that follows a non-compliance year. For example, if the annual compliance rate was 97% in year  $t - 1$  and increased to 100% in the subsequent year  $t$ , one may worry that the inequality direction could change once the generation from new capacity,  $\tilde{G}_{s,t}$ , is excluded, thereby violating the exclusion restriction.

We address this by calculating the change in the compliance requirement across years  $t - 1$  and  $t$  that was needed to shift the status from non-compliance to full compliance (i.e.,  $\Delta\text{Compliance}_t = G_{s,t} - G_{s,t-1}$ ) and then comparing this to the generation from newly invested capacities in year  $t$  (i.e.,  $\tilde{G}_{s,t}$ ). Although we do not observe the exact amount of generation from new capacities, we approximate it by multiplying the new capacity ( $Y_{s,t}$ ) by the state-specific capacity factors for solar and wind generation reported by the EIA (using separate factors for solar and wind).<sup>52</sup>

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<sup>52</sup>We use the capacity factor in year 2023. The capacity factor is not dependent on the level of capacity and instead captures utilization rates determined by weather conditions. Source: [https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep\\_fuel/html/fuel\\_cf.html&sid=WI](https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_fuel/html/fuel_cf.html&sid=WI).

Because the maximum utilization of capacities is capped, the generation from renewable capacities available as of year  $t - 1$  will be similar in the subsequent year. This implies that any additional increase in the compliance requirement is expected to be met by generation from new capacities in year  $t$ . We check for years in which the additional generation from new capacity in year  $t$  exceeds the additional compliance requirement, namely  $\Delta\text{Compliance}_t < \tilde{G}_{s,t}$  – the condition corresponding to the case in which full compliance would not be met (i.e. the inequality would flip) when contemporaneous generation is excluded. A formal representation of the condition we check is:

$$\Delta\text{Compliance}_t = G_{s,t} - G_{s,t-1} < \tilde{G}_{s,t}. \quad (2)$$

Rearranging this condition gives

$$G_{s,t} - \tilde{G}_{s,t} < G_{s,t-1}. \quad (3)$$

Because year  $t - 1$  is non-compliant,  $G_{s,t-1} < \tau_{s,t-1} R_{s,t-1}$  holds. Thus, equation (3) becomes,

$$G_{s,t} - \tilde{G}_{s,t} < \tau_{s,t-1} R_{s,t-1}. \quad (4)$$

Since RPS target requirement ( $\tau$ ) increases over time by design, and retail consumption increases monotonically, the following holds:  $\tau_{s,t-1} R_{s,t-1} < \tau_{s,t} R_{s,t}$ . Therefore, equation (4) becomes,

$$G_{s,t} - \tilde{G}_{s,t} = G_{s,t}^* < \tau_{s,t} R_{s,t}. \quad (5)$$

Equation (5) characterizes the violation of the inequality in the opposite direction when excluding the generation coming from new capacities coming online in year  $t$ . Therefore, checking the condition shown in equation (2) for full-compliance year ( $t$ ) that follows a non-compliance year is equivalent to identifying sample observations in which the inequality in the opposite direction does not hold. We categorize these years as non-compliance years instead.<sup>53</sup>

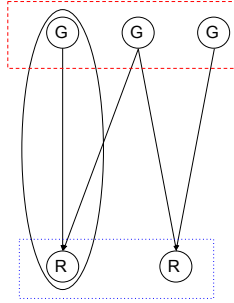
## C Relationships between the three measures of vertical separation

We explain how the continuous measures are constructed using [Figure B.1](#). In the generation sector, shown in the upper red dashed box, one of the three generators (G) is owned by a downstream retailer (R), shown in the lower blue dotted box. To calculate  $VS_{\text{gen}}$ , we compute the share of generation capacities that are not owned by a retail firm. Assuming equal capacities for all three generators,  $VS_{\text{gen}}$  is  $\frac{2}{3}$ . On the other hand, in the retail sector (blue box), one of the two retail firms owns a generator. The share of retail sales of the firm that does not own generation assets represents  $VS_{\text{retail}}$ . Assuming equal market shares,  $VS_{\text{retail}}$  is  $\frac{1}{2}$ . This example demonstrates that the two continuous measures of vertical separation,  $VS_{\text{gen}}$  and  $VS_{\text{retail}}$ , do not necessarily coincide.

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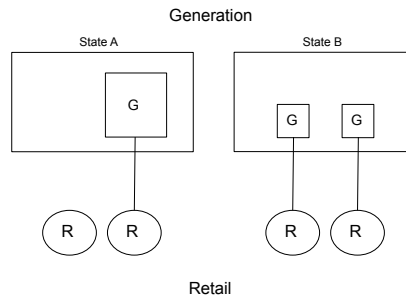
<sup>53</sup>There were only two state-year combinations in which this condition was violated.

Figure B.1: Construction of continuous VS measures



*Notes:* Arrows represent sales of power from generation entities to retailers. Ovals represent joint ownership. When constructing the VS measure using the generation capacity data (red dashed rectangle), we obtain  $VS = 0.66$  (assuming equal generation capacities). However, when using the retail sales data (blue rectangle at bottom), then  $VS = 0.5$  (assuming equal sizes of retail sales).

Figure B.2: Comparison of VS measures



*Notes:* The figure describes the status of vertical relationship between the generators and retailers, which differ across two states A and B. Lines between retail (R) and generation (G) indicate that a vertical relationship (integration) exists between these sectors.

The key difference between  $VS_{gen}$  and  $VS_{retail}$  lies in the sector where the shares of vertically linked firms are calculated. We believe  $VS_{retail}$  more accurately reflects the vertical linkages relevant to our research question. This is demonstrated in [Figure B.2](#), which depicts two states with the same number of retail firms but differing vertical ownership statuses. In state A, half of the retail sector is vertically integrated with upstream generators, though the integrated generator's capacity is large. In state B, all retail firms are integrated with generators, but integrated generators are smaller in capacities. Since all retail firms in state B have vertical ties with the upstream, our notion of vertical integration suggests that it is more pervasive in state B, making state A more vertically separated than state B.  $VS_{retail}$  captures this by assigning a higher value to state A, while  $VS_{gen}$  assigns a lower value to state A due to the large size of the vertically integrated generator.

[Table B.1](#) presents summary statistics for the three measures of vertical separation. While these measures differ from one another, they are somewhat correlated. [Figure E.3](#) in the Online Appendix

Table B.1: Summary statistics of measures of vertical separation (VS)

	Mean	Min	Max	S.D.
Binary ( $VS_{\text{binary}}$ )	0.50	0	1	0.51
Generation capacity ( $VS_{\text{gen}}$ )	0.50	0.04	1	0.37
Retail sales ( $VS_{\text{retail}}$ )	0.28	0	1	0.39

Notes:  $N = 31$ . See main text for a description of the three different ways to measure vertical separation. The three measures take on values in the unit interval.

depicts the pairwise correlations, showing the highest correlation of 0.8 between the two continuous  $VS$  measures. However, when comparing these measures at the state level, significant differences emerge for some states. This is shown in Figure B.3, where each dot represents the combination of  $VS_{\text{gen}}$  and  $VS_{\text{retail}}$  for each state.<sup>54</sup>

## D REC Channel Investment

As discussed in Section 4.5, if the REC market channel functions effectively, the presence of an attractive REC market is expected to increase the difference in RPS-driven investment patterns between vertically integrated and vertically separated structures, resulting in a more negative coefficient for the main variable of interest in the regression. On the other hand, if the REC market channel is not effective – meaning it is not a reliable source of investment for wholesale firms – the presence of an attractive REC market would have minimal effect or reduce the difference in RPS-driven investment, resulting in minimal change or a more positive coefficient for the main variable of interest.

From this, we know that while the REC market channel ( $Z$ ) itself does not affect the contracting channel investment ( $Y$ ) directly, it could change the differential effects across vertical structures, our main coefficient for  $VS \times$  Non-compliance ( $X$ ). We can formalize this problem as

$$Y = \beta_0 + (\beta_1 + \beta_2 Z) X + \varepsilon,$$

where the effect of  $X$  could be affected by  $Z$ . If  $Z$  is present, the effect of  $X$  on  $Y$  is more intensified if  $\beta_1$  and  $\beta_2$  have the same sign, and more subdued if  $\beta_1$  and  $\beta_2$  have different signs.

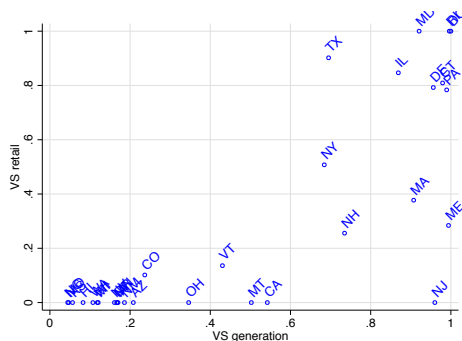
Since we do not include  $Z$  in the analysis, we can assess the direction of the bias for  $\beta_1$  in this case. We estimate the linear model

$$Y = b_0 + b_1 X + v \quad \text{where} \quad v = (\varepsilon + \beta_2 Z X).$$

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<sup>54</sup>For example, in California,  $VS_{\text{gen}}$  is slightly above 0.5, while the  $VS_{\text{retail}}$  is close to 0, indicating that California’s retail sector has a strong vertical ties with the generation sector. In California, although a large portion of generators are not tied to retailers, all retailers operating within the state own generation capacity in the wholesale sector.

Figure B.3: Vertical separation measures by state: retail sales and generation capacity



*Notes:* For most states, the Vertical Separation measure using retail sales data is similar to that obtained using generation capacity shares.

Then the bias of  $b_1$  would be represented by

$$\text{bias} = \frac{\text{Cov}(X, \beta_2 ZX)}{\text{Var}(X)} = \beta_2 \frac{\text{Cov}(X, ZX)}{\text{Var}(X)}.$$

The direction of bias depends on the sign of  $\beta_2$  since the sign of the accompanying factor is positive because  $\text{Var}(X) > 0$  and  $\text{Cov}(X, ZX) > 0$ . To see why, by expanding  $\text{Cov}(X, ZX)$  we obtain

$$\begin{aligned} \text{Cov}(X, ZX) &= E[X^2 Z] - E[X]E[ZX] \\ &= E[X^2]E[Z] - E[X]E[Z]E[X] \\ &= E[Z](E[X^2] - E[X]^2) \\ &= E[Z]\text{Var}(X) > 0, \end{aligned}$$

where the second line assumes  $\text{Cov}(X, Z) = 0$  (weak version of independence), which holds because the REC price and  $VS \times$  Non-compliance are uncorrelated. Since  $Z$ , which is a price value, is positive,  $E[Z] > 0$  and  $\text{Var}(X) > 0$ , making the entire expression positive.

The bias expression can be further reduced to:

$$\text{bias} = \beta_2 \frac{E[Z]\text{Var}(X)}{\text{Var}(X)} = \beta_2 E[Z]$$

The sign of  $\beta_2$  depends on the effectiveness of REC market channel, as discussed earlier. Thus, we can test whether the REC market channel has a crowding out effect (wholesalers viewing this as a reliable channel) or the opposite effect (REC market channel not working well). The former would be the case where signs of  $\beta_1$  and  $\beta_2$  are the same and the latter is where they have opposite signs. Since our coefficient  $\beta_1$  has a negative sign, this indicates that bias will be negative if the REC market is working well, and bias is positive if not. In other words, if the former case, our main

regression without REC market channel variable ( $Z$ ) would estimate  $b_1$  that is larger in magnitude than when including it, and if the latter case, the estimate would be smaller in magnitude than when including it.

## Online Appendix

### E.1 A Simple Model of Investment and Market Structure

We start with elements from the models in [Coria and Jaraite \(2024\)](#) and [Brown and Sappington \(2022\)](#) but with crucial differences to adapt it to the RPS policy.

**Vertically separated.** To gain tractability, we only consider the case of an upstream monopolist and a downstream monopolist. The downstream electricity retailer purchases its power from the upstream generator. The profits of the downstream firm are

$$\pi_D^{VS} = p_r q_D - p_w(1 - \tau)q_D - p_c \tau q_D$$

where  $p_r$  is the retail price,  $p_w$  is the wholesale price,  $q_D$  is the quantity sold by the retailer and it is exogenous in the model,  $p_c$  is the price of a REC credit or the price established in a bilateral contract and exogenous to the model,  $\tau \in [0, 1)$  is the RPS requirement. The first term is simply the gross profits from selling  $q_D$  units of electricity. The second term is the cost associated with purchasing power that is not subject to the RPS regulation. The last term is the costs imposed by the regulation.

Note that *full compliance* occurs when the downstream firm can find enough  $\tau q_D$  units of renewable output through contracts or through the REC market:

$$\tau q_D \leq q_s,$$

where  $q_s$  is the amount of renewables output.

There is no compliance if that is not the case. In particular, when in the following equations we refer to Non-compliance, we refer to the situation  $\tau q_D = q_s$ .

Upstream, the profits are different depending on the compliance status:

$$\begin{aligned} \text{Compliance: } \pi_U^{VS} &= p_w(1 - \tau)q_D + \underbrace{p_c \tau q_D}_{\text{RPS revenue}} - \underbrace{c_f(q_D - q_s) - c_s(q_s)}_{\text{variable costs}} - C_{VS}(I_{VS}) \\ \text{Non-compliance: } \pi_U^{VS} &= p_w(q_D - q_s) + \underbrace{p_c q_s}_{\text{RPS revenue}} - \underbrace{c_f(q_D - q_s) - c_s(q_s)}_{\text{variable costs}} - C_{VS}(I_{VS}) \end{aligned}$$

where  $q_f = q_D - q_s$  is the quantity of electricity from fossil fuels,  $c_f$  and  $c_s$  are the variable cost functions for fossil fueled power plants and for renewable plants, and  $C_{VS}(I_{VS})$  is the cost of investing in  $I_{VS}$  units of renewables capacity. If there are more retailers or more upstream firms we just need to take this into account with aggregate quantities and capacity constraints within a proper competition model.

If we take the first order condition of the upstream firm with respect to the investment amount and remembering that  $q_D$  is a constant:

$$\begin{aligned} \text{Compliance: } & (c'_f(q_D - q_s) - c'_s(q_s)) \frac{\partial q_s}{\partial I_{VS}} + \tau q_D \frac{\partial p_c}{\partial q_s} \frac{\partial q_s}{\partial I_{VS}} = C'_{VS}(I_{VS}) \\ \text{Non-compliance: } & (-p_w + p_c + c'_f(q_D - q_s) - c'_s(q_s)) \frac{\partial q_s}{\partial I_{VS}} + q_s \frac{\partial p_c}{\partial q_s} \frac{\partial q_s}{\partial I_{VS}} = C'_{VS}(I_{VS}) \end{aligned} \quad (6)$$

where the second term on the LHS is negative if we assume  $\frac{\partial p_c}{\partial q_s} < 0$  and  $\frac{\partial q_s}{\partial I_{VS}} > 0$ . The first inequality captures a scarcity effect in which if there is plenty of renewable output, the price of RECs would decrease. The second inequality represents that investing in renewable capacity increases renewable output. We can further assume that  $c'_s(q_s) = 0$  but this is irrelevant for what follows.

**Vertically integrated.** Now there is only one firm with profits function

$$\pi^{VI} = p_r q_D + p_w \underbrace{[q_f + q_s - q_D]}_{=0 \text{ if closed mkt}} + \underbrace{p_c [q_s - \tau q_D]}_{\text{credits sold}} - c_f(q_D - q_s) - c_s(q_s) - C_{VI}(I_{VI})$$

and a different investment costs function  $C_{VI}(I_{VI})$ .

Note that *full compliance* occurs when  $q_s - \tau q_D > 0$  and the policy is just *non-compliant* when  $q_s - \tau q_D = 0$ .

Taking the first order condition with respect to the investment amount:

$$\begin{aligned} \text{Compliance: } & (p_c + c'_f(q_D - q_s) - c'_s(q_s)) \frac{\partial q_s}{\partial I_{VI}} + (q_s - \tau q_D) \frac{\partial p_c}{\partial q_s} \frac{\partial q_s}{\partial I_{VI}} = C'_{VI}(I_{VI}) \\ \text{Non-compliance: } & (c'_f(q_D - q_s) - c'_s(q_s)) \frac{\partial q_s}{\partial I_{VI}} = C'_{VI}(I_{VI}). \end{aligned} \quad (7)$$

Similarly to the VS case, assume that  $\frac{\partial p_c}{\partial q_s} < 0$  and  $\frac{\partial q_s}{\partial I_{VI}} > 0$ .

**Comparing optimal investment amounts.** Suppose that one extra unit of renewable capacity produces the same additional amount of output regardless of the market structure, in other words assume that

$$\frac{\partial q_s}{\partial I_{VS}} = \frac{\partial q_s}{\partial I_{VI}}.$$

Subtract [Equation 7](#) from [Equation 6](#):

$$\begin{aligned} \text{Compliance: } & -p_c \frac{\partial q_s}{\partial I_{VI}} + (2\tau q_D - q_s) \frac{\partial p_c}{\partial q_s} \frac{\partial q_s}{\partial I_{VI}} = C'_{VS}(I_{VS}) - C'_{VI}(I_{VI}) \\ \text{Non-compliance: } & (-p_w + p_c) \frac{\partial q_s}{\partial I_{VI}} + q_s \frac{\partial p_c}{\partial q_s} \frac{\partial q_s}{\partial I_{VI}} = C'_{VS}(I_{VS}) - C'_{VI}(I_{VI}) \end{aligned} \quad (8)$$

The left-hand-side of the Compliance expression above is guaranteed to be negative since  $\frac{\partial p_c}{\partial q_s} < 0$  and if we assume that  $\tau$  cannot be too small:

$$\tau > \frac{q_s}{2q_D}.$$

The left-hand-side of the Non-compliance expression is negative if the inverse elasticity of REC prices with respect to renewables output is bounded from above by a negative number

$$\frac{q_s}{p_c} \frac{\partial p_c}{\partial q_s} < \frac{p_w - p_c}{p_c},$$

which is achieved if  $p_c > p_w$ . That is consistent with the observation that if there is no compliance, the value of RECs is most likely higher than that of the non-regulated electricity output. The inequality above can be interpreted as follows. The inverse elasticity cannot be too close to 0 because that would indicate that the REC price does not react too much to changes in renewable output, and if that was the case, then more investment in renewable capacity would have no effect whatsoever on the value of a REC.

**Relationship between investment costs.** Therefore, for both the Compliance and the Non-compliance cases we have

$$C'_{VS}(I_{VS}) < C'_{VI}(I_{VI}). \quad (9)$$

We make the following assumptions regarding the two cost functions. (1) the cost functions are increasing,

$$C'_i(\cdot) > 0$$

for  $i \in \{VS, VI\}$ , and (2) the investment costs under vertically separated structures  $C_{VS}$  increase faster than the investment costs under vertically integrated markets  $C_{VI}$ , or equivalently

$$C'_{VS}(x) \geq C'_{VI}(x) \quad (10)$$

for any given level of investment  $x$ . Assumption (2) would hold if marginal investment costs in vertically separated markets increase substantially more as the investment size grows than in vertically integrated markets since the latter have a higher monopsony power and ability to bargain.

By combining [Equation 9](#) with [Equation 10](#) we get

$$C'_{VS}(I_{VS}) < C'_{VI}(I_{VI}) \leq C'_{VS}(I_{VI})$$

and therefore, by assumption (1),  $I_{VS} < I_{VI}$ . In other words, the investment under the VS market structure is lower than in the vertically integrated case.

If the two cost functions are identical, assumption (1) alone and [Equation 9](#) takes us to the exact same conclusion.

**The role of the RPS requirement  $\tau$ .** The LHS of [Equation 8](#) in the Compliance case can be rewritten as follows

$$2q_D \frac{\partial p_c}{\partial q_s} \frac{\partial q_s}{\partial I_{VI}} \tau + (\text{terms that do not depend on } \tau)$$

and we know that the whole expression is negative. In addition, the slope  $2q_D \frac{\partial p_c}{\partial q_s} \frac{\partial q_s}{\partial I_{VI}}$  is negative itself.

Since the slope is negative, an increase in  $\tau$  makes the whole expression more negative while approaching the Non-compliance case. This has the consequence that as  $\tau$  increases, there is a larger difference between the two types of investment:  $I_{VS} \ll I_{VI}$ .

## E.2 Data and Variables

### E.2.1 FERC Form 1: Identifying the Contracting Channel Investment

EIA Form 860 contains the list of power plants along with the name of the plant’s owner. There are two types of owners appearing in the data: Independent Power Producers (IPPs) and Electric Utilities. Since the electric utilities are the companies operating in the retail sector, we can sort out the generators that are owned by electric utilities, namely the generators directly invested and operated by the downstream retailer, from this EIA dataset. The generation capacities sorted out in this way are referred to as vertically integrated investments.

However, electric utilities also actively contract with the IPPs to invest in renewable capacity. These contracted generation assets are not directly invested by the utilities, and for that reason, IPPs are listed as their owners in the EIA Form 860. Therefore, we cannot sort out such contracted assets solely from the EIA data.

To complement the EIA and to find the contracting relationships, we use the FERC Form 1 data. The FERC Form 1 data, *yearly purchased power and exchanges* section, lists the companies from which electric utilities purchase electricity. The form includes information such as the name of the power plant owner, the type of contract (e.g., LU indicates a long-term agreement), and the name of the retail company that set up the contract. We can verify from this form that retail companies do contract with and purchase a substantial amount of electricity from IPP invested renewable assets, through long-term purchasing agreements.

For example, PG&E (Pacific Gas Electric Co.), one of the electric utilities in California, owns many power plants that appear in the EIA Form. However, FERC Form 1 data show that the company has purchasing contracts with renewable generators not listed as owned by PG&E in the EIA Form. Examples include *Mega Renewables*, *EDF Renewables*, *Pristine Sun*, *Alamo Solar*, *Agua Caliente Solar*, *AV solar ranch*, and *Bear Creek Solar*. These facilities do appear in the EIA Form 860, but PG&E is not listed as their owner, and they are part of IPP investments. This suggests that the directly invested capacity (vertical integration case, with owner listed as the retail company) is the lower bound of retail company’s total contracting channel investment.

We cross-checked using the retail company’s compliance reports to make sure that the FERC

Form 1 information accurately captures the contracting relationship between the retail company (electric utility) and the IPP invested renewables. [Figure E.1](#) is an excerpt from the RPS compliance report filed by one of the electric utilities in Arizona, APS (Arizona Public Service), in 2016. The table shows a list of renewable resources acquired by APS either through direct investment (ownership = ‘APS’) or by contracting (ownership = ‘3rd party PPA’). A substantial amount of generation used for compliance comes from third-party PPA, which are capacities invested by IPPs.

**Steps.** We identified renewable generation assets contracted with each major electric utilities from the FERC Form 1 data. Since the FERC data itself does not contain basic information about the generation assets, such as the nameplate capacity, we matched each assets in the FERC Form to the EIA dataset. Since there is no common identifier that links the FERC data and the EIA data, we manually matched the names of generation assets in both datasets. For example, *Alamo Solar* is listed as contracted assets of PG&E in the FERC data, and we found Alamo Solar from the EIA dataset and encoded the basic information.

While the FERC dataset enables us to identify the contractual relationship as well as the exact identities of the firms and generators involved, there are limitations to this data. First, not all retail companies appear in the dataset. In our analysis, we restrict the sample to retailers with at least 5% of the retail market share (based on residential customers). Even so, not all retailers file the FERC Form, leaving some out. For example, since Texas is not regulated by FERC, none of the electric utilities in Texas appear in this FERC form. Another issue is that some electric utilities appear to contract with major IPPs rather than with individual renewable assets. For example, an electric utility might have contracts only with large IPPs that supply a diverse set of generation sources (e.g., Exelon, Calpine, NextEra), including renewables, or with large IPPs that specialize in renewable asset investments (e.g., Avangrid, Brookfield Renewables, Iberdrola Renewables). In these cases, we assume that the large IPPs contract with or invest in renewables on behalf of the electric utilities. For these utilities, we cannot separate out contracting channel investments and instead use state-wide renewable additions as the main variable.

To address this limitation, we use two types of capacity investment variables in our analysis. The first is the total state-level capacity of new renewable generators sourced through the contracting channel by retail firms in each state. This variable combines: (i) new generators owned by IPPs but contracted with retail firms (identified from the FERC data) and (ii) new generators vertically integrated with retail firms (identified from the EIA 860).<sup>55</sup> The second variable is the total state-level capacity of new renewable generation, without separating the capacities by their sourcing channels. Although the first variable is our primary focus, we use the second variable for states

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<sup>55</sup>Note that we cannot further separate out the capacities possibly invested with the motive to supply unbundled Renewable Energy Credits (RECs) from their generation, which is a limitation we elaborate on in [Section 4.5](#).

Figure E.1: Renewable Investment: IOU vs. IPP

Table 1b - Renewable Resources

Resource	Technology	Ownership	MWac <sup>1</sup>	MWdc <sup>1</sup>	Production (Actual)	Production + (Annualized) <sup>2</sup>	Multiplier Credits	Total MWh or Equivalent
<b>GENERATION:</b>								
Aragonne Mesa	Wind	3rd Party PPA	90		236,847			236,847
High Lonesome	Wind	3rd Party PPA	100		243,509			243,509
Perrin Ranch	Wind	3rd Party PPA	99		191,913			191,913
Snowflake White Mountain Power	Biomass	3rd Party PPA	14		100,901			100,901
Sexton (Glendale Landfill)	Landfill Gas	3rd Party PPA	3		19,295			19,295
Northwest Regional Landfill Gas	Landfill Gas	3rd Party PPA	3		22,855			22,855
Salton Sea/CE Turbo	Geothermal	3rd Party PPA	10		73,874			73,874
Ajo	Solar PV	3rd Party PPA	5		9,219			9,219
Badger 1 Solar	Solar PV	3rd Party PPA	15		39,707			39,707
Gillespie 1 Solar	Solar PV	3rd Party PPA	15		42,787			42,787
Prescott	Solar PV	3rd Party PPA	10		25,618			25,618
Saddle Mountain	Solar PV	3rd Party PPA	15		35,827			35,827
AZ Sun: Chino Valley	Solar PV	APS	19		46,476			46,476
AZ Sun: Cotton Center	Solar PV	APS	17		42,798			42,798
AZ Sun: Foothills I/II	Solar PV	APS	35		110,820			110,820
AZ Sun: Hyder I	Solar PV	APS	16		42,004			42,004
AZ Sun: Hyder II	Solar PV	APS	14		43,826			43,826
AZ Sun: Paloma	Solar PV	APS	17		39,257			39,257
AZ Sun: Gila Bend	Solar PV	APS	32		104,802			104,802
AZ Sun: Luke AFB	Solar PV	APS	10		18,441			18,441
AZ Sun: Desert Star	Solar PV	APS	10		14,817			14,817
Small Solar Projects	Solar PV	APS	4		7,443		3,721	11,164
Solana CSP	Solar CSP	3rd Party PPA	250		718,834			718,834
<i>Gross Total</i>			<b>803</b>		<b>2,231,870</b>		<b>3,721</b>	<b>2,235,591</b>
<i>Adjustments</i>								
	Special Contracts <sup>7</sup>				(40,095)			(40,095)
	Green Choice Sales				(78,129)			(78,129)
	Wholesale DE Allocation				(41,923)			(41,923)
<b>Subtotal Generation</b>			<b>803</b>		<b>2,071,722</b>		<b>3,721</b>	<b>2,075,443 (A)</b>
<b>DISTRIBUTED ENERGY (DE):</b>								
<i>Recipients:</i>								

Notes: This is taken from APS (Arizona Public Service)'s RPS compliance report filed for 2016. Table shows a list of renewable resources acquired either through direct investment (ownership = 'APS') or by contracting (ownership = '3rd party PPA').

with missing FERC data.

## E.2.2 State-level Variables

We specify state-level market variables to control for any differences across states that may affect the investment decision. We have compiled datasets from the EIA Electric Power Annual, including total annual net summer capacity and net generation to account for the electricity generation scale differences across states.<sup>56</sup>

We also control for the general profitability of renewable generation in each state. States have different weather conditions that result in different operation hours of renewable generation. For example, a solar panel may operate longer hours in Arizona than in Minnesota and a wind plant may generate longer hours, and more continuously, in Idaho than in Arizona. Operating longer hours means higher profits from the regular spot market and bilateral market. To capture this difference resulting from weather, we calculate the annual generation per MW of existing renewable generation capacity at the state level, which represents the average capacity factor of renewable

<sup>56</sup><https://www.eia.gov/electricity/annual/>

generation in each state.<sup>57</sup>

Lastly, we obtain data on the annual net interchange (net flows) between the states within the same interconnection from the EIA Electric Power Annual to account for any physical trades of renewable generation across states that could have been caused by the RPS. Although it is ideal to check net flows at the daily or hourly level, we had to resort to the annual data to match the frequency of the main dataset. Since renewable generation investments affect the import/export volumes of a given year, we take a lag of this variable and include it in the regression. The net interchange data capture some of the spillovers of the RPS policy in generation in addition to the spillovers in capacity that our contract-level data already account for.

## E.3 Additional Factors Affecting RPS Compliance

### E.3.1 Spillover effect: Out-of-state investment

The RPS policy in one state can influence renewable investment in neighboring states if compliance is possible using out-of-state renewable generation (Hollingsworth and Rudik (2019)). A retail company (electric utility) in one state can contract with out-of-state renewable generation assets that are planned for construction to source electricity from those plants once they are operational. While Hollingsworth and Rudik (2019) examined the cross-state spillover of electricity generated from renewable assets, FERC data allow us to analyze spillovers in invested capacities across states. From the contract data, we can identify which out-of-state power plants are tied to a state’s electric utilities through purchasing power agreements, thereby establishing a link between power plants and electric utilities (retailers).

**Summary of capacities by the retailer’s state** We established a link between a specific renewable generator and electric utility (retail company), along with the capacity size, and the year in which the generators became operational. We then summarized the average size of renewable capacities contracted by electric utilities in each state where these utilities are located.

Table E.1 summarizes the in-state and out-of-state capacities. From the RPS Years columns (using sample years after RPS enactment), about 80% of the capacity amounts contracted by retail companies in California (with an average size of 825.7 MW) are constructed within the same state, while 20% (with an average size of 266 MW) are located out-of-state, sourced from five nearby states. In contrast, retail companies in Oregon primarily contract with out-of-state generators, with about 90% of the contracted capacity amounts (average size of 238.8 MW) located outside Oregon.

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<sup>57</sup>To avoid incorporating contemporaneous year capacity additions, we use the operating hours per MW of renewable capacity with a one year lag.

Table E.1: Average In-state, Out-of-state Contracted Capacities: By Retailer’s State

State (retail)	Full Sample				RPS Years			
	In-state (MW)	Out-state (MW)	% out	# states	In-state (MW)	Out-state (MW)	%out	# states
AZ	117.02	58.12	0.3	2	117.02	58.12	0.3	2
CA	775.73	243.99	0.2	7	825.69	266.08	0.2	5
CO	218.55	49.17	0.2	3	230.32	94.00	0.3	2
DE	11.30	89.25	0.9	2	11.30	89.25	0.9	2
IA	112.93	21.50	0.2	1	112.93	21.50	0.2	1
IL	.	199.70	.	1	.	199.70	.	1
MA	15.00	52.28	0.8	4	15.00	52.28	0.8	4
MI	68.39	4.00	0.1	1	113.72	.	.	0
MN	82.97	90.90	0.5	3	78.75	90.90	0.5	3
MO	.	300.00	.	1	.	.	.	0
NC	212.99	29.19	0.1	3	285.54	32.40	0.1	2
NH	27.73	.	.	0	33.53	.	.	0
NM	88.21	160.49	0.6	2	72.72	186.73	0.7	2
NV	97.73	108.00	0.5	1	96.54	108.00	0.5	1
NY	10.75	.	.	0	.	.	.	0
OH	81.00	600.30	0.9	1	81.00	600.30	0.9	1
OR	59.82	314.55	0.8	6	37.63	238.80	0.9	3
RI	5.03	.	.	0	3.50	.	.	0
VT	5.00	52.67	0.9	2	5.00	77.00	0.9	1
WA	504.49	132.53	0.2	4	68.58	18.50	0.2	1
WI	11.10	175.00	0.9	1	11.10	175.00	0.9	1
<i>N</i>	21							

*Notes:* This table presents in-state and out-of-state contracted capacities by state, summarized from our FERC identified contracted capacity data. *State* (retail) denotes the state in which a retail company with data entries in the FERC dataset is located. Capacities of power plants (solar and wind only) contracted with a retailer in the state are summed over the years at the state level. The *Full sample* summary includes all years in the sample, while *RPS years* covers the years after the state has enacted the RPS policy. *In-state capacity* refers to the total capacity of contracted generators located within the retailer’s state, and *Out-state capacity* refers to the total capacity of contracted generators located outside the retailer’s state. *# states* indicates the number of these outside states, and *% out* shows the percentage of out-of-state capacities relative to the total contracted capacities.

**Summary of capacity amounts by the renewable plant’s state** We also summarize the capacities by the states where the renewable power plants that contracted with retailers are located, as shown in [Table E.2](#). The table displays the average size of renewable generation capacities in each state contracted with in-state retailers (in-state MW) and out-of-state retailers (out-of-state MW). Based on the RPS Years columns, generators in states like California, Colorado, North Carolina, and Ohio are mostly contracted to in-state retailers, whereas those in other states have roughly half or more of their capacities contracted with out-of-state retailers.

**Summary and discussion.** This basic summary of contract data shows that sourcing renewables is not restricted to the state level but can be expanded to cover neighboring states, indicating a possible spillover of state-level policy. There is substantial heterogeneity in cross-state contracting patterns: some states source only within their own state, some rely exclusively on other states, and many have varying proportions of both.

The determination of a state’s compliance hinges on the inclusion of renewable generation from out-of-state sources. Consequently, a state is deemed non-compliant if, even after accounting for renewable electricity generated outside its borders, it fails to meet the RPS requirement. Hence, our assumption that all in-state capacities brought online during a non-compliant year contribute to RPS compliance, heavily influenced by RPS policies, remains valid despite the presence of the spillover effect.

Nevertheless, the actual size of new investments induced by the state’s RPS policy will be under/over-measured if the spillover effect is not accounted for. For example, if a retailer in California contracts with a solar plant in Arizona to comply with the RPS policy, the solar capacity in Arizona is driven by the RPS policy in California, not by the policy in Arizona. Thus, the actual capacity induced by California’s RPS policy is under-measured, while that of Arizona is over-measured.

Using contract-level data addresses the spillover issue by including capacities contracted by retailers in the state, regardless of their sourcing locations. In other words, we account for all capacities contracted with retail companies in California, irrespective of where these assets are located. For instance, solar capacity in Arizona contracted by a California retailer will be included in California’s RPS-induced capacity. This approach helps mitigate potential under- or over-measurement of capacities associated with the state’s RPS policy.

However, it is important to note that these data do not capture spillovers related to unbundled RECs. Retailers can also meet compliance by purchasing unbundled RECs from other states. If new capacity is built outside the state to supply credits to buyers within the state, this investment occurs through the REC market channel. While we have included net interchange data – reflecting

Table E.2: Average In-state, Out-of-state Contracted Capacities: By Plant's State

State(plant)	Full Sample				RPS Years			
	In-state(MW)	Out-state(MW)	%out	#states	In-state(MW)	Out-state(MW)	%out	# states
AZ	117.02	151.12	0.6	1	117.02	149.34	0.6	1
CA	775.73	75.60	0.1	5	825.69	75.60	0.1	5
CO	218.55	.	.	0	230.32	.	.	0
CT	.	28.45	.	1	.	28.45	.	1
DE	11.30	11.80	0.5	1	11.30	11.80	0.5	1
GA	.	1.00	.	1	.	.	.	0
IA	112.93	243.33	0.7	3	112.93	143.33	0.6	2
ID	.	83.07	.	3	.	96.40	.	2
IN	.	800.00	.	2	.	800.00	.	2
MA	15.00	4.50	0.2	1	15.00	5.00	0.2	0
MD	.	40.00	.	1	.	40.00	.	1
ME	.	52.66	.	1	.	52.66	.	1
MI	68.39	149.00	0.7	1	113.72	149.00	0.6	1
MN	82.97	21.50	0.2	1	78.75	21.50	0.2	1
MT	.	124.10	.	2	.	102.25	.	1
NC	212.99	.	.	0	285.54	.	.	0
ND	.	11.90	.	1	.	11.90	.	1
NH	27.73	48.00	0.6	1	33.53	48.00	0.6	1
NJ	.	4.00	.	1	.	.	.	0
NM	88.21	270.77	0.8	2	72.72	95.00	0.6	1
NV	97.73	113.91	0.5	2	96.54	125.44	0.6	2
NY	10.75	.	.	0	.	.	.	0
OH	81.00	.	.	0	81.00	.	.	0
OK	.	199.00	.	1	.	199.00	.	1
OR	59.82	251.12	0.8	2	37.63	318.50	0.9	1
PA	.	46.70	.	2	.	46.70	.	2
RI	5.03	25.00	0.8	1	3.50	25.00	0.9	1
SC	.	14.61	.	1	.	12.20	.	1
SD	.	175.05	.	1	.	175.05	.	1
UT	.	208.67	.	1	.	264.58	.	1
VT	5.00	.	.	0	5.00	.	.	0
WA	504.49	684.65	0.6	2	68.58	90.00	0.6	1
WI	11.10	.	.	0	11.10	.	.	0
WY	.	110.67	.	2	.	86.00	.	1
<i>N</i>	35							

*Notes:* This table presents in-state and out-of-state contracted capacities by state, summarized from our FERC identified contracted capacity data. State (plant) denotes the state in which a contracted renewable power plant is located. Capacities of power plants (solar and wind only) that are contracted are summed over the years at the state level. The *Full sample* summary includes all years in the sample, while *RPS years* covers the years after the state has enacted the RPS policy. *In-state* capacity refers to the total capacity of power plants contracted with retailers located in the same state as the generators, while *Out-state* capacity refers to the total capacity of power plants contracted with retailers located outside the plant's state. *# states* indicates the number of these outside states where contracted retailers are located, and *% out* shows the percentage of out-of-state capacities relative to the total contracted capacities.

the net flow of imports between states – to account for some spillover related to physical electricity generation, this does not fully address the limitation because the unbundled REC trading does not involve physical electricity flow into the grid and is thus not captured by net interchange variations. Nevertheless, since our analysis assumes the REC market channel investments are unaffected by vertical structure, the inability to separately account for this channel’s investments will not critically impact our main empirical results.

### **E.3.2 Other policies affecting renewable investment**

It is important to recognize that while the RPS policy is the oldest at the federal level in the US, other incentives for renewable generation have been put in place in some states and at the federal level in recent years. Two such policies are the feed-in-tariffs and the Federal Tax Investment Credit, respectively. However, the main difference between those policies and the RPS is that the former do not represent a mandate and impose no obligations on stakeholders, whereas the RPS policy stipulates an obligation. Abroad, other countries have adopted policies to incentivize the investment on renewables assets as well. A similar policy to the RPS exists in Sweden and Norway, the Electricity Certificate System (<https://t.ly/FkoCq>, see [Coria and Jaraite \(2024\)](#) for a study on this policy) as well as in China ([Wang et al. \(2021\)](#)). The feed-in-tariffs is a particularly prominent policy in Europe and Canada but it is not market-based. These tariffs offer a fixed production subsidy ensured over extended periods, providing stability and certainty for investors ([Lamp and Samano \(2023\)](#)). In Germany, feed-in-tariffs are the main incentive for small installations but for utility-scale assets, firms must bid in federal-level renewable energy auctions to get the right to realize the investment and to determine the level of support they will receive ([Lamp et al. \(2024\)](#)).

### **E.3.3 Interconnection costs**

Interconnection cost can be a determinant of the renewable investment decision. However, our analysis does not specifically consider the interconnection issues or bottlenecks for the following reasons. First, the interconnection cost is a small part of the total investment cost. Using Laurence Berkeley Lab’s estimate of median interconnection cost of \$50,000/MW, we can calculate that for a wind power plant of 70MW (Laurel Hill Wind Farm, in PA), the interconnection cost takes up roughly 1/50 of the total construction cost. And for a solar project of 20MW (Tinton Hills Solar, PA), the interconnection cost takes up 1/80 of the construction cost. Given the small size, this cost is not a critical barrier for renewable projects to enter.

Recent studies by the Berkeley lab report that interconnection requests have increased recently, and currently, there is a long queue of interconnection requests which could slow down the investment process ([Joachim et al. \(2023\)](#)). Typically, a renewable project developer requests an interconnection

study even before it secures finance for the project. Securing the finance and developing a viable plan for construction is more challenging than completing the interconnection studies. Indeed, once the developers secure finance through a long-term contract with the demand side (electric utilities or others), they receive priority over other smaller, uncertain projects in the queue.

Historically, the percentage of projects that requested interconnection studies and eventually completed construction has been low (around 30 percent), so having a long queue or higher average interconnection cost does not necessarily mean that developers face a significant hurdle in their process. Studies show this completion rate was consistently low over time, even when the number of renewable investments was very small (when the renewable boom was yet there). Suppose the elongated interconnection process is a critical barrier and matters to investment. In that case, we should have seen a higher completion rate for years with less renewable entry competition, but we don't. Many of those projects in the queue would never have been completed anyway. The average increase in the interconnection cost also masks the fact that many unattractive projects have requested interconnection, most of which would not be completed. The less attractive project (located too far away from the transmission lines) receives a high estimate of interconnection cost, forcing them to opt out of the investment process. This is not necessarily a bad outcome from an economic perspective, as we can sort out the inefficient projects. For these reasons, our analysis does not specifically consider or worry about the interconnection queue or cost.

#### **E.3.4 REC market data**

Unfortunately, we do not have good data on REC prices in every market. We do have data for the PJM market. In Section 4.5, we show the potential direction of bias that arises from omitting the REC market data.

## E.4 Additional Tables and Figures

Table E.3: Renewable investment, RPS enactment, and market structure

	(1)	(2)
VS	28.15 (47.87)	82.06 (53.50)
After RPS	52.45 (38.96)	31.12 (37.00)
After RPS $\times$ VS	-89.05 (70.52)	-93.59* (54.92)
Net summer capacity (MW)		0.0185* (0.0106)
Net generation (GWh)		-0.00324 (0.00259)
Renewable per cap. lag (GWh per MW)		0.0287*** (0.0107)
Net flow lag (GWh)		-0.270 (1.606)
Constant	788.0*** (33.12)	200.4 (233.0)
$N$	1000	1000
Adj. $R^2$	0.41	0.44
Dep. var. mean	129.80	129.80
Market FE	✓	✓
Year FE	✓	✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New renewable capacity (MW). Years before and after RPS enactment in each state. Only states that enacted an RPS policy at some point. Using a continuous measure of vertical separation (retail sales). The data combine EIA and FERC information, see main text for further details. Standard errors clustered at the state level.

Table E.4: [EIA data] Fossil-fueled powered plants investment, RPS enactment, and market structure

	(1)	(2)
VS	-276.4* (162.9)	-107.9 (113.9)
After RPS	31.21 (55.06)	58.89 (48.24)
After RPS $\times$ VS	301.2** (132.2)	145.4 (139.5)
Net summer capacity (MW)		0.0280* (0.0167)
Net generation (GWh)		-0.00340 (0.00419)
Renewable per cap. lag (GWh per MW)		-0.0313 (0.0240)
Net flow lag (GWh)		-1.326 (2.444)
Constant	1156.7*** (46.80)	74.68 (296.3)
$N$	1000	1000
Adj. $R^2$	0.27	0.31
Dep. var. mean	292.00	292.00
Market FE	✓	✓
Year FE	✓	✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New fossil capacity (MW). Years before and after RPS enactment in each state. Only states that enacted an RPS policy at some point. Using a continuous measure of vertical separation (retail sales). EIA data only. Standard errors clustered at the state level.

Table E.5: [EIA data] Renewable investment and compliance using binary measure of vertical separation

	(1)	(2)	(3)	(4)
Non-compliance x VS	-89.45 (202.7)	-89.01 (207.1)	-92.01 (66.66)	-107.7* (55.63)
Non-compliance	47.04 (61.36)	47.79 (63.17)	76.22 (56.58)	90.14* (45.81)
RPS goal (GWh)		-0.00203 (0.0257)	-0.00421 (0.0238)	-0.0175 (0.0265)
Net summer capacity (MW)			0.0817** (0.0388)	0.0787** (0.0358)
Net generation (GWh)			-0.00452 (0.00917)	-0.00286 (0.00835)
Renewable per cap. lag (GWh per MW)			-0.00976 (0.0150)	-0.0103 (0.0152)
Net flow lag (GWh)			2.653 (4.952)	3.540 (4.996)
Constant	936.1*** (125.8)	938.0*** (111.2)	-3881.2*** (516.9)	-4073.9*** (670.7)
$N$	388	388	388	388
Adj. $R^2$	0.46	0.46	0.59	0.59
Dep. var. mean	176.02	176.02	176.02	176.02
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New renewable capacity (MW). EIA data only. For each state, only years when RPS policy had been put in place. Dynamic effects with a window +/-2 years. Standard errors clustered at the state level.

Table E.6: [EIA data] Renewable investment and compliance using a continuous measure of vertical separation (generation capacity)

	(1)	(2)	(3)	(4)
VS x Non-Compliance	-209.3 (158.7)	-210.9 (162.7)	-172.8 (109.1)	-212.5** (88.00)
Non-Compliance	131.0 (138.8)	134.4 (152.8)	139.3 (92.83)	173.1** (76.07)
RPS goal (GWh)		-0.00499 (0.0267)	-0.00682 (0.0264)	-0.0122 (0.0273)
Net summer capacity (MW)			0.0799** (0.0373)	0.0795** (0.0364)
Net generation (GWh)			-0.00394 (0.00882)	-0.00364 (0.00861)
Renewable per cap. lag (GWh per MW)			-0.0103 (0.0152)	-0.00883 (0.0150)
Net flow lag (GWh)			3.045 (4.903)	3.385 (4.794)
Constant	895.1*** (59.42)	900.0*** (48.04)	-3944.5*** (515.3)	-3992.8*** (608.1)
$N$	388	388	388	388
Adj. $R^2$	0.47	0.46	0.59	0.59
Dep. var. mean	176.02	176.02	176.02	176.02
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New renewable capacity (MW). EIA data only. For each state, only years when RPS policy had been put in place. Dynamic effects with a window +/-2 years. Standard errors clustered at the state level.

Table E.7: [EIA data] Renewable investment and compliance using a continuous measure of vertical separation (retail sales)

	(1)	(2)	(3)	(4)
VS x Non-Compliance	-400.8*	-404.3*	-237.3**	-237.5**
	(222.0)	(228.7)	(106.4)	(95.63)
Non-Compliance	159.3	165.2	122.6*	132.6**
	(121.6)	(137.8)	(61.37)	(55.72)
RPS goal (GWh)		-0.00947	-0.00791	-0.0130
		(0.0318)	(0.0283)	(0.0296)
Net summer capacity (MW)			0.0780**	0.0774**
			(0.0347)	(0.0334)
Net generation (GWh)			-0.00421	-0.00400
			(0.00844)	(0.00835)
Renewable per cap. lag (GWh per MW)			-0.0130	-0.0129
			(0.0164)	(0.0161)
Net flow lag (GWh)			1.885	2.149
			(4.954)	(5.013)
Constant	797.8***	806.3***	-3715.8***	-3727.5***
	(71.76)	(57.13)	(441.6)	(580.6)
<i>N</i>	388	388	388	388
Adj. <i>R</i> <sup>2</sup>	0.49	0.48	0.60	0.59
Dep. var. mean	176.02	176.02	176.02	176.02
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New renewable capacity (MW). EIA data only. For each state, only years when RPS policy had been put in place. Dynamic effects with a window +/-2 years. Standard errors clustered at the state level.

Table E.8: [EIA data] Fossil-fueled plants investment and compliance using binary measure of vertical separation

	(1)	(2)	(3)	(4)
Non-compliance x VS	330.7 (289.7)	336.3 (290.7)	3.637 (179.9)	137.7 (183.6)
Non-compliance	-107.2 (91.89)	-97.81 (88.90)	-41.08 (97.35)	-191.9** (79.83)
RPS goal (GWh)		-0.0257 (0.0326)	-0.0454 (0.0576)	-0.00127 (0.0584)
Net summer capacity (MW)			0.0700 (0.0590)	0.0844 (0.0506)
Net generation (GWh)			-0.0367** (0.0141)	-0.0444*** (0.0134)
Renewable per cap. lag (GWh per MW)			-0.0133 (0.0812)	-0.00495 (0.0864)
Net flow lag (GWh)			-11.27 (12.12)	-15.69 (10.45)
Constant	1080.4*** (143.1)	1104.1*** (130.8)	4969.2*** (1705.1)	5973.7*** (1680.3)
$N$	388	388	388	388
Adj. $R^2$	0.34	0.34	0.38	0.41
Dep. var. mean	324.25	324.25	324.25	324.25
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New fossil capacity (MW). EIA data only. For each state, only years when RPS policy had been put in place. Dynamic effects with window +/-2 years. Using a discrete measure of vertical separation (binary). Standard errors clustered at the state level.

Table E.9: [EIA data] Fossil-fueled plants investment and compliance using a continuous measure of vertical separation (generation capacity)

	(1)	(2)	(3)	(4)
VS x Binding	342.0 (292.9)	335.9 (291.4)	195.5 (255.5)	316.5 (213.5)
Binding	-149.9 (141.5)	-137.2 (144.5)	-159.6 (175.6)	-307.4* (159.2)
RPS goal (GWh)		-0.0187 (0.0344)	-0.0438 (0.0580)	-0.0209 (0.0553)
Net summer capacity (MW)			0.0692 (0.0598)	0.0677 (0.0556)
Net generation (GWh)			-0.0364** (0.0145)	-0.0379** (0.0138)
Renewable per cap. lag (GWh per MW)			-0.0159 (0.0799)	-0.0238 (0.0890)
Net flow lag (GWh)			-10.82 (11.55)	-10.94 (10.90)
Constant	1211.0*** (63.93)	1229.4*** (69.49)	4925.5*** (1599.8)	5308.3*** (1553.0)
$N$	388	388	388	388
Adj. $R^2$	0.34	0.34	0.38	0.39
Dep. var. mean	324.25	324.25	324.25	324.25
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New fossil capacity (MW). EIA data only. For each state, only years when RPS policy had been put in place. Dynamic effects with window +/-2 years. Using a continuous measure of vertical separation (generation capacity). Standard errors clustered at the state level.

Table E.10: [EIA data] Fossil-fueled plants investment and compliance using a continuous measure of vertical separation (retail sales)

	(1)	(2)	(3)	(4)
VS x Binding	559.1* (322.0)	554.3* (321.4)	411.8 (271.3)	468.5 (296.4)
Binding	-158.3* (86.96)	-150.2 (91.04)	-194.8 (135.1)	-291.2** (115.2)
RPS goal (GWh)		-0.0130 (0.0396)	-0.0411 (0.0613)	0.00179 (0.0636)
Net summer capacity (MW)			0.0720 (0.0565)	0.0614 (0.0512)
Net generation (GWh)			-0.0357** (0.0139)	-0.0349** (0.0129)
Renewable per cap. lag (GWh per MW)			-0.0128 (0.0780)	-0.00493 (0.0777)
Net flow lag (GWh)			-8.555 (12.65)	-7.612 (11.74)
Constant	1344.4*** (89.04)	1356.1*** (99.33)	4503.2** (1692.3)	4872.0*** (1450.4)
$N$	388	388	388	388
Adj. $R^2$	0.35	0.34	0.39	0.41
Dep. var. mean	324.25	324.25	324.25	324.25
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New fossil capacity (MW). EIA data only. For each state, only years when RPS policy had been put in place. Dynamic effects with window +/-2 years. Using a continuous measure of vertical separation (retail sales). Standard errors clustered at the state level.

Table E.11: Wind plants investment and compliance using a continuous measure of vertical separation (retail sales)

	(1)	(2)	(3)	(4)
VS x Binding	-290.1 (172.9)	-281.3 (171.4)	-128.1** (57.86)	-96.46 (68.24)
Binding	81.23* (44.49)	66.13 (41.50)	52.53* (27.21)	19.83 (38.41)
RPS goal (GWh)		0.0243** (0.0108)	0.0248*** (0.00784)	0.0159 (0.00969)
Net summer capacity (MW)			0.0176** (0.00780)	0.0191** (0.00893)
Net generation (GWh)			0.00678*** (0.00114)	0.00643*** (0.00108)
Renewable per cap. lag (GWh per MW)			-0.0146 (0.0165)	-0.0166 (0.0170)
Net flow lag (GWh)			8.870*** (2.080)	8.845*** (2.194)
Constant	394.6*** (26.00)	372.7*** (27.70)	-2875.9*** (301.9)	-2919.6*** (384.5)
<i>N</i>	388	388	388	388
Adj. <i>R</i> <sup>2</sup>	0.48	0.48	0.55	0.54
Dep. var. mean	135.84	135.84	135.84	135.84
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

*Notes:* Dependent variable: New wind-powered capacity (MW). The data combine EIA and FERC information, see main text for further details. For each state, only years when RPS policy had been put in place. Dynamic effects with window +/-2 years. Using a continuous measure of vertical separation (retail sales). Standard errors clustered at the state level.

Table E.12: Solar plants investment and compliance using a continuous measure of vertical separation (retail sales)

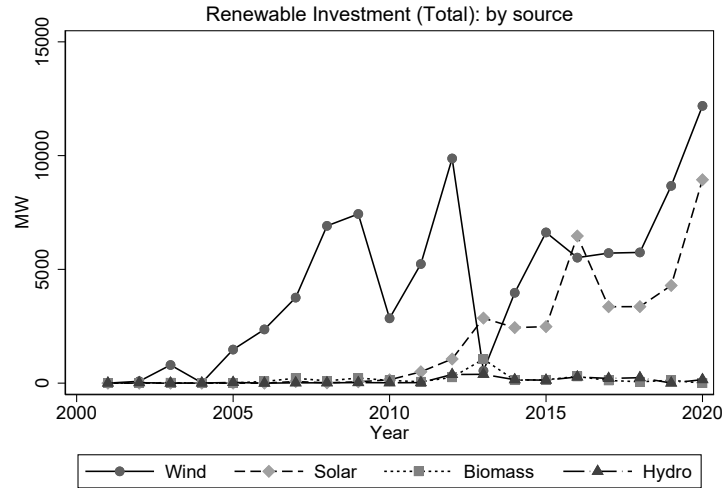
	(1)	(2)	(3)	(4)
VS x Binding	-161.5 (128.6)	-171.0 (141.7)	-148.8** (69.04)	-117.0** (48.09)
Binding	120.0 (108.1)	136.3 (127.8)	100.4** (46.41)	87.10** (35.58)
RPS goal (GWh)		-0.0261 (0.0292)	-0.0259 (0.0239)	-0.0259 (0.0253)
Net summer capacity (MW)			0.0735** (0.0316)	0.0722** (0.0310)
Net generation (GWh)			-0.0134* (0.00744)	-0.0133* (0.00750)
Renewable per cap. lag (GWh per MW)			0.00444 (0.0107)	0.00511 (0.0101)
Net flow lag (GWh)			-7.690* (3.897)	-7.895* (3.926)
Constant	573.3*** (63.87)	596.8*** (48.97)	-1007.5** (467.4)	-934.9** (451.5)
$N$	388	388	388	388
Adj. $R^2$	0.33	0.33	0.56	0.56
Dep. var. mean	47.24	47.24	47.24	47.24
Market FE	✓	✓	✓	✓
State FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Dyn. Effects				✓

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

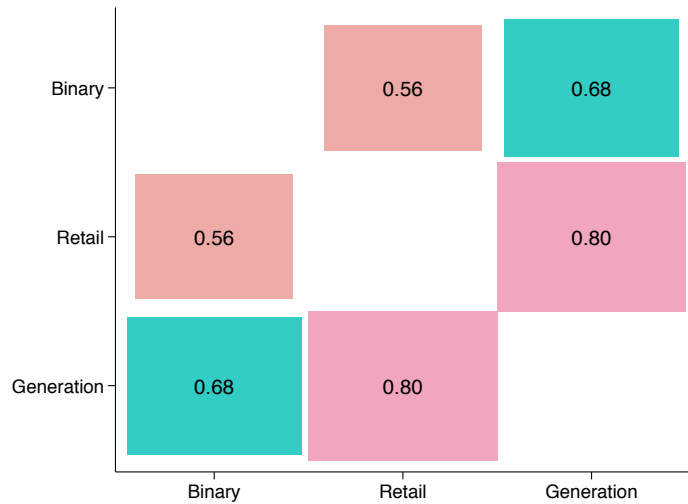
*Notes:* Dependent variable: New solar-powered capacity (MW). The data combine EIA and FERC information, see main text for further details. For each state, only years when RPS policy had been put in place. Dynamic effects with window +/-2 years. Using a continuous measure of vertical separation (retail sales). Standard errors clustered at the state level.

Figure E.2: Renewable Investment: by Energy Source



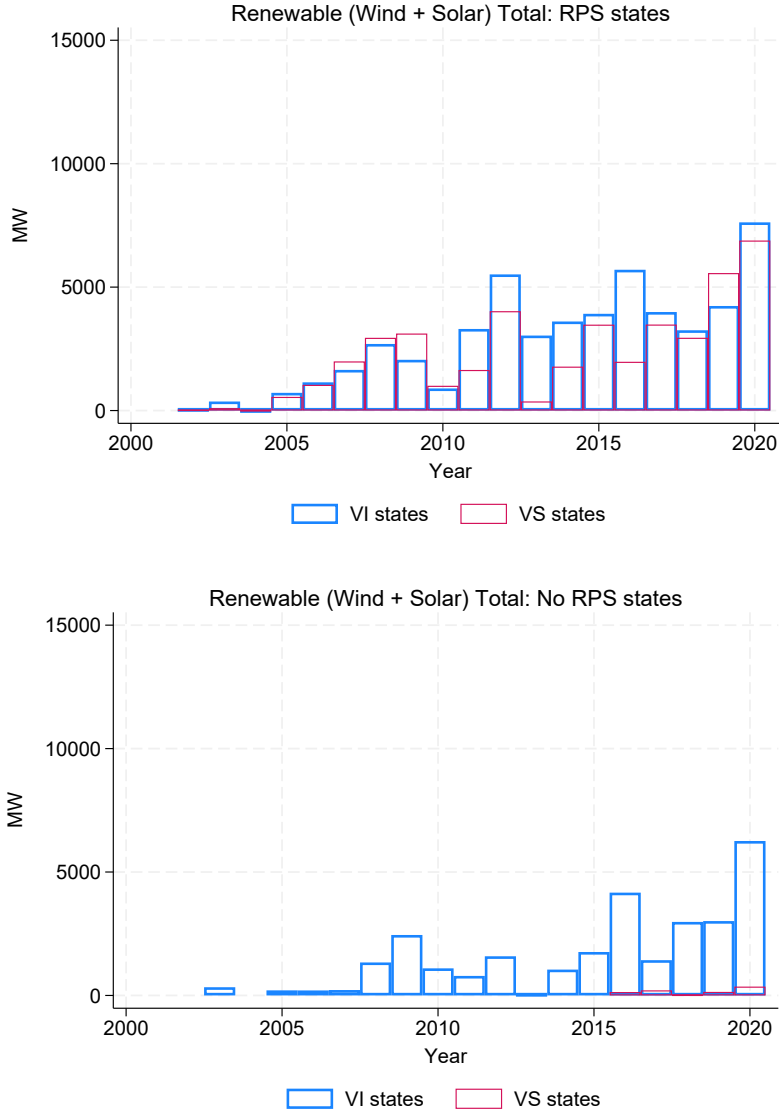
*Notes:* The lines show a national summary of new renewable capacity additions by year and by energy source.

Figure E.3: Correlation matrix of different Vertical Separation measures



*Notes:* Pairwise correlations between our three measures of vertical separation: a binary classification (as it has been commonly assumed in the literature), a measure using generation capacity, and a measure using retail sales volume.

Figure E.4: Renewable Investment: Comparison Between VI and VS States



Notes: The graphs show total renewable generation capacities of states categorized as VI states ( $VS_{\text{binary}} = 0$ ) and VS states ( $VS_{\text{binary}} = 1$ ). We present these separately for states that enacted RPS (“RPS states”, top figure) and those that did not (“No RPS”, bottom figure). Units: MW.

Table E.13: VS (retail) measure: Summary statistics by state

state	$\min_{VS}$	$\max_{VS}$	$sd_{VS}$	avg. diff. ( $VS_t - VS_{2002}$ )
AZ	0.00	0.00	0.00	0.00
CA	0.00	0.00	0.00	0.00
CO	0.10	0.12	0.00	0.01
CT	0.79	0.84	0.01	0.01
DC	1.00	1.00	0.00	0.00
DE	0.70	0.79	0.02	-0.05
HI	0.00	0.00	0.00	0.00
IA	0.00	0.00	0.00	0.00
IL	0.63	0.85	0.07	-0.06
KS	0.00	0.00	0.00	0.00
MA	0.00	0.37	0.16	-0.28
MD	1.00	1.00	0.00	0.00
MI	0.00	0.00	0.00	0.00
MN	0.00	0.12	0.02	0.11
MO	0.00	0.00	0.00	0.00
MT	0.00	0.06	0.01	0.00
NC	0.00	0.00	0.00	0.00
NH	0.25	0.33	0.02	0.04
NJ	0.00	0.00	0.00	0.00
NM	0.00	0.00	0.00	0.00
NV	0.00	0.00	0.00	0.00
NY	0.50	0.55	0.01	0.01
OH	0.00	0.07	0.03	0.02
OR	0.00	0.00	0.00	0.00
PA	0.75	0.79	0.00	0.00
RI	1.00	1.00	0.00	0.00
TX	0.79	0.90	0.03	-0.06
VT	0.07	0.13	0.01	-0.01
WA	0.00	0.00	0.00	0.00
WI	0.00	0.00	0.00	0.00

*Notes:* Table provides summary statistics of the annual VS measure for states that enacted RPS. In the analysis, we fix the VS measure at its 2002 level. The “avg. diff.” value shows the mean difference between the annual VS and the 2002 level.