The Effects of Utility Revenue Decoupling on Electricity Prices

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June 2021

Abstract

Revenue decoupling (RD) is a regulatory mechanism that allows adjustments of retail electricity rates for the regulated utility to recover its required revenue despite fluctuations in its sales volume. The U.S. utility data in 2000-2019 reveals that RD is associated with about a 4-percentage point higher growth rate of residential electricity prices within the first year after RD is implemented relative to carefully matched non-decoupled utilities with similar pre-RD sales trends. Theoretically, unexpected sales declines would lead to higher electricity prices while unexpected sales increases would lead to lower prices. While RD adjustments have reportedly yielded both refunds and surcharges, our analysis indicates that electricity prices demonstrate downward rigidity and statistically significant upward adjustments for the utilities subject to RD. The asymmetric movement in retail prices may be associated with the political economy underlying the adoption and the implementation of RD.

Keywords Utility regulation; revenue decoupling; electricity sector
JEL classification L94, Q41, Q48

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1 Introduction

In an effort to curb pollution externalities associated with fossil fuel energy use, policymakers continue to push for improved energy efficiency and distributed electricity generation. Under the traditional natural-monopoly regulation (i.e., cost-of-service or rate-of-return regulation), however, the volumetric electricity prices are set above the marginal costs and hence the profits tend to increase with the sales volume. Therefore, a utility's interest—to sell more electricity—is misaligned with the regulatory agenda of attaining energy efficiency and conservation (Eto et al., 1997). Despite such throughput incentive, the sales of electricity have not been growing over the last decade in the United States, leading to concerns that the utilities are not able to recover the fixed costs.

Among the potential regulatory options, revenue decoupling (RD) has emerged as an approach to help utilities overcome the disincentive to support the state's energy-efficiency agenda (Morgan, 2013). Revenue decoupling is generally defined as a rate-making mechanism designed to "decouple" the utility's revenues from its sales, where the revenue is set to cover the utility's costs of distribution. By making the utility's revenue independent of sales, RD removes the utility's disincentives to promote customer efforts to reduce energy consumption or to expand distributed generation that often utilizes renewable energy (Kushler et al., 2006) .

Table 1 provides a simple illustration of how RD works.[1] Consider a scenario where the actual sales in the current year are 1 percent lower than the baseline amount of 1 million kWh. Without any revenue adjustment mechanism, this translates to about 1 percent revenue shortfall in the said year. Hence, any shock that lowers demand, be it due to energy efficiency improvement or conservation (or any exogenous income shock), results in lower equity earnings. Under RD, the (volumetric) electricity rate increases so that the

[1]This illustration is based on a simple full decoupling mechanism. In reality, there are a number of ways to implement RD, but the guiding mechanism is the same (i.e., except for flat distribution that is discussed later, all of them have a true-up mechanism that adjusts the electricity rates in order to secure the required revenue). For a more complete discussion of RD, see Regulatory Assistance Project (2011).

required revenue is earned. RD, in effect, provides a mechanisms for customers to receive refunds or pay surcharges based on whether the revenues the utility actually received from customers were greater or smaller than the revenues required to recover the fixed cost.[2] The frequency of true-ups is annual in many cases while some states apply rate adjustments monthly (Morgan, 2013).

Table 1: An example of how RD works.

	No RD in place	**RD in place**
Revenue Requirement	$115,384,615	
(Based on expenses, allowed return, taxes)		
Sales Forecast (kWh)	1,000,000,000	
Actual Sales (kWh)	990,000,000	
Unit Price ($/kWh)	0.1154	0 .1166
Decoupling Adjustment ($/kWh)	−−	0 .0012
Actual Revenue	$114,230,769	$115,384,615

Source: The Regulatory Assistance Project (RAP), 2011.

As of February 2020, 15 states and the District of Columbia have implemented RD for 46 electric utilities.[3] Many states implemented RD during and immediately after the U.S. financial crisis in 2000. As a growing number of states have ventured into adopting policies and regulations with energy efficiency objectives, debates on the effectiveness of revenue decoupling emerged. Conservation advocates argue that RD can enhance generation and distribution efficiency by providing utilities the incentives to reduce costs and not through increases in sales (Regulatory Assistance Project, 2011; Sullivan et al., 2011). They also argue that RD is necessary, if not sufficient, for utilities to promote energy efficiency and/or invest in renewables (Costello, 2006; Lowry and Makos, 2010). RD improves a utility's financial situation and lowers risks, thereby potentially reducing the cost of capital (Costello, 2006). RD is considered to be less contentious, and hence less costly

[2]Note, however, that the difference can occur for many reasons, including weather and economic conditions that are not entirely within the control of the customers nor the utility. In this context, it is apparent that RD insulates the utility from business risks that are now absorbed by the customers (Moskovitz et al., 1992).

[3]The data is from https://www.nrdc.org/sites/default/files/decoupling-maps-package-01.18.17.pdf, retrieved on February 25, 2020.

to set rates and conduct cost recovery, than the Loss Revenue Adjustment (LRA). Other policies including LRA requires sophisticated measurement and/or estimation. Moreover, it is easier for state commissions to administer/monitor as opposed to other alternatives (Costello, 2006; Lowry and Makos, 2010; Moskovitz et al., 1992; Shirley and Taylor, 2006). Recent studies find that the utilities under RD are associated with higher expenditure on demand-side management, indicating larger efforts on energy efficiency improvements (Kahn-Lang, 2016; Datta, 2019).

Critics of RD, on the other hand, argue that the policy is a blunt instrument to promote energy efficiency, particularly on the part of the utility. Because utilities must rebate the difference between price and costs to consumers, they no longer have an incentive to minimize costs under RD (Kihm, 2009). Knittel (2002), for example, showed that RD is not effective in influencing utilities to improve generation efficiency because they do not receive significant economic gains from producing energy more efficiently. Moreover, critics suggest that the policy not only transfers the business risks from the utility to the customers but also may cause customers in one rate class to absorb some of the impact of demand downturns in another class (Lowry and Makos, 2010). Residential electric bills, for instance, may increase due to a downturn in the industrial demand.

Despite the controversies, little work has been done to provide clear evidence regarding the effects of RD on electricity prices. One of the potential consequences of RD, given the trend that electricity sales are not growing in many states, is the increase in retail electricity rates, particularly for residential customers. Previous studies on the effects of RD on electricity rates argue that the associated change in electricity rates have been negligible (Morgan, 2013; Kahn-Lang, 2016). In the U.S. between 2005 and 2012, 23% of the recorded 1,244 RD adjustment cases involve retail rate adjustments between 0 and 1 percent, and more than half of the cases are within the 0-3% range though more surcharge adjustments (i.e., upward rate adjustments) than refund adjustments have been observed (Morgan, 2013). A caveat about this observation is that it captures only the immediate decoupling adjustment similar to the one presented in Table 1. As of 2011, 11 out of 29 states allowed the revenue requirement to be adjusted between rate cases (Morgan, 2013). According to Lazar et al. (2016), the revenue requirements are adjusted for (1) inflation and productivity; (2) accounting for changes in numbers of customers; (3) dealing with attrition in separate cases; and (4) the application of specified rules to modify revenue levels over time. Such adjustments may involve rooms for discretionary price adjustments. In addition, changes in electricity prices may affect energy users' incentives to invest in energy efficiency improvement (such as efficient appliances or solar panels), which generate feedback effects on the demand for electricity and thus opportunities for further RD adjustments. Thus RD may induce not only immediate electricity rate changes but rate changes over time.

Can we compare electricity prices over time in states with and without RD? Care must be taken because the states and utilities with and without RD may have different economic characteristics, market power and political influence (Kim et al., 2016), which might explain some of the differences in the prices. For example, US Democratic Party has generally pro-environment stance (Teodoro et al., 2020) while Republican legislators can play a pivotal role in stopping climate policies (Kim et al., 2016). With RD complementing other energy efficiency policies, implementing RD may strongly depend on current political environment, which can then lead to biased estimated effect as the probability of being treated is no longer random.[4] In this study, we compare treated investor-owned utilities (those under RD mechanism) with control-group utilities (those that are not subject to RD)[5] with otherwise similar characteristics to assess the impact of RD on residential electricity rates. Our study design examines utility companies in 16 states that had implemented RD mechanism over the 2000-2019 period and compares the changes electricity rates with

[4]An anonymous referee pointed out that while Republican state governments may seem to be more interested in protecting utility profits and shifting risk from demand variance onto ratepayers, it is more likely that RD is implemented along other energy efficiency policies that are more popular to Democrats.

[5]We define a utility as an investor-owned electric service provider operating in a particular state, which means that utilities operating in two or more states are treated as unique utilities.

control utilities after the RD implementation.

Here are the key results. First, we find that the predicted probability of implementing decoupling is about 5 times lower than average for those state-years when the governorship and the majority of the two chambers of legislative branch are affiliated with the Republican Party, but higher for those utilities with larger market share. Second, we find that decoupling tends to accelerate growth in electricity rates rather substantially over several months upon implementation. In the first twelve months after the implementation, we see residential electricity rates grew by about 4 percentage point higher relative to those that did not experienced policy switch to RD. Third, we find indications of asymmetric price adjustments for decoupled utilities. In particular, we see significant increases in the growth of residential power prices in times when the actual sales are lower than the projected. In contract, we do not find strong evidence for any downward price adjustment under the cases of higher-than-projected sales. We provide insights about how potential mechanism behind the observed price effect and policy implications on key issues surrounding residential electricity consumption.

In what follows, we review the effects of decoupling on the retail electricity prices and possible reasons for asymmetric price adjustments (Section 2). Our empirical strategy to identify the effect of RD on residential prices is discussed in Section 3. We then provide an empirical evidence of the effect of decoupling on residential rates in Section 3. Section 5 provides a summary and discussion of the policy implications.

2 Revenue decoupling and its price implications

2.1 The effect of decoupling on electricity prices

We explain how decoupling works by applying a simple framework of an electricity market served by a regulated utility. Suppose $x(p; A)$ is the market demand for grid-supplied electricity given retail price p and parameter (demand shifter) A, with derivatives

$\partial x/\partial p < 0$.[6] Parameter A represents the degree of energy efficiency, energy conservation efforts by the consumers, or the extent of distributed generation such as investment in rooftop solar photovoltaics (PV) by the consumers. An increase in A lowers the demand for grid-supplied electricity: $\partial x/\partial A < 0$.

The regulated utility either specializes in electricity distribution or constitutes a vertically integrated utility that engages in generation and distribution. Let $\bar{F} > 0$ be the fixed cost of providing electricity services (fixed and given in the short run). Though not essential for the analysis, assume that the marginal cost $c > 0$ is constant, which would include the fuel costs (pass-through to consumers) as well as the marginal cost of distribution. The total cost is given by $cx + \bar{F}$.

The utility's revenue consists of volumetric charges and fixed charges to energy users. We assume that the number of energy users (customers) N, as well as the fixed fee per customer, f is fixed throughout the analysis. In many cases, the fixed payment is much smaller than the fixed cost of operating the utility. The observed volumetric electricity rates tend to exceed the marginal cost of electricity while the monthly fixed charges for electricity users are not sufficient to cover the fixed cost of electricity services (Friedman, 2011). With $F \equiv \bar{F} - Nf$, the utility's profit is given by

$$\pi = px - cx - F.$$

Here we study the effect of an exogenous change in the demand shifter A.[7] Changes in A represent, for example, when solar PV penetration increases as a result of lower costs of PV or when energy users engage in conservation efforts.

We consider two regulatory regimes: (1) traditional rate of return regulation with no revenue decoupling (no RD); and (2) the RD regime. With no RD, the volumetric electricity

[6] We focus on the aggregate demand of residential, commercial, and industrial sectors and do not consider cross-subsidization across sectors in electricity pricing—issues to be investigated in future studies.

[7] Between rate cases, the equilibrium outcome is the same with or without revenue decoupling as long as the utility's sales volume (x) is the same. Differences arise when the sales change.

price stays the same between rate cases except for fuel cost adjustments, which are pass-through to consumers.[8] Thus the rate adjustments involve regulatory lag—changes in the economic environment of the electricity market does not induce rate changes right away (Joskow, 1974; Regulatory Assistance Project, 2011). With RD, the regulatory lag is much shorter: the price is adjusted so that the utility earns the required revenue to cover the cost of distribution, which is $R - cx + F$ if we assume that the marginal cost of distribution is zero:

$$px(p; A) = cx(p; A) + F.$$

Total differentiation of both sides with respect to p and A yields

$$xdp + (p - c)\{(\partial x/\partial p)dp + (\partial x/\partial A)dA\} = 0.$$

This implies

$$\frac{\partial p}{\partial A} = \frac{(p-c)\partial x/\partial A}{x\left(1 + \frac{p-c}{p}\frac{\partial x}{\partial p}\frac{p}{x}\right)},$$

which is negative if the demand for electricity is inelastic (i.e., if $\frac{\partial x}{\partial p} > -1$).[9] Therefore, in the empirically relevant case with inelastic electricity demand, the grid-supplied electricity consumption decreases, and the price p increases, as A increases.

2.2 Asymmetric price adjustment under decoupling

Revenue decoupling is designed so that the utility earns the required revenue regardless of the direction of unexpected changes in the electricity sales. That is, the adjustments due to

[8] The discussion here assumes there are no price adjustments due to fuel cost fluctuations, but our empirical study below takes them into account.

[9] The expression is negative as long as the demand for electricity is not highly elastic. In terms of the growth rate, the equality implies

$$\frac{\dot{p}}{p} = \frac{p-c}{p}\frac{1}{1 + \frac{p-c}{p}\frac{\partial x}{\partial p}\frac{p}{x}}\frac{\dot{x}}{x}.$$

If the elasticity is small in magnitude, the rate of change of the price is bounded by the share of the distribution costs in the price multiplied by the rate of change in the sales.

decreases in sales and those due to increases in sales would occur in a symmetric manner.

However, price adjustments may not occur symmetrically for a number of reasons. A critical assumption for symmetric price adjustments is that the required revenue is fixed; and the regulator can implement the price adjustments mechanically. As mentioned earlier, the revenue requirement is not necessarily fixed between rate cases in many states. The literature on natural monopoly regulation argues that the regulated utility's costs are private information (Settle and Tschirhart, 2003; Armstrong and Sappington, 2007). Different regulators, when approving the price, may place different weights on consumer surpluses and utilities' rents. To the extent that the utility has private information about their costs, the utility may have an incentive to report higher costs and prevent the price from being lowered when the sales are higher than expected (i.e., due to a drop in A in our model). A regulator that places a higher welfare weight on the utility may be more willing to accommodate price increases upon sales drop than to lower the price upon sales increase. Such political economy factors may prevent the revenue decoupling from working in a symmetric manner if the revenue requirement may be adjusted between the rate cases.[10]

Decoupling may have a long-term effect on the prices beyond the rate cases. Lim and Yurukoglu (2018) apply a model of dynamic natural monopoly regulation to investigate the consequence of time inconsistency of regulation and asymmetric information between the regulator and the regulated electricity distributors. Their empirical model takes into account the political environment's effects on the regulated utility's incentive to invest in grid reliability improvement. Their findings indicate that the political environment may matter when a state adopts decoupling (as discussed in the next subsection). It also indicates long-term implication of decoupling: to the text that decoupling is associated

[10] The literature on the theory of utility regulation largely focuses on the optimal regulation given asymmetric information between the regulator and the utility (Armstrong and Sappington, 2007). Most studies focus on how close the regulation can be to marginal cost pricing; and do not consider institutional constraints such as fixed cost recovery under the rate of return regulation (where the volumetric price exceeds marginal costs, not only because of asymmetric information, but because a large portion of the utility's fixed costs is recovered through volumetric prices rather than monthly fixed charges to energy users in practice).

with increased energy efficiency, more renewable energy or grid modernization, it may induce more investment by the utility and hence higher electricity rates beyond the rate cases.

Some empirical studies indicate that asymmetric price movements may be relevant to the electricity markets. Peltzman (2000) documents that prices rise faster than they fall in many markets although the price movements in the regulated markets (such as utilities) are not considered. Mokinski and Wölfing (2014) find related asymmetry with the retail electricity prices in Germany after the European Union Emissions Trading System (EU-ETS) was implemented: the electricity prices rose when the allowance price increased while the electricity prices did not fall as much when the allowance price decreased. This episode reinforces the view that the regulator has incomplete information about the regulated utilities' costs (Lim and Yurukoglu, 2018).

Does asymmetry matter for utility revenue decoupling? Cappers et al. (2020) find that the annual rate adjustments due to revenue decoupling in 2005-2017 are distributed symmetrically. However, they also indicate that an upward rate adjustment tends to be associated with more upward adjustments in later periods. Their conclusion is based on whether decoupling adjustments (surcharge or credit) are followed by surcharge or credit. In the next section, we investigate whether such asymmetric price adjustments are present empirically after taking into account other confounding factors of price movements.

2.3 Adoption of revenue decoupling

The preceding discussion describes what happens under revenue decoupling, but it does not explain why some states adopt decoupling while others do not.

Some utility regulation experts argue that it was necessary for the utilities' and the regulator's interests to be aligned as the regulator pursues policies to enhance energy efficiency or distributed generation. According to Regulatory Assistance Project (2011), decoupling "is used primarily to eliminate incentives that utilities have to increase profits by increasing sales, and the corresponding disincentives that they have to avoid reductions in sales. It is most often considered by regulators, utilities, and energy-sector stakeholders in the context of introducing or expanding energy efficiency efforts."

When the utility expects a decrease in sales, it may have an incentive to exert expenditures to lobby for the adoption of decoupling. Kang (2016) finds that lobbying by the energy sector has a statistically significant effect on the enactment of relevant policies. Though the analysis applies to the policies discussed in the United States Congress, it implies that similar influence may apply for state policies. To the extent that the weight on the utility's rents in the regulator's objective function is large enough, a prospect of downward sales forecast (due to renewables integration or further distributed generation) may induce the regulator to adopt revenue decoupling. Consequently, this raises a concern that RD adoption does not occur exogenously; and states that adopt decoupling and those that do not (or utilities with and without RD) may be different. The empirical investigation below addresses this concern.

3 Empirical Investigation

3.1 Data

We apply United States Energy Information Administration (EIA)'s monthly data for the period covering January 2000 - December 2019 on about 160 unique investor-owned utilities to investigate how RD affected the retail electricity rates.[11] We drop utilities that adopted RD (or some form of RD) prior to January 2000 (mostly those in Illinois), the beginning of the sample period. The data contain information about the utilities' sales (in kWh), revenues, and the average electricity prices by end-use sector. Regarding information about the timing of revenue decoupling implementation by each utility in a

[11] Our dataset spans up to February 2020, but decided to limit the analysis to December 2019 to avoid the potential effect of the COVID-19 pandemic.

particular state for the period 2000-2019, we referred to the information provided by the American Council for Energy-Efficient Economy (ACEEE) State Energy Efficient Policy Database (2021). We combine this database with the comprehensive data for 2000-2010 by Kahn-Lang (2016) and Morgan (2013). In some cases where the actual date is unavailable, we checked the relevant public utilities commission dockets to determine the actual RD implementation date of a particular utility. For information on the affiliation of the state government in each period, we use the dataset from Ballotpedia.

The descriptive statistics in Table 2 indicates that the utilities that experienced decoupling have higher average prices than those without decoupling. This observation applies to residential and overall (i.e. residential, commercial, and industrial) prices. Decoupled utilities have higher sales and share in total sales, about twice as much as non-decoupled utilities, both for residential and overall customers. Interestingly, decoupled utilities are more common in states that had governors affiliated to Democratic Party and more so when the same party holds the governorship and both legislative houses. In contrast, decoupling is less popular in areas or periods when the Republican Party holds the trifecta.[12] To the extent that Democratic Governors and legislatures may pursue energy efficiency or renewables integration more aggressively, this observation is consistent with the political economy factors that may explain the adoption of RD.

By simply comparing utilities that were decoupled during the sample period with those that remained non-decoupled, we observe significant divergence in the average residential real electricity rates as more utilities get decoupled over time (panel (a) in Figure 1). Towards the end of 2019, the average monthly electricity rates from decoupled utilities increased to \$0.09/kWh, which is significantly higher than the average for non-decoupled utilities (about \$0.07/kWh). This translates to about a \$20 increase in the monthly electric bill for an average electric customer, about 10-fold adjustments compared to the previous

[12] A trifecta means that either the Democratic or Republican Party holds the governorship and both legislative houses. For Nebraska, where there is a unicameral legislature, Democrat (Republican) trifecta refers to situations where the governor is affiliated with Democratic (Republican) Party. For Washington, DC, we take the affiliation of the City Mayor to define a trifecta and governorship.

estimate of $2.30 per month.[13] The result holds even if we use nominal power rates. (panel (b) in Figure 1). In the next section, we subject our findings to more robust analyses.

Table 2: Summary Statistics

	Non-Decoupled			Decoupled		
	N	Mean	SD	N	Mean	SD
Residential price, nominal, $/kWh	61799	0.112	0.071	9315	0.136	0.061
Residential price, real, $/kWh	61799	0.070	0.051	9315	0.084	0.035
Overall price, nominal, $/kWh	62905	0.104	1.265	9332	0.125	0.057
Overall price, real, $/kWh	62905	0.065	0.801	9332	0.076	0.032
Residential sales, Million mWh	62712	0.204	0.452	9332	0.457	0.608
Overall sales, Million mWh	63046	0.541	1.090	9347	1.030	1.496
Share in total residential sales, own	63078	0.128	0.183	9347	0.291	0.291
Share in total overall sales, own	63078	0.126	0.184	9347	0.285	0.288
Share in total residential sales, others	63078	0.778	0.238	9347	0.581	0.292
Share in total overall sales, others	63078	0.766	0.242	9347	0.575	0.289
Democrat governor = 1, 0 else	63078	0.399	0.490	9347	0.588	0.492
Democrat trifecta = 1, 0 else	63078	0.137	0.343	9347	0.421	0.494
Republican trifecta = 1, 0 else	63078	0.435	0.496	9347	0.074	0.263
No. of unique state-utility pairs			345			46
Years			2000-2019			
No. of observations			72425			

Note: Figures are for investor-owned utilities only. Decoupled utilities are those in a particular state that had adopted RD, which means that the values include pre- and post-RD regime. Non-decoupled utilities are those that had not adopted RD during the sample period. Real prices are in 1999 USD. Share of others refer to share of other investor-owned utilities in overall sales (i.e. including sales from municipal utilities and cooperatives). A trifecta means that either the Democratic or Republican Party holds the governorship and both legislative houses. For Nebraska, where there is a unicameral legislature, Democrat (Republican) trifecta refers to situations where the governor is affiliated with Democratic (Republican) Party. For Washington, DC, we take the affiliation of the City Mayor to define a trifecta and governorship.
Source: U.S. Energy Information Administration; Ballotpedia.

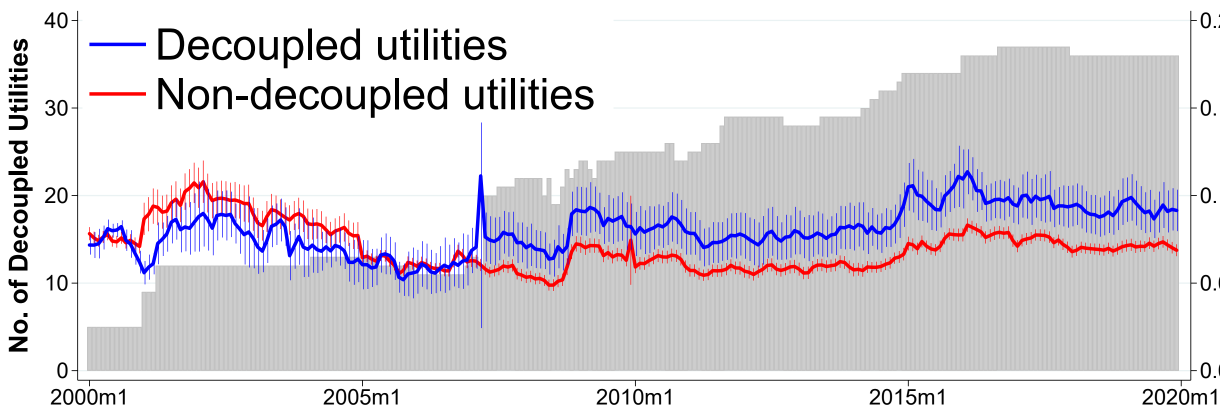
3.2 Empirical Strategy

Our empirical analysis to identify the effect of revenue decoupling on electricity prices consists of three features. First, we focus on the change in the regulation from non-RD

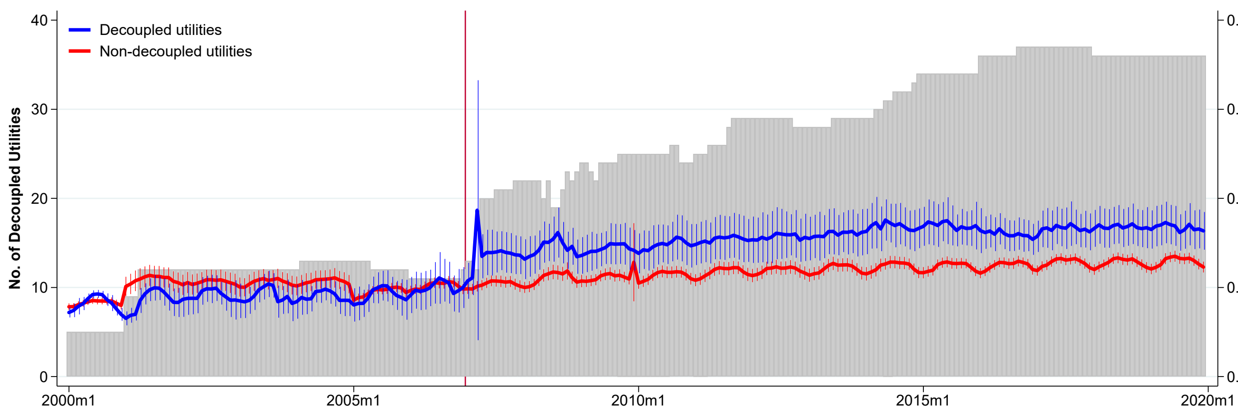
[13] This calculation assumes an average monthly consumption of 1,000kWh, following a previous study that assessed the effect of RD implementation on electricity rates (Morgan, 2013).

Figure 1: Effect of implementing Revenue Decoupling

(a) Average monthly real electricity prices of decoupled and non-decoupled utilities



(b) Average monthly nominal electricity prices of decoupled and non-decoupled utilities



The curves represent the average electricity price in $/kWh (right axis), with vertical lines indicating the 95% confidence interval. The shaded vertical bars correspond to the number of decoupled utilities (left axis). Prices have been deflated using CPI specific for the energy sector, with December 1999 as the base period.

to RD for a given utility operating in a particular state.[14] In particular, we consider the utilities that are observed at least 12 months prior to the adoption of RD and 36 months thereafter. By focusing on within state-utility changes, we are able to account for the effect of unobserved individual characteristics across utilities that may bias our estimates.

Second, we apply difference-in-difference approach (hereafter referred to as DD) to compare electricity prices of decoupled utilities with those that remain without RD. The

[14]We define a utility as an investor-owned electric service provider operating in a particular state, which means that utilities operating in two or more states are treated as unique utilities.

association between policy changes and subsequent outcomes are easily assessed with pre-post comparisons. This design is valid only if there are no underlying time-dependent trends in outcomes that are correlated to the policy change. In our case, if electricity prices were already increasing even before the implementation of RD, perhaps due to idiosyncratic shocks influencing the electricity demand among the affected households, then using pre-post study would lead to biased estimates and potentially erroneous association of the effects of RD implementation. The DD approach solves this issue by taking into account initial difference in prices between decoupled and non-decoupled before the adoption of RD, and the difference in prices between the two groups after the policy adoption, thus implicitly taking into account unobserved factors that may affect prices faced by the treatment or the control group.

Our estimating equation is provided below:

$$\Delta p_{it} = \alpha + \delta RD_{it} + \lambda_t + \varepsilon_{it}, \tag{1}$$

where Δp_{it} is the change in the electricity price charged by utility i in period (month-year) t relative to the same month a year ago, and RD_{it} is a dummy variable that turns to unity when RD is applied to the utility. The term λ_t represents time fixed effects to account for the month-year specific shocks that are common to all utilities (e.g. macroeconomic shocks, fuel price surges, etc). The error term ε is assumed to be independent between utilities but correlated within the same utility in a particular state. To address this concern, we clustered our standard error at the state-utility level. Coefficient δ measures the effect of implementing RD on the outcome variable.

One major issue in employing the above specification is that the estimate of δ could be biased if the control and treatment groups have different pre-treatment characteristics (Dehejia and Wahba, 2002). In our context, this can happen if utilities suffering from a decline in sales, possibly due to increased share in distributed generation or improved energy efficiency among customers, lobby for RD implementation. To minimize this concern, for each utility in the treatment group, we combine the difference-in-difference approach with propensity score matching. By employing this technique, we control for potential selection bias by restricting the comparison to utilities with homogeneous characteristics, trends and situation. We also limit our analysis to those utilities that did not implement Lost Revenue Adjustment Mechanism (LRAM). LRAM is another energy policy that promotes energy efficiency amongst utilities by allowing them to recover incurred losses in revenues resulting from any energy efficiency program (Gilleo et al., 2015). By removing utilities that had LRAM, we are confident that the observed difference between states that had RD and those that had none are not contaminated by the effect of LRAM. Our matching procedure resulted in 27 matched pairs of utility-state entities, out of the 46 that implemented RD.

In the context of this study, the propensity score is the predicted probability of a utility adopting decoupling. In constructing the pairs of observations matched on the propensity score, we make sure that the matched control observations are assigned only from the same period to eliminate the possibility the estimated differences in outcome variables are associated with unobserved shocks (e.g., fuel price surges) that may affect the treatment and control utilities differently.

4 Results

4.1 A simple model of RD adoption

As previously mentioned, it is probable that those utilities that adopted RD are different and may have faced varying situations from those that did not or, due to certain reasons, were not able to adopt the policy. In particular, the summary statistics presented above reveals substantial differences in terms of the share in state-level sales, the price they charge to their customers as well as the political environment that surrounds them. Nonetheless, these differences do not explicitly state the direction of causality. We, address the causality issue by applying propensity score matching to identify the effect of within-utility switch to RD on residential price changes. As a first step, we provide a simple model of policy switch to RD by estimating a probit model of the binary outcome of a utility in a state adopting RD. All explanatory variables are lagged a month before the adoption.

Table 3 presents the results of the RD adoption model. The estimates indicate that electric utilities that adopted RD are heavily influenced by the political economy and less on whether it has a declining trend in its sales. In particular, we find that those states with Republican trifecta government have significantly less likelihood of implementing RD. This supports the idea that RD is complementary to other energy efficiency and conservation policies that are less popular to the Republican Party. Results provided no strong evidence to the notion that decoupling is a way for utilities in ”death spiral”[15] to receive special regulatory treatment to survive. In the meantime, utilities with larger market power (as measured by its share in total residential electricity sales) have higher probability of adopting RD, with those in the 75^{th} percentile having 30% higher predicted probability relative to those in the 25^{th} percentile. Those in states controlled by Republican are four-fold unlikely to adopt RD.[16]

We assess the performance of our matching procedure by comparing the sample means of the variables used in the matching of treatment and control groups (see Table A.1). We find no statistically significant difference in the pre-RD period for the variables that were used in matching, suggesting that our matched sample exhibit homogeneity in pre-treatment variables that can render varying adoption probabilities between decoupled and non-decoupled utilities. Moreover, we also find no statistically significant difference between the means of the two groups for other variables that are not used in the matching, including nominal and real residential price trends and pre-RD levels (except that the

[15]The utility death spiral refers to a situation wherein utilities are stuck with growing stranded assets as a result of increased growth in distributed generation (e.g., household solar PV).

[16]Comparison is based on predicted probabilities calculated using the sample values of other predictor variables.

Table 3: Probit results. Predicting adoption of RD among electric utilities.

	Dependent Variable: Switch to RD
Residential sales trend	-0.000
	(0.000)
Democratic trifecta=1, 0 else	0.104
	(0.112)
Republican trifecta=1, 0 else	-0.396**
	(0.159)
Share of utilities to overall sales	0.601***
	(0.134)
Constant	-3.352***
	(0.077)
Chi^2 (Wald)	39.73
Prob > Chi^2	< 0.001
Pseudo R^2	0.043
N	60677

The table reports probit coefficients followed by standard errors clustered at the utility level in parentheses. *, **, *** indicate statistical significance at the 10, 5 and 1% levels, respectively.

overall pre-RD price trends are different with marginal significance). Thus our procedure is not subject to potential bias associated with selection on unobservables that affect both assigning of treatment and outcome of interest.

After obtaining the matched pairs, we examine the effect of adopting RD on electricity prices using the DD approach (equation 1).

4.2 OLS Results

Before we proceed to our results based on our matched sample, we perform a simple OLS regression on the unmatched sample. In this procedure, we ignore potential bias associated with self-selection of utilities to the policy and just controlling for utility- and time-fixed effects, and our matching variables. The results (Table 4) show that residential customers experienced an increase in electricity rates following the utility's adoption of revenue decoupling. In particular, we find an average increase of about 2.5% in residential electricity prices associated with RD implementation when we transformed the outcome variable into logarithm. The estimated increases in the prices are within the estimated range of what the previous studies find, which are based only on the size of the actual RD adjustment (Morgan, 2013).

Table 4: The effect of adopting RD on prices, unmatched sample.

	Price (levels)				Price (log-transformed)			
	Nominal		Real		Nominal		Real	
with Rd =1 , 0 else	0.008	0.008**	-0.001	0.000	0.017	0.025*	0.017	0.025*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)	(0.01)	(0.03)	(0.01)
Time-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Utility-state fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Matching controls	No	Yes	No	Yes	No	Yes	No	Yes
R-sq. (adj.)	0.805	0.815	0.870	0.872	0.874	0.910	0.877	0.912
Observations	67163	62175	67163	62175	67163	62175	67163	62175

Note: The table shows the result of estimating the fixed effect regression on the unmatched sample. Each column in each panel represents a separate regression for a particular outcome variable. Matching controls include the variables in the probit model (see Table 3). The standard errors, clustered at the utility-state level, are in parentheses. *, **, *** indicate statistical significance at 0.10, 0.05, and 0.01 level, respectively.

Another important observation is the downward bias in the estimated parameter of the RD switch associated with the omission of time-varying controls, such as those relating to the utility's market power and political environment, which are strongly correlated with the RD adoption. This reinforces the importance of carefully selecting more comparable controls in terms of the pre-RD adoption characteristics to accurately determine the causal effect of RD implementation on the residential electricity prices. It is also noteworthy to mention that up to this point, we remain agnostic about whether the utility with RD experienced sales growth that is lower than projected, which could allow RD to adjust prices in between rate cases. we discuss this issue in detail in the following section.

4.3 Price responses to unexpected changes in sales under RD

Decoupling as a mechanism is supposed to work symmetrically over unexpected increases in sales (that should result in downward price adjustments) and unexpected decreases in sales (that should result in upward price adjustments). Morgan (2013) reports that both downward and upward price adjustments have been observed. In this section, we simultaneously determine the effect of adopting revenue decoupling and the potential asymmetry in price adjustments to unexpected changes in the utility's electricity sales. We also employ the difference-in-difference combined with propensity score matching as discussed in Section 3.2.

We do not have direct observations on the revenue requirements of each utility. To come up with a proxy for unexpected changes in sales, we first calculate the average growth rate of the relevant sales over the previous 12 months. We call this variable *projected*. Next, we compare these growth rates with those of the average growth rates in the year when the utility adopted RD. Then we generate an indicator variable called $(projected > actual)$ that turns to unity when the growth rate in sales in the year prior to RD is higher than the rate in the year of RD implementation. We repeat this process in the second and the third year after the RD implementation. In other words, our indicator variable turns on when the projected demand growth is higher than the actual. We also create the indicator variable $(projected < actual)$ that turns to unity when the projected demand growth is lower than the actual.

We estimated equation 1 with additional controls: the above indicator variables and the interaction with our RD dummy. If RD works symmetrically, we would expect that the sign of the interaction term would be negative (positive) and statistically significant in the periods when the projected demand growth is higher (lower) than the actual. That is, utilities are expected to provide rebates to consumers in the form of lower power rates when the actual sales exceed the projected.

The results are presented in Figure 2[17]. We have two remarkable observations. First, the estimated effect on the decoupled utilities' residential electricity price growth is positive and fairly significant when it had lower-than-projected sales growth. The effect of decoupling translates to more than 4-percentage point increase in the growth of residential power rates in the first year of implementation relative to those utilities that experienced the same lower-than-projected sales growth but did not adopt decoupling. This confirms the upward adjustment in prices that decoupling is designed to have in times of having lower-than-projected sales. The result holds for both real or nominal prices. The estimated effect slightly increased in year and declined in year 3. The estimated effect in the third year is positive but statistically insignificant. We interpret this result as a possible confounding effect associated with the likely occurrence of rate cases in this period.

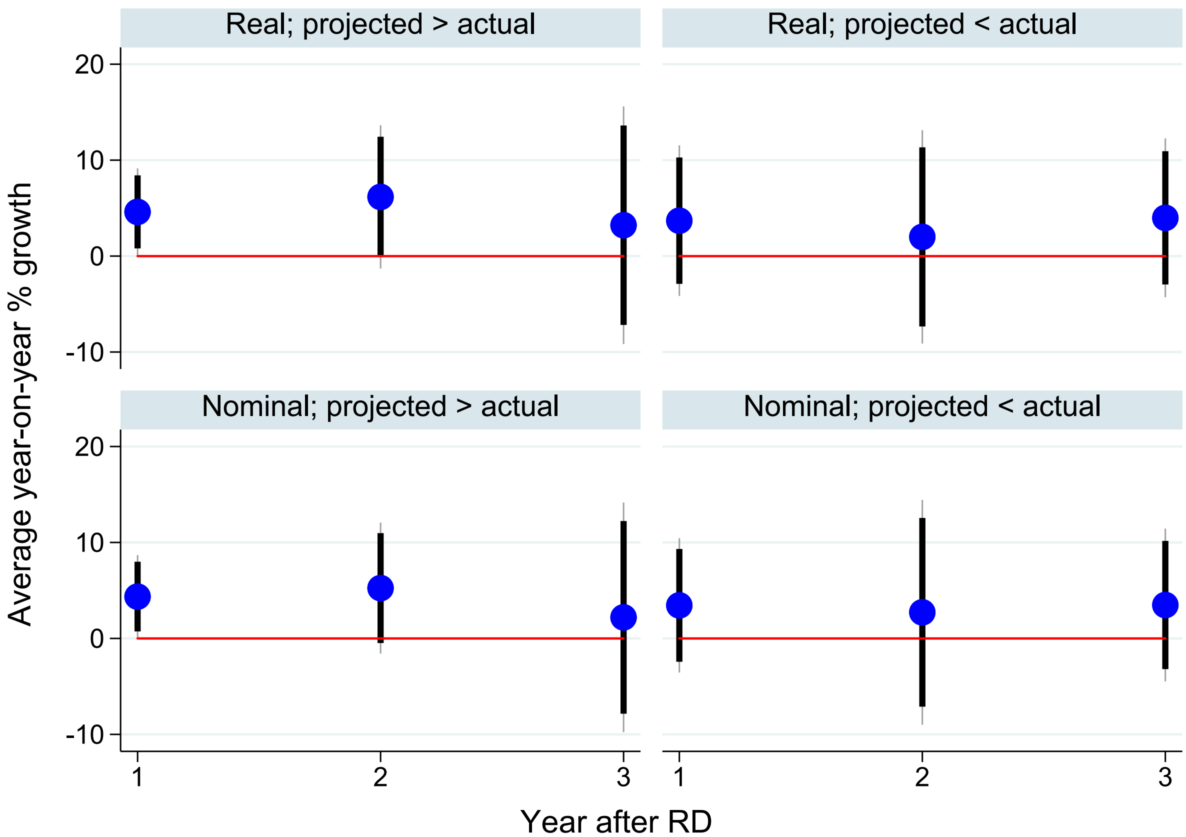
Second, the estimated effect is still positive even for those that had higher-than-projected sales growth, although the estimate remains to be statistically insignificant in all three periods. One way to interpret this result is that, at best, we do not see strong evidence to support the notion that price adjustments under the revenue decoupling scheme is symmetric. At worst, there is a tendency to have upward price adjustment on the average in periods where sales have been unexpectedly higher than were projected. This implies that, at least, utilities experiencing unanticipated sales growth would not have price reductions. Furthermore, there seems to be downward rigidity in electricity prices during periods of unanticipated sales growth such that the customers would still pay higher prices than those who are served by non-decoupled utilities.

It is possible that the observed association between RD and adjustments in retail prices can be partially explained by other policies that make energy use more expensive or that higher prices motivate energy efficiency, which motivates decoupling.[18] A case in point could be the The Regional Greenhouse Gas Initiative (RGGI), which is considered the the first mandatory market-based program in the United States to reduce greenhouse gas

[17] Detailed results are presented in Tables A.2-A.3.

[18] We are grateful for the anonymous referee in raising this very important issue.

Figure 2: Asymmetric price impact of RD, matched sample



Notes: Estimated effects resulting from Wald test using estimated parameters in equation 1. The blue dots pertain to average year-on-year growth) relative to the year before the RD implementation; thick black vertical lines -90% confidence interval (CI); thin gray vertical lines - 95% CI). Projected revenue is defined as the average growth in residential prices in the year prior to RD; actual revenue is as the average growth in residential prices in the year(s) after implementing RD. Nominal prices are deflated using consumer price index specific to energy sector, with December 1999 as the base period.

emissions (RGGI, 2021). The project, which aims to cap and reduce power sector CO_2 emissions, was first implemented in 2009 and includes states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont, and Virginia. The other energy policy is the Loss Revenue Adjustment Mechanism (LRAM) that promotes energy efficiency amongst utilities by "allowing a utility to recover revenues that are reduced specifically as a result of energy efficiency programs" (Gilleo et al., 2015).

We addressed this issue in two ways. First, prior to matching, we removed all states that had LRAM using data collected from Gilleo et al. (2015). By removing utilities that had LRAM, we are confident that the observed differences between utilities that had RD and those that had none are not contaminated by the potential effect of LRAM on retail prices. Second, we expand the analysis by performing a robustness check to control for the potential effect of RGGI. Using data from RGGI (2021), we included a dummy variable that turns to unity when a state-utility entity had become part of the RGGI and 0 otherwise. Results are presented in Tables A.4-A.5 and Figure A.1. The results are qualitatively the same as that of the baseline estimation method. In fact, the estimated effect after controlling for the potential effect of RGGI is now slightly higher and more precisely estimated.

5 Discussion

Several U.S. states have adopted revenue decoupling as one of the many policy measures to alleviate utilities' disincentives to invest in energy efficiency and conservation. Whether decoupling improves efficiency of the electricity sector has been a subject of debate (Kihm, 2009; Brennan, 2010; Morgan, 2013), but few studies have investigated the policy's price impacts by addressing other confounding factors and possible endogeneity of revenue decoupling.

The empirical evidence and the policy insights presented above suggest that the current implementation of RD does not ensure symmetric price adjustments against the utilities' sales fluctuation relative to the required revenues; and may induce upward adjustments in the volumetric prices on average. The question remains: what explains the asymmetric rate adjustment under decoupling? What alternatives would be more efficient while aligning electricity utilities' incentives with societal goals? As for the first question, the literature hints at possible mechanisms though they do not apply to the electricity markets with price regulation (Peltzman, 2000; Kimmel, 2009). Here we discuss the second question further.

There are two main types of designing RD for public utilities. The first one, which is discussed here, applies frequent true-ups on volumetric rates to ensure that the utility's actual revenue is equal to its revenue requirement. The second one, called the straight-fixed variable (SFV) rate design, sets fixed charges (such as the monthly customer charge) to recover the full fixed costs of service delivery while variable costs are recovered through variable charges. At the moment, the second type of RD is more common in natural gas than in electric utilities (Lazar and Gonzalez, 2015).

Covering revenue shortfalls through the SFV does not come without costs. These costs include the potential increases in consumption with lower volumetric charges and possible distributional concerns when low-earning households would pay fixed monthly charges similar to high-income earners. In fact, the gap between the social marginal costs (that mainly consist of the marginal external costs of air pollution associated with fossil-fuel thermal electriitity generation) and the retail electricity prices exhibit wide variations across the United States (Borenstein and Bushnell, 2018): the current retail price exceeds the social marginal costs most notably in California, but also in New England and many parts of several other states while the opposite applies to the rest (mainly the Midcontinent ISO and PJM, Figure 9, p.21). While many states in the former group have implemented RD and thus the further retail price increases may be welfare reducing (e.g., California, New England, and several Western states), the same does not apply to those states with RD where the social marginal costs exceed the retail prices.

SFV, together with the inclusion of the marginal external costs to the electricity prices, may induce limited price increases in the regions of the United States where the retail price is already high relative to the social marginal costs. Such pricing reforms may enhance both efficiency and equity when the current volumetric rates diverge significantly from the social marginal costs. (Borenstein et al., 2021). In other states where the retail prices are lower than the social marginal costs, social marginal cost pricing would enhance efficiency.

At a time when further renewables integration and decarbonization initiatives may reduce the marginal costs of electricity services, this study's finding provides another argument regarding how efficient electricity pricing should achieve the fixed cost recovery.

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Supplementary Notes

(for Online Publication)

Appendix A Supplementary Figures and Tables

Table A.1: Balancing Tests.

Variables	Non-decoupled	Decoupled	difference	p-value
Used in matching				
Average residential real price$_{(t-1,t-12)}$	0.874	0.967	-0.093	0.427
Residential sales trend$_{(t-1,t-12)}$	2.878	1.871	1.008	0.794
Democrat trifecta$_{t-1}$	0.259	0.296	-0.037	0.767
Republican trifecta$_{t-1}$	0.148	0.111	0.037	0.692
Share in state-level residential sales$_{t-1}$	0.294	0.245	0.049	0.479
Not used in matching				
Average residential nominal price$_{(t-1,t-12)}$	1.531	1.666	-0.134	0.535
Residential real price trend$_{(t-1,t-12)}$	-0.167	4.636	-4.803	0.212
Residential nominal price trend$_{(t-1,t-12)}$	2.643	7.856	-5.213	0.171
Overall real price trend$_{(t-1,t-12)}$	-1.174	4.097	-5.270	0.151
Overall nominal price trend$_{(t-1,t-12)}$	1.349	7.756	-6.407	0.087
Overall sales trend$_{(t-1,t-12)}$	2.092	0.689	1.403	0.583
Overall revenue trend$_{(t-1,t-12)}$	2.337	7.731	-5.394	0.170
Share in state-level residential sales$_{t-1}$, others	0.653	0.582	0.072	0.334
Share in state-level overall sales$_{t-1}$	0.273	0.238	0.035	0.602
Share in state-level overall sales$_{t-1}$, others	0.662	0.571	0.091	0.217
Real price levels (not used in matching)				
rp$_{t-1}$	0.073	0.083	-0.010	0.338
rp$_{t-2}$	0.074	0.082	-0.008	0.411
rp$_{t-3}$	0.073	0.082	-0.008	0.424
rp$_{t-4}$	0.072	0.080	-0.007	0.448
rp$_{t-5}$	0.073	0.081	-0.008	0.404
rp$_{t-6}$	0.074	0.083	-0.009	0.352
rp$_{t-7}$	0.072	0.082	-0.010	0.337
rp$_{t-8}$	0.072	0.079	-0.007	0.467
rp$_{t-9}$	0.072	0.079	-0.007	0.508
rp$_{t-10}$	0.072	0.079	-0.007	0.446
rp$_{t-11}$	0.073	0.080	-0.007	0.449
rp$_{t-12}$	0.074	0.079	-0.004	0.679
Nominal price levels (not used in matching)				
p$_{t-1}$	0.129	0.144	-0.014	0.459
p$_{t-2}$	0.129	0.140	-0.011	0.557
p$_{t-3}$	0.129	0.140	-0.010	0.599
p$_{t-4}$	0.128	0.137	-0.009	0.621
p$_{t-5}$	0.127	0.137	-0.010	0.574
p$_{t-6}$	0.127	0.139	-0.012	0.509
p$_{t-6}$	0.127	0.143	-0.015	0.424
p$_{t-8}$	0.128	0.139	-0.011	0.532
p$_{t-9}$	0.127	0.139	-0.011	0.537
p$_{t-10}$	0.126	0.138	-0.012	0.489
p$_{t-11}$	0.126	0.138	-0.012	0.491
p$_{t-12}$	0.128	0.134	-0.006	0.724

Notes: Figures reflect the unconditional means of variables for the matched RD and non-RD utilities during the month before they adopted RD, unless otherwise stated. Trends are measured in percentage difference at $t-1$ relative to $t-12$. p-values are for testing the statistical significance of the mean difference between the two groups.
Source: U.S. Energy Information Administration; Ballotpedia.

Table A.2: Regression result, testing asymmetry in RD-related price adjustments.

	Year-on-year growth rate in residential power prices											
	Nominal						Real					
Variables	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
RD = 1; 0 else	3.692	2.000	3.985	4.607*	6.168	3.219	3.444	2.722	3.483	4.361*	5.247	2.194
	(4.004)	(5.675)	(4.222)	(2.314)	(3.811)	(6.319)	(3.573)	(5.979)	(4.062)	(2.208)	(3.482)	(6.104)
(Projected > actual) = 1, 0 else	-3.968*	-2.959	4.194				-3.365	-2.193	4.157			
	(2.144)	(2.775)	(4.819)				(2.071)	(2.845)	(4.689)			
RD*(Projected > actual)	0.915	4.168	-0.766				0.917	2.525	-1.289			
	(4.694)	(7.258)	(7.720)				(4.256)	(7.372)	(7.509)			
(Projected < actual) = 1, 0 else				3.968*	2.959	-4.194				3.365	2.193	-4.157
				(2.144)	(2.775)	(4.819)				(2.071)	(2.845)	(4.689)
RD*(Projected < actual)				-0.915	-4.168	0.766				-0.917	-2.525	1.289
				(4.694)	(7.258)	(7.720)				(4.256)	(7.372)	(7.509)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-sq (adj.)	0.04	-0.07	-0.07	0.04	-0.07	-0.07	0.58	0.56	0.39	0.58	0.56	0.39
N	648	648	647	648	648	647	648	648	647	648	648	647

The table shows the results of estimating equation 1 on matched sample. Each column in each panel is a separate regression for a particular outcome variable in years after RD relative to pre-RD period (12 months prior to RD implementation). *Project* refers to average revenue growth in the pre-RD period, while *actual* refers to revenue growth in the period being analyzed (i.e. years after the RD implementation). Standard errors clustered at the utility-state level are in parentheses. *, **, *** indicate statistical significance at 0.10, 0.05, and 0.01 level, respectively.

Table A.3: Results from linearly combining estimated parameters (Wald tests).

Estimated parameters	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
	Year-on-year growth in real residential prices					
$\beta_{RD} + \beta_{RD*(projected>actual)}$	4.361*	5.247	2.194			
	(2.208)	(3.482)	(6.104)			
$\beta_{RD} + \beta_{RD*(projected<actual)}$				3.444	2.722	3.483
				(3.573)	(5.979)	(4.062)
	Year-on-year growth in nominal residential prices					
$\beta_{RD} + \beta_{RD*(projected>actual)}$	4.607*	6.168	3.219			
	(2.314)	(3.811)	(6.319)			
$\beta_{RD} + \beta_{RD*(projected<actual)}$				3.692	2.000	3.985
				(4.004)	(5.675)	(4.222)

The table shows the results of performing Wald tests to the linear combination of the relevant estimated parameters in Table A.2. Each column in each panel are generated from a separate regression for a particular outcome variable in years after RD relative to pre-RD period (12 months prior to RD implementation). *projected* refers to average sales growth in the pre-RD period, while *actual* refers to average sales growth in the period being analyzed (i.e. years after the RD implementation). Standard errors are in parentheses. *, **, *** indicate statistical significance at 0.10, 0.05, and 0.01 level, respectively.

Table A.4: Regression result, testing asymmetry in RD-related price adjustments, controlling for RGGI implementation.

Estimated parameters	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3						
	Year-on-year growth rate in residential power prices											
	Nominal						Real					
Variables	Year 1	Year 2	Year	Year 1	Year 2	Year	Year 1	Year 2	Year	Year 1	Year 2	Year
RD = 1; 0 else	5.152	3.026	3.234	5.330**	7.052	2.019	4.707	3.362	2.523	4.986**	5.799	0.662
	(4.573)	(5.280)	(7.310)	(2.503)	(4.691)	(14.172)	(4.020)	(5.424)	(7.002)	(2.409)	(4.314)	(13.699)
Projected > actual	-3.605*	-2.735	4.116				-3.051	-2.054	4.057			
	(2.012)	(2.707)	(4.518)				(1.966)	(2.775)	(4.364)			
RD*(Projected > actual)	0.178	4.026	-1.215				0.279	2.436	-1.862			
	(4.883)	(7.168)	(9.966)				(4.372)	(7.267)	(9.708)			
Projected < actual				3.605*	2.735	-4.116				3.051	2.054	-4.057
				(2.012)	(2.707)	(4.518)				(1.966)	(2.775)	(4.364)
RD*(Projected < actual)				-0.178	-4.026	1.215				-0.279	-2.436	1.862
				(4.883)	(7.168)	(9.966)				(4.372)	(7.267)	(9.708)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-sq (adj.)	0.05	-0.07	-0.07	0.05	-0.07	-0.07	0.58	0.56	0.39	0.58	0.56	0.39
N	648	648	647	648	648	647	648	648	647	648	648	647

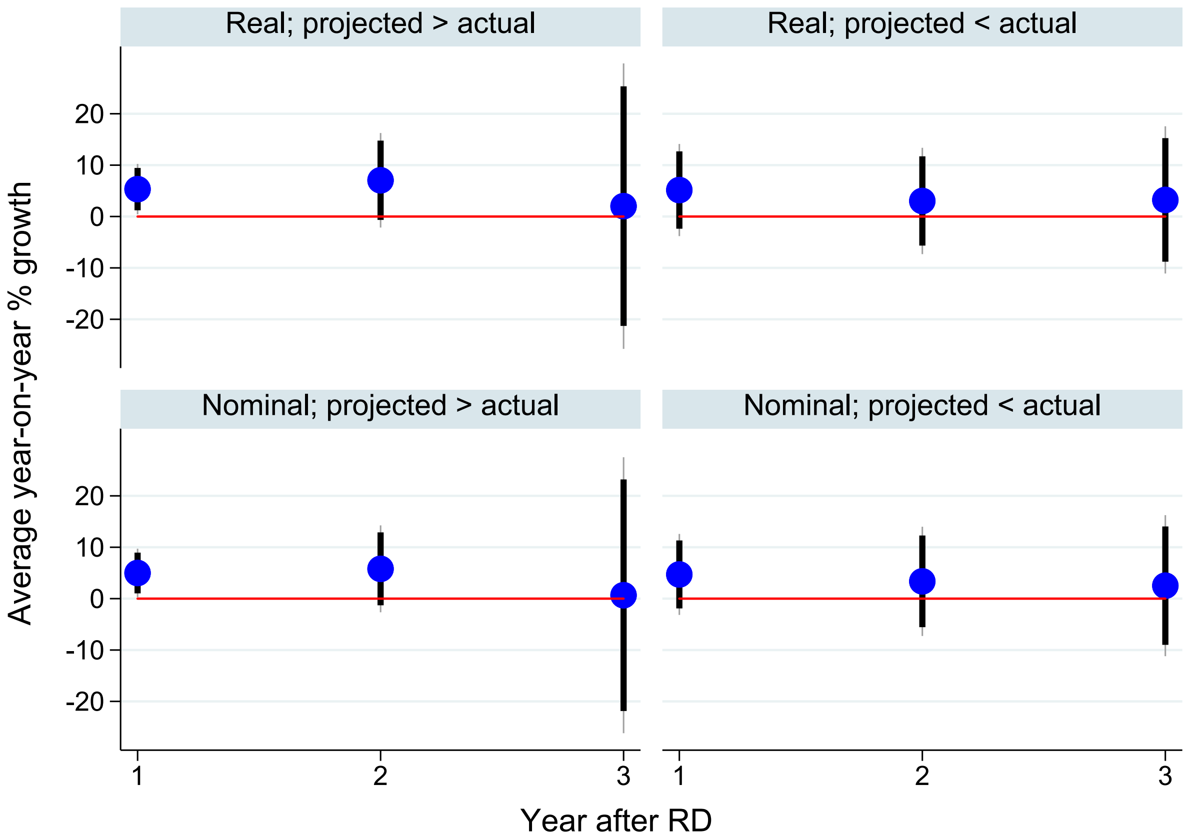
The table shows the results of estimating equation 1 on matched sample, c, controlling for the implementation of the Regional Greenhouse Gas Initiative. Each column in each panel is a separate regression for a particular outcome variable in years after RD relative to pre-RD period (12 months prior to RD implementation). *Project* refers to average revenue growth in the pre-RD period, while *actual* refers to revenue growth in the period being analyzed (i.e. years after the RD implementation). Standard errors clustered at the utility-state level are in parentheses. *, **, *** indicate statistical significance at 0.10, 0.05, and 0.01 level, respectively.

Table A.5: Results from linearly combining estimated parameters (Wald tests), controlling for RGGI implementation.

Estimated parameters	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
	Year-on-year growth in real residential prices					
$\beta_{RD} + \beta_{RD*(projected>actual)}$	5.330**	7.052	2.019			
	(2.503)	(4.691)	(14.172)			
$\beta_{RD} + \beta_{RD*(projected<actual)}$				5.152	3.026	3.234
				(5.152)	(5.280)	(7.310)
	Year-on-year growth in nominal residential prices					
$\beta_{RD} + \beta_{RD*(projected>actual)}$	4.986**	5.799	0.662			
	(2.410)	(4.313)	(13.699)			
$\beta_{RD} + \beta_{RD*(projected<actual)}$				4.707	3.362	2.523
				(4.020)	(5.424)	(7.002)

The table shows the results of performing Wald tests to the linear combination of the relevant estimated parameters in Table A.4. Each column in each panel are generated from a separate regression for a particular outcome variable in years after RD relative to pre-RD period (12 months prior to RD implementation), controlling for the implementation of the Regional Greenhouse Gas Initiative . *projected* refers to average sales growth in the pre-RD period, while *actual* refers to average sales growth in the period being analyzed (i.e. years after the RD implementation). Standard errors are in parentheses. *, **, *** indicate statistical significance at 0.10, 0.05, and 0.01 level, respectively.

Figure A.1: Asymmetric price impact of RD, matched sample, controlling for RGGI.



Notes: Estimated effects resulting from Wald test using estimated parameters in equation 1, controlling for the implementation of the Regional Greenhouse Gas Initiative. The blue dots pertain to average year-on-year growth) relative to the year before the RD implementation; thick black vertical lines -90% confidence interval (CI); thin gray vertical lines - 95% CI). Projected revenue is defined as the average growth in residential prices in the year prior to RD; actual revenue is as the average growth in residential prices in the year(s) after implementing RD. Nominal prices are deflated using consumer price index specific to energy sector, with December 1999 as the base period.