Renewable Portfolio Standards, Vertical Structure, and Investment*

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March 18, 2024

Abstract

The efficacy of policies imposed on industries or firms largely depends on the market structure. We illustrate this impact by examining how Renewable Portfolio Standards (RPS) influence investment decisions. The RPS requires the in-state downstream electricity providers to procure a minimum percentage of their electricity sales from renewable generation upstream. The goal of the policy is to incentivize the upstream sector to invest in renewable generation capacity. We examine how the effectiveness of the RPS policy in inducing renewable investments upstream differs by the nature of the vertical structure of the electricity market, exploring the heterogeneity in vertical structures (relations) across states. We find that the overall investments that comply with the policy are lower in the states characterized as vertically separated. This suggests that there is a misalignment between regulation design and market structure.

JEL codes: L42, L94, Q42, Q48

Keywords: Renewable portfolio standards, renewable energy, electricity markets, vertical relations, market structure

*We thank Philippe Barla, Victor Dee, Jackson Dorsey, Natalia Fabra, Akshaya Jha, Valerie Karplus, Laura Lasio, Mathieu Marcoux, and participants at presentations of early versions of this paper at SUNY-Albany and HEC Montreal for their comments.

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1 Introduction

One of the great mistakes is to judge policies and programs by their intentions rather than their results. – Milton Friedman

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 when a policy targets markets and industries, as the efficacy of the policy may depend on whether the incentives it creates align with firms' incentives under the prevailing market structure. This paper highlights the importance of market structure as a determining factor in the outcomes of the policy, exploiting an empirical setting where one can observe the same policy in action under different market structures. We quantify the effects of a policy aimed at increasing certain type of investment in the electricity sector – the Renewable Portfolio Standards – and how this outcome depends on the extent to which the market is vertically integrated.

The Renewable Portfolio Standards (RPS) are a set of policies in the US that have for objective to increase the generation capacity from renewable sources. Specifically, the RPS require that a minimum percentage of electricity supply in a state is met by generation from renewable sources. The policy is enacted at the state level, and as of November 2022, 29 states and the District of Columbia had established an RPS.[1] The Energy Information Administration claims that half of the growth in renewable generation since 2000 is due to the RPS mandates alone.[2]

Although there is a rich set of studies evaluating the outcomes of the RPS policy – which we describe in the literature review section – there has not been an evaluation of the policy's impact on investment in renewable capacity that accounts for the underlying market structure. We argue that this interaction is important when considering how the policy creates incentives to invest, especially in the context of the electricity industry being a vertical supply chain. This emerging factor presents a nuanced interaction that may either reinforce or challenge the prevailing deregulation trend in the US, often characterized by the segmentation of traditionally vertically integrated electricity markets. Our research highlights a fundamental tension between the objectives of deregulation and the necessity of expanding renewable energy efforts.

We focus on the fact that the RPS policy places an obligation on the downstream sector – electric

[1] 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). As of date, there is no federal RPS or similar policy in place.

[2] "Roughly half of all growth in U.S. renewable electricity generation and capacity since 2000 is associated with state RPS requirements" (https://t.ly/PPXYK).

utilities or the other retail electric providers – to achieve the goal of an increased renewable share in the upstream generation sector. The policy, therefore, creates a linkage between the vertically related sectors in the electricity industry. Since downstream retail companies are responsible for inducing new investment upstream, the policy's effectiveness in achieving the goal depends on the vertical relationship between the retail and wholesale sectors – specifically, to what extent the retail and wholesale sectors are integrated.

An interesting aspect of the US electricity industry is that the degree and prevalence of vertical ties between the retail and wholesale sectors vary significantly across states. Since the early 1990s, the deregulation and restructuring processes in the US electricity sector have given place to a patchwork of market structures across the country. Before deregulation, most markets in the US consisted of a vertically integrated company that owned assets in both the retail and wholesale parts of the supply chain. The restructuring process, which accompanied deregulation, separated these vertical ties to create competitive markets, but not completely and not uniformly across states.[3] Nowadays, after several waves of deregulation, 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 relationships coexist in most states, including those underwent restructuring, creating varying degrees of vertical structures at the state level. We use this variation in the overall extent of vertical separation/integration across states in our analysis.

We explore two channels through which the policy can induce new investments. First, a retailer can comply with the RPS policy by entering into contracts with an upstream firm that invests in new renewable generation capacity.[4] We refer to this as the *contracting channel*. In the vertically integrated case, this contracting is complete and internalized, where an electric utility directly invests in capacity through its affiliate operating in the generation sector. By constructing a power plant, the utility avoids uncertainty in compliance costs but incurs an investment cost to build the renewable asset. Contracting is possible even in the vertically separated case, though it may not be as complete as in the integrated case. Another channel of compliance is through the market, where a retailer can comply by purchasing Renewable Energy Credits (RECs) sold by renewable generators. We refer to this as the *REC credit market channel*. In this case, the retail company complying does not bear the investment cost but faces the uncertainty of credit prices and the risk

[3] For example, California suspended the restructuring process after experiencing an electricity crisis in 2001. This incident also influenced restructuring processes in other states.

[4] As we explain later in the paper, the implementation of the RPS policy relies on the issuing of a Renewable Energy Credit (REC) for each unit of electricity output produced from approved renewable energy sources. The RECs can be traded under certain rules and those firms that need to comply with the policy must acquire RECs via their own output or through the REC market.

of non-compliance. Also, it is uncertain whether credit prices would be sufficient to incentivize entry of renewable generation, as power producers are not obligated to meet the policy requirements and would invest only if the market provides ample incentives to do so.

While these two channels may coexist, the extent to which the policy's effect on state-level investments differs by vertical structure depends on the amount of investments incurred through the contracting channel. The stronger the vertical relationship between the downstream retailer and upstream generators, the more closely aligned the retailer's need to comply with the policy is with the upstream investment incentives. This gives the retailer an advantage in setting up investment contracts, resulting in a higher investment coming through the contracting channel. Moreover, due to the variable nature of renewable energy, enforcing contracts is challenging, and the stronger the retailer's presence in the generation sector, the easier enforcement becomes. On the other hand, any new investments happening through the REC market channel respond only to the incentives created by the REC market, which are not necessarily affected by the vertical structure. Therefore, we expect the RPS policy to more effectively induce investments in a more vertically integrated setting than in a vertically separated environment.

To quantify this relationship, we use a combination of data from various sources. First, we collect data on renewable generation capacity, investment, and information on firms and power plants in the generating sector from the Energy Information Administration (EIA Form 860). We also collected information on retail electricity providers (EIA Form 861), including the retailer's identity, total sales, and the number of customers. We complement our dataset with key variables at the state level obtained from EIA Electric Power Annual. This electricity sector data is then combined with the dataset on Renewable Portfolio Standards (RPS) compiled by the National Renewable Energy Laboratory (Barbose (2021)). For each state that has enacted RPS and for each year, we observe the annual minimum percentage requirement (i.e., RPS target levels) on clean energy sales, which are announced and publicly known several years in advance. The data also reports the compliance status of each state – indicating whether the state fully complied with RPS requirements that year, and if not, how far it was from the requirement.

Our empirical strategy aims to explore the relationship between annual state-level renewable investments driven by RPS policy and the state's vertical structure. Since RPS requirement levels are published in advance, firms may plan ahead and ensure their invested capacities are ready by the compliance year. We aggregate new investments in wind and solar generation capacities that come online each year for each state. By using this measure, our analysis focuses on the outcomes of individual-level decisions at an aggregate level, rather than analyzing individual firm's decisions to invest. However, identifying whether the invested capacity is driven by the policy presents a challenge. To address this, we construct a binary variable categorizing years as policy-binding or not in the sense that if the state did not achieve compliance, all new renewable investment's output must be used to comply with the policy, i.e. the policy was binding. Therefore, we anticipate a stronger influence of the RPS policy on renewable investments during these non-compliance years. By focusing on these binding years, we implicitly assume a causal relationship between the policy and investment.

We use three different measures to characterize a state's vertical market structure, capturing the rich heterogeneity in vertical linkages between firms in the upstream and downstream. A binary indicator assigned to restructured states was often used in the literature to indicate vertical separation, as the restructuring resulted in separating the generation sector from the retail sector. Additionally, we define 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 in the downstream level. The second measure, our preferred measure, computes the market share of retail companies that do not own generation assets in the upstream level. This aggregate measure effectively captures the varying degrees of existing firm-level vertical linkages across states.

Our main results are obtained from a regression of new annual investment on renewable capacity on the interaction of the measure of vertical integration with the variable that captures whether the RPS policy was binding or not in a given year. We add a rich set of controls and fixed effects as well. We argue that since the RPS schedules are announced in advance and do not change over time, whether the RPS is binding is not a function of current investment because the investment realized this year was decided to be built years in advance. In addition, we assume the market structure to be fixed at the level of the first year that the RPS was enacted, since new additions on renewable generation do not largely change the composition of the share of vertically integrated assets. With these considerations in mind, we find that states with a vertically separated structure invest less in renewable capacity than their vertically integrated counterparts by a factor between 1.4 and 2.3 times the overall average investment in renewables. In other words, having a vertically integrated structure appears to be more prone to internalize the incentives of the RPS policy.

In the main results we implicitly assume that the difference in investment outcomes is mainly driven by the contracting channel. Ideally, one should separate in the data the investments directly related to each channel. However, due to data limitations, we are only able to give a partial answer to this question. We estimate a variation of our main model in which we substitute the binding policy indicator with an average of REC prices, we find that renewable investments in vertically separated markets would increase more than in vertically integrated markets if the value of REC prices is high. Even though this result may seem to be in contradiction with our main set of results, what we find is that the investment due to the RPS through the contracting channel is much smaller in the vertically separated states relative to the integrated states.

Our results underscore the importance of the market structure in the evaluation of policy outcomes. In the case of the electricity sector, our results indicate that there may be a misalignment in objectives. On one hand, deregulation was supposed to increase market efficiency and provide the correct incentives for new investment. On the other hand, more recent policies with specific investment objectives have more difficulty to find their way through when the upstream and downstream sectors are owned by different entities.

Related literature. There are two main strands of the literature related to this paper. First, there is the literature concerned with the effects of the Renewable Portfolio Standards on emissions, electricity prices, and other outcomes. Greenstone and Nath (2021) find that RPS enactment has a negative impact on emissions but causes an increase in electricity prices. Similarly, Feldman and Levinson (2023) find a decrease in emissions and in natural gas generation, albeit the impacts are small. Wolverton et al. (2022) focus on electricity prices for the manufacturing sector and find slightly higher prices in RPS states than in non-RPS states. Hollingsworth and Rudik (2019) examine the spillover effect of RPS policy and measure the reduction of emissions associated with it. Fullerton and Ta (2022) set a general equilibrium model around the RPS policy in addition to reduced-form evidence of the effect of RPS on market outcomes including the retail price. Abito et al. (2022) study the REC market trading mechanism. Hong et al. (2023) study the effect of the RPS on bonds of different companies in the electricity sector.

There is rather a small set of studies explicitly studying the effect of RPS on renewable capacity investment. Yin and Powers (2010) examine the relationship between new renewable investment and a measure of RPS stringency and find a positive effect but without conditioning on the market structure. More recently, Deschenes et al. (2022) answers the same question using staggered differences-in-differences methods. While Deschenes et al. (2022) find that RPS has a causal effect on the wind investments but not on solar, they do not consider market structure or the role of vertical relationship in their analysis. Our paper is the first to consider the interplay between vertical relationships and the RPS policy, suggesting that its effects may not be entirely technology-specific, but that it could be a consequence of the market structure also.

Second, our paper is related to the industrial organization literature that relates market outcomes and the extent to which the market is vertically integrated, especially in the context of investment. Transaction cost theory suggests that difficulty of specifying and enforcing a contract is an important factor determining the extent to which the firms are vertically integrated (Joskow (2003), Lafontaine and Slade (2007)). Our paper is broadly related to this literature as we draw on this literature to argue that the stronger vertical relationship leads to more effective contract specification as well as enforcement. There is a stream of literature that focuses on the fact that investments in power plants being relationship-specific, thus prone to hold up problems. Joskow (1987) studies the relation between coal power plant investment and the extent of vertical relationship between input coal suppliers and coal plants. More recently, Ryan (2023) shows that the hold up problem arising from counter-party risk of investing in solar capacity can be significant especially for renewable assets, and can result in inefficient level of investment (procurement). Although not directly related to this literature, 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 the capacity investment in electricity market.

Our paper is also broadly related to the empirical studies exploring the relationship between vertical integration and various market outcomes. Mansur (2007) finds that market power is exercised to a lesser extent in vertically integrated markets than in restructured markets. MacKay and Mercadal (2022) conclude that in some cases, regulated prices may be better than de-regulated prices. Luco and Marshall (2020) find empirical evidence that vertical integration in multi-product firms decreases prices only in the products where the double marginalization problem is eliminated but prices actually increase in other products from the same integrated firm.

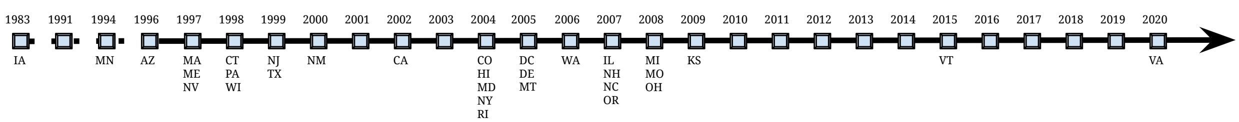
2 Institutional Background and the Importance of Market Structure

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 or year (EIA (2022)). Specifically, the policy obligates the retail electricity providers (utilities) to source a certain percentage of their electricity sales (load supplied to the households) to come from renewable sources. These resources include wind, solar, geothermal, biomass, and some types of hydroelectricity and in some cases, include landfill gas, municipal solid waste, and ocean energy. Which energy source is considered renewable differs by state, but wind and solar are the dominating sources among the diverse set of renewables. Some states impose a minimum requirement separately for solar and the rest of the renewables.[5]

The RPS policy exists in 30 states and the District of Columbia as of 2023, which implies that the policy applies to 58% of total U.S. retail electricity sales (Barbose (2023)). The adoption times vary across states. Early adopters include Iowa, Montana, and Arizona, whereas Vermont and Virginia are the most recent adopters in 2015 and 2020, respectively. Figure 1 shows a timeline of these adoption events.

Figure 1: RPS enactment by state



Notes: Year in which the state implemented an RPS policy for the first time. Data from Barbose (2021).

When the state decides to adopt the RPS policy, the annual minimum percentage requirements (i.e., targets) are set and announced several years in advance. The annual target level increases gradually over time. Although the state may revise the target levels occasionally, it is usually the case that retail electricity companies know the target levels of subsequent years at the time of the state's RPS policy adoption. The magnitude and the growth rate of the annual target levels differ by state. However, anecdotal evidence suggests that the levels and growth rates of targets are determined based on specific characteristics of each state. Therefore, the annual RPS target levels are fairly exogenous.[6]

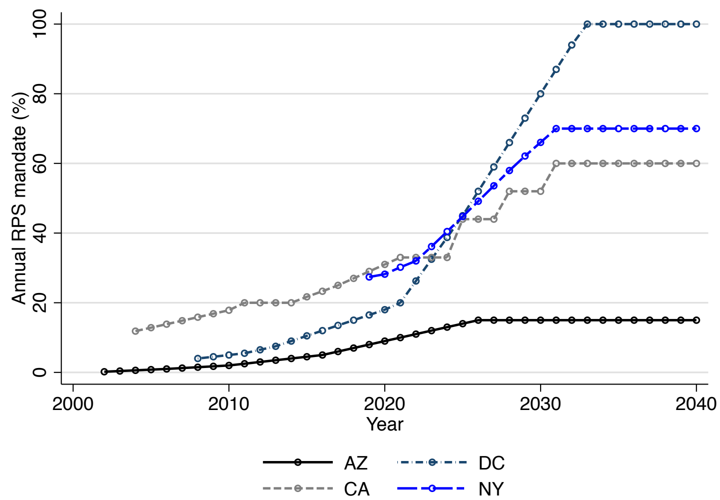
Figure 2 shows the annual RPS mandate as a percentage of total sales for four states: Arizona, DC, California, and New York. Each state enacted its RPS policy at different points in time and with different speeds in the changes in their target levels. Arizona was an early adopter with a very gradual 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 get to a target of 100% by 2033. New York and California exhibit a behavior in between the two first examples but once again

[5] 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 (2021).

[6] 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://images.edocket.azcc.gov/docketpdf/0000063561.pdf (p. 85-86).

with different enactment years. These schedules are public information and announced before the enactment of the policy in the state.

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 (2021).

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), or Renewable Energy Credits, 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 C.8 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.

There are several ways in which retail electricity providers can comply with the RPS policy. First, the provider could generate the required amount either from their own generation or through a long-term contract with renewable generators upstream. For each MWh of electricity generated from the renewable generator, the retail electricity provider receives a credit. This is referred to as the bundled REC as the credit is bundled with purchasing the actual electricity generation. While the retail company can set up a long-term Purchasing Power Agreement (PPA) with an existing renewable generator in the wholesale market, the new renewable generators have to be built in order to keep up with the increasing target levels. This gives retail providers an incentive to invest in renewable power generation, either constructing the plant themselves or setting up a long-term PPA contract with a new renewable generator in the stage of planning.

Second, the retail electricity providers can purchase credits in the spot market for renewable energy credits (i.e., REC market). The credits supplied in the spot market are referred to as unbundled credits, as it does not require the retailer to purchase the electricity that produced the credit. Any renewable generator, regardless of whether it is owned by Independent Power Producers (IPPs) or utilities, can sell its generation in the spot market if the state has a de-regulated generation sector.[7]. Similar to other spot markets, transactions of RECs occur through the brokers, and the market exists at the state level. The increasing RPS target levels would increase the demand for credits in the REC market, which could induce new investments that would increase the supply of credits in the market.

Most of the states require RECs produced within the state to be used to comply with the state's RPS goal. This is to induce more renewable generation to occur within the state. However, some states allow credits produced in another state to be used for compliance, therefore with a possibility of spillover effects across states (Hollingsworth and Rudik (2019)). Even in this case, they restrict the eligible credits to the ones produced within the interconnection in which the state belongs to (Abito et al. (2022)).

A state implementing RPS policy does not always meet the RPS target levels. That is, the compliance status can vary over time. If a certain year is designated as a "non-compliance" year, this means that the total size of the RECs procured by the retail providers in the state together, regardless of being bundled/unbundled or purchased from other states, was below the level of the state's minimum RPS requirement.

2.3 Deregulation vs Vertical Integration

The electricity sector is composed by three main segments: generation, transmission, and distribution. A common market structure prevailing until before the 1990s consisted of one single company owning the assets across the three main segments. Such configuration corresponds with what we

[7] In some states, renewable generators are allowed to retain and bank the credits for use at a later point in time but must be used within a certain time period (Greenstone and Nath (2021)).

know as a vertically integrated market.

However, several states went through "deregulation" processes of their electricity sector starting in the late 1990s. We can distinguish two main cases. First, the deregulation of wholesale generation sector refers to the opening of the generation sector to competition by allowing different companies (e.g. unregulated electricity plants (IPPs)), to participate in generation. The deregulation of the wholesale sector is accompanied by implementing a spot wholesale market for electricity, operated by "independent system operators" and "regional transmission organizations", to allow for trade of electricity not settled in bilateral contracts. The generating companies in a restructured market can sell electricity in the spot market or through bilateral long-term contracts.

Second, the deregulation and restructuring of the retail electricity sector refers to opening the retail service market to different retailers that can compete for customers within the same geographical market. Such restructuring of the distribution (retail) sector is often accompanied by 'Retail Electricity Choice' programs that enable end-use customers (including residential, industrial, and commercial customers) to choose their electricity provider from either the legacy electric utilities or from competitive retail suppliers, such as retail marketers.[8] Electric utilities serve as local monopolists in their geographical markets when retail choice is not allowed, essentially meaning that in those cases there is no 'retail market'.

There could be various degrees and forms of deregulation in both sectors across different states. Some states may have fully deregulated and restructured both the wholesale and retail markets. Others may have a restructured wholesale market while still maintaining a closed distribution (retail) sector, resulting in the absence of retail market competition (e.g., Kansas, Oklahoma, Minnesota). In some states, the wholesale market is not restructured (closed to competition), but the retail sectors are open for competition (e.g., Georgia, Oregon).

The vertical integration nature of the market may or may not have been kept after the deregulation process. There are several instances where legacy companies still own generation assets and they have the monopoly of distribution (for example, PG&E in California). In this case, only the generation sector was deregulated, and only a fraction of the entire electricity sector can be understood as vertically integrated (owned by the same company) since some retailers also own generation assets. In other instances, both the generation and the distribution sector were dereg-

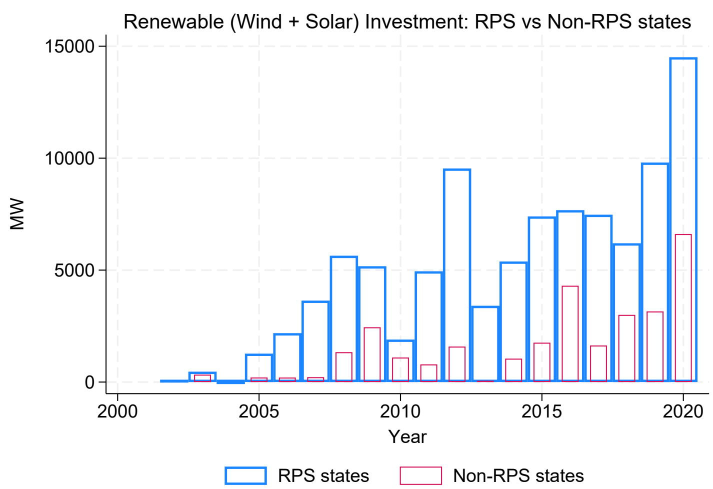
[8] Source: https://www.nrel.gov/docs/fy18osti/68993.pdf. However, the specifics of these retail choice programs differ across states. As of 2018, 13 states and the District of Columbia have active, statewide *residential* retail choice programs. In Texas, for example, a retail choice program is mandatory under state law and more than 87% of residential customers choose their retail suppliers. On the other hand, retail choice programs are available only to the non-residential customers in some states (Michigan, Oregon, Nevada, Georgia, and Virginia) according to the EIA, Today in Energy, Nov 2018, https://www.eia.gov/todayinenergy/detail.php?id=37452).

ulated (for example, ERCOT in Texas), but there exist companies with assets in both sectors (for example, Reliant). Therefore, vertical integration nowadays is not always a binary characteristic of an electricity market, since it is possible that only a fraction of the market consists of assets upstream and downstream owned by the same firms.[9]

We define vertical integration as the retail company's capability to source electricity from its own generation assets in the wholesale market. Even if both sectors are deregulated and restructured, not every firm in that state is vertically integrated. Hence, we need to delve deeper into the firm-level linkage between the wholesale and retail sectors to derive a measure of vertical integration that aligns with our analysis. The degree of vertical integration would vary significantly across states, even for those with the same binary indicator, once we consider information about the firm-level integration status.

2.4 Vertical Structure and Renewable Investment

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 have not.

The RPS policy is imposed on the downstream retail electricity providers. Since the RPS target level (requirement) ramps up across years, the retail electricity provider cannot comply with the policy unless new investments in renewable generation in the upstream generation sector occur over

[9]Another aspect of deregulation is the effect on electricity prices at the wholesale level due to the low marginal costs of renewables and their interaction with the ownership structure (Bahn et al. (2020)).

time. Especially given the small share of renewable generation capacity by 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.[10] Figure 3 shows a steady growth in invested renewable capacities over time, with significantly larger capacity additions in the states that adopted RPS compared to those that did not.

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 happen depends on the vertical relationship between the downstream and upstream companies. Due to different deregulation/restructuring status, states have very different vertical structures. For example, some states still have a retail sector vertically integrated with the wholesale sector, whereas in many states the two sectors are completely separated. However, the design and structure of the RPS policy, though it is a state-level policy, is fairly similar across states.

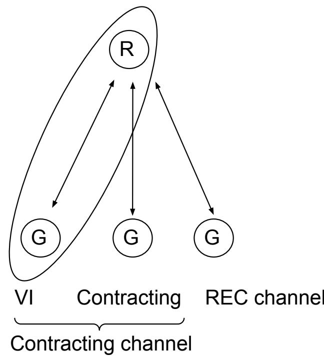
In this section, we discuss how the difference in vertical structure affects the state's compliance through investments.

Two channels of RPS compliance. As discussed in Section 2.2, the aggregate level of renewable investments complying with the RPS policy, the main dependent variable used in our analysis in our empirical analysis below, can be driven by two channels: the contracting channel and the REC market channel. Figure 4 illustrates the two channels that a retailer can use to comply with the RPS policy.

The contracting channel refers to a retailer investing in new renewable generation capacity by entering into contracts with the upstream company that plans to construct renewable generation facilities. We include the vertical integration case, where the retail firm integrated with the upstream invest in renewable generation directly through its own affiliate, as part of this contracting channel. While the vertical contracting channel and vertical integration are different concepts, in principle, the vertical integration is considered an extreme case of the contracting, and the contracting can achieve similar outcomes as in vertical integration unless the incomplete contracting issue is severe (Lafontaine and Slade (2007); Joskow (2003)). Therefore, the contracting channel here encompasses vertical contracting and vertical integration. The contract usually takes the form of a long-term purchasing power agreement (PPA) at a specified price for the unit of MWh generated by the renewable facility, and the developer of renewable generation facility can recover the cost

[10] 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.

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.

of investment from these payments. In the vertically integrated case, the retail company builds its own renewable generation assets by incurring the fixed investment cost. In both cases, a retailer acquires the bundled credits (RECs).

The REC market channel involves a retailer relying on the supply of renewable credits to meet the RPS requirement. In this case, the retailer must wait for the credit market to incentivize new renewable investments in the upstream sector so that new credits can be supplied to the market. In other words, the retailer does not have control over the wholesale firm's decision to invest in new renewable generation capacity. If the upstream firm finds the revenue from selling the credits in the REC market to be profitable enough to cover the fixed cost of investment, the new investment will occur upstream.

To an upstream firm considering the installation and operation of renewable generation capacity, these are two channels through which they can cover the upfront investment costs of capacity investment. If the wholesaler enters into a direct contract or integration with a downstream retailer, the burden of the investment cost is shifted to the retailer. As an exchange, electricity generated from the contracted renewable capacities can be used to fulfill the retailer's RPS requirement. On the other hand, if the wholesaler relies on the credits market, they would supply the credits obtained from generating eligible renewable capacity to the REC market and receive the REC market price as revenue. These two channels coexist in the current electricity market.

The effect of vertical structure on investment. The extent to which the efficacy of the policy differs between vertically separated and vertically integrated markets mainly depends on the amount of investments incurred through the contracting channel.

If a retailer is vertically integrated with a wholesale company, it is easier to comply with the RPS by inducing new investments through the contracting channel, as the retail firm can simply construct renewable generation in the upstream. Even if the retailer cannot directly invest in renewable capacity due to lack of experience, having an affiliate (integrated) firm upstream and actively engaging in wholesale generation gives the retailer an advantage in terms of contracting with a renewable project developer. This is the case because writing and enforcing a long-term contract, which involves a purchase agreement of daily electricity generation for a specified duration, requires the retailer adequately stating the contractual terms to the seller.

Therefore, the stronger the vertical relationship between the retailer and the upstream wholesale generators is, the retailer's need to comply with the policy is more closely aligned with the upstream investment incentives. The investment lowers the cost of retailers by avoiding non-compliance penalties, and such benefit is more internalized the closer the ties between the two firms are.

On the contrary, if the retailer and wholesaler are vertically separated, and the retail company does not have a presence nor experience in the wholesale generation, the difficulty in setting up a contract for new investment intensifies. The retail companies having lack of knowledge would find it difficult to agree on a contractual term that aligns the incentives of both retail and wholesale companies. Such difficulty can lead to incomplete contracts, creating an incentive on the upstream generators to hold up investment, eventually resulting in offering less contracts, thus lowering investments in the upstream.

Moreover, due to the variable and uncertain nature of renewable energy sources output, setting up a contractual term agreeing on the amount of generation to buy and sell ex ante, at a daily frequency, would make the contracting even more difficult. Enforcing the contract is also difficult for renewable generation as the generation depends critically on weather conditions that are hard to perfectly forecast without having an adequate knowledge and information about market operations. This gives support to our argument that a retailer having some presence (some degree of vertical relationship) in the upstream sector would have an advantage over those not in terms of inducing new investment to comply with the RPS policy.

Note that the investment tied to the REC channel (selling or buying unbundled credits in the REC market) is not likely to be affected by the vertical structure. Any firm, either upstream or downstream and regardless of their vertical relationship structure, can trade in the REC market.[11] This, in turn, implies that any difference in the overall investment levels (investments to comply with the RPS requirement) between different vertical structures mainly results from the difference in the investment levels coming through the contracting channel. This is an important assumption we make to address the challenge of separating out the investments tied to contracts due to the difficulty of observing contracts. Information on whether a specific power plant has established a purchasing power contract with any of the retailers is generally confidential. Therefore, we instead provide a justification based on theoretical predictions that the variation in the part of the investment responding differently to the extent of vertical relationship is tied to the contracting channel, which we cannot directly observe in the data.

3 Data

Renewable Generation Capacity and Investment: EIA Form 860. The capacity investment data at the generator-plant-utility (firm) level were obtained from the EIA Form 860. The data report the generator's name-plant capacity, location (state), status (i.e., operating, proposed, retired, etc.), the energy source of the generator, along with the type of the firm that owns the generator (IOU (investor-owned utility) or IPP). While the frequency of the dataset is at the year-month level, we aggregated the data to the annual level to match the time frame of the RPS policy. We identified new investment using the 'status' indicator of each generator, categorizing renewable generators (projects) that changed their status from 'proposed' to 'in operation' as new investments.

We aggregate new investments at the state(s)-year(t) level, combining data from state-firm-generator levels. Time t is the year when the generator completed construction and commenced operation, not the year when the generator was first proposed. This is based on the observation that firms involved in investments – retailers and wholesale project developers – typically determine the year of a new plant's operation when negotiating contracts or initiating construction.[12] Moreover, the annual RPS target levels (requirements) are published in advance (e.g., 10 years). This advanced notice enables both retail and wholesale firms to plan ahead, making investment decisions before year t to meet the requirements of that year based on the projections regarding their shortcomings in acquiring renewable energy. For these reasons, we assume that any new investment in year t would

[11] We will discuss more about the REC market channel investment in Section 4.5.

[12] For example, the construction duration, determined from the EIA Form 860 by calculating the years between the first proposal of the plant and the start of its operations, varies significantly (with an average of approximately 2 to 3 years) across projects. Industry reports provide evidence that project commissioners and developers initially agree on the project completion year and subsequently adjust the construction pace to meet that deadline (`power-technology.com` provides online reports with details on the development of renewable projects).

be influenced by the RPS requirement for that year, particularly if it was strategically planned for the purpose of RPS compliance.

While the types of energy sources categorized as renewable may vary by state, both wind and solar generation are included in this category across all states. Furthermore, the RPS policy predominantly targets wind and solar generation, as other forms of renewable energy, such as hydroelectric generation, have already reached full capacity and can only be constructed in restricted locations. In Figure C.2 in the Appendix, other types of renewable generation capacities, such as biomass and hydro, do not increase over time, and the size of investment is also significantly smaller than wind and solar generation capacity. Therefore, our analysis focuses only on wind and solar generation capacity.

As discussed earlier, identifying whether a specific investment is tied to a purchasing power contract is challenging. The EIA Form 860 provides information about the owner of a power plant as well as the type of owner – electric utility or IPP – which allows us to identify power plants that are directly invested by electric utilities (part of retail companies), fitting into the case of vertical integration. However, electric utilities/retail companies can also establish long-term purchasing contracts with IPP invested capacities. Although these capacities are tied to retail companies through contracts, they are listed as invested and owned by IPPs in the EIA Form 860. Thus, a substantial portion of IPP invested capacities are contracted with retail companies. We have partially verified this by examining the FERC Form 1 (Yearly purchased power and exchanges), with a more detailed discussion provided in Appendix A. As shown in Figure C.3, the overall size of the capacity directly invested by electric utilities (identifiable from EIA Form 860) is small relative to those invested by IPPs, suggesting that directly invested capacities alone do not represent the RPS-driven capacities.[13] For this reason, we do not further separate out the capacity and use the state-level aggregate capacity for our analysis.

RPS Policy Data. Data on timing and target levels of the RPS are publicly available. We use a dataset constructed by Barbose (2021), which reports the states that have enacted an RPS, the year when the RPS started in each state, the RPS target levels (in %) along with the RPS requirements in MWh for each state over time. The RPS target is reported in percentage and the RPS requirement levels are simply total annual electricity sales within a state (MWh) multiplied by the target level (%).

[13] Furthermore, there are retail companies other than electric utilities that must comply with RPS policy, which do not show up in the owner section of EIA data.

We also use the annual percentage of RPS compliance data compiled by Barbose (2021). These data report the actual percentage of compliance, which is the percentage of total sales (MWh) that was used for complying out of total sales, for states that enacted an RPS policy. For example, suppose that the total annual sales in California in year 2005 was X MWh and the RPS target was 4%. This means that $RPS_{2005,CA} = X \times 0.04$ MWh amount of electricity must be sourced from renewables in that year. If the compliance percentage in CA that year was 80%, it means that retailers in CA were able to meet only 80% of the RPS requirements by acquiring credits (either bundled or unbundled), which is $RPS_{2005,CA} \times 0.8$ MWh.

The RPS policy is imposed at the individual retail electricity providers and the compliance is verified at the firm level. However, Barbose (2021) only reports the compliance at the state level, thus unless the percentage of the state's compliance is 100%, we cannot identify the compliance/non-compliance status at the firm level. That means, we cannot identify which of the retail firms in the state failed to meet the requirement. However, this is not a significant data limitation as we carry the analysis at the state level.

State-level control 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.[14]

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. The difference in operation hours could be starker in winter than in summer. Operating longer hours means higher profits from the regular spot market and bilateral market. To capture this difference resulting from weather, we compute annual generation per MW of the existing renewable generation capacity at the state level, which represents the average capacity factor of renewable generation in each state.[15]

Lastly, we obtain data on the annual net interchange (net flows) between the states from the EIA Electric Power Annual reports to account for any physical trades of renewable generation across states that could have been caused by the RPS. While it makes more sense 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

[14] https://www.eia.gov/electricity/annual/

[15] To avoid incorporating contemporaneous year capacity additions, we use the operating hours per MW of renewable capacity with a lag of 2 years.

dataset. Since the investment of renewable generation affects the import/export of a given year, we take a lag of this variable and include it in the regression.

The net interchange data can capture some of the spillover effects of RPS policy. As pointed out in Hollingsworth and Rudik (2019), an RPS policy in one state can influence renewable investment in nearby states if the state allows for compliance using out-of-state renewable generation. Since we do not observe which out-of-state power plants are tied to the state's RPS policy, we instead specify the annual net flow of electricity coming from interconnected states. If new out-of-state renewable capacity is built and contracted to supply electricity to retailers in the state, the net flow into the state will increase as a result. Variation in the net flow of electricity will, therefore, capture some of the spillover effect, if it exists.[16] Section B.1 in the Appendix offers a more detailed discussion of the spillover effects.

Firm Data. We obtain firm-level data from the EIA Form 860 (wholesale firms) and the EIA Form 861 (retail firms). The EIA Form 860 provides information about generating firms, including Independent Power Producers (IPPs) and Investor-Owned Utilities (IOUs), that own generators. From this dataset, we can compute firm-level variables, such as the firm's total capacity and generation composition. The EIA Form 861 provides information about retail electricity providers (retail firms) that serve customers within each state. This dataset reports the company name, total sales (in MWh), and the number of customers.

We use these datasets in several ways. First, to explore the vertical linkage between wholesale firms (generation) and retail firms (retail electricity providers), firm-level data are required. While neither dataset explicitly specifies information about the linkage, such as which wholesaler the retailer is connected to, we are able to partially match the two datasets to obtain information, although not perfectly. We will elaborate on the usage of the identified linkage information later in Section 4.2 and Appendix B expands on other relevant factors affecting compliance with the RPS.

4 Empirical Analysis

To ensure compliance with the RPS, the requirements of which increase over time, states must ultimately make investments. Our goal is to explore how the patterns (growth and trend) of new investments in renewable generation, specifically wind and solar, differ among RPS-adopted states

[16] The net flow of electricity from the new out-of-state renewable capacity will not be constrained by transmission line capacity. If the transmission line were insufficient to cover the increased flow, the retail company wouldn't have pursued the option of acquiring out-of-state capacity for compliance in the first place.

with varying vertical structures. We first explain the key variables of our main specification and elaborate on the empirical strategy.

4.1 Binding Years: Variation in the compliance status

Several other studies examining RPS policy employ a staggered Difference-in-Differences (DiD) analysis, with the adoption of the RPS policy used as the treatment. However, our approach differs from them in that we do not investigate the causal relationship between the RPS policy and renewable investment by using the enactment of the RPS as the treatment, but rather the influence of the market structure and whether the policy is binding or not.

While we also tried such standard DiD type of regressions, shown in Table C.1, we believe such an analysis is not perfectly suitable in our case. One reason for this is the renewable generation capacity, wind and solar in particular, being small with no variation in most states prior to the start of the RPS, along with a small number of states in the treated group within the same cohort.[17] Moreover, there is significant heterogeneity in the states' investment responses to the RPS policy even after its adoption. This variation arises from the fact that states have different initial stocks of renewable generation eligible for compliance. The importance of accounting for the renewable capacity that existed before the RPS adoption has also been recognized in other studies (Greenstone and Nath (2021), Deschenes et al. (2022)).

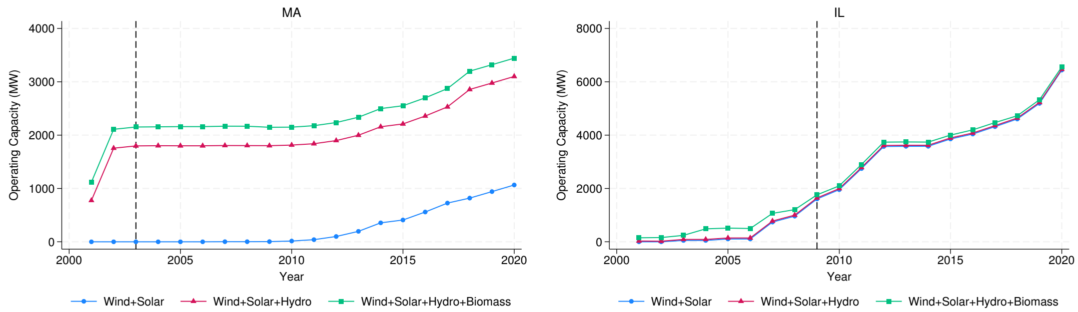
Figure 5, which displays the cumulative capacities across different group categories, provides an example of two states that differ in the initial levels of renewable capacity and how new investments respond differently to the policy. In the case of Massachusetts (left panel), wind and solar capacities do not increase until several years after the adoption of the RPS (depicted by the vertical dashed line) because the state's cumulative renewable capacity, including hydro and biomass, was sufficient for compliance during the initial years, which had low RPS requirements. Investments then rose steadily as the target levels progressively increased over time. On the other hand, renewable capacity in Illinois (right panel) comprises mostly of wind and solar, with a relatively small existing renewable capacity at the start of the RPS. Thus, investments in new wind and solar capacities occur from the onset of the RPS start year.[18]

This, in turn, suggests substantial heterogeneity in investment responses even within the post-

[17] The small treated sample is especially problematic when employing a staggered differences-in-differences approach where the treated group is defined in each year.

[18] While the existing capacity at the RPS start year appears similar in both states, the size of the RPS obligation in the first year of adoption was more than two times bigger in Illinois than in Massachusetts. That is, the requirement in the latter in the first year of the RPS was 498,344 MWh whilst in Illinois in its first RPS year was 1,210,441 MWh.

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 years across states. Moreover, the variation in compliance status, driven by the changing RPS target level, introduces more interesting variation in investment patterns than the pre-post-RPS treatment indicator. New investments occur when the RPS requirement (target) becomes binding for the state; at this point, the state (or its retail firms) cannot achieve compliance with the existing renewable capacity.

Therefore, we introduce a binary measure termed 'Binding Years', which indicates the years when the state fails to achieve full compliance with the RPS. The measure introduces year-to-year compliance variation for the post-RPS period, for the states that have adopted RPS policy. In any given year where full compliance has not been attained, we anticipate that the entire new investments in renewable generation in that binding year will be utilized by retail companies in the state to meet the RPS requirement. All new investments, regardless of being sourced through contracting or with an intention to sell credits in the REC market, would have to be used to comply with the state's obligation if the state is below compliance.[19] Not using any leftover credits or credits generated from newly invested renewable capacities in this binding year does not make much sense. Thus, the influence of the RPS policy on renewable generation investments is expected to be notably stronger during these binding years compared to non-binding years where the state has already achieved full compliance with the policy. By leveraging compliance/non-compliance

[19] This also applies in the case when the state allows out-of-state credits being used by in-state retailers to comply with the RPS, which was studied exclusively in Hollingsworth and Rudik (2019) and Abito et al. (2022). Note that the state's compliance/non-compliance designation factors in the credits/electricity imported outside of the state (i.e., credits ultimately used by retail companies for compliance). Thus, the state being non-compliant indicates that regardless of credits being imported, the credits generated within the state, including those generated from the new investments, were still not enough to meet the requirement. This, in turn, implies that all in-state investment in that binding year can be attributed to policy compliance purposes regardless of the size of the imports/trades among adjacent states.

Figure 6: RPS requirement, RPS goal, and Binding Years: 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 Binding Years. The Binding Years indicate the years when the state was in full compliance with the RPS policy.

data at the state level, we assume a causal relationship between the RPS policy and investment, instead of establishing one empirically.

To account for the degree to which the compliance is incomplete, we introduce the RPS Goal variable. This variable shows how much of the target was not attained in the given year. For example, if the attainment percentage is 60% with a total target requirement of X MWh, the RPS goal is 40% $\times X$ (MWh). This variable complements our "Binding" variable, which is a binary indicator, thus not reflecting the degree to which the state fails to meet the compliance.

Figure 6 shows an example of variables, Binding Years, and RPS Goal for Connecticut. The solid line represents the annual RPS requirement at the state level, which is simply RPS target (%) $\times$ Total electricity sales (MWh), and 'Binding Years' are indicated with the X marker. The RPS goal variable exists for binding years, which are also shown on the graph.

4.2 Different Measures of Vertical Structure

We construct a variable that measures the degree of vertical separation at the state level, which we call VS (Vertical Separation). Our objective is to quantify the extent to which the generation sector is vertically separated from the retail sector within the state. While the vertical structure at the firm-plant level is clearly binary, representing the prevalence of vertical integration/separation at the state level goes beyond a binary indicator. We introduce three different versions of this variable and will conduct empirical analyses for all three cases. In each case, we keep the VS variable constant over time, fixed at the level calculated at the beginning of our sample period.

4.2.1 Binary indicator for vertical separation.

Our first measure is a binary variable that labels each state as either vertically integrated or as vertically separated, based on whether the state has restructured their electricity sector. As discussed in Section 2.3, restructuring can happen at either wholesale or retail markets, or both. We assign the indicator $VS = 1$ to the "restructured" states that have restructured both the generation (wholesale) and retail sectors. Our binary indicator is constructed based on the list of restructured states used in several sources (Fabrizio et al. (2007), Borenstein and Bushnell (2015), Barbose (2021), MacKay and Mercadal (2022), and the EPA[20]).

Restructuring is associated with increased separation between generation and retail. The generation companies in a restructured wholesale market include many independent power suppliers (IPP) that are not tied to the retail sector. The retail service providers, the demand side of the wholesale market, must also participate in this competitive wholesale market to purchase electricity on spot or through bilateral contracts. While the retail market restructuring is more related to the decreased concentration/market power in the retail electricity market, having an increased share of retail companies that are not legacy electric utilities can be translated to increased separation between the generation and retail.

The challenge of analyzing electricity restructuring, according to Borenstein and Bushnell (2015), is that there is no unified definition of restructuring, with restructuring and deregulation often used interchangeably, and restructuring of wholesale and retail not distinguished. In practice, many states categorized as restructured for having restructured the generation sector have not restructured the retail market. However, all of the states with restructured electricity sector had its generation sector restructured.

4.2.2 Continuous measures using firm-level information

While the binary indicator at the state level is widely used in many studies, this indicator does not reflect the heterogeneity in generation ownership at the firm level, within a state. As discussed in Section 2.4, the restructuring (or deregulation) in practice was not a clear cut process, and even if the state is indicated as vertically separated for having restructured, the electric utilities (retail

[20] https://www.epa.gov/greenpower/understanding-electricity-market-frameworks-policies

companies) can still participate in the wholesale sector by owning and operating generation assets. In other words, generation and retail may not be completely separated even if the state is assigned a value $VS = 1$. Moreover, the prevalence of vertical ties between generation and retail can differ across states that have restructured.

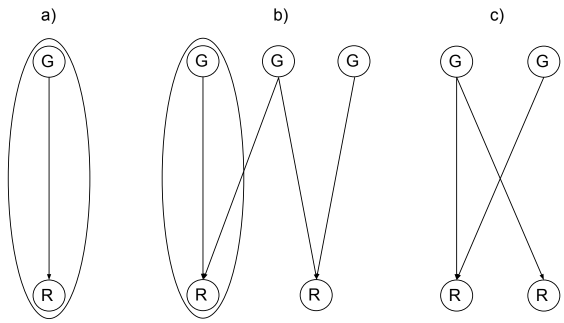
Therefore, we devise continuous measures that capture different degrees of vertical separation across states, exploiting the firm-level observation of vertical relationships between the generation and retail sectors. Since our analysis is at the state level, the continuous measures are also constructed at the state level.

Vertical separation measure using generation capacity data. We first construct a measure of vertical separation using the data on generator capacity in the wholesale generation sector. This measure, therefore, explores the firm-level vertical status within the wholesale market. Specifically, we use the information from the EIA Form 860 plant-level data which indicates the owner of the power plant along with the information whether the owner is an electric utility (IOU) or an Independent Power Producer (IPP). The information allows us to identify the plants directly owned by IOUs that operate in the retail sector. We compute the fraction of generation capacity within the state that is not owned by these utility companies. Note that we measure this share using the physical capacity which represents the scale, not the utilized capacity (i.e. sales or share). We fix the measure to the share in year 2002, which is the year prior to the majority of the states adopting an RPS, in order to address the concern that capacity shares could change throughout the sample as new investments occur in the industry.

Vertical separation measure using the retail provider and generator. The previous measure using the generation sector data did not particularly use the information of the retail market. Since the RPS primarily affects retail electricity providers, it is important to incorporate information about the retail firms. Therefore, we devise a second continuous measure which reflects more directly the degree of vertical separation, exploring the link between retail electricity provider and generators. Specifically, we compute the fraction of retail sales from retail electricity providers in the state that do not own any generation assets in the generation sector. This measure better captures the existence of vertical linkages between the large-scale retail companies and generators, accounting for the concentration of retail electricity providers.

We use the EIA Form 861, which collects data from distribution utilities (IOUs) and power marketers of each state. The data contain the name of the entity, ownership status, total annual sales,

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.

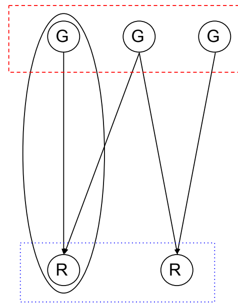
revenues, average price, and other information at the state level. We match the retail providers that show up in this retail sector file with the entities that own and operate power generators in the wholesale market (EIA Form 860 data). We computed the share of retail sales (total annual electricity sales in MWh) of retail companies that own a power plant upstream, which is the share of vertically integrated retail companies.[21] Thus, our continuous measure of VS retail is the fraction of the share of sales coming from retail companies that do not own a power plant upstream. In the regression, we fix the measure to the share in year 2002, which is the year prior to majority of the states have adopted RPS, in order to address the concern that market shares could change throughout the sample due to retailer's compliance strategy to RPS policy and their new investments.

4.2.3 Relationships between the three measures of vertical separation.

To further understand the need for a continuous measure of vertical separation, Figure 7 portrays the three possible configurations in the electricity sector. Each of these possibilities can be present in the same state. The simplest configuration occurs when all the generation and the retail assets belong to the same company, this is the fully vertically integrated case. Another case is when there is a retailer owned by a company that has generation assets as well but it also buys power from a generation entity that belongs to a different company. This is a case of partial vertical separation. And last, a case where the generation and retail sectors do not share any ownership in common, this is the fully vertically separated case.

[21] Note that we keep the retail providers having at least 5% of the market share in terms of total annual sales.

Figure 8: Construction of continuous VS measures

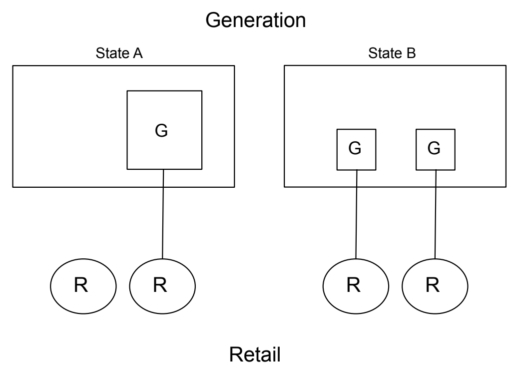


Notes: Arrows represent sales of power from generation entities to retailers. Ovals represent joint ownership. When constructing the VS measure using the generation capacity data (red dashed rectangle), we obtain VS = 0.66 (assuming equal generation capacities). However, when using the retail sales data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

Figure 8 shows an example of the construction of our different measures of market structure. First, within the generation sector, shown in the upper box in red color, one generator (G) among a total of three generators is owned by one of the downstream retailers (R) shown in the box below. Therefore, we can compute the proportion of generation capacities that do not have an ownership connection with the retail sector and this becomes our measure of vertical separation using generation capacity. Assuming that all generation assets shown in the figure have the same capacity, the VS measure is $\frac{2}{3}$. On the other hand, within the retail sector, shown in the box below in blue color, one of the retailers among the two owns a generator in the upstream level. Therefore, we can compute the share of retail electricity sales of companies that do not own a generator in the upstream level, which becomes the measure of vertical separation using retail market sales. If we assume that retailers have the same market share in this example, the VS measure is $\frac{1}{2}$. As shown by this example, our two continuous measures of vertical separation do not necessarily coincide.

The difference stems from within which sector the prevalence of the existing vertical linkages between the two vertically related sectors are measured. We believe that the continuous VS measure based on the "retail" sector data more accurately captures the vertical linkages relevant to our research question. That is, since RPS targets retail electricity providers, how much of the retail sector is vertically separated matters more than how much of the wholesale sector is vertically integrated. Figure 9 demonstrates this with an example of two states that have different types of vertical relationships. Each state has the same number of retail companies, but different vertical ownership status. In state A, only half of the retail sector is vertically integrated with generators in the upstream, though the size of the generators integrated is big. In state B, all companies in the retail sector are integrated with the generators upstream. Since we care more about how pervasive

Figure 9: 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) is established between these sectors.

the vertical integration/separation is among the retailers, we would consider the vertical integration (linkages) to be more common (propagated) in state B than in state A because the entire retail sector has been integrated with generators to some extent. That implies that state A should have a higher degree of vertical separation pertinent to our analysis. However, due to the large size of the generation capacity owned by one retail firm, the VS measured within the generation sector using the capacity data will assign a lower value of VS to state A than state B, suggesting that state B is more vertically separated than state A. On the other hand, the VS measured within the retail sector will assign a higher value of VS to state A than state B, suggesting that state A is more vertically separated.

These vertical separation measures are limited in the sense that we can only observe the assets directly owned by retail companies, and that we cannot observe the generation assets that are contracted but not owned by the retailer. Therefore, when using this VS measure we maintain the assumption that owning some assets and being involved in the operation in the upstream market would give the retail firm advantage in terms of inducing investment through the contracting channel. Thus, whether the retailer has a large ownership in the upstream level in the past is not a direct indicator of future investments in renewables through the contracting channel. All retailers are constrained by the policy, an obligation proportional to their sales, thus the size of the individual retailer's integrated generation upstream level is not too relevant.

Table 1 shows the summary statistics of our three measures of vertical separation. The three measures differ from one another, but they are somewhat correlated. Figure C.1 in the Appendix depicts the pairwise correlations of the three measures, showing highest correlation of 0.8 between

Table 1: Summary statistics of measures of vertical separation

	Mean	Min	Max	S.D.
Binary	0.48	0	1	0.50
Generation capacity	0.50	0.04	1	0.37
Retail sales	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.

the two continuous VS measures. Nevertheless, when comparing these measures at the state level, the two measures greatly differ for some states. This is shown in Figure 10 where each dot represents the combination of the retail sales- and the generation capacity-based measure for each state. For example, in California, a vertical separation measure using generation capacity is slightly above 0.5, while the retail sales-based measure is close to 0, thereby classifying California as fully vertically integrated. This is the case because there is a large proportion of independent generators not tied to retailers in the wholesale sector, but all retailers operating within California own generation capacity in the wholesale sector.

4.3 Main specification

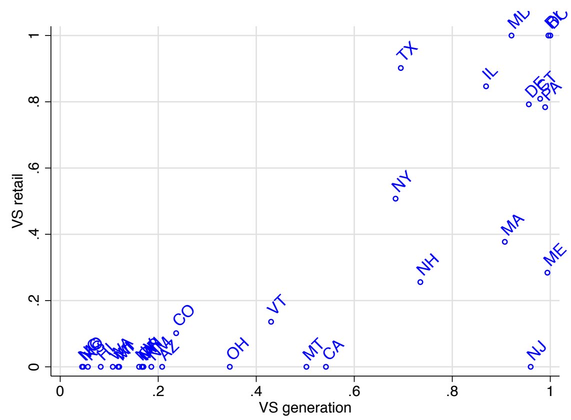
Taking into account all of the previous considerations, we estimate the following regression model:

$$\begin{aligned} \text{Renewable Investment}_{s,t} \quad &= \alpha_0 + \alpha_1 \text{ RPS Goal}_{s,t} + \alpha_2 \text{ Binding Years}_{s,t} \\ &+\beta \text{ VS}_s \times \text{Binding Years}_{s,t} + \textstyle\sum_{\tau=-2}^{\tau=+2} \lambda_\tau D_{s,t^*+\tau} \\ &+ \textstyle\sum_{\tau=-2}^{\tau=+2} \gamma_\tau D_{s,t^*+\tau} \times \text{VS}_s + \boldsymbol{\beta}'\mathbf{X}_{s,t} + \varepsilon_{s,t} \end{aligned} \tag{1}$$

We estimate this using only the states that have enacted an RPS policy. Thus, our empirical analysis differs from a standard difference-in-difference estimation, where states with an RPS would be considered as treated and states that have not adopted an RPS would serve as the control group. This is because the adoption of an RPS itself does not explain states' investment change, which seems to be driven more by the increasing levels of policy targets as well as compliance projections, as explained in Section 4.1. Moreover, the RPS-related variables (data) are missing for the states that have not adopted the policy, therefore, we focus solely on the states that have adopted the policy.

As explained in Section 3, the dependent variable Renewable Investment$_{s,t}$ represents the aggregate level of new investments in wind and solar generation capacities in state s in year t. Note 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 out-

Figure 10: 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.

comes of individual-level decisions in an aggregate sense. The schedule of goals established by the RPS is set up several years in advance. The investment is decided at some point so that the plant can go online at the time needed to comply with the RPS. Therefore, compliance is a consequence of investment that was determined in the past but becomes available today, at the time when we measure compliance. In other words, we distinguish between two types of investments: those made at the firm level but not yet realized (at some point before t) and the amount of realized investment (or contemporaneous and online for the first time at time t).

The main variable of interest is the interaction of the state's market structure (VS) and Binding Years. Therefore, the coefficient β captures to what extent the investment increases influenced by the policy differ across different vertical structures conditional on non-compliance. We also control for RPS Goal, which captures how far the state is to comply with the policy.[22] $\mathbf{X}_{s,t}$ includes state-level controls, such as total capacity, total net generation within the state, net import flows into the state from neighboring states, average profitability of a MW renewable capacity, as well as year fixed effects and market (RTO) fixed effects. Note that we included state fixed effects to control for any policy changes happened within the state that could potentially affect the investment. Standard errors are clustered at the state level.

In order to capture time trends that are common to all states but that only occur around the point in time where the RPS policy is binding in certain states, we add time dummies associated with each year before and after the event (the year in which the RPS regulation is binding in a

[22]We do not include VS as a separate regressor since we include state fixed effects.

given state). We use a window of two years before and after the event. These dummies are different than the Year fixed effects. This is inspired by some of the specifications in Greenstone and Nath (2021).[23]

The data span from 2002 to 2020, including the states that have eventually adopted RPS by 2020.[24] 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. Because each state enacted RPS in different years, we have an unbalanced panel data set. Note that most states, a total of 18 states, adopted an RPS policy between 2002-2008, and the data are not significantly unbalanced. Although our sample spans over the period 2002 to 2020, the RPS compliance data does not exist for latter years of the sample in some states.

Our estimate on the interaction term has a causal interpretation in regression (1) as long as the following assumption holds. If the residuals are uncorrelated with the state's market structure (VS) and uncorrelated with the extent to which the RPS is binding. For the former, the market structure in each state has evolved over time as a consequence of several factors that have all being unrelated to the RPS policy because the policy is relatively new and because we keep the level of VS fixed throughout our analysis. For the latter, whether the RPS is binding or not in a given year depends on *past* investment decisions but not on current decisions. Recall that we assume that the industry plans ahead because the targets are announced in advance, and therefore, the investment that comes online at time t was decided before time t.

4.4 Results

The results from regression (1) using the three different measures of vertical separation (discrete, generation capacity, and retail sales) are shown in Table 2, Table 3, and Table 4. In the three cases, our variable of interest (Binding x VS) has a negative and statistically significant coefficient except for some specifications with the generation capacity vertical separation measure. Both with the classical method of categorizing market structures in a discrete way (Table 2) and with our preferred measure through retail sales (Table 4), our coefficient of interest reveals that renewable investment is lower when the RPS policy is binding and the retail sector is more separated from the generation sector relative to states that are less vertically separated (more integrated).

[23] An example of the use of these dynamic effects specifications in a different context is Vannutelli (2022).

[24] We do not to use investment data prior to 2002 because the restructuring process was completed in most of the states by 2002 and that investment data prior to 2002 are contaminated with the investment boom that resulted from restructuring.

Table 2: Renewable investment and compliance using binary measure of vertical separation

	(1)	(2)	(3)	(4)
Binding x VS	-336.4*	-337.3*	-239.8**	-199.7**
	(179.8)	(183.1)	(97.38)	(78.36)
Binding	148.3	151.5	131.9**	117.5**
	(116.7)	(130.6)	(61.19)	(57.14)
RPS goal (GWh)		-0.00591	-0.00643	-0.0210
		(0.0314)	(0.0282)	(0.0303)
Net summer capacity (MW)			81.67**	83.64**
			(36.84)	(33.34)
Net generation (MWh)			-0.00520	-0.00572
			(0.00875)	(0.00858)
Renewable per cap. lag (MW)			0.000682	0.0191
			(0.0240)	(0.0285)
Net flow lag (MWh)			1.473	0.915
			(4.839)	(4.894)
Constant	802.6***	808.3***	-3752.5***	-3758.6***
	(69.85)	(54.33)	(513.2)	(643.1)
N	388	388	332	332
ar2	0.48	0.48	0.59	0.59
DV_mean	176.02	176.02	205.25	205.25
MarketFE	✓	✓	✓	✓
StateFE	✓	✓	✓	✓
DynEffects				✓

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: Dependent variable: New renewable capacity (MW). 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.

To show the importance of controlling for different factors, we start with simple regressions that only include the interaction term, whether the policy is binding, the distance to achieve the RPS goal, and market and state fixed effects, for each of the three measures of vertical separation. In all those cases, except in Table 2 when using the vertical measure based on generation capacity, the coefficient of interest is already negative and statistically significant.

Using column (4) of our three specifications as our main result, we find that the investment size is larger in binding periods, indicated by the coefficient on "Binding". We do not have an overall estimate for the vertically separated states because such a variable would be collinear with the states fixed effects. Our primary coefficient β, on the interaction variable $Binding \times VS$, shows that vertically separated states invest significantly less in renewable generation than integrated states, especially when the RPS's influence on investment is stronger (Binding).

As discussed above, our preferred measure of vertical separation is given by the retail sales (Table 4). Using columns (3) and (4) from that table, the coefficient on the interaction term ranges from -243 to -404.3. Equivalently, on average, conditional on having a binding RPS policy, states with a vertically separated structure invest less in renewables than their vertically integrated counterparts by a factor between 1.4 and 2.3 times the overall average investment in renewables. Therefore, our results are economically relevant. Note that even if we use the results from the other two measures of vertical separation, the effect is between 0.93 and 1.92 times, slightly lower than our results using our preferred measure of integration.

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. Natural gas investment is not affected by the RPS regulation; thus, these additional regressions serve as a natural placebo test for vertical structure's effects on the RPS-induced renewable investment.

Table C.5, Table C.6, and Table C.7 show the result of regression 1 specification 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 4 specifications each) we find a positive coefficient. 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 "Binding" has a negative and statistically significant sign in Column (4) of the three tables, indicating that when the RPS policy is binding, there is less

Table 3: Renewable investment and compliance using a continuous measure of vertical separation (generation capacity)

	(1)	(2)	(3)	(4)
Binding x VS	-209.3	-210.9	-194.8	-191.5*
	(158.7)	(162.7)	(129.3)	(95.70)
Binding	131.0	134.4	145.4	155.8**
	(138.8)	(152.8)	(94.44)	(70.49)
RPS goal (GWh)		-0.00499	-0.00541	-0.0243
		(0.0267)	(0.0256)	(0.0284)
Net summer capacity (MW)			83.85**	83.66**
			(39.81)	(37.14)
Net generation (MWh)			-0.00485	-0.00429
			(0.00921)	(0.00876)
Renewable per cap. lag (MW)			-0.00558	0.0117
			(0.0236)	(0.0254)
Net flow lag (MWh)			2.442	2.871
			(4.917)	(4.875)
Constant	895.1***	900.0***	-3978.6***	-4100.2***
	(59.42)	(48.04)	(595.4)	(684.1)
N	388	388	332	332
ar2	0.47	0.46	0.58	0.59
DV_mean	176.02	176.02	205.25	205.25
MarketFE	✓	✓	✓	✓
StateFE	✓	✓	✓	✓
DynEffects				✓

Standard errors in parentheses

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

Notes: Dependent variable: New renewable capacity (MW). 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 4: Renewable investment and compliance using a continuous measure of vertical separation (retail sales)

	(1)	(2)	(3)	(4)
Binding x VS	-400.8*	-404.3*	-321.6**	-243.1**
	(222.0)	(228.7)	(126.2)	(108.5)
Binding	159.3	165.2	125.5**	122.2**
	(121.6)	(137.8)	(57.76)	(53.26)
RPS goal (GWh)		-0.00947	-0.00491	-0.0289
		(0.0318)	(0.0272)	(0.0311)
Net summer capacity (MW)			81.85**	82.91**
			(36.77)	(33.53)
Net generation (MWh)			-0.00538	-0.00570
			(0.00873)	(0.00881)
Renewable per cap. lag (MW)			-0.00567	0.00498
			(0.0247)	(0.0291)
Net flow lag (MWh)			0.236	-0.582
			(5.174)	(5.999)
Constant	797.8***	806.3***	-3619.4***	-3556.2***
	(71.76)	(57.13)	(520.9)	(752.6)
N	388	388	332	332
ar2	0.49	0.48	0.59	0.59
DV_mean	176.02	176.02	205.25	205.25
MarketFE	✓	✓	✓	✓
StateFE	✓	✓	✓	✓
DynEffects				✓

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: Dependent variable: New renewable capacity (MW). 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.

investment on non-renewable 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, Table C.3 and Table C.4 show the results from the same model from this section but with a dependent variable that measures the investment on wind capacity and on 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. Similarly to the results when aggregating both types of investment, the coefficient on the interaction term is negative in all specifications. However, it is only statistically significant when controlling for market and state fixed effects in the case of wind, and in two specifications in the case of solar. Although these results are not in contradiction to the main findings, they seem to suggest a weaker evidence for our hypothesis. One should see the results in Table C.3 and Table C.4 as only an approximation since we do not have the information for the state- and technology-specific RPS goals for each year and the RPS goal variable used in these alternative regressions is the same as for the aggregate investment amounts.

4.5 The Effect of Renewable Energy Credits (RECs) on Investment

As explained in Section 2.4, there are two main channels through which the investments can occur: the contracting channel and the Renewable Energy Credit (REC) market channel. We have implicitly assumed that the differential effect of vertical structure on investment is driven mainly by the contracting channel and that the REC market channel investment will not critically differ by vertical structure. The best way to empirically verify our research question is to separate out the new investments directly related to the contracting channel and use them in the analysis. Unfortunately, we cannot clearly distinguish between the new capacity amounts invested through a contractual agreement and those invested with an intention to sell their unbundled renewable energy exclusively in the renewable energy credits (REC) market, because it is difficult to obtain data on contractual agreements (e.g., Power Purchase Agreement (PPAs)) between the generator and the retailer (see Appendix A for details). Therefore, the aggregate level of renewable investments complying with the RPS policy, the main dependent variable used in our analysis, contains investments occurring through both channels.

While the second-best practice would be to specify the REC market variables in our main regression to control for the variation in investment explained by the REC market condition, we do not include the REC market related variables in our analysis due to data limitations. The REC market data, especially the spot prices of credits, are not publicly available. Only several states report monthly summary statistics of the Solar REC prices.[25]

We should worry about the omitted variable problem if the REC market variables are determinants of the renewable investment and affect our main variable of interest $VS\times$ Binding. We will discuss the limitations and potential bias that may arise from omitting the REC market variables in our analysis.

REC market variable as an omitted variable. While the REC market is indispensable for firms' compliance strategies facing the RPS policy, REC market prices are volatile and significantly influenced by the state's compliance status towards the RPS.[26]. This is particularly true for solar renewable credits (RECs). Table 5 shows the summary of monthly REC prices for solar in the PJM market from 2008 to 2020. The weighted average is the index of individual transaction prices, and the lowest and highest prices represent the minimum and maximum of all individual transaction prices. The prices are highly volatile, ranging from 0 up to about 700 \$/MWh, even within the same month. A price of zero occurs when there is excess supply (with very low or zero demand for credits relative to those issued).

This high volatility in prices indicates that renewable project developers would not make investment decisions solely based on revenues earned from selling their credits in the REC market. The revenue stream, which depends on the market price of RECs, would be volatile and heavily dependent on the compliance status of the state's RPS. In other words, the REC market cannot be a reliable source for both generators to make investments and for retailers to meet policy requirements. This means that the influence of REC-related variables on the new investments made for compliance reasons is weak. If so, the direction of influence is more from the $VS\times$ Binding interaction to the REC market variables than the reverse, in which case omitting the REC market variable is less worrisome.

Vertical market structure and compliance channels. Despite the possibility that omitting the REC market variables may not pose a significant threat to our identification, we discuss the relationship between the REC market and our main variable, $VS\times$ Binding, based on the understanding

[25] For example, summary statistics of REC prices in states that belong to the PJM Interconnection are available through PJM-GATS (Generation Attribute Tracking System (https://www.pjm-eis.com/), which is a trading platform designed to meet the needs of buyers and sellers of RECs. PJM-GATS reports solar-weighted average prices for transactions in the PJM market that include pricing from long- or mid-term contracts as well as spot prices for solar-only capacity.

[26] https://www.nrel.gov/docs/fy14osti/61042.pdf

Table 5: 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.

of firms' incentives, to determine the sign of the direction of the bias.

If the REC market channel of investment affects our main treatment variable $VS\times$ Binding, which intends to capture the difference in investment patterns attributable to the vertical market structure, omitting the REC market variables could bias our estimate. Therefore, we provide a discussion on whether the presence of an attractive REC market condition could potentially crowd out the investment happening through the contracting channel by considering investment incentives of a renewable project developer in the wholesale market and a retail company that needs to comply by inducing investment.

We first consider how the wholesale generator's incentives to invest through the contracting channel would be affected by the presence of a more attractive REC market. The presence of another option for wholesale firms, which is the REC market, can have an impact on the contracting channel, more so in the vertically separated market. That is, if the contracting is costly and both parties do not end up in an agreeable term, a renewable project developer in the wholesale market can resort to the REC market to finance its investment cost. This implies that an attractive REC market –high REC prices, low REC price volatility– could crowd out the investment happening through the contracting channel, more so in the vertically separated environment where the contracting channel is relatively more difficult for firms to pursue; wholesale generators would be more willing to move away from the contracting channel in a market where the commitment for this channel is weak.

We also consider how the retail firms' incentives to invest through contracting channel would be affected by the presence of a REC market. Note that the REC market condition perceived as attractive to the wholesalers –high REC price– is unattractive to the retail companies that are on the buyer side of the credits. Retailers, regardless of the vertical structure, would prefer complying with the REC market over directly investing as long as the credit prices are stable and lower than the long-term contract payments. However, when the REC market condition is not favorable (e.g. high credit price), retailers would want to go for the contracting channel, although whether they are able to effectively secure a contract now differs by vertical structure.

In equilibrium, incentives of both sides matter. To summarize, wholesalers have greater incentives to move away from contracting channel and switch to (a more attractive) REC market, more so when they are operating in a vertically separated environment. On the other hand, retailers, regardless of vertical structure, would have stronger incentives to seek for contracting when the REC market conditions are favorable to wholesalers, indicating that upstream and downstream incentives do not align in response to REC market conditions. The problem of misaligned incentives is more problematic in vertically separated markets, eventually affecting the level of contracting channel investments in equilibrium compared to not having the REC market option. In the vertically integrated situation, incentives of retailers and wholesalers are aligned, thus the wholesaler will keep investments to the level that is demanded by the integrated retailer despite having a more favorable alternative REC market option. Therefore, in the vertically integrated case, investment happening through the contracting channel works well and is less affected by the conditions of the REC market. To conclude, presence of a REC market is expected to intensify the difference in the pattern of RPS-driven investment between vertically integrated and vertically separated structures, indicating a more negative coefficient for the main variable of interest.

Sub-sample regression. To assess this conjecture, we conduct an analysis using a small sample of states within the PJM interconnection in which the REC market data are available. However, PJM reports summary statistics of the prices of solar renewable credits (SREC) and does not release data on non-solar REC which includes wind or biomass. Therefore, we restrict our analysis to the investments in *solar* generation capacity within states that are part of the PJM interconnection. We use weighted average value of individual transaction prices for the RECs for solar at the state-month level from year 2008 to 2020. We take the average of these monthly prices to the year level to make the time consistent with our main data set. We adjusted the compliance status variable for states with separate RPS target levels and compliance status for solar generation capacity.

We run the same regression as in (1) using this subsample, specifying the average REC price variable as one of the control variables and using only solar investment amounts as our dependent variable. Table 6 columns (1) and (2) show the result. Column (1) is the basic regression without REC variables specified, column (2) adds the REC price of the same year as an additional control. Due to the possibility that credits can be traded between states within PJM, the standard errors are clustered at the year level.[27]

[27] While most of the states require retailers to acquire credits issued within the same state, some states allow them to purchase credits from other states to meet the RPS requirement. For example, Pennsylvania allows credits purchased within the PJM interconnection to be used for compliance (Abito et al. (2022)). Also, due to the small sample size, the cluster size is too small if clustered at the state level.

Table 6: With REC price as a control: Solar investment in PJM (using VS_{retail})

	(1)	(2)	(3)	(4)
Binding x VS	-60.96*	-74.03*		
	(31.56)	(41.53)		
Binding	35.56	62.68		
	(26.41)	(46.33)		
RPS goal (GWh)	0.00120	0.00119	0.00150	-0.000583
	(0.00352)	(0.00361)	(0.00342)	(0.00296)
Net generation (MWh)	0.00307*	0.00294**	0.00156	
	(0.00154)	(0.00130)	(0.00136)	
Net summer capacity (MW)	16.00	14.10	16.48	18.96*
	(9.531)	(10.31)	(10.55)	(9.576)
REC price ($/MWh)		-0.155	-0.275	-0.302*
		(0.129)	(0.155)	(0.161)
REC price x VS			0.275	0.315*
			(0.166)	(0.165)
Constant	9.858	60.08	-3.379	-8.674
	(10.89)	(49.01)	(31.26)	(27.64)
N	93	92	92	92
r2	0.64	0.65	0.66	0.66
DV_mean	32.35	32.71	32.71	32.71

Standard errors in parentheses

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

Notes: Dependent variable is the new solar capacity that enters each state every year. This analysis includes only PJM states. All regressions include state, year FE, and dynamic dummies. Standard errors are clustered at the year level. The Binding variable has been adjusted to capture compliance for solar-specific requirements in states that have a separate requirement for solar. Columns (3) and (4) show the regression with REC price replacing the role of the Binding variable.

Despite the small sample size, the variable of interest (Binding $\times VS$) has a statistically significant coefficient in both columns, consistent with our main results in the previous section. While the *REC price* variable in column (2) is significant, we are concerned of a false rejection of the null hypothesis arising from the small-sample issue. Despite all these issues, when comparing results of columns (1) and (2), we find the coefficient of our main variable, Binding $\times VS$, changes from -60.96 to -74.03 when we add the REC price as a control variable, indicating that the investments induced by the RPS in the vertically separated (VS) states decrease further when controlling for the REC price in the regression. This result corresponds to our conjecture that the investment difference across vertical structures would intensify if we account for the presence of an attractive REC market option. This implies that results from our main estimation, which omits this variable due to data limitations, could be small (attenuation bias with positive direction); the negative estimate for the Binding $\times VS$ variable would be larger in magnitude when REC market variables have been controlled for. However, note that it is difficult to definitively make a strong argument based on this small-sample regression.

Lastly, we also tried a variant of the main regression by substituting the role of the "Binding" variable by replacing it with the "REC price" variable. This is shown in columns (3) and (4) of Table 6. This regression intends to capture the pattern of new renewable investment that is explained by (correlated with) the REC market variables (e.g. credit price). As shown in the positive coefficient for the REC price $\times$ VS variable, the investments in the vertically separated (VS) states would increase more than in the integrated states if investments were responding solely to the REC market incentives. However, note that in our main regression shown in (1), which includes both the contracting and REC market channels, we found a negative coefficient for the Binding $\times VS$ variable. We can interpret this set of results as follows; while the VS state investments would be greater than in vertically integrated states if responding to REC market conditions (REC channel), the extent by which investment responds to the regulation through the contracting channel is significantly smaller in the VS states than in the integrated states, which results in a strong negative coefficient for our main regression.

5 Conclusion

We have shown that the amounts of investment on renewable generation capacity as a consequence of the restrictions imposed by the Renewable Portfolio Standards policy largely differ depending on the market structure of the electricity sector in a given state. Vertical separation between the generation and the retail sectors diminishes the effectiveness of the policy relative to the vertically integrated markets. These results put in perspective the long-term movement in the US towards deregulation in electricity markets and its potentially unintended effects on the transition towards a less carbon-intensive electricity sector.

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Appendices

A Identifying Contracting Channel Investment

Section 3 discusses the challenge of separating out the investments tied to the contracting channel, primarily due to contracts being unobserved. Here, we address the limitation of EIA Form 860's 'sector' information, which allows us to distinguish generators directly invested by firms within the electric utility sector.

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. While this form is known for reporting errors and may not be entirely reliable, we can verify from this form that retail companies do purchase a substantial amount of electricity 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 EIA Form 860, but PG&E is not listed as the owner, and they are part of IPP investments. This suggests that the directly invested capacity (with owner listed as the retail company) is the lower bound of retail company's total contracting channel investment.

This can also be confirmed by the retail company's compliance reports. Figure A.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.

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

Table 1b - Renewable Resources

Resource	Technology	Ownership	MWac[1]	MWdc[1]	Production (Actual) +	Production (Annualized)[2] +	Multiplier Credits =	Total MWh or Equivalent	
GENERATION:									
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	
Gross Total			803	-	2,231,870	-	3,721	2,235,591	
Adjustments									
Special Contracts[7]					(40,095)			(40,095)	
Green Choice Sales					*(78,129)*			(78,129)	
Wholesale DE Allocation					*(41,923)*			(41,923)	
Subtotal Generation			***803***		***2,071,722***		***3,721***	***2,075,443***	(A)
DISTRIBUTED ENERGY (DE):									
Residential:									

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').

B Additional Factors Affecting RPS Compliance

B.1 Spillover Effect: Out-of-state Investment

RPS policy in one state can influence renewable investment in nearby states if the state allows for compliance using out-of-state renewable generation (Hollingsworth and Rudik (2019)). Unfortunately, we do not observe which out-of-state power plants are tied to the state's RPS policy.

While we have specified net interchange data – net flow of imports between states – to capture some of the spillover effects of RPS policy, this does not perfectly address this limitation. The increase in net interchange may capture the electricity flowing from PPA-contracted capacities out of state, i.e., compliance through bundled RECs.

However, the state can also comply by purchasing unbundled RECs supplied from other states. Such trading does not require physical electricity flowing into the grid, thus not captured by net interchange variation. But if new capacity was built outside the state to supply credits in the market, this is the investment happening through the REC market channel. We assume throughout the paper that the REC market channel investment is not affected by the vertical structure, thus it will not critically affect our main empirical results.

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-measured if not accounting for the spillover effect. For example, if a retailer in CA contracted with a solar plant in AZ to comply with the RPS policy, the solar capacity in AZ is driven by the RPS policy in CA, not by the policy in AZ. Thus, the actual capacity induced by CA's RPS policy is under-measured, whereas that of AZ is over-measured. Instances like this actually exist; as discussed in Appendix A, PG&E in CA has set up a PPA agreement with a utility-scale solar farm, *Agua Caliente Solar*, in AZ.[28].

Note that it is likely that the exporting state – subject of spillover – is likely to have already fully

[28] This contract is identified from FERC Form 1: Yearly purchased power and exchanges

complied with the RPS policy. Indeed, AZ was fully compliant for the year when Agua Caliente farm was built (2014) whereas CA was not yet compliant. Also, High Lonesome wind plant in NM has established PPA with APS in AZ and the plant started operating in 2009. While NM was 100% compliant in 2009, AZ was non-compliant in 2009 (only 90% in 2009). A similar policy to the RPS exists in Sweden and Norway, the Electricity Certificate System (https://t.ly/FkoCq). It is important to recognize that while RPS-type policies play a significant role in incentivizing renewable energy investment in the US, they are not the sole mechanism in use in other countries. Another prevalent policy, particularly prominent in Europe and Canada, is the feed-in tariffs. These tariffs offer a fixed production subsidy ensured over extended periods, providing stability and certainty for investors (see Lamp and Samano (2023)).

B.2 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.

B.3 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 subsection 4.5, we show the potential direction of bias that arises from omitting the REC market data.

C Additional Tables and Figures

Table C.1: Renewable investment, RPS enactment, and market structure

	(1)	(2)
VS	31.73	89.71
	(47.16)	(111.3)
After RPS=1	48.56	4.362
	(41.22)	(41.80)
After RPS=1 × VS	-84.50	-134.9
	(71.16)	(106.6)
Net summer capacity (MW)		23.84
		(15.96)
Net generation (MWh)		-0.00417
		(0.00418)
Renewable per cap. lag (MW)		0.0256*
		(0.0143)
Net flow lag (MWh)		-0.508
		(2.708)
Constant	727.9***	50.00
	(35.04)	(320.1)
N	1000	711
ar2	0.42	0.46
DV_mean	126.30	176.29
MarketFE	✓	✓

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). Standard errors clustered at the state level.

Table C.2: Fossil-fueled powered plants investment, RPS enactment, and market structure

	(1)	(2)
VS	186.3	-5607.8***
	(178.5)	(952.3)
After RPS=1	167.3	34.55
	(104.0)	(94.27)
After RPS=1 × VS	57.99	-177.2
	(184.7)	(248.3)
Net summer capacity (MW)		-4.417
		(35.19)
Net generation (MWh)		-0.0213**
		(0.00897)
Renewable per cap. lag (MW)		-0.0541
		(0.0326)
Net flow lag (MWh)		-5.617
		(4.031)
HHI Resid. Sales		0.0213
		(0.0436)
Constant	1095.8***	6231.8***
	(93.05)	(785.5)
N	950	711
ar2	0.319	0.364
DV_mean	305.993	274.221
MarketFE	✓	✓
StateFE	✓	✓

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). Standard errors clustered at the state level.

Table C.3: Wind plants investment and compliance using a continuous measure of vertical separation (retail sales)

	(1)	(2)	(3)	(4)
Binding x VS	-263.9	-257.6	-179.9***	-109.4
	(173.6)	(172.7)	(62.74)	(64.66)
Binding	59.06	48.44	52.16	20.86
	(41.57)	(41.28)	(33.97)	(35.08)
RPS goal (GWh)		0.0171*	0.0196**	-0.00289
		(0.00970)	(0.00886)	(0.0162)
Net summer capacity (MW)			5.577	5.462
			(5.901)	(5.532)
Net generation (MWh)			0.00818***	0.00860***
			(0.00167)	(0.00165)
Renewable per cap. lag (MW)			-0.0215	-0.0149
			(0.0184)	(0.0209)
Net flow lag (MWh)			9.032***	9.429***
			(2.068)	(2.612)
Constant	245.8***	230.3***	-2502.0***	-2630.5***
	(25.17)	(24.84)	(227.2)	(580.5)
N	388	388	332	332
ar2	0.50	0.50	0.55	0.55
DV_mean	127.82	127.82	148.94	148.94
MarketFE	✓	✓	✓	✓
StateFE	✓	✓	✓	✓
DynEffects				✓

Standard errors in parentheses

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

Notes: Dependent variable: New wind-powered capacity (MW). 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 C.4: Solar plants investment and compliance using a continuous measure of vertical separation (retail sales)

	(1)	(2)	(3)	(4)
Binding x VS	-137.7	-147.5	-142.9*	-131.8*
	(117.4)	(130.0)	(75.71)	(70.61)
Binding	100.1	116.8	72.28*	97.89**
	(100.1)	(119.0)	(36.13)	(46.80)
RPS goal (GWh)		-0.0269	-0.0249	-0.0265
		(0.0289)	(0.0220)	(0.0205)
Net summer capacity (MW)			76.93**	78.06**
			(33.98)	(33.04)
Net generation (MWh)			-0.0136*	-0.0144*
			(0.00758)	(0.00789)
Renewable per cap. lag (MW)			0.0157	0.0198
			(0.0161)	(0.0159)
Net flow lag (MWh)			-8.850*	-10.11*
			(4.531)	(4.943)
Constant	541.8***	566.1***	-1148.4**	-951.6**
	(59.68)	(46.35)	(509.1)	(410.6)
N	388	388	332	332
ar2	0.29	0.29	0.52	0.53
DV_mean	46.57	46.57	54.41	54.41
MarketFE	✓	✓	✓	✓
StateFE	✓	✓	✓	✓
DynEffects				✓

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: Dependent variable: New solar-powered capacity (MW). 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 C.5: Fossil-fueled plants investment and compliance using binary measure of vertical separation

	(1)	(2)	(3)	(4)
Binding x VS	404.9	402.1	452.0	499.5
	(313.1)	(311.1)	(311.2)	(301.7)
Binding	-114.9	-104.9	-234.7	-334.3**
	(81.47)	(82.07)	(146.3)	(127.4)
RPS goal (GWh)		-0.0184	-0.0434	0.0125
		(0.0386)	(0.0664)	(0.0756)
Net summer capacity (MW)			87.62	74.25
			(62.89)	(56.13)
Net generation (MWh)			-0.0373**	-0.0386**
			(0.0154)	(0.0159)
Renewable per cap. lag (MW)			-0.103	-0.128
			(0.125)	(0.142)
Net flow lag (MWh)			-5.007	-4.813
			(12.90)	(12.27)
Constant	1318.0***	1335.5***	3603.0*	4704.0***
	(91.46)	(105.2)	(1886.0)	(1592.4)
N	388	388	332	332
ar2	0.34	0.34	0.39	0.42
DV_mean	324.25	324.25	354.69	354.69
MarketFE	✓	✓	✓	✓
StateFE	✓	✓	✓	✓
DynEffects				✓

Standard errors in parentheses

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

Notes: Dependent variable: New fossil capacity (MW). 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 C.6: Fossil-fueled plants investment and compliance using a continuous measure of vertical separation (generation capacity)

	(1)	(2)	(3)	(4)
Binding x VS	342.0	335.9	390.2	422.6
	(292.9)	(291.4)	(335.3)	(333.5)
Binding	-149.9	-137.2	-272.1	-352.0*
	(141.5)	(144.5)	(191.2)	(202.0)
RPS goal (GWh)		-0.0187	-0.0453	0.00546
		(0.0344)	(0.0625)	(0.0710)
Net summer capacity (MW)			83.34	87.74
			(66.28)	(60.95)
Net generation (MWh)			-0.0379**	-0.0422**
			(0.0162)	(0.0169)
Renewable per cap. lag (MW)			-0.0921	-0.121
			(0.121)	(0.139)
Net flow lag (MWh)			-6.771	-8.301
			(11.34)	(9.947)
Constant	1211.0***	1229.4***	4019.2**	4753.5***
	(63.93)	(69.49)	(1770.8)	(1543.2)
N	388	388	332	332
ar2	0.34	0.34	0.38	0.40
DV_mean	324.25	324.25	354.69	354.69
MarketFE	✓	✓	✓	✓
StateFE	✓	✓	✓	✓
DynEffects				✓

Standard errors in parentheses

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

Notes: Dependent variable: New fossil capacity (MW). 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 C.7: Fossil-fueled plants investment and compliance using a continuous measure of vertical separation (retail sales)

	(1)	(2)	(3)	(4)
Binding x VS	559.1*	554.3*	670.2	587.9
	(322.0)	(321.4)	(423.8)	(439.3)
Binding	-158.3*	-150.2	-238.5	-279.1**
	(86.96)	(91.04)	(146.6)	(133.7)
RPS goal (GWh)		-0.0130	-0.0463	0.0625
		(0.0396)	(0.0653)	(0.0881)
Net summer capacity (MW)			87.39	69.21
			(61.81)	(49.88)
Net generation (MWh)			-0.0367**	-0.0357**
			(0.0152)	(0.0145)
Renewable per cap. lag (MW)			-0.0925	-0.102
			(0.122)	(0.126)
Net flow lag (MWh)			-2.130	1.452
			(13.61)	(12.14)
Constant	1344.4***	1356.1***	3263.9	3905.9**
	(89.04)	(99.33)	(1931.5)	(1617.0)
N	388	388	332	332
ar2	0.35	0.34	0.39	0.45
DV_mean	324.25	324.25	354.69	354.69
MarketFE	✓	✓	✓	✓
StateFE	✓	✓	✓	✓
DynEffects				✓

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

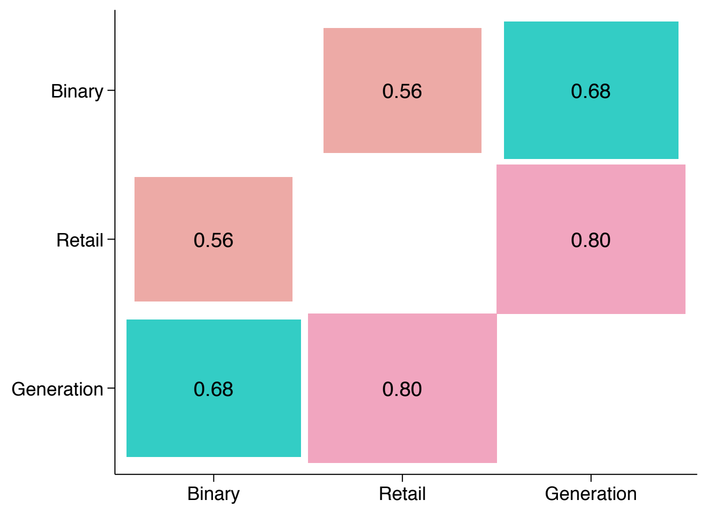
Notes: Dependent variable: New fossil capacity (MW). For each state, only years when RPS policy had been put in place. Dynamic effects with window +/-2 years. Using a continuous measure of vertical separation (retail sales). Standard errors clustered at the state level.

Table C.8: 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)

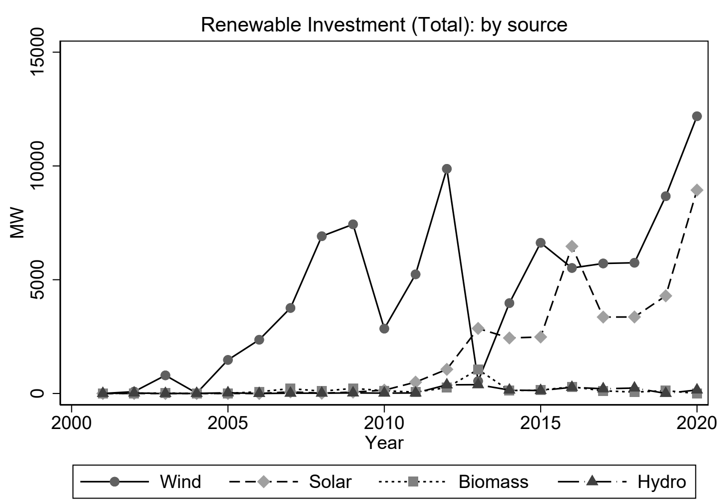
Source: Heeter et al. (2014).

Figure C.1: Correlation matrix of different Vertical Separation measures



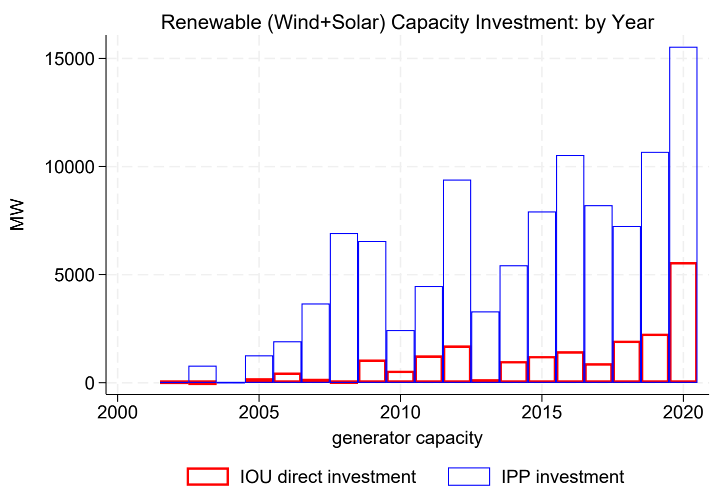
Notes: Pairwise correlations between our three measures of vertical separation: a binary classification (as it has been commonly assumed in the literature), a measure using generation capacity, and a measure using retail sales volume.

Figure C.2: Renewable Investment: by Energy Source



Notes: The capacity sum shows a national summary of new renewable capacity additions by year and by energy source.

Figure C.3: Renewable Investment: IOU vs. IPP



Notes: The IOU direct invested capacity is the sum of capacity of generators listed with owner being part of electric utility sector, and IPP invested capacity is for those generators with owner listed as IPP in the EIA Form 860.