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Paying for performance: The role of policy in energy storage deployment

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ABSTRACT

Energy storage has long been viewed as a solution to the growing challenge of intermittent electricity supply. However, energy storage deployment remains limited despite falling costs. One reason for this is current market rules that inadequately compensate storage for the value it can provide. A recent policy change in the United States (FERC Order 755) seeks to rectify this by requiring grid operators to compensate providers of frequency regulation services based on their speed and accuracy. This seemingly subtle change has a beneficial effect for fast-acting storage resources. Using a difference-in-differences method, exploiting the fact the Order covers only a subset of U.S. electricity regions, we find the order increases the likelihood projects are built to provide frequency regulation services by about 37%. While cost barriers remain to widespread storage deployment, our results suggest improving market rules to properly reflect the value of storage can overcome many regulatory barriers impeding investment.

1. Introduction

Electricity systems around the world are in transition. Spurred by climate policies targeting greenhouse gas (GHG) emissions, as well as rapidly declining costs, renewable energy has become an increasing share of the supply mix for electricity grids (IEA, 2018). This brings benefits in the form of lower GHG emission intensity, however, the intermittent nature of wind and solar power brings new operational challenges to maintaining grid reliability (Gowrisankaran et al., 2016).

Energy storage has long been viewed as part of the solution to overcome the issue of managing a more variable supply mix. Storage can provide a wide variety of beneficial services: from smoothing supply volatility by load leveling, maintaining reliability by quickly responding to power plant failures, alleviating transmission congestion, and providing emergency power supply (Zhao et al., 2015; Aneke and Wang, 2016; Després et al., 2017). While it can operate in traditional energy markets, it is also capable of providing important ancillary services such as voltage support, frequency regulation, and other fast-acting services (Yu and Foggo, 2017). Yet despite its promise, deployment of storage remains limited.

This paper considers the role regulatory barriers play in limiting storage deployment. In doing so, we build on issues identified by Sioshansi et al. (2012), who provide a survey of regulatory barriers and market impediments to storage deployment. To date, however, there has been no comprehensive quantitative analysis of how market rules affect storage investment.[1] This paper tries to fill this gap.

Specifically, we examine how the rate and focus of storage deployment is affected by new rules in the market for frequency regulation—fast acting ancillary services to maintain the reliability of the grid—that better reflect attributes storage can provide. In 2011, the Federal Energy Regulatory Commission (FERC), which regulates transmission and wholesale electricity in interstate commerce, passed Order 755 directing independent system operators (ISOs) and regional transmission operators (RTOs) to consider speed and accuracy in designing tariffs for the provision of frequency regulation services (Federal Energy Regulatory Commission, 2011). This policy, known as the Performance-Based Regulation (PBR), increases the compensation received by fast-acting storage resources in the frequency regulation market. In doing so, this better reflects the attributes storage is able to provide and in turn increases their compensation for the provision of frequency regulation services.

We employ a difference-in-differences (DID) model to identify the causal effect of the introduction of FERC Order 755 on investment in new storage projects and their composition. Using a novel database consisting of all grid-connected energy storage projects in the United

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[1] In related work, Paine et al. (2014) analyse how different market rules affect optimal dispatch decisions and site location decisions for pumped hydro storage—a subset of the electricity storage landscape. Our paper excludes pumped hydro storage.

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States between 2008 and 2016, we compare trends in storage investment specifically targeting frequency regulation as a primary revenue source between organized wholesale electricity markets covered by the FERC Order and regions that are not, before and after the announcement of FERC 755.[2]

We estimate the causal effect of the policy change at two levels. First, at the project level, we estimate how the policy affects the composition of storage projects—i.e. the average size of individual projects and their likelihood of targeting frequency regulation. Second, aggregating our data to the ISO level, we estimate the effect of the policy on overall storage investment.

We find this particular policy increased the likelihood of investment in a new storage project with the ability to perform frequency response by about 37%. The average size of individual projects also increases significantly, more than doubling in the affected regions relative to the control group. In aggregate, the policy change resulted in an increase in the total number of frequency regulation-targeting storage projects in the affected regions relative to the control group of regions not covered by the Order. The estimated overall investment effect was also positive, though only weakly statistically significant.

While many cost barriers remain (Schmidt et al., 2017), our results suggest improving market rules can overcome regulatory barriers that are impeding investment. For perspective as to the magnitude of this result, we can compare to the estimated effect of policy incentives on wind power investment in the United States by Hitaj (2013), who finds wind power capacity increased by 24% in years prior to the expiration of production tax credits.

Our paper fits into a broader and growing literature on energy storage. Carson and Novan (2013) consider both the private and social economics of energy storage, accounting for the effect more storage deployment has on emissions. They find, similar to Holland and Mansur (2008), that depending on the region, storage can have an adverse impact by increasing off-peak prices and enabling more production from coal power. Abrell and Rausch (2016) and Hittinger and Azevedo (2015) find the environmental impact can be either positive or negative depending on the level of renewable penetration and assumptions on grid emissions intensity. Linn and Shih (2016) takes a dynamic view, noting that the presence of storage can induce more renewables, thus improving the long run environmental outcomes as compared to the static findings above. Notably, most of this literature considers storage being used for energy arbitrage. Our paper focuses on the role of storage in providing ancillary services, and the investment impact related to removing the regulatory barriers in that area.

The existing literature on storage investment consists mostly of descriptive analysis. Bhatnagar et al. (2013) and Wilson and Hughes (2014) report the key market and regulatory barriers to energy storage deployment in the United States. Kintner-Meyer (2014) provides an overview of policies and market factors driving the development of large-scale storage in the North American jurisdictions. Focusing on the US frequency regulation markets, Xu et al. (2016) compare market payments under FERC 755 and their impact on the revenue of storage units across ISOs and RTOs that have organized wholesale electricity market. Another strand of literature focuses on technical engineering-based models of profit maximization for a storage unit under different market rules (e.g. He et al., 2016; Dowling et al., 2017; Nguyen et al., 2017; Kazemi and Zareipour, 2018; Xu et al., 2018). Our paper differs from most of the existing literature in utilizing quasi-experimental variation in policy changes across regions to empirically estimate the effect of policy on storage investment.

2. Background

2.1. Frequency regulation market

The electric power system must instantaneously and continuously balance supply and demand. Any gap between generation and load causes the grid frequency to deviate from its standard rate (60 Hz in the United States). Maintaining grid frequency close to its standard rate is crucial to keep the system stable. When there are major deviations in grid frequency, generation and transmission equipment disconnect themselves to avoid damages, and in the worst case cascading blackouts can occur as a result.

To avoid such events, system operators procure spare capacity to adequately respond to frequency deviations. This service is compensated via market auctions by the ISO/RTO in competitive markets.[3] In particular, ISOs and RTOs announce the amount of frequency regulation capacity required for the next day, and market participants submit offers to provide capacity for frequency regulation service. The equilibrium price clears the market for frequency regulation.

2.2. FERC order 755

In October 2011, the Federal Energy Regulatory Commission (FERC) implemented Order 755 to remove unnecessary barriers and incentivise faster ramping units such as energy storage systems to participate in the frequency regulation market. Order 755 requires ISOs and RTOs to compensate frequency regulation providers for the speed and accuracy with which they can provide frequency regulation services, rather than just the cost of the electricity and the overall capacity provided.[4] This was significant for energy storage providers as storage technologies are much faster than the best-performing gas peakers.

The ruling directs ISOs and RTOs under FERC jurisdiction to pay for frequency regulation using a two-part compensation structure, recognizing both capacity and performance. In the first part, frequency regulation providers are paid for the amount of *capacity* they are willing to set aside for frequency regulation. This allows providers to recover the opportunity cost of any foregone revenue from energy sales or other foregone services. This part of the tariff is how most ISO/RTOs compensated frequency regulation prior to FERC Order 755.

The second part of the structure introduces *performance-based* payments based on the speed and accuracy of providers offering frequency regulation. The concept of 'mileage' is introduced, whereby frequency regulation providers are paid based on the cumulative distance of upward and downward adjustments made over a period in which they are offering frequency regulation, rather than simply the net amount delivered. Fig. 1 illustrates this concept more clearly. In this hypothetical example, the provider is offering an amount of 'regulation up' capacity (the ability to increment generation) as shown by the dashed red line. At the end of this time interval, the net amount delivered shown by the height of the last point (f). However, the provider, based on its ability to quickly ramp up and down in short time spans, has covered a much greater 'mileage' distance, in this example rising and falling sequentially through points (a) to (f). Mileage payments are calculated as the sum total distance of the thick green bars.

Resources with faster ramping capability are able to deliver more frequency regulation in short time spans, covering more 'mileage' and are thus compensated fairly for this ability under Order 755. Slower resources, who may deliver the same net energy by the end of a period but

[2] The 6 ISO/RTOs covered by FERC Order 755 are the California Independent System Operator (CAISO), Midcontinent Independent System Operator (MISO), New York Independent System Operator (NYISO), Independent System Operator of New England (ISO-NE), Southwest Power Pool (SPP), and Pennsylvania-Jersey-Maryland Interconnection (PJM). Areas not covered by the Order include non-ISO/RTO balancing authorities operating throughout the US, as well as the Electric Reliability Council of Texas (ERCOT), which operates wholly within the state of Texas and is not synchronized to the rest of the US grid and thus not subject to FERC jurisdiction.

[3] In regulated jurisdictions, frequency response is compensated via bilateral contracts and/or cost of service regulated rates.

[4] The Order excludes ERCOT, which although an RTO, is not subject to FERC jurisdiction.

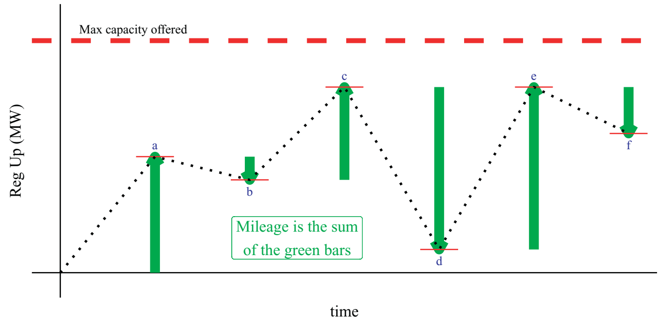


Fig. 1. Mileage explained. *Notes*: In this illustration, a storage provider offers a maximum amount of Regulation Up capacity (shown by the red dashed line. The operator signals dispatch requests at intervals (a) through (f), causing the frequency regulation provider to ramp up and down its unit along the dotted blue line. The increments and decrements covered by these dispatch requests are shown by the thick green lines. The sum total of the thick green lines represents the 'mileage' payment awarded to the provider.

Table 1
Installed capacity by system operator.

System operator	Projects	Power (MW)	Power Share (%)
California Independent System Operator	120	448.5	46.8
ISO New England	40	24.9	2.6
PJM Interconnection	34	167.2	17.4
Electric Reliability Council of Texas	21	75.5	7.9
New York Independent System Operator	18	40.1	4.2
Midcontinent Independent System Operator	6	23	2.4
Southwest Power Pool	3	1.4	0.1
Balancing Authority of Northern California	3	1.3	0.1
Imperial Irrigation District	1	30	3.1
Other	127	146.5	15.3
Total	373	958.4	99.9

Note: System Operators are ranked by the number of storage projects. All projects that are not active within ISO/RTO teritorries are labeled as. Pumped Hydro Storage projects are excluded form the sample.

are unable to respond as effectively to intra-period signals, do not collect as much in mileage payments.

Another aspect of the performance-based component is that mileage payments are adjusted for accuracy. To the extent providers' actual dispatch deviates from the requested dispatch, their payments are reduced. This adds more value to resources that can deliver frequency regulation more accurately.

The recognition of the value of speed and accuracy of frequency regulation benefits most storage technologies, which are capable of delivering fast-responding accurate dispatches. In this paper, we empirically estimate the responsiveness of investment in storage projects with respect to this change in policy that better recognizes storage attributes.

3. Empirical methodology

3.1. Data

The data come from the publicly available United States Department of Energy's Global Energy Storage Database (GESDB), which provides an archive of electrical energy storage projects across the world (Hernández et al., 2016). The GESDB records information on project size, technology, location, use cases, and announcement dates.

The main sample consists of 750 projects, but year is not reported for 265 of them. The remaining 485 projects cover the period of 1996 to 2018. As we are interested in battery storage technologies, 9 pumped hydro storage projects are excluded from the sample. Moreover, we restrict the sample to 4 years before and after the implementation of FERC 755 to identify the short-run impacts of the policy. The final sample used in the analysis comprises 373 projects.

Table 1 presents summary statistics tabulated by ISO/RTO. The majority of projects and storage capacity is deployed in the CAISO. In particular, there are 120 projects in the CAISO market with total capacity of about 450 MW (47% of total US installed storage capacity). ISO-NE and PJM stand on the second and third place in terms of the number of projects, with 40 and 34 projects, respectively. ERCOT, which is not subject to FERC jurisdiction, lists 21 projects with 7.3% share of US installed capacity.

The number and size of storage projects by use case are shown in Fig. 2a. Frequency regulation is the fifth largest (tied) use case in

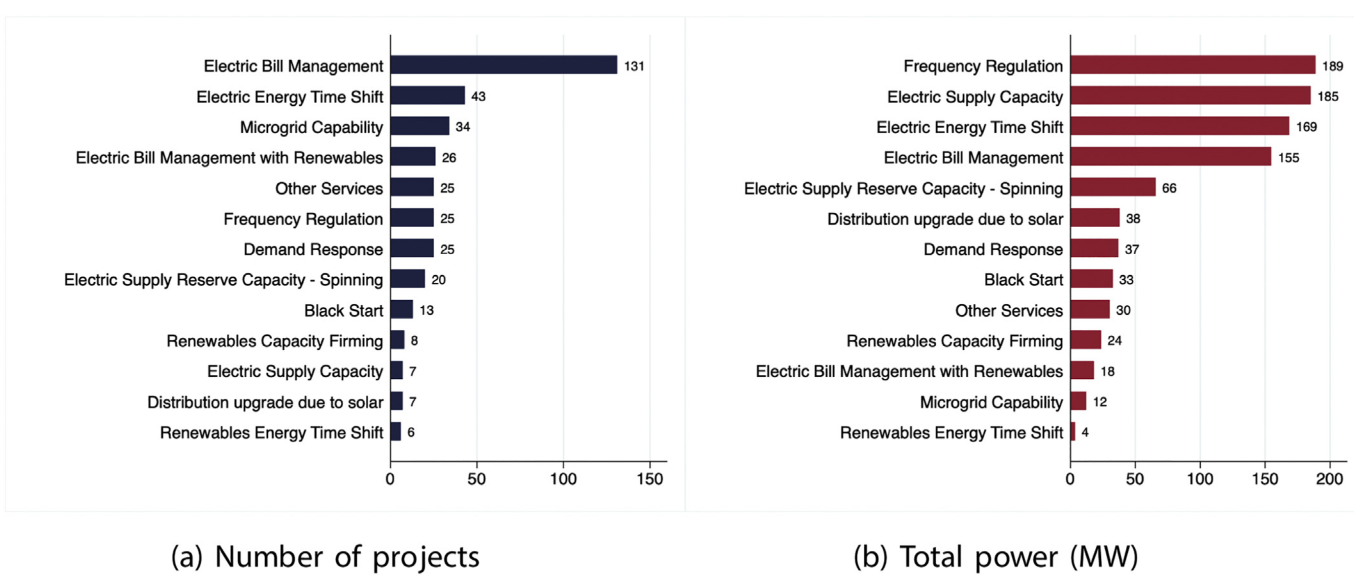
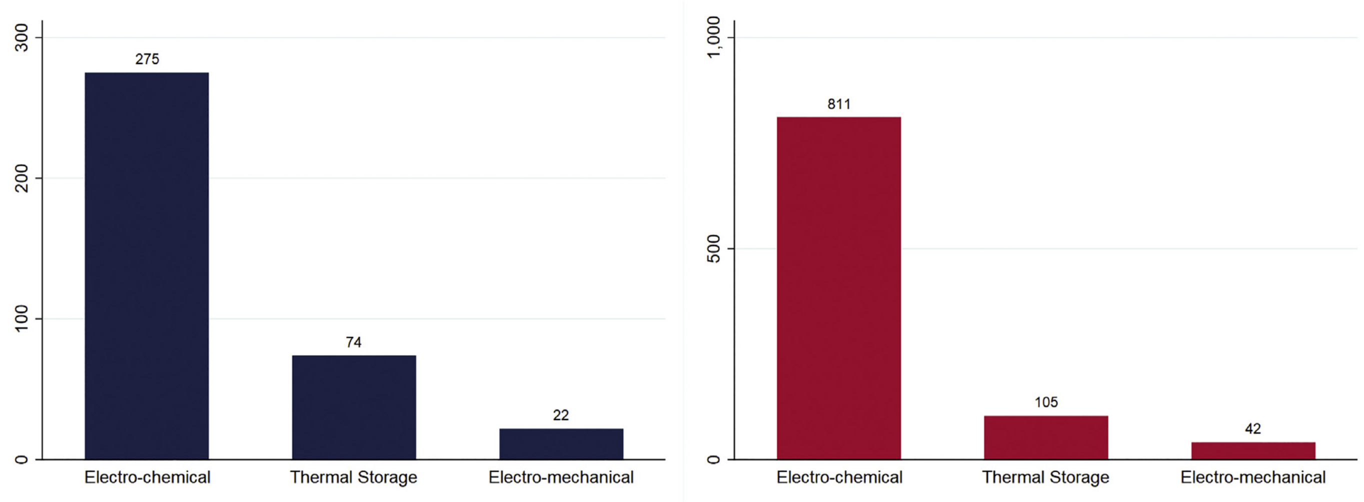


Fig. 2. Projects by service. *Notes:* Panel (a) presents the total number of projects used for each service and panel (b) presents the total power of projects. While frequency regulation is tanked four in terms of the number of projects, it is the top use case in terms of size. The sample does not include pumped hydro storage. Projects that report more than one service are counted for each service separately.



(a) Number of projects

(b) Total power (MW)

Fig. 3. Projects by technology. *Notes:* Panel (a) shows the total number of projects by technology and panel (b) presents the total size of projects by technology. Pumped hydro storage is excluded from the sample.

terms of the number of projects (Fig. 2a), however, it is the top use case in terms of installed capacity (Fig. 2b).[5] This suggests most projects targeting frequency regulation are of relatively large size.

Fig. 3 illustrates the number and size of storage projects by technology. Electro-chemical storage is the top technology used for storage projects followed by thermal and electro-mechanical technologies. All battery storage, including Lithium-ion and flow batteries are considered as electro-chemical storage technologies. Thermal storage technologies are chilled water and ice thermal storage. Finally, flywheels and compressed air energy storage (CAES) form the electro-mechanical category.

3.2. Empirical strategy

We use a difference-in-difference approach to evaluate the effect of FERC Order 755. The first difference is over time, with a dummy variable indicating whether or not the project was announced before or after the policy was announced in October 2011. The second difference is across groups; only FERC members including CAISO, PJM, MISO, ISO-NE, NYISO and SPP, were directly affected by the new frequency regulation market rules. All projects within these ISOs and RTOs define the treated group. The comparison (control) group are all other projects that are not within an ISO/RTO or are located in non-FERC jurisdiction ERCOT.[6]

The basic difference-in-differences comparison is implemented by estimating the following regression:

$$y_{it} = \alpha + \beta(FERC_i \times Post2011_t) + REGION_i + \mu_t + \varepsilon_{it} \quad (1)$$

where i denotes project/region, t indexes years, and y_{it} is the outcome variable of interest. The variable $FERC_i$ is a dummy for treatment group (1 if the project is in FERC jurisdiction and 0 otherwise); $REGION_i$ is a dummy variable at either the FERC level (making it the same as the $FERC_i$ variable) or the more granular ISO level to control for group-specific trends; $Post2011_t$ is a dummy equal to 1 for observations after 2011 and 0 otherwise[7]; μ_t are time fixed effects to control for common changes in macroeconomic conditions. The coefficient of interest is β which measures the effect of FERC Order 755 on the treated group relative to the control group, after the Order's implementation.

We estimate Eq. (1) at two levels: the project and ISO group level. With the project level analysis, we are interested in how attributes of individual projects change in the treated region (FERC) after the introduction of the policy. With respect to Eq. (1), the subscript i refers to individual project observations. We consider two dependent variables at the project level: (1) a dummy variable equal to 1 if provision of frequency regulation service is indicated, or 0 otherwise; and (2) the size (power capacity) of the project. In the first regression, β indicates the relative likelihood of a project in the FERC region targeting frequency response, relative to the non-treated region after the policy change. The β from the second regression indicates how the average size of projects change in the affected region as a result of the policy.

To assess how the policy may have affected overall storage investment, we aggregate our data to the ISO group level, using both the count of projects by ISO-year and aggregate capacity of announced storage projects, again by ISO-year. In this case, the subscript i in Eq. (1) refers to the aggregated ISO level observation. Regressions at the group level estimate by how much overall storage investment changed in the affected regions, using trends in the unaffected region as our implicit counterfactual.

The validity of the difference-in-difference model depends on the assumption that trends in the control group provide a valid counterfactual for the trends that would have occurred in treated ISO/RTOs absent the new payment system. This assumption is arguable if FERC members and non-members were on different trajectories prior to the FERC 755 ruling. Fig. 4 plots the number of storage projects over time across control and treated groups. It shows the procurement of storage in treated and control groups were on similar trajectories when the new payment system was announced. In the years following the policy change, however, the number of projects in the treatment group begins to rise at a faster pace relative to the control group. There is no evidence of an

[5] Pumped storage, which is the largest storage technology type in terms of capacity, is excluded from this sample.

[6] An alternative approach could simply look at cross-sectional differences in storage deployment across regions. However, this would assign all differences in storage deployment to whether or not a region falls under FERC Order 755 jurisdiction. Ideally, a robust suite of controls could account for otherwise unobservable variables, however, ex-ante this full suite of controls is unknown to the econometrician. A DID approach using regional fixed effects controls for differences by region without requiring defining a full set of controls and the potential for omitted variable bias.

[7] Because the policy announced in October 2011 and analysis is at the year level, 2012 is specified as the year policy enacts.

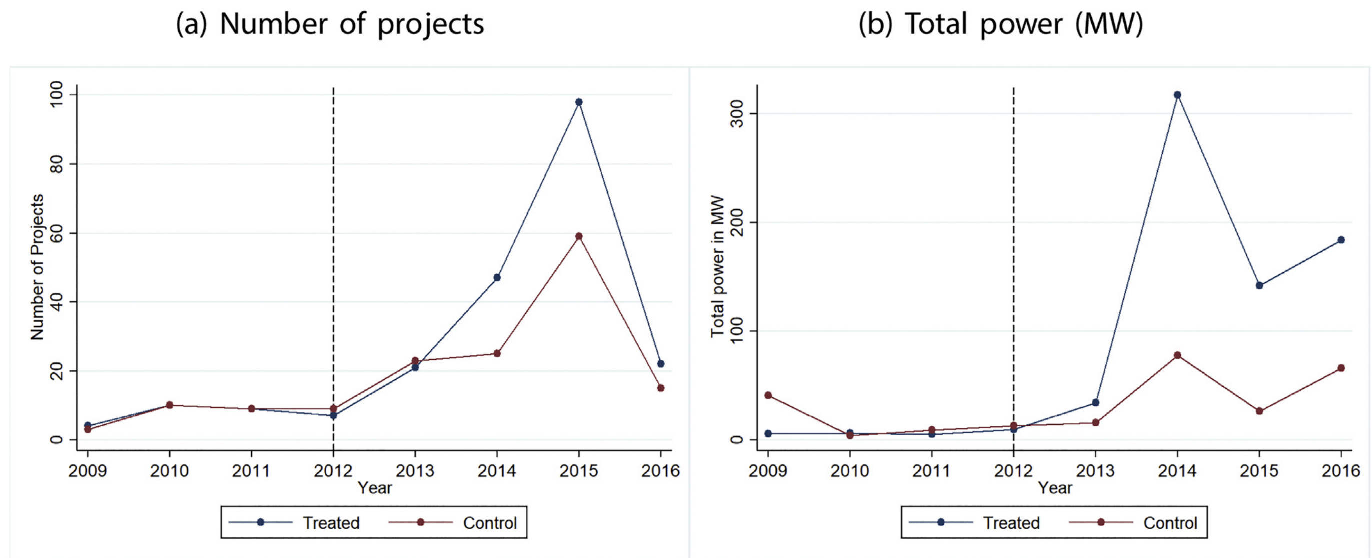


Fig. 4. Common trends. *Notes:* Panel (a) presents the total number of projects across treated and control groups. Panel (b) presents total size of these projects across treated and control groups. Both figures cover the period of 2009–2016. Vertical dashed line represents the year policy takes effect. Source: Own calculations, based on GES Database.

anticipation effect as the number of projects does not increase for the FERC members in the year the policy change takes effect.

In addition to the basic difference-in-differences design, we consider a variant of Eq. (1) in which we introduce leads and lags to consider responsiveness to the policy over time.

$$y_{it} = \alpha + \sum_{\tau} \beta_{\tau}(FERC_i \times D_{\tau}) + REGION_i + \mu_t + \xi_{it} \tag{2}$$

D_{τ} is a dummy variable equal to 1 in year τ and 0 otherwise. τ is normalized to be the number of years before (negative) or after (positive) the year the policy was enacted. In our case, τ runs from -3 to $+4$.[8]

4. Empirical results

4.1. Baseline results

Results for the project-level analysis are shown in Table 2. Panel A examines projects targeting the provision of frequency response, with the dependent variable being a dummy equal to 1 if the project is used for frequency response and 0 otherwise. Each column shows the results with a different set of fixed effects. Column (1) shows that in the base model with no fixed effects, the likelihood of new projects used for frequency response increases by roughly 28% after the FERC order, relative to the control group. The increase is more pronounced if various fixed effects are included. Our preferred results, controlling for both *Year* and *ISO* fixed effects, are reported in column (3) which shows a 37% increase in the likelihood of projects with frequency response. This specification controls for both time shocks experienced uniformly by all jurisdictions and time-invariant differences across ISO/RTOs. As the ISO/RTOs often cover a broad area including a few states, we, also estimate the model by including year and state fixed effects. Column (4) shows a similar 38% increase in this case.

The other outcome variable of interest is installed power capacity size in log(megawatts). The estimates are presented in Panel B of Table 2. We find the capacity size of announced projects more than triples—increasing by 260% to 390% depending on model specification. These large magnitudes imply that the policy led to an increase in the average size of storage projects in the affected regions.

8 2008 was dropped from the event study due to low sample size in that year.

Table 2
Impact of FERC Order 755 on Energy Storage Systems; Project level.

	(1)	(2)	(3)	(4)
Panel A: *Project targeting frequency regulation*				
Treat = 1 ×	0.245 ***	0.270 **	0.315 ***	0.320 ***
Post = 1	(0.0728)	(0.112)	(0.0838)	(0.0832)
R^2	0.054	0.101	0.263	0.393
Observations	374	374	374	374
Panel B: ln(*power*)				
Treat = 1 ×	1.394 ***	1.336 ***	1.591 ***	1.302 **
Post = 1	(0.269)	(0.386)	(0.404)	(0.488)
R^2	0.053	0.173	0.236	0.367
Observations	346	346	346	346
Year FE	No	Yes	Yes	Yes
ISO FE	No	No	Yes	No
State FE	No	No	No	Yes

Note: The table reports results from DID regressions to identify the impact of FERC 755. Each observation is a project announced in a year. Panel A reports the results for the number of projects. Sample is restricted to years between 2008 and 2016. Reported in parentheses are robust standard errors clustered at the ISO level. $^*p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$.

Table 3
Impact of FERC Order 755 on Energy Storage Systems; ISO level.

Sample:	(1)	(2)
	Projects targeting frequency regulation	All projects
Panel A: *Number of projects*		
Treat = 1 ×	0.769 ***	0.430
Post = 1	(0.210)	(0.346)
R^2	0.579	0.798
Observations	55	55
Panel B: ln(*power*)		
Treat = 1 ×	1.882 *	1.293
Post = 1	(0.835)	(1.032)
R^2	0.621	0.672
Observations	55	55
Year FE	Yes	Yes
ISO FE	Yes	Yes

Note: The table reports results from DID regressions to identify the impact of FERC 755. Each observation is an ISO/RTO in a year. Column (1) of Panel A reports the results for the total number of projects announced with frequency response. Column (2) of Panel A reports total number of projects with any usecase. Column (1) and (2) of Panel B show the results for the total size of projects with frequency response and all usecases, respectively. Sample is restricted to years between 2008 and 2016. Reported in parentheses are robust standard errors clustered at the ISO level. $^*p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$.

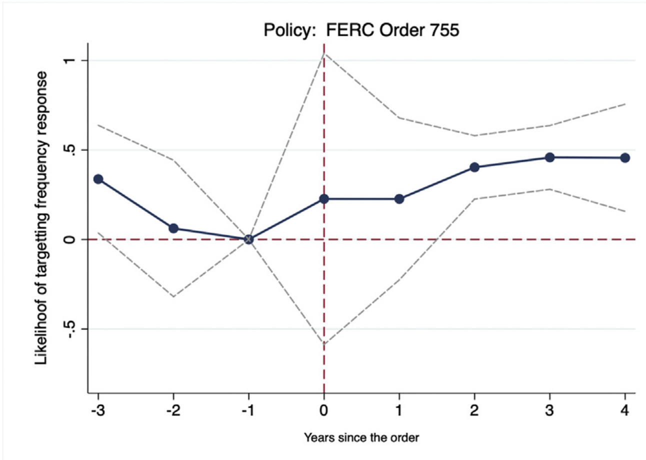


Fig. 5. Event study results. *Notes:* Estimates are based on Eq. (2). The variable of interest is a dummy, which is equal to 1 if the project provides frequency regulation service and 0 otherwise. The solid line represents the coefficients on the interaction terms and the dashed lines show the 95% confidence intervals.

Our second set of results involve Eq. (1) run at the ISO group level, with results shown in Table 3. In the first part (Panel A), we consider the aggregate count of projects, both the total of all projects by ISO and the subset targeting frequency response. We see a large and statistically significant increase in the number of frequency regulation projects being built in FERC-jursdiction ISOs, relative to the control group. The overall number of projects also increases, however the results at this aggregated level are not statistically significant.

In Panel B, we repeat the above exercise, this time with the dependent variable being the sum of power capacity announced in each region, again log-transformed to consider percentage changes. Here, again, we see the total size of projects built for frequency regulation increasing in the treated region. The result for all projects is similarly positive, yet not statistically significant.

Fig. 5 plots the estimated coefficients of the dynamic model in Eq. (2) for the likelihood of projects targeting frequency regulation. A 95% confidence interval is illustrated by dashed line. There is no evidence for an anticipation effect as the coefficients are not significant prior to the policy change.[9] While the contemporaneous impact of policy is positive, it is not significant. The increase in the number of projects becomes significant roughly two years after the policy was implemented.[10]

4.2. Sensitivity analysis

In 2013, the California Public Utility Commission (CPUC) enacted the Assembly Bill 2514 which sets a mandate to the investor-owned utilities to procure 1325 MW of storage by 2020. These storage resources can be used in ancillary services, transmission, distribution, or other purposes and they must be operational by 2024. This policy mandate risks confounding the estimated effect of FERC 755. To guard against this possibility, we perform a sensitivity analysis in which California projects are excluded from the sample.

Table 4 shows the results which indicates the effect of FERC 755 is robust to the exclusion of California. The estimated effect of the policy on regions outside California is similar in magnitude to the full sample–an increase in the likelihood of projects targeting frequency regulation as a use case in the range of 36–50%.

Table 4
Impact of Order 755 on likelihood project targets freq. Regulation, excl. California.

	(1)	(2)	(3)	(4)
Treat $= 1 \times$	0.333 ***	0.354 **	0.309 **	0.405 **
Post $= 1$	(0.0768)	(0.130)	(0.116)	(0.119)
Year FE	No	Yes	Yes	Yes
ISO FE	No	No	Yes	No
State FE	No	No	No	Yes
Observations	209	209	209	209

Note: The table reports results from DID regressions to identify the impact of FERC 755. Each observation is a project announced in a year. Panel A reports the results for the number of projects. Sample excludes all projects in California and is restricted to years between 2008 and 2016. Reported in parentheses are robust standard errors clustered at the ISO level. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Finally, we note the possibility that general equilibrium and spillover effects could affect our estimates. On the former, a large increase in the level of investment is likely to affect the equilibrium price of frequency regulation services, and in turn slow storage investment. Our view in this regard is that (a) most of the storage projects in our sample remain in development, and thus have not yet affected frequency regulation spot markets; and (b) that the amount of announced storage projects remains small relative to the overall size of frequency regulation markets. Thus we do not believe general equilibrium effects would play a significant role in biasing our estimates at this time. On the latter, spillover effects, it is possible that projects targeting frequency regulation are widely deployed, beyond the FERC-covered regions. Our imprecise estimates do not rule out this possibility. If this is the case, our estimated effects would be biased downwards, and thus providing a conservative estimate of the effect of the policy.

5. Conclusion

Our results indicate that reforming market rules in the market for frequency regulation—namely, properly recognizing speed and accuracy of dispatch—can have a material effect on storage deployment.

We interpret our results of the effect of the introduction of FERC Order 755 in late 2011 in the following way. First, there was a clear increase in the likelihood of individual projects being built to provide frequency regulation services. In that sense, developers were responsive to the policy. There was also an increase in the average size of individual storage projects. Second, using our group-level analysis, there was a clear increase in the level—not just the likelihood—of storage investment targeting frequency regulation. Overall, however, though we estimate a positive effect on investment for all storage projects, we cannot reject the null hypothesis of no increase. This implies a few possibilities. One is that storage investment for frequency regulation cannibalized alternative uses for storage projects—this would be the case if the "all projects effect" was indeed zero or less. Another possibility we cannot exclude is that the effect on all projects is positive, and overall storage investment increased, driven largely by more investment into frequency regulation projects.

Regardless of the final interpretation above, our findings highlight that while there may remain cost barriers to widespread storage deployment, there exists niche opportunities—in particular ancillary service, to which battery storage technologies are well-suited—that are economically marginal, whereby properly reflecting the value they can provide can tip an investment decision positive.

Ensuring storage resources are treated fairly in electricity markets can enable more rapid and broad deployment. In electricity systems that are rapidly decarbonizing, getting prices right for the services that can effectively manage increased intermittency is crucial. FERC Order

[9] The coefficient is significant at $\tau = -3$, however, we believe it is likely due to having very few observations for 2008 and not due to any anticipatory effect.

[10] This delayed response is in line with related work by Doraszelski et al. (2018) who examine the frequency regulation market in the United Kingdom and find equilibrium convergence takes time as market participants learn and respond to rival behavior in this new market.

755 shows just how much investment can respond when storage resources are compensated for the value they provide.

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