# Energizing Change: How Policies and Experience Drive R&D

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## ABSTRACT

Given the significance of firm R&D investment in supporting successful technological shifts, this paper asks whether policy incentives can drive firms to invest in R&D. We use data from the U.S. electric utilities industry, a setting in which most state governments have enacted renewable portfolio standards (RPSs) mandating renewable electricity. We examine whether these policies also motivate firms to increase investment in R&D. We find a positive relationship between RPSs and R&D investment, but primarily among firms with previous experience generating renewable electricity. Notably, electric utility firms focus their investments on external R&D rather than on internal R&D projects. By highlighting how policy incentives for technological change and firm technological experience work together to stimulate R&D efforts, this research deepens our understanding of technological search.

## INTRODUCTION

Established firms often lead in the scaling up of new, industry-changing technologies (Balasubramanian 2011, Chen et al. 2012, King and Tucci 2002, Mitchell and Singh 1992, Sosa 2009). When new technologies have social benefits, like mitigating climate change, governments often use policies to motivate firm actions (Aragon-Correa et al. 2019, Ashford and Heaton 1983, Bennear 2007, Blind 2016, Doshi et al. 2013, Menz 2005, Sharma 2001). For instance, the federal Clean Air Act of 1970 reduced air pollution in part by mandating car manufacturers to sell cleaner vehicles (Becker 2005, Schmalensee and Stavins 2019). In the U.S. electric utilities industry, state-level renewable portfolio standards (RPSs) require large and established electric utility firms to increase the share of renewably sourced electricity that they sell by a certain deadline (e.g., 25% renewable by 2025) (Delmas and Montes-Sancho 2011, Lyon and Yin 2010). RPSs have been associated with increases in renewable electricity (Yin and Powers 2010). Beyond directly increasing renewable output, such policies signal a broader technological shift and thus may also indirectly motivate firms to invest in research and development (R&D) (Costello 2016). This study, by examining the relationship between the enactment of RPSs and firms' R&D investments, enriches the literature on how R&D investment drives technological search, adaptation, and change (Agarwal and Helfat 2009, Arora, Belenzon, et al. 2018, Eklund and Kapoor 2019, Margolis and Kammen 1999, Zhao 2006).

We focus on firm heterogeneity in R&D investments. More specifically, we ask which firms—those with related technological experience or those without—increase their R&D investments in response to RPS policies. Related experience is an important determinant of adaption to technological change. Theories of technology strategy diverge in their implications for the role of related technological experience. Some studies suggest that firms with such experience may not need to invest in R&D to respond to technological shifts; the investing firms will likely lack related technological experience (Bayus and Agarwal 2007, Furr 2019, Lopes-Bento and Simeth 2024, Sørensen and Stuart 2000, Tripsas and Gavetti 2000). Other research suggests that only firms with related technological experience will have sufficient knowledge to benefit from increasing their R&D, and thus that experience will lead to more investment in R&D (Arora, Cohen, et al. 2018, Cohen and Levinthal 1990, Helfat and Lieberman 2002). Given these divergent predictions, we take an abductive approach in this paper.

We focus on established firms in the utilities industry facing RPS, a policy-induced technological shift. Two aspects of the U.S. electric utilities industry are worth highlighting. First, the structure of the industry, both in terms of competition and innovation, has been strongly shaped by government involvement (Dutt and Mitchell 2020, Eklund and Kapoor 2019, Fremeth and Marcus 2011). Electric utility firms are typically large, established, and quasi-monopolist incumbents with long-term agreements with state governments guaranteeing fixed electricity prices. They do not face strong competitive pressures to invest in R&D (Fabrizio 2013). Still, utility firms have historically invested in some R&D to improve technological development in the industry (the D of R&D) (Costello 2016, Zhang and Gimeno 2010). Second, since the early 2000s, many state governments have enacted RPSs to increase renewable output and to encourage a transition to green energy (Lyon and Yin 2010). As most electricity has long come from non-renewable sources, like coal and natural gas in the U.S. (EIA 2013), RPSs represent a substantive change. Thus, while they did not mandate R&D spending, RPSs may have led some firms to invest in R&D to adapt to the policy-induced technological shift.

Electric utility firms mainly invest in R&D externally, meaning they invest in the projects of technology specialist firms, universities, and other external entities rather than investing in internal projects, i.e., internal R&D (Costello, 2016). External R&D is common in many industries as a way for established firms access new knowledge (Arora, Cohen, and Cunningham, 2018; Berchicci, 2013; Capron and Mitchell, 2009; Hagedoorn and Wang, 2012; Santamaría, Nieto, and Barge-Gil, 2009; Cassiman and Veugelers, 2006; Dahlander *et al.*, 2016; Eklund and Kapoor, 2022; Grimpe and Kaiser, 2010; Wadhwa, Bodas Freitas, and Sarkar, 2017). Knowledge acquired via external R&D can improve the quality of inventive solutions (Chatterji and Fabrizio, 2016; Criscuolo *et al.*, 2018; Tether and Tajar, 2008), even in settings in which firms have traditionally prioritized internal R&D (Arora, Belenzon, and Patacconi, 2018a). In our analyses, we thus disaggregate total R&D investment into internal R&D and external R&D and focus primarily on external R&D. We further distinguish between the type of external R&D:

technological (e.g., investments in new technologies or process innovations pursued by a partner such as a university, start-up, or research institute) or non-technological (e.g., geographic feasibility studies and regulatory assessments done by an external partner). To assess how RPSs influence firms' R&D investments, we link data on the most active period of RPS enactment—from 2000 to 2010—with data on firms' annual external R&D investments from the Federal Electric Regulatory Commission (FERC) (McGrew 2009).

We find no significant relationship, on average, between RPSs and R&D. However, firms with related technological experience, that is, those with some experience in generating renewable electricity, increase their R&D investments substantially. This increase comes primarily from external R&D. For a one-standard-deviation increase in RPS strength, firms with related technological experience invest 2.7% more in logged external R&D dollars, equivalent to a 14.9% increase in real USD. In contrast, firms without related technological experience do not increase their R&D investments in response to RPS. Moreover, firms possessing related technological experience invest primarily in technology-related R&D.

Our results have important implications for strategy research assessing the impact of government policies on firms' actions, and for research on technological search. First, our result suggests that ambitious policies—such as RPSs that aim to spark such a major change—may need to account for firms related technological experience when considering which firms will adapt and lead technological change. Our experience-based results provide insight into why the long-lasting effects of apparently strong and flexible policies may end up being small. Such policies may only incentivize a small share of firms—those with related technological experience—to adapt their strategies rather than just waiting to comply. In terms of policy design, while a challenging goal can push firms to invest in R&D (Berry et al. 2021), giving firms more time to adapt to a challenging goal allows them to delay action (Dutt and Joseph 2019). Hence, policies like RPSs—with big goals over long time horizons— may lead to fewer and smaller immediate investments in R&D and thus slower adaptation.

Extending prior research on technological search, we highlight another activity primarily driven by technologically experienced firms (Berchicci 2013, Cassiman and Veugelers 2006, Escribano et al.

2009, Grimpe and Kaiser 2010, Hoang and Rothaermel 2010). Specifically, we find that policies mandating technological shifts only induce R&D investments among firms with prior experience with the mandated technology. Our finding is essential for strategy research on the role of experience in shaping R&D and technology investments (Chen et al. 2012, Furr 2019, Nerkar and Roberts 2004). Knowing who invests early is important because early movers drive the development of new markets and niches (Helfat and Lieberman 2002, King and Tucci 2002, Zott 2003). Without the adaptive investments in external R&D projects of technologically experienced firms, the shift towards renewable energy in U.S. electric utilities likely would have been even slower than it has been to date (Aggarwal et al. 2017, Eklund and Kapoor 2019, King and Lenox 2001, Moeen 2017). More broadly, policies may fall short of their larger goals if most firms have little related experience and thus invest little in adapting and making broader changes—in other words, when they aim to minimally comply.

## RPSs AND R&D IN THE U.S. ELECTRICITY INDUSTRY

We study the link between RPSs and R&D investing by Investor-Owned Utilities (IOUs) in the regulated U.S. electricity industry from 2000 to 2010.[1] IOUs are established, large, and public firms (e.g., Duke Energy) that generate and distribute electricity, and they are subject to RPSs.

The electricity industry has some key differences with oft-studied R&D–intensive industries such as pharmaceuticals. First, electric utility firms are heavily regulated in distinct ways. Their operational activities (e.g., electricity generation sources) and competition (e.g., price setting) are regulated at the state level. Their R&D is reported to and monitored by the federal government, which also makes substantive (and usually complementary) public R&D investments (Costello 2016, Sterlacchini 2012). Second, electric utility firms' R&D investments typically focus on applied rather than basic research, e.g., on the efficiency and reliability of electricity generation and distribution (a specific example would be turbine efficiency). Even further, some R&D expenses are directed towards understanding whether a

[1] While 16 states have been deregulated over time, many historical structural features, including local monopolies and little innovative investment, continue to characterize the industry (Regulation and Electric Utility Industry Monopoly Status Focus of NRRI Paper 2022, Zhang and Gimeno 2010).

technology can be used in a specific location rather than on developing the technology directly (e.g., a "Wind Feasibility Study" which explores location-related technical and political feasibility). We identify the latter expenses as non-technological R&D, and, in some analyses, separate them from technological R&D.

Historically, external R&D[2] is more common than internal R&D for electric utility IOUs.[3] The primacy of external R&D in the electricity industry is likely because utilities firms typically do not invent electricity-generation technologies.[4] Many of these technologies, e.g., wind turbines, are created by outside inventors. Further, some electric utility firms do not invest in R&D, and those that do typically focus on improving usability and efficiency. Firm R&D has also declined over time. These patterns could be due to business model choices or lack of competitive pressures. Unlike firms in technologically driven industries, electric utility firms' long-term contracts with state governments mean they have often delayed adopting new technologies until regulations bind and delayed or avoided significant R&D activity (Barbose, 2021; Fischer, 2010; Wiser *et al.*, 2007).

A significant shift towards green energy was initiated by state governments in passing RPSs across 29 states from 2000 to 2010 (Carley 2009, Fabrizio 2013, Fremeth and Marcus 2011, Lyon and Yin 2010, Wiser et al. 2007).[5] U.S. renewable electricity capacity was low before RPSs emerged (under 10% of total electricity produced (Menz 2005)). State RPSs apply to all IOUs firms operating and supplying electricity to consumers in that state. Although RPSs are broadly similar across states—

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[2] External R&D is investing in R&D projects outside of the firm, including those of suppliers, customers, other firms in the industry (often via plural sourcing (Parmigiani, 2007)), technology specialists (e.g., university laboratories or start-ups), and other knowledge providers (Arora, Cohen, and Walsh, 2016; Laursen and Salter, 2006).
[3] Beginning with foundational work on absorptive capacity, much research has explored the complementarity between internal and external R&D (Cassiman and Veugelers, 2006; Hagedoorn and Wang, 2012). We focus on external R&D largely because it is the dominant form of R&D in our setting, where only a few firms perform internal R&D.
[4] The available R&D data helpfully identify the investments as internal or external and provide information as to whether the investments are targeted at technology development or towards other R&D activities (e.g., to the Electric Power Research Institute (EPRI)). However, the data lack comprehensive details that would enable us to isolate renewable R&D investment from other R&D.
[5] A few states had long-standing renewable requirements prior to this period, which may have led some firms to invest in R&D. However, this should reduce the likelihood of us finding an effect. Further, the 2000s were a period of significant change in this industry for most of the country.

requiring that some share (5% to 40%) of the total electricity provided comes from solar, geothermal, biomass, wind, and/or hydro sources by a date 5 to 30 years in the future—the exact mandated share and binding date of the regulation varies by state and across years, which has created differences in RPS "stringency" (Carley et al. 2018).[6]

**MOTIVATING THE QUESTION**

Policy incentives aimed at pushing firms to make technological changes often mandate ambitious targets, though usually with flexibility in how the targets are met (Cecere and Corrocher 2016, Dutt and Joseph 2019, Fabrizio 2013). Flexible regulations can have high rates of compliance precisely because they give firms time and autonomy to react (Hoffmann et al. 2009). Strong policies with future-focused targets may also encourage firms to invest in new technologies beyond narrow compliance via R&D investment (Cette et al. 2016, Majumdar and Marcus 2001, Yuan and Zhang 2020). Through R&D, firms can acquire technology specific knowledge and develop technology specific capabilities (Eggers and Park 2018, Katila 2002, Ter Wal et al. 2017, Veugelers and Cassiman 1999).

Firms often engage in R&D investment in a response to large technological shifts. For instance, firms intensified their R&D investment in response to the electronic computing revolution of the 1940s to 1960s (Agarwal and Helfat 2009). There is typically heterogeneity in R&D investment based on firm characteristics, including related technological experience (Arora et al. 2023, Eggers and Park 2018, Hoang and Rothaermel 2010, Sampson 2005). Related technological experience affects both a firm's need to learn about new technologies, and their ability to deploy new knowledge towards commercial use (Cohen and Levinthal 1990). While firms with related technological experience may not need to invest in R&D relative to a less experienced peer to meet the requirements posed by RPSs, they might be better positioned than inexperienced firms to learn from the new knowledge gained via R&D.

[6] For instance, Michigan adopted RPSs in 2008 and required firms operating in the state to provide 15% renewable electricity by 2015. Comparatively, Hawaii adopted RPSs in 2001, setting a target of 10% renewables by 2010, increasing to 30% by 2020 and 100% by 2045. These differences, along with differences in existing renewable electricity capacity, have created variations in the stringency of RPSs over states and across time (see the figure in Appendix A). Details at: https://programs.dsireusa.org/system/program/detail/606.

This dual nature of related technological experience portends a lack of clear directional prediction on the relationship between such experience and R&D. One stream of research suggests that related technological experience will increase R&D. In this vein, firms with related technological experience should have a better understanding of the technology (all else equal), thus allowing them to better evaluate and absorb knowledge gained from external R&D, and thus benefit relatively more from their investment (Arora, Cohen, et al. 2018, Helfat and Lieberman 2002, Moeen 2017, Rockart and Dutt 2015). Furthermore, in settings like ours, where firms typically invest little in technological development, related technological experience can enable faster and easier search for new knowledge (Escribano et al. 2009, Fabrizio 2009). That is, the biggest differences arise between firms that invest something and firms that invest nothing. Unlike investments in internal R&D, the fixed costs and barriers to entry are lower for external R&D. Following such logic, when a policy targeting technological change appears, firms with related technological experience will be better equipped to invest as they will be more capable of absorbing the new knowledge. By extension, related technological experience should lead to increased R&D investment when firms face a technological shift.

On the other hand, firms without related technological experience have a greater need to adapt. The gap between where they are at the time of policy enactment and where they will need to be when the policy binds is larger relative to experienced firms. Firms without technological experience in generating renewable energy will need to acquire more knowledge to figure out how to comply than experienced firms and therefore will have more to gain from increasing R&D investments (Arora, Cohen, et al. 2018, Capron and Mitchell 2004, Dutt and Mitchell 2020, Lopes-Bento and Simeth 2024).

Beyond need, firms without related technological experience may lack the routines that allow them to scale up operations to meet policy mandates (Nigam et al. 2016, Parmigiani and Howard-Grenville 2011, Pavitt 2003). This lack of routines suggests such firms may be more likely to increase R&D for two reasons. First, they may not be able to comply with the policy without some investment in adaptations. Second, and following a more nuanced logic, if the new technological shift pushes firms into a significantly new area, the absence of routines may allow firms without related technological experience to significantly change more easily than more experienced firms. Existing research comparing entrants and incumbents in situations of large technological shifts builds this reasoning. For example, in the personal computer industry Bayus and Agarwal (2007) found that later entrants were able to outperform earlier, diversifying entrants because they were able to adapt to the evolving technology and market needs. Similarly, in the U.S. solar photovoltaic industry, Furr (2019) found substantial, industry-specific experience diminished firms' ability to learn and adapt. More broadly, entrants are better at adapting to change (Anderson and Tushman 1990, Henderson and Clark 1990, Utterback and Abernathy 1975). In our context, we look at industry incumbents who vary in their related technological experience. Unlike entrants, firms lacking technological experience are unlikely to be more agile as a whole compared to their technologically experienced peers. Yet, they have a relatively greater need to adapt to the technological shift and a better ability to adapt, we might expect related technological experience to lead to lower investment in R&D following a policy mandate.

In sum, there are reasons to expect that firms with related technological experience will invest relatively more in R&D when facing a policy incentive for technological change. On the other hand, firms without related technological experience have a greater need to gain new knowledge and thus could also be expected to invest relatively more in R&D. As there is not a clear directional prediction as to which firms will increase their R&D, we turn to the data to test how related technological experience conditions firms' R&D investments when facing RPSs.

## DATA AND METHODS

Our empirical context is the regulated U.S. electricity industry from 2000 through 2010 (Dutt 2013, Fabrizio 2013, Sine et al. 2005). Following prior research (Fabrizio 2013), our sample focuses on investor-owned utilities (IOUs, e.g., Duke Energy), who supply most of the electricity in the U.S. and are heavily regulated (including via RPSs).[7] During these years, 29 states enacted some form of RPSs (Carley

[7] We lack data from a few states that have electricity IOUs that are privately owned firms, and hence data on firm characteristics to be used as control variables are not available for these states. In addition, our sample does not include IOUs that are active solely as holding companies and that do not generate any electricity because these IOUs

et al. 2018).[8] Firms report their R&D activity to the Federal Electric Regulatory Commission (FERC), including separately internal R&D investments (e.g., internal investments on projects such as "Combustion and Fuel Effects" to improve generation processes) and external R&D investments (e.g., investments with partners, "University of Wisconsin - Stray Voltage Analysis," "Edison Electric Institute Groundwater Analysis").[9]

To build a dataset tracking firms' external R&D investment and the state-year RPS policy incentives, we used three main data sources: (1) data describing firms' operational activities from Platts, a private company that tracks all operations in this industry, (2) firm R&D investment data from the FERC, and (3) state-level data on RPSs from the Database of State Incentives for Renewables and Efficiency (DSIRE). We linked in additional data for control variables from the U.S. Census Bureau and the Sierra Club. Prior research on electric utilities typically aimed to explain operational activities such as electricity generation (Fabrizio 2013, Lyon and Yin 2010, McGrew 2009). We are among only a handful of scholars examining R&D investments that are mandatorily reported to FERC and publicly posted but have typically been more difficult to extract and use (Margolis and Kammen 1999, Sanyal and Cohen 2009).

**Sample**

Our final unbalanced panel dataset contains 1,065 firm-year observations tracking 130 electric utility firms (at the subsidiary level, e.g. Duke Energy Florida, Duke Energy Ohio) across 43 states from 2000 through 2010. Firms must respond to the electricity regulations in their state of operation. All variables are firm-year (e.g., external R&D) or state-year (e.g., RPS Strength). The sample includes both firms in states with RPS policy incentives (pre- and post-RPS) and those in states without, and it covers most

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are not responsive to RPS regulations. We ran robustness tests including these holding companies with the relevant electricity measures imputed to 0. Results were consistent.

[8] For instance, Michigan adopted RPSs in 2008 and required firms operating in the state to provide 15% renewable electricity by 2015. Comparatively, Hawaii adopted RPSs in 2001, setting a target of 10% renewables by 2010, increasing to 30% by 2020 and 100% by 2045. These differences, along with differences in existing renewable electricity capacity, have created variations in the strength of RPSs over states and across time (see the figure in Appendix A). Details at: https://programs.dsireusa.org/system/program/detail/606.

[9] The available R&D data helpfully identify the investments as internal or external and provide information as to whether the investments are targeted at technology development or towards other R&D activities (e.g., to the Electric Power Research Institute (EPRI)). However, the data lack comprehensive details that would enable us to isolate renewable R&D investment from other types of R&D.

states, including the most populous states of California, New York, and Texas. Overall, the sample is representative of the industry (EIA 2013).

## MEASURES

### Outcome Variables: Logged R&D Investment

***R&D investment (Total, Internal, External):*** The primary outcome of our main analysis tracks R&D spending. Firms must report research, development, and demonstration expenses (R&D for short, as demonstration expenses are minimal) to the FERC annually.[10] Firms report R&D at the project level, including whether the investments are internal or external R&D. Given skewness in R&D investment, we used the natural log of R&D (in USD) +1. To test the robustness of our results, we also ran the analysis using an R&D intensity measure that divided R&D by firm-year revenues (Xu, Zhou, and Du, 2019; Yu, Minniti, and Nason, 2019); results are consistent.

***External technological R&D:*** We further disaggregated external R&D into technological and non-technological. We considered all expenses on technology-based research (e.g., "Electro and Magnetic Field Effects Research Study"), development (e.g., "Groundwater Data Management Software Development"), and, to a much lesser extent, demonstration ("Fuel Cell Demo"), each of which when done with external actors ("University of Georgia") as falling into the category of *External technological R&D*.[11] The types of organizations involved were primarily universities, start-ups, and technology research groups.

[10] Sixty-two firms in the sample never invested in R&D, either internal or external. Historically, both the federal government and electric utility firms have invested in electricity-related R&D. However, over time these investments have decreased (Costello, 2016). Raw data from our sample shows that most R&D expenses are invested externally, matching other research on this context (Costello, 2016). Firms' external R&D investment ranges from a few thousand to several million U.S. dollars annually.

[11] As part of their declaration to FERC, companies must include a description of whom they paid for their R&D expenses along with the nature of the expense. Using these descriptions, we classified all technological expenses—those that were pure science, research, and/or implementation focused, and technological innovations—as *External technological R&D* and categorized others as *External non-technological R&D.* While there may be noise in the non-technological category, the lion's share of these R&D dollars went to non-technological industry trade/lobbying groups.

***External non-technological R&D:*** The second type of external R&D captures all other external R&D expenses, the majority of which went to policy-focused actors, such as trade groups ("Electric Power Research Institute" and "Edison Electric Institute") that conduct research on the regulatory and business aspects of the industry (e.g., studies of wind turbines' yield of electricity in a given location).

**Explanatory Variables**

***RPS strength:*** Our main independent variable is a measure of the strength of the RPS policy incentive, post policy enactment. We use a measure developed by public policy academics evaluating RPS efficacy (Carley and Miller 2012). Several studies have tested and validated the measure in studies of RPSs impact on electricity output at the state-year level (Carley et al. 2018). The measure is calculated as follows:

$$\frac{\boldsymbol{Renewable\ gap}(\%_{\boldsymbol{Finalyear}} - \%_{\boldsymbol{Startyear}})}{\boldsymbol{Time\ gap}\ (Finalyear - Startyear)} \times \boldsymbol{RPS\ Share_t}$$

*Renewable gap* is the gap between the starting percentage of renewable electricity in a state when the RPS policy was enacted and the goal percentage when the RPS binds. The greater the gap, the stronger the policy incentive. The renewable gap is then divided by the *Time gap*, which measures (in years) the time from when the RPS was enacted (*Startyear)* until the year it binds (*Finalyear)*. The shorter the time until the deadline, the stronger the incentive. This ration is then multiplied by *RPS Share*, the share of electricity generation covered by the RPS in the state-year. We also separately analyze the *Renewable gap* and *Time gap* dimensions of RPS in robustness analyses.

RPS strength generally increased across time in RPS-active states during the 2000 through 2010 period of study, a period of intense policy change (see the figure in Appendix A). These values could change several times in a state during our sample period because most states amended these laws, often several times.[12]

[12] Values are negative in some (rare) state-years if the final mandate, i.e., the required percentage of renewable electricity, is lower than the starting percentage, for instance, in states with large existing hydroelectric capacities (Carley *et al.*, 2018). While the graphs focus on the positive range of regulatory strength, we used the full data to conduct the empirical analyses. Moreover, to mitigate the effect of extreme values, we used a standardized value of this measure, with a mean of 0.139 and standard deviation of 0.971. Results are consistent using the raw measure.

***Renewable experience:*** To capture the presence of renewable technology–related experience, we measured the share of renewable electricity (i.e., the sum of megawatts of solar, geothermal, biomass, wind, and/or hydroelectricity divided by the total megawatts of electricity) generated by the firm in the year before the RPS policy was enacted. For firms in states with no RPS, we code this variable with their share of renewable electricity in 2001. Results are similar using an indicator capturing the presence of any renewable-generating experience.

**Control Variables**

In addition to RPS strength and renewable experience, firms may invest in R&D because of other state- and firm-specific factors that may correlate with our key independent variables. All models include year and state fixed effects.[13]

At the state-year level, we controlled for factors that may affect R&D investing (Delmas and Montes-Sancho 2011, Lyon and Yin 2010). First, the price of electricity likely predicts several strategic actions of firms; thus, we account for *price_electric*. Second, consumer spending power might also influence R&D expenses; thus, we account for *gdp_percapita*. Third, to account for variation in pro–natural environment sentiment in each state, we include the total number of Sierra Club members using *sierraclubmem*. Fourth, to account for the extent to which a state legislature focuses on passing regulations to protect the environment, which in turn might influence firms' willingness to invest in related R&D, we include the share of Democrats (versus Republicans and Independents) in the state legislature through *pctdem*.

At the firm-year level, we controlled for several factors. First, some firms are also water utilities and therefore may invest in R&D for other activities; thus, we included an indicator for *diversification*. Second, larger firms might respond differently to regulatory shifts; thus, we controlled for (the log of) firm-year revenues in USD or *ln_elecrev*. Third, some firms are more technologically adept than others, which may drive investment in external R&D; thus, we controlled for firms' *stock_patents*. Fourth,

[13] We did not include firm fixed effects in our regressions, doing so would select out a significant portion of our sample.

*buy_percent* account for the share of electricity bought by each firm in each year (as total megawatts of electricity bought by the total megawatts of electricity sold by the firm in the prior year).

As the outcome variable is a logged continuous measure of R&D expenses, we ran the main models with OLS using the reghdfe command in Stata 17 with standard errors clustered at the firm level.

## RESULTS

### Descriptive Statistics and Correlations

Table 1a reports descriptive statistics for the sample. R&D expenses are non-trivial, but modest. The average annual R&D expenditure in our sample is $1.97 million (median is $75K), while for R&D-active firms it is $2.2 million (median: $950K), representing less than 10% of revenues for R&D-active firms. On average, firms have 191 megawatts of renewable generating experience (median: 2 megawatts). For firm-years with some renewable experience, the average is 335 megawatts (median: 48 megawatts). Renewables account for about 10% of the total amount generated for firms who generate some renewable electricity. Table 1b includes correlations across our analytical variables.

[INSERT TABLES 1a and 1b ABOUT HERE]

### RPS Strength and External R&D

Prior research and our data suggest that the primary mode of R&D investment in this industry is external. Given we can separate external and internal R&D, we regress *RPS_strength* and *Renewable experience* on the three different R&D outcomes: total, and separately external, and internal.

Model 1 shows the direct effect of *RPS_strength* and *Renewable experience* on *Total R&D*. In Model 2, we add the interaction between *RPS_strength* and *Renewable experience*. We find a positive correlation between the interaction and *Total R&D*. For the average firm, which has a 6% share of renewable experience, a one-unit increase in *RPS_strength* (roughly a one-standard-deviation increase in the strength of the RPS) is associated with a 2.06% increase in logged total R&D in USD. This translates to a 7.85% increase in real R&D. The average R&D-active firm invests about $1.97 million per year; an increase of 7.85% a year would increase R&D investment to $2.125 million.

Next, we break down *Total R&D* into *External R&D* and *Internal R&D.* Models 3 and 4 predict *External R&D*. Model 3 includes the main effects and Model 4 the interaction between *RPS_strength* and *Renewable experience*. The interaction is statistically significant and shows a 2.7% increase in logged external R&D dollars, which implies a 14.9% increase in actual dollars. Thus, a one-standard-deviation increase in *RPS_strength* translates to an increase of about $78,000 in external R&D per year for firms investing in some R&D. For the average R&D-active electric utilities firm, external R&D is the primary recipient of R&D investment in this time period.

Last, it is possible that firms are also changing their investment in *Internal R&D* in response to RPS; we examine this in Models 5 and 6. Model 5 includes the main effects and Model 6 the interaction between *RPS_strength* and *Renewable experience*. Here, we do not see any statistically significant correlation between either variable or the interaction term and *Internal R&D*.

These results suggest that, for the average firm, the RPS-driven investment in R&D is in external R&D. In unreported tabulations, we found the few electric utility firms that possess patents invested significant more in internal R&D as *RPS_strength* increased, and not in external R&D. These rare firms invested the largest amounts in R&D. These rare exceptions are not indicative of widespread R&D strategies in this industry during this time. Overall, these models suggest firms facing RPSs and possessing renewable experience substantially increase investments in external R&D.

[INSERT TABLE 2 ABOUT HERE]

**Types of External R&D: Technological and Non-technological**

Beyond the magnitude of the R&D investment, the type of external R&D also matters. In our context, two types of external R&D are relevant: *External technological R&D*, aimed at gathering knowledge about technological issues, and *External non-technological R&D*, typically aimed at regulatory and business issues. Given that we examine the role of relation technology experience, we might expect experienced firms to primarily invest in technological R&D. On the other hand, prior research has suggested that experienced firms, by virtue of their lower search costs, may seek greater breadth of knowledge (Dutt and

Lawrence 2022, Leiponen and Helfat 2010). Because it is *ex ante* unclear what to expect, we empirically explore how *Renewable experience* and *RPS_strength* drive variation in the type of *External R&D*.

We examine *External technological R&D* in Models 1 and 2. We see that Model 2 shows a similar pattern as our main findings; there is a positive correlation between the interaction and *External technological R&D*. For the average firm, a one-unit increase in *RPS_strength* is associated with a 2.3% increase in logged USD spent on *External technological R&D*. This is equivalent to about a 10% increase in real USD. The results for *External non-technological R&D* reveal a similar pattern. We see a positive correlation between the interaction and *External non-technological R&D*. For the average firm with *Renewable experience*, a one-unit increase in *RPS_strength* is associated with a 1.6% increase in logged USD spent on *External non-technological R&D*, which translates to a 5% increase in real USD.

Together, these results suggest that related technological experience is positively associated with increased R&D investments of both types, though *External technological R&D* increases relatively more compared to *External non-technological R&D*. Once again, only the firms that have some relevant technological experience in generating renewables seem to invest in either type of external R&D, and substantially more in external technological R&D.

[INSERT TABLE 3 ABOUT HERE]

**Split Dimensions of RPSs: Renewable Gap and Time Gap**

So far, we have focused on Carley et al.'s (2018) integrated measure of RPS strength, which we chose based on because it is the state-of-the-art in related policy research. However, each key dimension—*Renewable gap* and *Time gap*—could possibly have a distinct impact on firms depending on their *Renewable experience*. To understand if one of these two dimensions is more critical in terms of motivating R&D investments, we also conducted analyses with each measure separately.

In Table 5, Models 1 and 2 focus on the *Renewable gap,* the difference between the existing renewable capacity and that required by the state RPS. We see that, the bigger the gap, the more firms with renewable generating experience invest in external R&D. A one-unit increase in the gap is associated with a 0.24% increase in *External R&D*; in real terms, a 10% increase in the renewable gap implies a 12.7% increase in external R&D spending.

In Models 3 and 4, we focus on the *Time gap*, or the number of years until compliance with RPSs in the firm's state of operation. Here, the coefficient of the interaction term is negative. Thus, for each additional year a firm has until compliance, experienced firms invest less in *External R&D* by 0.31%. This finding is consistent with prior research suggesting that electric utility firms are likely to wait to make investments because of regulatory instability (Dutt and Joseph 2019, Fabrizio 2013). We find the firms waiting to invest in *External R&D* are renewable experienced firms. Models 5 and 6 include both dimensions together; both sets of results hold.

[INSERT TABLE 4 ABOUT HERE]

## ROBUSTNESS

### Coarsened and Exact Matching Results

A limitation of our research design is that *RPS_strength* is not exogenous: these policies are neither unanticipated by firms nor unrelated to firm characteristics (Borenstein and Bushnell 2015, Costello 2016, EIA 2017). It is possible that an omitted variable, which captures state-level features distinct from our controls, is driving both *RPS_strength* and *External R&D*. To account for the aspects of these features of each state that are unchanging over time, we included state fixed effects in all models.[14]

However, state and year fixed effects do not solve the omitted variable for time varying factors. Though we controlled for several state-year factors in the main analysis, ideally, we would be able to exogenously vary RPSs. Prior research has shown that some features of a state—percentage of Democrats and GDP—that predict RPSs, could be used as potential instruments for other dependent variables. However, these factors might also predict firms' R&D strategies (Lyon and Yin, 2010), making them inappropriate instruments for our analyses. We could not find strong instruments that would predict

[14]In unreported analyses, we included year of RPS as a fixed effect and found no changes to the results. We do not include these fixed effects in the main models as they effectively drop all firms that are in states without RPS.

*RPS_strength* but not R&D investment. Thus, we did not implement an instrumental variables approach (Bound, Jaeger, and Baker, 1995; Semadeni, Withers, and Trevis Certo, 2014; Wolfolds and Siegel, 2019). As a next-best approach, we include a matched sample analysis of the main models in Appendix B using the Coarsened and Exact Matching (Iacus, King, and Porro, 2012). CEM models cannot eliminate concerns of omitted variable bias; rather they triangulate the main results to highlight whether there is consistency across different subsamples of the data. Overall, the results from the matched sample analysis are consistent with our main analysis (see Appendix B for details).

**Policy Mechanism Test**

We now provide additional evidence that the relationships we observe in our main results are driven by the RPS policies, leveraging variation in *Regulatory uncertainty*. Higher regulatory uncertainty makes firms less likely to view policies as binding. Prior research suggests such uncertainty leads firms to delay making new investments in electricity-generation assets (Dutt and Joseph 2019, Fabrizio 2013). Perceived stability of regulation is relevant for testing the policy mechanism in this setting as there is a history of regulatory repeal. Based on prior research showing a strong link between green regulation and Democratic state senates (Coley and Hess 2012), we measured regulatory uncertainty using the percentage of Democrats in the state legislature. In our period of this study, states with Democratic legislatures showed more support for environmental issues relative to states with Republican legislatures (McCright et al. 2014). Firms should therefore expect RPSs to be more stable in states with a larger share of Democrats in their senate. Accordingly, we found that firms in states with a higher share of *pctdem* in the study period tended to invest substantially more in external R&D. Models 1 and 2 in Appendix C illustrate this result. Results are similar with other measures of regulatory uncertainty, such as the repeal of deregulation reform as used in Fabrizio (2012).

**Alternative Explanations**

Our interpretation of our main results is that firms lacking related technological experience are less likely to adapt when facing policy-induced technological shifts, i.e., to invest in R&D when facing RPSs which signal a shift towards green energy. However, an alternative explanation could be that such firms adapt *differently*. We thus examine two plausible alternative adaptative actions: lobbying and corporate strategy investments (e.g., acquisitions).

First, it is possible that firms lacking relevant experience in generating renewables respond to the policy changes by lobbying the government and shaping the policy environment rather than investing in R&D. To examine this, we used OLS models with the logged lobbying dollars as our dependent variables. Models 3 and 4 in Appendix D1 show these results. The results in Model 3 show positive but non-significant correlations between both *RPS_strength* and *Renewable experience* and *Lobbying*. In Model 4, we see that the interaction is insignificant. In short, all firms lobby, and there does not appear to be any differences in lobbying expenditures based on *Renewable experience* or its interaction with *RPS_strength.*

Second, Appendix D2 explores heterogeneity in acquisitions that firms might deploy instead of investing in external R&D. In many industries, incumbent firms acquire new knowledge via acquisitions (Agarwal and Helfat 2009, Ahuja and Katila 2001, Karim and Mitchell 2000). This might also apply in the electricity industry. If so, we might expect firms lacking renewable experience may use acquisitions to source external knowledge instead of R&D. Acquisitions are not common in our sample; only about 10 acquisitions happen in this period. In columns 1 & 2 of Appendix D2 we see no significant positive association between the likelihood of an acquisition and *Renewable experience.* In columns 3 and 4 we consider a count of any corporate activity, i.e., a count of acquisitions, alliances, and divestitures. We included divestitures as they might free up resources to invest in new assets. In our sample period, we observe a total of 37 events. There does not seem to be any statistically meaningful correlation between *Renewable experience* and corporate strategy events. Together, these alternative explanation analyses support our interpretation of our main findings.

**Limitations**

Ideally, to further improve the rigor of the analyses, we would causally identify the effect of *RPS_strength* on *External R&D.* As described above, we employed state fixed effects and matching-on-observables in our attempts to limit the impact of omitted variable bias. However, we cannot claim a causal interpretation of our results. Furthermore, our data end in 2010. It is possible that firms without related technological experience started investing in R&D post-2010, and experience merely hastened R&D investment. Moreover, we cannot show much evidence illustrating what pushes non-experienced firms to invest in R&D (or other adaptive activities).

Second, while we investigate alternative adaptive actions, including internal R&D, lobbying, and corporate investments (e.g., acquisitions), we are unable to clearly pin down what firms without related technological experience might be doing instead of R&D. Our results are consistent with them waiting to comply (for instance, by buying renewable electricity from third party suppliers). However, we cannot provide decisive evidence.

Third, while the U.S. electricity industry provides useful advantages in policy-related variation and data availability on external R&D, it also limits the generalizability of our results. It is a highly regulated industry in which firms do not tend to compete based on innovation (or at all). Thus, it is possible that the role of policy-induced technological shifts and related technological experience on external R&D in industries less exposed to regulation and/or industries that tend to compete based on innovation (and therefore spend more on R&D) would be substantively different.

## DISCUSSION AND CONCLUSIONS

This paper examines how policies that signal technological shifts can increase firms' R&D investments (Bird et al. 2005, Fey and Birkinshaw 2005, Margolis and Kammen 1999). We find that RPS policies are associated with increased external R&D by some firms. Firms use external R&D to gain access to knowledge and technologies, products, and processes unavailable internally across a wide range of industries (Cassiman and Veugelers 2006, Criscuolo et al. 2018). External R&D can build markets for technologies, products, and processes, enabling specialization and potential gains from trade (Arora and Gambardella 2010). Drawing knowledge from the external market is exceedingly common, yet we lack a systematic understanding of how policy-induced shifts may relate to external R&D investing. This paper examines whether and how such shifts influences R&D investing in partners outside the boundaries of the focal firm.

Not all firms respond equally in terms of their R&D investments. Only firms with related technological experience increase their investment in external R&D. Given experienced firms are more likely to be able to comply with the RPS policy targets without much effort (and likely without any R&D investment), it is somewhat surprising they would be the ones spurred to adaptation. However, these firms also possess the absorptive capacity to understand the ramifications of the policy and the operational knowledge to invest in R&D (Arora, Cohen, et al. 2018, Helfat and Lieberman 2002, King and Tucci 2002, Rockart and Dutt 2015). Meanwhile, the firms without any renewable electricity generating experience appear to want to wait before investing in making longer-term technological changes via R&D. Given their lack of related technological experience, we might have expected such firms would have had, *ex ante,* a greater need to adapt via R&D (Bayus and Agarwal 2007, Furr 2019, Lopes-Bento and Simeth 2024, Sørensen and Stuart 2000, Tripsas and Gavetti 2000). That these inexperienced firms do not adapt despite their need to do so suggests that, at least in this case, ability bests need. By incorporating experience-based heterogeneity, our findings supplement prior research that focused solely on technological change as the environmental shift driving firms' technological activities (Dosi 1982, Eggers and Park 2018).

Our research makes two main contributions. First, we show that policy incentives that foreshadow a technological shift are an important, if non-universal, trigger to R&D, and in particular external R&D. However, these incentives do not affect all firms equally—early adoption is primarily driven by firms with related technological experience. This finding highlights why even strong and flexible policies, such as RPSs, may initially result in limited and slow responses. This heterogeneity in firm responses has implications both for policymakers designing such incentives and for scholars studying how experience shapes technological adaptation and search behaviors.

Second, we show that related technological knowledge is a strong predictor of whether firms adapt to a technological shift, even within an industry of structurally similar firms. Importantly, this pattern extends beyond internal R&D to include external R&D as well. In our study, the few firms at the technology frontier prioritize internal R&D, but the vast majority invest in R&D externally. The use external R&D as a means of adaptation is likely more prevalent in industries such as electric utilities, where firms typically focus on providing integrated services, rather than on developing new technologies. However, this pattern—of drawing knowledge from organizations outside the focal—is increasingly prevalent even in industries at the technological frontier (Arora, Cohen, et al. 2018).

Relatedly, we expand our understanding of the relationship between firm experience and external R&D by looking at the types of external R&D (Ancona and Caldwell 1990, Arora et al. 2014, Capron and Mitchell 2009). We see that experienced firms invest primarily in technology-related R&D, but they also invest in gathering other types of knowledge— and relatively more so than inexperienced firms (Dutt and Lawrence 2022, Leiponen and Helfat 2010). This finding suggests that, when facing a policy incentive, firms that understand how to use the relevant technologies will seek the necessary knowledge externally to supplement their expertise.

In sum, policy incentives that signal a technological shift can push firms to invest in R&D, conditional on related technological experience. The ability to adapt seemingly trumps need to do so when faced with significant technological change.

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**TABLE 1a: Descriptive Statistics of analytical variables**

| | Mean | S.D. | Min | Max |
|---|---|---|---|---|
| Total R&D (logged) | 7.633 | 6.81 | 0 | 17.069 |
| External R&D (logged) | 6.533 | 6.673 | 0 | 17.069 |
| Internal R&D (logged) | 4.67 | 6.198 | 0 | 16.83 |
| External tech R&D (logged) | 3.67 | 5.757 | 0 | 16.4 |
| Ext. non-tech R&D (logged) | 5.603 | 6.463 | 0 | 17.029 |
| RPS_strength | 0.065 | 1.006 | -7.273 | 2.41 |
| Renewable exp (share) | 0.049 | 0.175 | 0 | 1 |
| buy_percent | 0.44 | 0.329 | 0 | 1 |
| ln_elecrev | 19.997 | 1.911 | 9.473 | 23.366 |
| price_electric | 8.433 | 2.953 | 4.243 | 29.201 |
| gdp_percapita | 0.041 | 0.013 | 0.027 | 0.407 |
| pctdem | 0.5 | 0.124 | 0.12 | 0.89 |
| sierraclubmem | 16240.3 | 23859.92 | 470 | 175000 |
| stock_patents | 2.048 | 10.234 | 0 | 102 |
| diversification | 0.33 | 0.47 | 0 | 1 |

**Table 1b: Correlations Table**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total R&D | 1 | | | | | | | | | | | | | | |
| External R&D | 0.872 | 1 | | | | | | | | | | | | | |
| Internal R&D | 0.713 | 0.488 | 1 | | | | | | | | | | | | |
| External tech R&D | 0.594 | 0.676 | 0.528 | 1 | | | | | | | | | | | |
| Ext. non-tech R&D | 0.777 | 0.896 | 0.382 | 0.466 | 1 | | | | | | | | | | |
| RPS_strength | 0.089 | 0.029 | 0.089 | 0.016 | 0.042 | 1 | | | | | | | | | |
| Renewable exp | -0.039 | -0.017 | 0.032 | 0.083 | -0.048 | -0.085 | 1 | | | | | | | | |
| buy_percent | -0.254 | -0.233 | -0.167 | -0.134 | -0.22 | -0.065 | 0.057 | 1 | | | | | | | |
| ln_elecrev | 0.59 | 0.489 | 0.393 | 0.317 | 0.447 | -0.001 | 0.045 | -0.246 | 1 | | | | | | |
| price_electric | 0.061 | 0.023 | 0.157 | 0.155 | -0.054 | 0.242 | 0.164 | 0.162 | 0.003 | 1 | | | | | |
| gdp_percapita | -0.001 | 0.01 | 0.012 | 0.065 | -0.008 | 0.01 | 0.098 | 0.054 | -0.01 | 0.272 | 1 | | | | |
| pctdem | 0.148 | 0.14 | 0.088 | 0.128 | 0.117 | 0.013 | 0.127 | 0.091 | 0.037 | 0.469 | 0.13 | 1 | | | |
| sierraclubmem | 0.038 | 0.004 | 0.09 | 0.109 | -0.07 | -0.175 | 0.372 | 0.063 | 0.173 | 0.259 | 0.124 | 0.153 | 1 | | |
| stock_patents | 0.182 | 0.002 | 0.269 | 0.066 | -0.055 | -0.018 | 0.067 | 0.059 | 0.252 | 0.14 | 0.047 | 0.067 | 0.38 | 1 | |
| diversification | 0.156 | 0.192 | -0.031 | 0.175 | 0.185 | -0.087 | 0.178 | 0.124 | 0.229 | 0.015 | 0.074 | 0.144 | 0.237 | 0.139 | 1 |

**TABLE 2: RPS Strength and Total, External, and Internal R&D**

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| DV | Total R&D | | External R&D | | Internal R&D | |
| RPS_strength | 0.032 | -0.519* | -0.161 | -0.879*** | 0.094 | 0.002 |
| | (0.121) | (0.265) | (0.157) | (0.290) | (0.124) | (0.247) |
| Renewable experience | -3.105 | -4.141* | -0.715 | -2.067 | 0.202 | 0.029 |
| | (2.167) | (2.130) | (2.429) | (2.356) | (1.449) | (1.621) |
| RPS_strength x Ren. exp. | | 2.060** | | 2.688*** | | 0.343 |
| | | (1.007) | | (0.981) | | (0.725) |
| buy_percent | -3.698*** | -3.551*** | -4.241*** | -4.050*** | -2.510* | -2.485* |
| | (1.341) | (1.324) | (1.346) | (1.327) | (1.295) | (1.298) |
| ln_elecrev | 1.529*** | 1.576*** | 1.273*** | 1.335*** | 0.943*** | 0.951*** |
| | (0.382) | (0.386) | (0.359) | (0.363) | (0.273) | (0.276) |
| price_electric | 0.294 | 0.300 | 0.145 | 0.153 | 0.145 | 0.146 |
| | (0.254) | (0.254) | (0.374) | (0.371) | (0.201) | (0.201) |
| gdp_percapita | 4.669 | 4.236 | 6.117 | 5.554 | 0.856 | 0.788 |
| | (5.235) | (4.971) | (6.113) | (5.730) | (3.543) | (3.517) |
| pctdem | -0.770 | 0.099 | 0.559 | 1.700 | -0.707 | -0.567 |
| | (2.329) | (2.350) | (2.901) | (2.890) | (2.115) | (2.135) |
| sierraclubmem | -0.000 | -0.000 | -0.000 | -0.000 | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| stock_patents | 0.014 | 0.014 | -0.102* | -0.101* | 0.084*** | 0.084*** |
| | (0.031) | (0.029) | (0.057) | (0.056) | (0.031) | (0.030) |
| diversification | 1.060 | 1.065 | 1.867 | 1.873 | -1.292 | -1.291 |
| | (1.155) | (1.158) | (1.130) | (1.133) | (1.067) | (1.068) |
| YEAR+STATE FE | YES | YES | YES | YES | YES | YES |
| Observations | 1,070 | 1,070 | 1,070 | 1,070 | 1,070 | 1,070 |
| R-squared | 0.567 | 0.571 | 0.484 | 0.492 | 0.456 | 0.456 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

**TABLE 3: RPS Strength, Renewable Experience, and Type of External R&D**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| DV | External Tech. R&D | | External Non-tech. R&D | |
| RPS_strength | -0.215 | -0.825*** | -0.128 | -0.574** |
| | (0.196) | (0.295) | (0.185) | (0.275) |
| Renewable experience | 1.394 | 0.193 | -0.825 | -1.702 |
| | (2.276) | (2.174) | (1.774) | (1.870) |
| RPS_strength x Ren. exp. | | 2.308*** | | 1.687** |
| | | (0.739) | | (0.800) |
| buy_percent | -2.372** | -2.203** | -3.217** | -3.093** |
| | (1.091) | (1.083) | (1.254) | (1.244) |
| ln_elecrev | 0.793*** | 0.848*** | 1.041*** | 1.081*** |
| | (0.262) | (0.271) | (0.315) | (0.317) |
| price_electric | -0.043 | -0.035 | 0.026 | 0.032 |
| | (0.247) | (0.247) | (0.361) | (0.360) |
| gdp_percapita | 3.870 | 3.439 | 4.013 | 3.698 |
| | (4.048) | (3.743) | (5.230) | (5.032) |
| pctdem | 4.213 | 5.151* | 1.143 | 1.829 |
| | (2.844) | (2.833) | (3.348) | (3.334) |
| sierraclubmem | -0.000** | -0.000** | 0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| stock_patents | -0.051 | -0.051 | -0.093** | -0.093** |
| | (0.056) | (0.055) | (0.040) | (0.039) |
| diversification | 0.161 | 0.167 | 2.174** | 2.179** |
| | (0.855) | (0.859) | (1.092) | (1.092) |
| YEAR FE + STATE FE | YES | YES | YES | YES |
| Observations | 1,070 | 1,070 | 1,070 | 1,070 |
| R-squared | 0.397 | 0.405 | 0.453 | 0.456 |

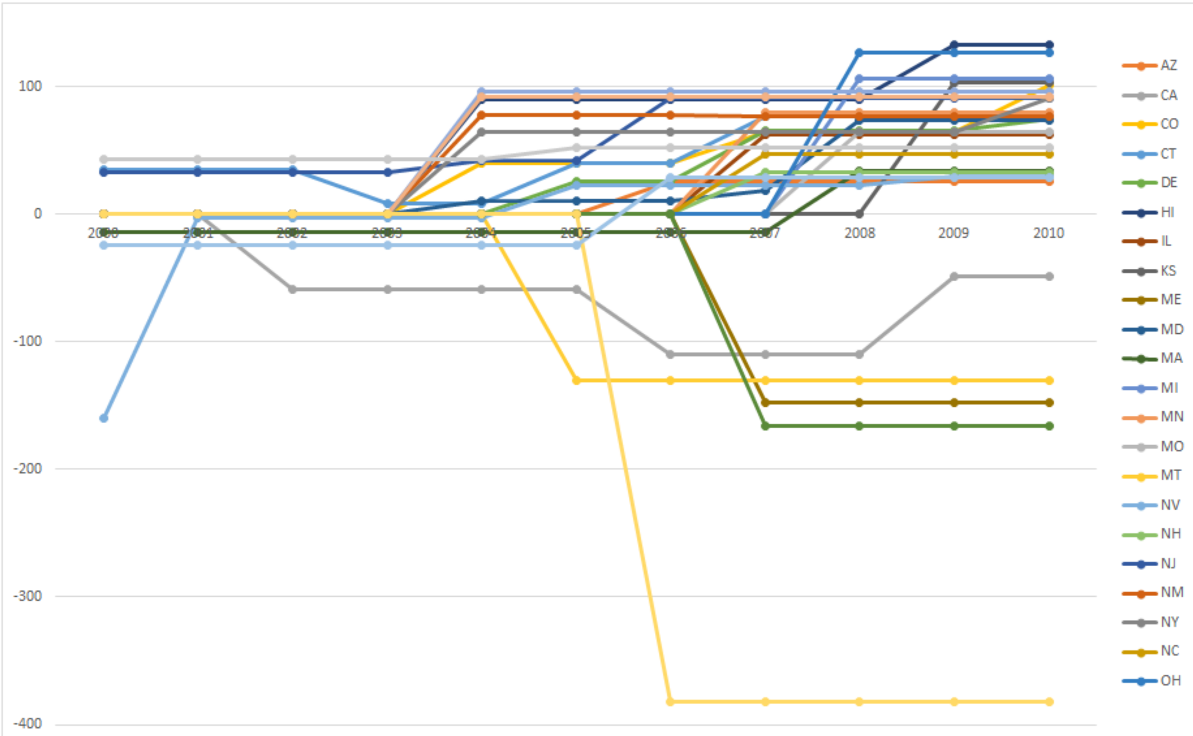
Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

**TABLE 4: RPS Strength Spilt Dimensions: Renewable Gap and Time Gap**

| DV: External R&D | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Renewable gap | -0.017 | -0.068** | | | -0.022 | -0.109*** |
| | (0.019) | (0.029) | | | (0.018) | (0.032) |
| Renewable experience | -0.713 | -1.781 | -0.813 | 1.338 | -0.800 | 1.076 |
| | (2.431) | (2.456) | (2.451) | (2.505) | (2.459) | (2.351) |
| Ren. gap x Ren. exp | | 0.241** | | | | 0.316** |
| | | (0.104) | | | | (0.123) |
| Time gap | | | 0.047 | 0.077* | 0.055 | 0.143*** |
| | | | (0.035) | (0.040) | (0.034) | (0.041) |
| Time x Ren. exp | | | | -0.313* | | -0.484*** |
| | | | | (0.173) | | (0.184) |
| buy_percent | -4.239*** | -4.076*** | -4.229*** | -4.265*** | -4.230*** | -4.069*** |
| | (1.346) | (1.330) | (1.344) | (1.348) | (1.345) | (1.327) |
| ln_elecrev | 1.273*** | 1.322*** | 1.276*** | 1.268*** | 1.271*** | 1.318*** |
| | (0.359) | (0.361) | (0.357) | (0.358) | (0.358) | (0.359) |
| price_electric | 0.145 | 0.141 | 0.154 | 0.165 | 0.195 | 0.271 |
| | (0.375) | (0.373) | (0.366) | (0.363) | (0.371) | (0.360) |
| gdp_percapita | 6.201 | 6.178 | 7.348 | 7.633 | 7.247 | 8.298 |
| | (6.151) | (6.044) | (6.395) | (6.579) | (6.190) | (6.130) |
| pctdem | 0.403 | 0.871 | -0.208 | -0.211 | -0.561 | -0.883 |
| | (2.907) | (2.966) | (2.926) | (2.938) | (2.920) | (3.034) |
| sierraclubmem | -0.000 | -0.000 | -0.000 | -0.000 | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| stock_patents | -0.102* | -0.103* | -0.102* | -0.100* | -0.101* | -0.098* |
| | (0.057) | (0.056) | (0.056) | (0.055) | (0.057) | (0.053) |
| diversification | 1.864 | 1.868 | 1.879* | 1.869 | 1.877* | 1.875* |
| | (1.129) | (1.130) | (1.129) | (1.131) | (1.129) | (1.129) |
| YEAR FE + STATE FE | YES | YES | YES | YES | YES | YES |
| Observations | 1,070 | 1,070 | 1,070 | 1,070 | 1,070 | 1,070 |
| R-squared | 0.484 | 0.490 | 0.485 | 0.487 | 0.485 | 0.497 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

## APPENDIX A: Regulatory Strength by State and Year



**APPENDIX B: Coarsened and Exact Match Results for RPS Strength, Renewable Experience, and External R&D**

Our goal in these CEM analyses was to match observations on as many relevant observable characteristics as possible to create comparable groups of control and treated observations. We took two approaches to matching. We matched observations using the Coarsened and Exact Matching procedure in Stata 17. The Table below includes a reproduction of our main results (columns 1 and 2), the CEM results from approach 1 (columns 3 and 4), and the CEM results from approach 2 (columns 5 and 6). Overall, the results from the matched samples are consistent with our main analyses. Greater *RPS_strength* is associated with increasing *External R&D*, and this association is driven by the firms that possess *Renewable experience*.

In the first approach, we matched at the firm-year level. The control firm-years have a zero level of *RPS_strength*, and the treated firm-years have a positive value of *RPS_strength*. This matching allows us to reduce concerns that the results are driven from firms in large-policy-incentive conditions differing from those in small-policy-incentive settings in observable ways. In essence, the procedure allows us to compare otherwise similar firm-years with high and low *RPS_strength*. We matched based on several firm-level and state-level features (Blackwell *et al.*, 2009). These include *ln_elecrev*, *diversification*, *HQ* (an indicator of whether the unit is a headquarters or a subsidiary), *cat_sourcing* (a categorical variable that measures whether firms source electricity by making it, buying it, or use a mix of the two), *elecinc* (income from electricity in USD), *elecempl* (total number of electricity employees), *total_electricity* (total megawatts of electricity generated), *lobby* (an indicator of whether the firm lobbied in a given year or not), *total_rd* (an indicator of whether the firm invested in R&D in a given year or not), and *RPS_state* (an indicator of whether the firm is in a state that eventually enacted RPSs or not). The matched sample statistics can be found in columns 3 and 4.

Our second approach was to match at the firm-level. Given that the pool of observations we could match on is smaller for this second matching approach, we reduce the matching variables to improve sample size. We match on *ln_elecrev*, *cat_sourcing* (a categorical variable that measures whether firms source electricity by making it, buying it, or use a mix of the two), *elecinc* (income from electricity in USD), *elecempl* (total number of electricity employees), *total_electricity* (total megawatts of electricity generated), and *total_rd* (an indicator of whether the firm invested in R&D in a given year or not), In columns 5 and 6 we share the results of the second matched sample analysis matching firm-year observations in states that never enact RPSs with firm years in states that do at some point get an RPS. We find similar results to the baseline models and the models in columns 3 and 4.

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| DV: External R&D | Full Sample | | CEM (1) | | CEM (2) | |
| RPS_strength | -0.161 | -0.879*** | -0.312 | -0.671** | -0.074 | -0.086 |
| | (0.157) | (0.290) | (0.261) | (0.323) | (0.327) | (0.326) |
| Renewable experience | -0.715 | -2.067 | 0.756 | -0.776 | 1.795 | 0.336 |
| | (2.429) | (2.356) | (1.598) | (1.604) | (1.607) | (1.393) |
| RPS_strength x Ren. exp. | | 2.688*** | | 1.361** | | 1.161*** |
| | | (0.981) | | (0.591) | | (0.296) |
| buy_percent | -4.241*** | -4.050*** | -2.208 | -2.188 | -2.250 | -2.268 |
| | (1.346) | (1.327) | (1.340) | (1.337) | (1.682) | (1.683) |
| ln_elecrev | 1.273*** | 1.335*** | 1.681*** | 1.684*** | 2.207*** | 2.202*** |
| | (0.359) | (0.363) | (0.330) | (0.329) | (0.415) | (0.415) |
| price_electric | 0.145 | 0.153 | -0.169 | -0.176 | -0.218 | -0.218 |
| | (0.374) | (0.371) | (0.414) | (0.410) | (0.178) | (0.178) |
| gdp_percapita | 6.117 | 5.554 | 5.691 | 5.445 | -135.476 | -137.335 |
| | (6.113) | (5.730) | (4.899) | (4.824) | (142.751) | (142.746) |
| pctdem | 0.559 | 1.700 | -2.328 | -1.667 | 0.806 | 0.794 |
| | (2.901) | (2.890) | (3.236) | (3.206) | (3.141) | (3.144) |
| sierraclubmem | -0.000 | -0.000 | -0.000 | -0.000 | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| stock_patents | -0.102* | -0.101* | 0.195*** | 0.199*** | 0.007 | 0.014 |
| | (0.057) | (0.056) | (0.041) | (0.040) | (0.035) | (0.035) |
| diversification | 1.867 | 1.873 | 1.857 | 1.875 | 0.864 | 0.868 |
| | (1.130) | (1.133) | (1.596) | (1.598) | (1.923) | (1.925) |
| YEAR FE + STATE FE | YES | YES | YES | YES | YES | YES |
| Observations | 1,070 | 1,070 | 640 | 640 | 628 | 628 |
| R-squared | 0.484 | 0.492 | 0.577 | 0.579 | 0.574 | 0.575 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

**APPENDIX C: Regulatory Uncertainty**

| | (1) | (2) |
|---|---|---|
| DV | External R&D | |
| RPS_strength | -0.879*** | 1.373 |
| | (0.290) | (1.700) |
| Renewable experience | -2.067 | -3.989 |
| | (2.356) | (10.194) |
| RPS_strength x Ren. exp. | 2.688*** | -5.003 |
| | (0.981) | (4.137) |
| pctdem | 1.700 | 1.815 |
| | (2.890) | (2.924) |
| RPS_strength x pctdem | | -4.111 |
| | | (3.103) |
| Ren. exp x pctdem | | 4.130 |
| | | (19.869) |
| RPS_strength x Ren. exp. x pctdem | | 13.469* |
| | | (7.948) |
| buy_percent | -4.050*** | -4.101*** |
| | (1.327) | (1.339) |
| ln_elecrev | 1.335*** | 1.340*** |
| | (0.363) | (0.366) |
| price_electric | 0.153 | 0.277 |
| | (0.371) | (0.305) |
| gdp_percapita | 5.554 | 5.592 |
| | (5.730) | (5.785) |
| sierraclubmem | -0.000 | -0.000 |
| | (0.000) | (0.000) |
| stock_patents | -0.101* | -0.096* |
| | (0.056) | (0.054) |
| diversification | 1.873 | 1.841 |
| | (1.133) | (1.138) |
| YEAR FE + STATE FE | YES | YES |
| Observations | 1,070 | 1,070 |
| R-squared | 0.492 | 0.494 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

**APPENDIX D1: Lobbying**

| | (3) | (4) |
|---|---|---|
| DV: | Lobbying (Logged USD) | |
| RPS_strength | 0.155 | 0.016 |
| | (0.140) | (0.329) |
| Renewable experience | 1.589 | 1.329 |
| | (2.121) | (2.431) |
| RPS_strength x Ren. exp. | | 0.522 |
| | | (1.118) |
| pctdem | -0.980 | -0.770 |
| | (2.284) | (2.326) |
| buy_percent | -2.342* | -2.308* |
| | (1.289) | (1.294) |
| ln_elecrev | 1.513*** | 1.524*** |
| | (0.357) | (0.362) |
| price_electric | -0.372** | -0.370** |
| | (0.147) | (0.147) |
| gdp_percapita | 4.825 | 4.716 |
| | (6.359) | (6.284) |
| sierraclubmem | -0.000* | -0.000* |
| | (0.000) | (0.000) |
| stock_patents | 0.081*** | 0.081*** |
| | (0.022) | (0.022) |
| diversification | 1.565 | 1.566 |
| | (1.063) | (1.063) |
| YEAR FE + STATE FE | YES | YES |
| Observations | 1,106 | 1,106 |
| R-squared | 0.531 | 0.531 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

**APPENDIX D2: Corporate Strategy**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| DV: | Acquisition (0/1) | | Corp Strat Event (N) | |
| RPS_strength | -0.010 | -0.012* | -0.010 | -0.004 |
| | (0.007) | (0.007) | (0.008) | (0.010) |
| Renewable experience | -0.001 | -0.006 | -0.001 | 0.010 |
| | (0.015) | (0.019) | (0.030) | (0.030) |
| RPS_strength x Ren. exp. | | 0.010 | | -0.021 |
| | | (0.014) | | (0.016) |
| buy_percent | 0.011 | 0.012 | -0.007 | -0.009 |
| | (0.007) | (0.008) | (0.015) | (0.015) |
| ln_elecrev | 0.002 | 0.002 | 0.006** | 0.006* |
| | (0.001) | (0.001) | (0.003) | (0.003) |
| price_electric | -0.002 | -0.002 | -0.008* | -0.007* |
| | (0.001) | (0.001) | (0.004) | (0.004) |
| gdp_percapita | 2.701*** | 2.699*** | 2.605*** | 2.610*** |
| | (0.052) | (0.054) | (0.111) | (0.109) |
| pctdem | -0.025 | -0.021 | 0.042 | 0.033 |
| | (0.029) | (0.027) | (0.097) | (0.096) |
| sierraclubmem | 0.000 | 0.000 | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| stock_patents | 0.001 | 0.001 | 0.002** | 0.002** |
| | (0.001) | (0.001) | (0.001) | (0.001) |
| diversification | -0.006* | -0.006* | 0.004 | 0.004 |
| | (0.004) | (0.004) | (0.010) | (0.010) |
| YEAR+STATE FE | YES | YES | YES | YES |
| Observations | 1,017 | 1,017 | 1,017 | 1,017 |
| R-squared | 0.217 | 0.218 | 0.109 | 0.110 |

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1